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Water Reuse Within a Circular Economy Context

2

GLOBAL WATER SECURITY ISSUES SERIES

Water Reuse
within
a Circular Economy Context

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Water Reuse within a Circular Economy Context

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GLOBAL WATER SECURITY ISSUES SERIES

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Foreword

Abou Amani
Director, UNESCO Division of Water Sciences a.i.

Improved water resources management to access safe and clean water for all is essential for basic human livelihood. The 2030 Agenda for Sustainable Development emphasizes the critical role of water by addressing the Goal 6 “Ensure access to water and sanitation for all” of the Sustainable Development Goals (SDGs).

We are experiencing a global pandemic that is leading us to a new normal. COVID-19 gave a significant adverse impact on our lives. Providing safe and clean water for all is a critical key to fight this crisis. Still, one third of people do not have access to safe drinking water, two out of five people do not have a basic hand hygiene facility globally, which places the already vulnerable in a higher risk.

The figures on access makes evident that the current system is not able to meet the increasing demand of water due to climate change and rapid urbanization. Lack of water availability will reduce crop production, augment environmental degradation and social conflict. In this context, unconventional water resources can play a critical role to achieve water security. The availability of safe and clean water supplies, depends on how this water is managed after its use. Worldwide, 80% of wastewater flows untreated back into the environment and 1.8 million people are exposed to contaminated water for their drinking water source. Water reuse is an opportunity. It provides new approaches to meet the increasing urban demand. According to UN-Water, water reuse can further be a solution to our response to the lack of water availability for crop production and industrial development.

The Intergovernmental Hydrological Programme (IHP), as the only intergovernmental programme of the United Nations system in water sciences and education, aims at enhancing the scientific base through research for sound decision making and related education and capacity development. Currently, the eighth phase of the Programme focused on water security. In line with UNESCO IHP’s strategy, the GWSI series provide case studies to achieve water security.

Although there is a plethora of evidence related to the positive benefits from water reuse, still not enough is being done. A comprehensive approach based on scientifically driven solutions, appropriate legislation steps and regulations, as well as institutional setting (governance), is essential to water being reused.

I wish to express our gratitude to i-WSSM, all authors, editors, and staff involved in publishing this series, which I believe can become a stepping stone to the path of Member States in achieving water security through water reuse.

Abou Amani
Director, UNESCO Division of Water Sciences a.i.

Foreword

Yang Su Kim
Director of UNESCO i-WSSM

Climate change, rapid urbanization, and population growth are threatening the basic human rights to use sustainable water resources.
The United Nations emphasizes the importance of providing clean and safe water resources as stated in the Goal 6 of the Sustainable Development Goals (SDGs), "Ensure access to water and sanitation for all".

Furthermore, the COVID-19 pandemic demonstrated the critical importance of water security for preventing diseases. Hand hygiene is a very important way to save lives and combat COVID-19, according to the World Health Organization. The COVID-19 crisis has highlighted again the critical importance of securing access to safe and clean water to help prevent the spread of disease.

The UNESCO International Centre for Water Security and Sustainable Management (i-WSSM) was established to contribute water security strategies through research, education, and global networks. In line with UNESCO's efforts, the Centre publishes the Global Water Security Issues (GWSI) Series to highlight the importance of knowledge-sharing to enhance capacity building to support water security. Following the first series, "Water Security and the Sustainable Development Goals", this series is entitled "Water Reuse within a Circular Economy Context". This second publication has been produced in collaboration with the International Water Resources Association (IWRA). Water reuse is one of the most important practices for water security and can be a solution to meet the lack of availability of water resources.

Ensuring an adequate amount and acceptable quality of water is fundamental for sustainable water resources. A lack of water availability resulting from climate change and an increase in demand from urbanization, population growth, and economic development, require new solutions to reduce the gap between availability and demand.
The circular economy model aims to optimize resource use and reuse in the economy and minimize the generation of waste. In this context, the circular economy model for water resources primarily focuses on more sustainable practices of using wastewater and other marginal water sources.

Even though water reuse has benefits that include improved agricultural production, reduced energy consumption, and environmental benefits, water reuse is not widely exploited due to a number of barriers, including the conventional approach of seeking new freshwater sources rather than reusing available water.

Non-traditional water resource use supports sustainable resource use and offers options to face water crises. Water reuse has the potential to fill the gap between availability and demand for agricultural, industrial and domestic purposes, while also providing financial benefits. Appropriate water reuse should be based on the state-of-the-art technology, standards, legislation and sound knowledge. We sincerely hope that this GWSI series can support decision-makers to include water reuse in their basket of solutions to achieve the SDGs.

Yang Su Kim

Director of UNESCO International Centre for Water Security and Sustainable Management

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Abbreviations & Acronyms

ADB	Asian Development Bank
ANA	National Water Agency (Brazil)
AQIS	Australian Quarantine and Inspection Service
AQUASTAT	FAO Global Information System on Water Resources and Agricultural Water Management
ASCE	American Society of Civil Engineers
ASP	Activated Sludge Process
ATD	Association Tissilte pour le Développement
AWTP	Advanced Water Treatment Plant
BBMP	Bruhat Bengaluru Mahanagara Palike (India)
BOD	Biological Oxygen Demand
BOM	Bureau of Meteorology (Australia)
BWSSB	Bengaluru Water Supply and Sewerage Board (India)
CCP	Critical Control Point
CFE	Federal Electricity Commission (Mexico)
CMF	Ceramic Microfiltration
CNEREE	Centre National d'Etudes et de Recherche sur l'Eau et l'Energi (Morocco)
COD	Chemical Oxygen Demand
CONAGUA	National Water Commission (Mexico)
CTA	Cellulose Triacetate
CTLSP	Local Technical Committee of the Project Supervision (Morocco)
CWSS	Cauvery Water Supply Scheme (India)
DEA	Office of Water and Wastewater Network (Morocco)
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DPA	Provincial Technical Department (Morocco)
DPR	Department of Petroleum Resources (Nigeria)
DS	Draw Solution
DSRM	Direction Régionale de Souss-Massa (Morocco)
DTSS	Deep Tunnel Sewerage System
eGHG	Equivalent Greenhouse Gas Emission
EIA	Environmental Impact Assessment
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FDFO	Fertilizer Drawn Forward Osmosis
FGN	Federal Government of Nigeria
FO	Forward Osmosis
FOMBR	Forward Osmosis Membrane Bioreactor
GAC	Granular Activated Carbon
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emission
GLA	Giga Litres per Annum
GRI	Global Reporting Initiative
GWP	Global Water Partnership
HACCP	Hazard Analysis and Critical Control Points
HLPW	High-Level Panel on Water
HRI	Health Risk Index
IBGE	Brazilian Institute of Geography and Statistics
IEA	International Energy Agency
IER	Ion Exchange Resin
IHP	Intergovernmental Hydrological Programme (UNESCO)
IMF	International Monetary Fund
INE	Instituto Nacional de Estadística (Spain)
IWA	International Water Association
IWRM	Integrated Water Resource Management
i-WSSM	International Centre for Water Security and Sustainable Management (South Korea)
JICA	Japan International Cooperation Agency
KNBS	Kenya National Bureau of Statistics
KSPCB	Karnataka State Pollution Control Board (India)
LAC	Latin America and the Caribbean
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LNG	Liquefied Natural Gas
MEWR	Ministry of Environment and Water Resources (Singapore)
MF	Microfiltration
MoUD	Ministry of Urban Development (India)
NEA	National Environment Agency (Singapore)
NEMA	National Environmental Management Authority (Kenya)
NESREA	National Environmental Standards and Regulations Enforcement Agency (Nigeria)
NF	Nanofiltration
NWS	National Water Strategy (Morocco)
O&M	Operations and Maintenance
OECD	Organisation for Economic Cooperation and Development
OHT	Overhead Tank

ONEE	National Office of Electricity and Water (Morocco)
PIR	Policy, Institutional, and Regulatory
PNA	National Liquid Sanitation and Wastewater Treatment Program (Morocco)
PPCP	Pharmaceuticals, Personal Care Product
PPP	Public-Private Partnership
PREM	Sustainability of Water Resources (Morocco)
PUB	Public Utilities Board (Singapore)
R&D	Research and Development
RADEEMA	Autonomous Agency of Distribution of Water and Electricity of Marrakech (Morocco)
RCF	Recycled Fibre Content
RFC	Recycled Fibre Content
RO	Reverse Osmosis
RWMP	Recycled Water Management Plan
SAP	Structural Adjustment Programme
SDG	Sustainable Development Goal
SEEA	System of Environmental and Economic Accounting
SFA	Singapore Food Authority
SS	Suspended Solids
STP	Sewage Treatment Plant
SUWANU	Sustainable water treatment and nutrient reuse options (Europe)
SWOT	Strengths-Weakness-Opportunities-Threats
TBL	Triple Bottom Line
TDS	Total Dissolved Solids
TMP	Thermomechanical Process
TSS	Total Suspended Solids
UF	Ultrafiltration
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Internationals Children's Fund
UN-Water	United Nations-Water
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
WARMA	Water Resources Management Authority (Kenya)
WDI	World Development Indicators
WEF	World Economic Forum
WFE	Water, Food and Energy Nexus
WHO	World Health Organization
WRT	Wastewater Treatment/Reuse System
WTP	Water Purification
WWAP	World Water Assessment Programme
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

Introduction

The theme for this second publication of the UNESCO i-WSSM Global Water Security Issues is water reuse within a circular economy context. The circular economy concept challenges the accepted paradigm of waste generation from resource use. Instead of a linear trajectory from product-to-use-to-disposal, a circular economy is careful to use resources in a way that allows for their reuse, while also benefiting from other products or consequences that result from those processes, such as using the heat generated during processing a resource. Making a transition from the traditional linear model to implementation of a circular economy model for water reuse will require technologies, facilitating policy and governance environments, and public engagement in all connected sectors and domains.

Water reuse is central to implementation of a circular economy model because water plays innumerable roles throughout the economy. Moreover, the importance of water cannot be overstated since it is a pillar of development, provides essential services for human health and safety, and supports life on this planet. Water reuse is a key strategy for water security. As discussed in several of the chapters in this publication, water reuse is necessary to meet the challenge of increasing water demands at a time when the changing climate is forcing changes to the water cycle.
As such, water reuse is also essential to achieve the Sustainable Development Goals (SDGs), in particular SDG 6, Ensure availability and sustainable management of water and sanitation for all, SDG 11, Make cities and human settlements inclusive, safe, resilient and sustainable, and SDG 12, Ensure sustainable consumption and production patterns

UNESCO Intergovernmental Hydrological Programme (IHP) recognizes water security is a key challenge for the 21st century during its 8th phase. The IHP works to build a scientific knowledge base for water resources management and governance, and facilitates education and capacity building. To develop tools to adapt to changing water availability, the IHP engages in, and supports, hydrological and socioeconomic research.
The current phase of the IHP focuses on thematic areas that include: addressing water scarcity and quality; water and human settlements of the future; and, water education as a water security strategy.
This UNESCO i-WSSM Global Water Security Issues is one initiative to translate science into action for a sustainable future.

The circular economy concept is discussed through a range of lenses in this publication. The Organisation for Economic Co-operation and Development

(OECD) conceives of the circular economy as a guiding framework, comprised of people, policies and places, that can provide a systemic and transformative approach to making efficient use of natural resources and optimizing their reuse (Chapter 1, Romano and Cecchi). The advantages of resource recovery and reuse can leverage the environmental and health benefits of wastewater treatment while also offering economic and financial opportunities from recovered energy, water, biosolids, and other resources to help sustain the operating costs of the systems (Chapter 2, Rodriguez et al.). Coupled with the circular economy concept can be the idea that economic growth is not an ultimate and absolute objective. Instead, material flows are narrowed and slowed through reduction, and greater importance is placed on increasing the recirculation of materials, including marginal water resources such as wastewater and stormwater (Chapter 7, Al-Saidi and Dehnavi). A System of Environmental and Economic Accounting can be applied to account for water and wastewater flows within a system boundary, for example a municipal ward of a populous city (Chapter 10, Ravishankar and Manasi). Water resource use extends into the waterbodies themselves since waste disposal to water takes up assimilative capacity that would otherwise be available to downstream users (Chapter 4, Stefan). One of the goals of the circular economy and water reuse identified in several Chapters is to reduce pressure on freshwater resources.

The water sector has long applied circular economy principles to both technical and institutional aspects of water resources, as stated by Romano and Cecchi (Chapter 1), but there remain many challenges. Each of the Chapters in this publication addresses multiple challenges of governance, social and/or technical aspects of water reuse, while also profiling international best practices. Wastewater can be treated to different qualities to meet specific needs but, to close the funding gap, it may be necessary to engage the private sector in a revised value proposition that shifts from waste production to resource recovery (Chapter 2, Rodriguez et al.). Strategic spending to improve wastewater performance and resource recovery, while considering the full life cycle of the infrastructure, is one step within an array of institutional, economic, regulatory, social, and technological challenges that must be overcome to achieve the needed paradigm shift. This challenge sounds daunting but it is not impossible. The success of Singapore's water reuse from municipal sources for potable and non-potable uses since 2003 is attributable to a comprehensive approach to water security that includes institutional and legal frameworks, which have evolved over time (Chapter 3, Tortajada and Bindal). Singapore provides a benchmark for successful water reuse from municipal sources.

Decision-making for water reuse must take into account many variables. For instance, to understand water availability, it is not sufficient to know only the volume of water available. A case study in Brazil highlights the importance of integrating quantity, quality and purpose in decision-making to assess water availability and for decision-making on water reuse investments by municipal and industrial stakeholders (Chapter 4, Stefan). This case study also raises the issue of closing the loop on soluble materials carried in water, some of which have their own cycles in nature (e.g. nitrogen and phosphorus). An analysis of water reuse by water-intensive industries in Australia profiles the utility of assessment tools, including triple bottom line and Life Cycle Assessment, to make decisions on investments in water recycling capacity in lieu of traditional waste treatment and disposal (Chapter 5, Han et al.). This holistic analysis for several water-intensive industries in Australia highlights the importance of considering energy, wastewater quality and other aspects in a circular economy approach. In Morocco, wastewater can provide a much needed source of water for crop irrigation, but mitigation of the potential risks of soil contamination and compromised human health require collaboration among scientists and policy makers to build capacity and elaborate policies and laws pertaining to wastewater treatment and reuse (Chapter 6, Tallou et al.).

Public education, acceptance and engagement in water reuse activities are key to fully deploying reuse and recovery strategies. A comparative review of the potential for marginal water to support sustainable local food production in Iran and Gulf Cooperation Council countries identifies the requirement to appropriately identify, analyze, treat and deliver water that must then be accepted by end-users and society (Chapter 7, Al-Saidi and Dehnavi). A Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis undertaken to define a regional strategic plan to promote urban reclaimed water for irrigation in the region of Andalusia in Southern Spain, where reuse practices lag other parts of the country, identified challenges and barriers, including acceptance among food-chain agents and the general public, and the higher cost of reclaimed water for irrigators (Chapter 8, Mesa-Pérez et al.). In Nigeria, wastewater reuse has sustained urban farming and many other activities but, as a literature review reveals, Nigerians in the low income category are exposed to environmental and public health risks from wastewater reuse and there is an urgent need for organizational and regulatory frameworks to ensure appropriate treatment for the reuse practices already established in the country (Chapter 9, Akpabio).

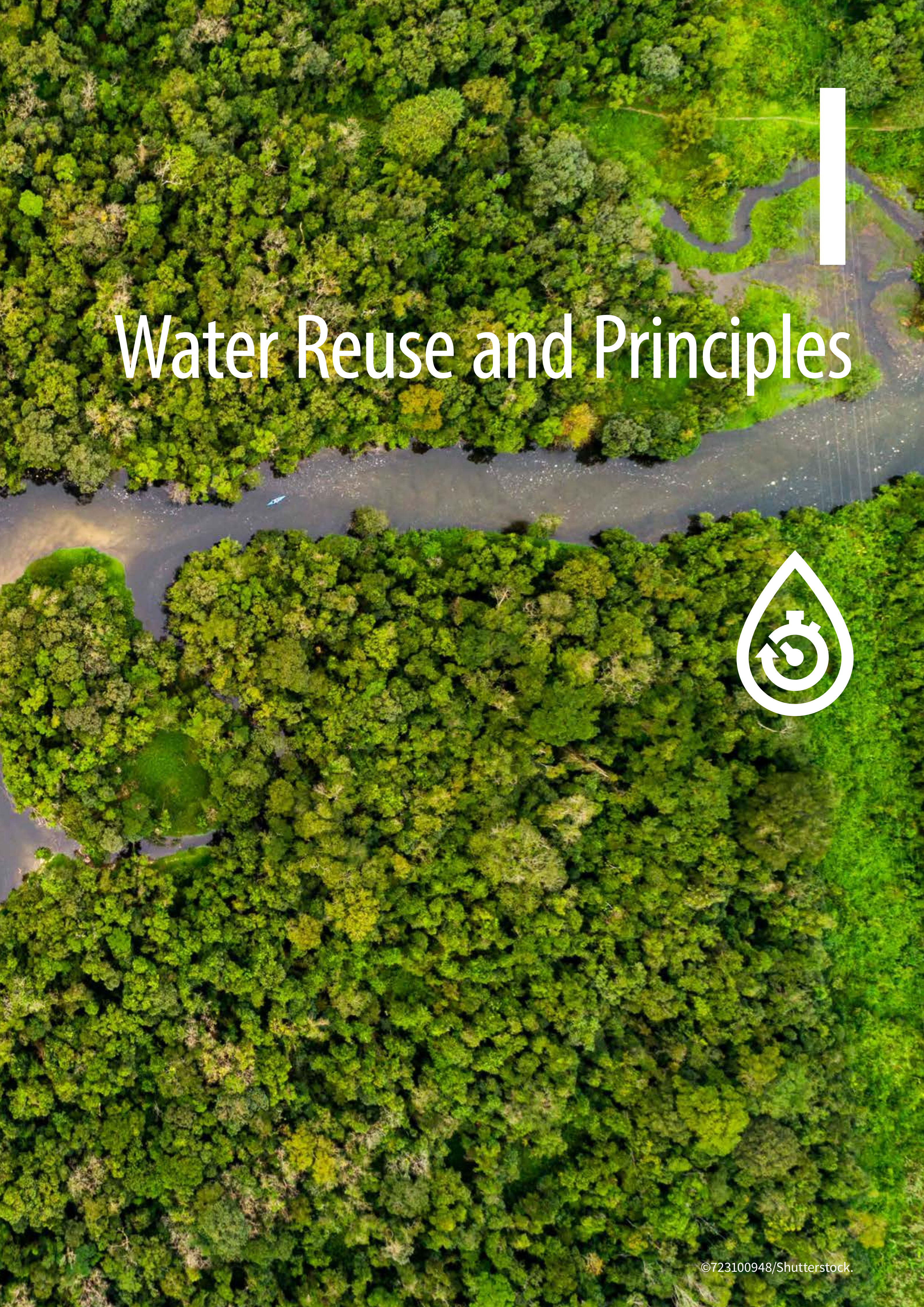
Surveys of stakeholder groups with particular interests can provide insights to attitudes and barriers, thereby informing policy development that can address specific needs of key influencers. Primary data collection through surveys of water tanker suppliers to a peri-urban ward in India indicates there is some potential for tankers to supply reused water to meet non-potable water needs of end-users, who were also surveyed (Chapter 10, Ravishankar and Manasi).
A next step in the process is to more broadly understand public acceptance and to use the peri-urban pilot testing model to scale up to a city wide practice. A survey of government officials, technical experts and greywater users in a municipal suburb in Kenya indicates there is promising potential for grey and wastewater recycling to reduce freshwater demands and to improve ecological conditions by reducing the volume of untreated wastewater released to the environment (Chapter 11, Rotich and Swatuk). While there has been significant progress over the past years with regards to water reuse policy in Kenya, the survey also revealed a need for government regulation and standardization of the industry, and highlighted some barriers due to knowledge and attitudes towards recycled water and the associated technologies.

As the requirement for holistic decision-making is expanded, the need for treatment technologies that can meet the challenges of water quality and efficient energy use become more apparent. Membrane technologies have been in use for some time where superior water quality is required for reuse, but forward osmosis technology in hybrid combination with other processes is an emerging option for lower energy consumption that offers higher water quality production (Chapter 12, Jang et al.).

This edition of the Global Water Security Issues provides examples, through case studies, of policy and technical innovations for water reuse, wastewater recycling and reduced water consumption that recognize the true value of water and close production loops. Biofuels, energy, fertilizers and high-grade reclaimed water are some of the recovered products that provide inputs to other processes. Institutional and governance regimes that are rising to the challenge to update regulations, create markets for recovered products, and address potential quality, health and safety issues are profiled. Rather than being a burden, with the necessary planning on a water basin or aquifer basis, marginal water resources can provide socio-economic opportunities that close the resource use loop while providing essential resources on local and regional scales.
Successful pilot projects may be scaled up if the social and economic conditions exist within a governance framework amenable to a circular economy.

I

Water Reuse and Principles



1

Water and the Circular Economy in Cities: Observations and Ways Forward

Oriana Romano and Luis Cecchi

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Abstract

By 2050, the global population will reach 9 billion people, 55% of which will be living in cities. Water demand will increase by 55% worldwide, in addition to the demand for energy and food. As such, wasteful use of water should be avoided. Instead, water should be reused or transformed into energy and secondary materials, following circular economy principles.
The paper explores the connection between water and the circular economy in cities and their surroundings. In particular, it provides a literature review on how the water sector is included in circular economy strategies in cities, metropolitan areas and regions. Based on the preliminary findings of the OECD report "The circular economy in cities and regions: Synthesis report" (forthcoming), the paper argues that beyond technical solutions, governance conditions are key for the water sector to apply circular economy principles, efficiently and effectively.

Keywords

Circular economy, water management, governance, cities, water reuse

01
Megatrends in Cities

Efficient and effective water management in cities, aiming to provide quality services to people and ecosystems, can be jeopardised by megatrends such as demographic growth and climate change, requiring a rethinking of how water as a resource is used, reused and transformed. In addition, investment needs and global frameworks calling for greater environmental sustainability and inclusiveness make the case for innovative practices in the water sector.

By 2050, the global population will reach 9 billion people, 55% of which will be living in cities (OECD/European Commission, 2020). Water demand will raise by 55% worldwide, in addition to the demand for energy and food. Cities consume almost two-thirds of global energy (IEA, 2016a), while 70% more food will be required in the coming decades, to feed a growing and richer population (FAO, 2009). As such, according to circular economy principles, wasteful use of water should be avoided. Instead water reuse and recycling practices should contribute to make the most of water resources once used.

> *“By 2050, the global population will reach 9 billion people, 55% of which will be living in cities.”*

Due to climate change, the number of cities at risk of droughts and floods is likely to increase in the coming decades. By 2050, four billion people will be living in water-stressed areas (OECD, 2012). Recently, the City of Cape Town (South Africa) has been close to the “Day Zero”, the risk of running out of water, due to persistent drought and external factors such as climate change and rapid population growth. In 2016, Rio de Janeiro and São Paulo (Brazil) were hit by the worst drought in 84 years (OECD, 2015a). According to the Greater London Authority (United Kingdom), the city is likely to face worrisome water shortages by 2040 (Water UK, 2016). Similarly, by 2050 more people will be at risk from floods: from 1.2 billion today to 1.6 billion (OECD, 2012). In 2019, the City of Venice (Italy) suffered from the worse flood since 1966 (Tide Forecasting and Reporting Centre, 2019). Water risks originate from multiple causes and cannot be solved through one-size fits all approach. The complexity of the challenges requires a systemic approach that would take into account water policies in relation to other ones, such as land use and spatial planning.

Significant investment is required to renovate and improve water infrastructure, such as water supply networks. According to OECD (2016), a total of 92% of surveyed cities (48 cities from OECD and non-OECD countries) reported significant challenges in terms of updating and renewing water infrastructure. Due to obsolete infrastructure and leakages in water supply systems, an average of 21% of water is lost before distribution. Globally, by 2050, the required investment for water supply and sanitation is estimated at 6.7 trillion dollars. This bill can triple by 2030 taking into account a wider range of water-related infrastructure (OECD, 2016a). As the future water infrastructure still has to be constructed, there is an opportunity to develop them avoiding linear lock-ins based on the “take, make, waste” logic.

The urgency of the challenges in cities calls for innovative practices and a long-term vision that makes the best use (and re-use) of available resources. The Sustainable Development Goal (SDG) 11 calls for inclusive, safe, resilient and sustainable cities. This is not achievable without acceptable levels of water security (Romano & Akhmouch, 2019). The circular economy can provide a systemic and transformative approach to achieve this vision (OECD, forthcoming).

02

Circular Economy and Water: Technical and Governance Approaches

The water sector has been applying circular principles for long. According to the literature review two main approaches can be identified in relation to the water and sanitation sector and the circular economy: a technical approach and a governance one.

The technical approach focuses on technical innovations for water reuse, wastewater recycling and reduced water consumption, aiming to keep the value of water at its highest for as long as possible, generate new inputs and material, while optimising production costs (e.g. at industry level) and closing loops. For example, these activities consist of generating biofuels from sewage sludge to provide energy (Nghiem *et al.*, 2017; Tyagi & Lo, 2013; Venkatesh & Elmi, 2013); using wastewater bio solids as an organic fertiliser, able to preserve the soil, while improving water quality through the recovery of nutrients (nitrogen and phosphorus) from wastewater effluents (Arup, 2018; Wielemaker *et al.*, 2018; Wolsterdorf, *et al.*, 2018; Norse, 2012); or using wastewater sludge for the manufacture of construction materials forming part of aggregates, bricks, cement, mortars or concrete (Smol *et al.*, 2015; Eliche-Quesada *et al.*, 2011; Asakura *et al.*, 2009; Maddison *et al.*, 2009). Water can be treated for reuse in recharging aquifers, supplying agricultural systems, as well as for refrigeration in industrial processes, irrigation of parks and gardens, street washing, and even for drinking water. For example, in Singapore, in 2003, the Public Utilities Board (PUB), Singapore's National Water Agency, introduced NEWater, a high-grade reclaimed water produced from treated used water, which exceeds the drinking water standards set by the World Health Organization and the US Environmental Protection Agency. NEWater is used primarily for non-potable industrial purposes at wafer fabrication parks, industrial estates and commercial buildings (OECD, 2016a). In the City of Granada (Spain), the bio factory transformed the concept of a wastewater treatment plant by producing energy and new materials. As such, the bio factory aims at : i) moving from being big consumers of energy to energy producers; ii) reusing treated water rather than only purifying and returning it to the natural environment; iii) transforming waste into resources, rather than dumping it into the landfill. The bio factory's goal is to reach zero waste, zero energy and zero emissions by 2020 (OECD, Forthcoming). In 2019, the bio factory almost reached its 100% energy self-sufficiency goal; 18.91 million m^3 of treated water have been reused for irrigation and for the maintenance of the minimum ecological flow of the local Genil River. In addition, from the 16 525 metric tonnes of fresh sludge material produced in the bio factory in 2019, 14.3% was reused for compost and 85.7% for direct application in the agricultural sector (Emasagra, 2019; OECD, Forthcoming).

The governance approach addresses the circular transition in the water sector through institutional and organisational aspects, such as regulation, policy coherence, and the capacity to innovate and adapt to changes.

Some authors showcase the need for updating the regulation of water infrastructure systems (Golthau, 2014; Monstadt, 2007) to scale up technical solutions (e.g. waste water treatment by halophyte filters, membrane filters for extracting medicinal residues in hospital wastewater, or extracting phosphates from the sewage system) and create a market for secondary products (Giezen, 2018; Kirchher *et al.*, 2017; Van Doren *et al.*, 2016).

At European level, as indicated by the Circular Economy Action Plan adopted in 2020, the EU Water Reuse Regulation will encourage circular approaches to water reuse in agriculture. The European Commission will also develop an Integrated Nutrient Management Plan and consider reviewing directives on wastewater treatment and sewage sludge (European Commission, 2020).

The recent regulation on minimum requirements for water reuse (European Parliament, 2020) aims to guarantee that reclaimed water is safe for agricultural irrigation, while promoting the circular economy and supporting adaptation to climate change. As part of the debates preceding the Regulation, EU Urban Partnership on Circular Economy[1] highlighted the need for reusing water for urban purposes (e.g. street and car cleaning and green spaces irrigation) and demanded a clearer risk assessment procedure and cooperation between industrial and municipal wastewater treatment plants and food producers to create positive industrial symbiosis[2](EU Partnership on Circular Economy, 2019).

Others scholars and organisations highlight the need to foster policy coherence across sectors within a system approach. For example, the Ellen Mac Arthur Foundation conceives water as a sub-system of a "system of systems" including environmental, agricultural, industrial and municipal systems. As such, it emphasises the importance of applying a systems perspective to enable policy makers to develop the right governance tools to meet the future water demands while creating value from resource efficiency and energy (Arup, 2018).

New distributed, off-the-grid, circular solutions challenge public authorities, utilities and stakeholders at large to adapt to contexts in constant evolution. For example, in Amsterdam (The Netherlands), the former industrial site of Buiksloterham was transformed into a residential one, applying circular economy principles, including decentralised sanitation systems. This raised a number of governance related questions, in particular for the water operator WATERNET in terms of use of public resources, scaling up the practice and on the role of institutions. As such, it was argued that the more people invest in decentralised systems, the more the cost of central systems will raise for those who remain connected to the central system and do not have the option to switch, while there are also high investment sunk costs to take into account (OECD, 2019).

In developing and emerging economies, enabling conditions and right investments could leapfrog developed countries in digital and materials innovation aimed at sustainable production and consumption patterns. (Preston *et al.*, 2019).

> *"The recent regulation on minimum requirements for water reuse aims to guarantee that reclaimed water is safe for agricultural irrigation, while promoting the circular economy and supporting adaptation to climate change."*

03

Water in Circular Economy Strategies in Cities

Governments at all levels are increasingly considering the circular economy as a new socio-economic paradigm aiming to foster efficient use of resources by minimising waste. As such, it can provide a policy response to the above-mentioned water challenges. Many countries, regions and cities in Europe started this process due to the adoption by the European Commission of a policy package to support the EU's transition to a circular economy, and related frameworks, such as the European Green Deal for sustainable growth (European Commission, 2015 , 2019b, 2019c).

By looking specifically at the role of the circular economy in cities and regions, the OECD (Forthcoming) defines it as a guiding framework whereby: services are provided making efficient use of natural resources as primary material and optimising their re-use; economic activities are planned and carried out in a way to close, slow and narrow loops across value chains and infrastructure is designed and built to avoid linear locks-in. These sections provide examples of how the water and sanitation sector is included in circular economy strategies in cities.

According to the preliminary results of the OECD Survey on the Circular Economy in Cities and Regions (OECD, Forthcoming), a total of 66% of the surveyed circular economy initiatives identified the water and sanitation sector as key for the circular economy, after the waste sector (78%).

Four cities (Amsterdam, Barcelona Metropolitan Area, Rotterdam and Paris) and a region (Flanders), from those contributing to the OECD Survey, have incorporated water and sanitation into their circular economy initiatives: Amsterdam focused on closing local nutrient cycles; Barcelona Metropolitan Area prioritised the creation of a water cluster and provided funds for research and development (R&D) in the sector. Water-related initiatives in Flanders consist of supporting companies in closing water loops and facilitating demonstration projects. In Rotterdam, actions concentrate in the health sector through filtering wastewater, while Paris is advancing in wastewater energy recovery to heat and cool public buildings and using technology to monitor water consumption in green public spaces.

3.1. The Netherlands: The Cities of Amsterdam and Rotterdam

The strategy "A circular economy in the Netherlands by 2050" (2016) considers key the interplay of the water sector and agro-food and calls for a revision of the EU fertilisers' regulation to foster the use of fertilisers from secondary materials, such as base materials from wastewater (e.g. phosphate or sludge and bio solids). It also encourages the adaptation of local plans to disconnect rainwater collection and install green roofs in new construction

In Amsterdam, the "Building blocks for the new strategy Amsterdam Circular 2020-2025" (2019) identifies the need to close local nutrient cycles from biomass and water flows. Water reuse allows nutrients recovering (e.g. phosphates from sewage) and reduces the use of synthetic fertilisers in the city and its surroundings. The city intends to raise awareness on the benefits of water reuse targeting students and citizens. A single-person household consumes 52,000 litres of water per year (on average 133.4 per day) (Waternet, 2019). The strategy also includes the creation of closed water cycles in buildings to reduce the consumption of drinkable water. Circular procurement is signalled as a key tool to promote these changes. Key stakeholders identified in the strategy are the utility companies, to facilitate innovation for nutrient recovery from wastewater, and public housing associations[3] for the implementation of closed water systems in buildings. The strategy foresees the use of organic waste and wastewater sludge as fertilisers in local peri-urban and urban farming to close local nutrient cycles, reduce transportation costs and increase the water absorption capacity of the city by expanding green spaces.

In the Rotterdam's "Circularity Programme 2019- 2023" (2019) water is a key part of the health sector focus, one of the four strategic sectors identified in the circular strategy (alongside construction, green streams such as organic waste, and consumer goods). The city is working with hospitals to make the health care sector more sustainable by filtering medicine residues[4] (e.g. medicine waste, hormone disruptors' remnants and cleaning agents) from wastewater and using them to generate energy (biogas through anaerobic digestion)[5]. Two hospitals in the city are already doing this (the Franciscus Gasthuis and the Erasmus MC).

3.2. Spain: The Barcelona Metropolitan Area

Water reuse is one of the main lines of action of the Spanish strategy for the circular economy to 2030 (España Circular, 2030)[6], alongside with production, consumption, waste management and secondary raw materials. Water reuse is explicitly incorporated as an individual axis, due to the importance of water in cities with a Mediterranean climate. Four main water reuse-related actions are planned in the Spanish strategy:

- Update of the regulatory frameworks on wastewater and sewage sludge reuse to guarantee that all sludge is treated in an appropriate and safe way;
- Support irrigation projects including wastewater reuse;
- Include water reuse actions in River Basin Management Plans;
- Promote research to establish the minimum quality criteria required for water reuse.

The Spanish government conceives wastewater reuse as a valuable tool to reduce the actual pressure for water in the country.

The Barcelona Metropolitan Area, in its "Green and Circular Economy Promotion Programme" (2019), incorporates the water sector as key for the circular economy, along with solar energy, energy efficiency, recycling and food. The Programme provides funding for R&D and the development of pilot projects, including water management. Finally, it identifies innovation opportunities related to water in the food sector (using alternative resources like rainwater or ground water for efficient irrigation); in the chemistry, energy and resources sectors (through innovation in wastewater treatment and resource recovery); and in the design sector, promoting a water saving culture (cisterns, wells, irrigation channels).

3.3. Belgium: Flanders Region

The Flanders region's "Vision 2050: A Long Term Strategy for Flanders" (2016) defined the circular economy as one of its seven priorities. The Flemish government identified four sub-themes: materials, water, energy, space and nutrition. Regarding water, the vision follows the line established by the EU Circular Package and the new Circular Economy Action Plan that aims at emphasising the reuse of water and the contribution of the bio-economy to a circular economy (European Commission, 2015; 2020). The programme "Circular Flanders" (2017) supports companies in closing water loops and facilitating demonstration projects that could be scaled-up to benefit the community. The Flanders European Waterhub has been created to develop, test and upscale water-related innovative projects. The creation of a water demonstrator space is projected. This is an experimental space where new water technologies can be tested in a real-life setting (e.g. filtering and water reuse solutions are being explored to reduce water use in the textile sector).

3.4. France: The City of Paris

As part of the "Circular Economy Plan of Paris 2017-2020", the City of Paris, France, incorporates the "cradle to cradle" approach for specific material flows: water, food, phosphate, waste, electricity and heating. Water-related applications of the circular economy in the Plan apply to the energy and waste management material flows. They consists in:

- Providing heating to public buildings from heat recovery from wastewater to sixteen public institutions[6];
- Exploring more sustainable ways of cooling buildings in the city. As of now, the heating system connected to Paris' non-potable water network is extracting energy from water to cool the City Hall building.
- Rationalising water use (e.g. meters in green areas) and remotely monitoring public water fountains, to prevent leaks and optimise consumption.

04

Ways Forward: A Governance Approach for The Circular Economy in the Water Sector

The cases analysed in this paper showed a mix of technical and governance approaches. The city of Amsterdam combined water reuse techniques with educational programmes and procurement tools. The Barcelona Metropolitan Area promotes the creation of the water cluster with different stakeholders and adopts an intersectorial approach, in relation to the interplay of the water sector with others, such as food and design. Likewise, the Flanders region has created different spaces for stakeholder collaboration with a strong technical innovation approach. The Rotterdam's strategy mainly focuses on applying technical solutions to the health sector, while the City of Paris is putting in place actions combined with technologies to rationalise the use of water.

“The circular economy can provide technically innovative solutions for facing and overcoming water risks.”

While there is no doubt that technical solutions play a fundamental role, they represent only part of the solution. Appropriate governance dimensions are key for the transition towards the circular economy, from raising awareness to engaging stakeholders, developing an appropriate information system and adequate regulation.

The circular economy is *transformative*, since it requires a rethinking of actual business models also in service provision (e.g. decentralised systems). It is *systemic*, because it takes into account water in connection with other sectors such as waste, energy, construction; and it is *functional*, as it connects cities and their surroundings, for example, by taking into account the flows of resources within urban and rural contexts (Romano & Eizaguirre, 2019; OECD, forthcoming).

As such, the “3Ps” analytical framework, *people, policies and places* (OECD, 2016a; OECD, forthcoming) can help diagnose key governance components to enable circularity in the water sector:

People: The circular economy is a shared responsibility across levels of government and stakeholders. Water operators can determine the shift towards new business models (e.g. fostering water reuse, decentralised water solutions, etc.). Citizens, on the other hand, can make choices regarding water consumption and waste prevention.

Policies: The circular economy requires a holistic approach that favours inter-sectoral coordination, while efficiently allocating resources. Per above, the application of circular principles to water entails fostering policy coherence between water and energy (e.g. energy recovery from sludge sewage treatment); water and agriculture (e.g. wastewater sludge used as organic fertiliser) or water and construction (e.g. wastewater sludge as input for construction materials). When interactions and complementarities are overlooked, the lack of a systemic approach might lead to the implementation of fragmented projects over the short-medium run, rather than sustainable policies in the long-run.

Places: Cities and regions are not isolated ecosystems, but spaces for inflows and outflows of materials and resources, in connection with surrounding areas and beyond. Therefore, adopting a functional approach is important for resource management and economic development. Typically, for the water sector, the functional area is represented by the basin. The hydrological boundaries of the basin do not correspond to the administrative boundaries of the cities and this mismatch can add complexity in managing water resources efficiently across a wide range of institutions in charge. Linkages across urban and rural areas (e.g. related to bio-economy, agriculture and forest) are key when it comes to recycling organic residuals to be used in proximity of where they are produced and to avoid negative externalities due to transport. The use of wastewater sludge generated in cities could provide compost and organic fertiliser to peri-urban farms and contribute to closing local nutrient cycles (Wielemaker *et al.*, 2018). Place-based solutions are required to overcome territorial mismatches and favour co-operation between cities and their surroundings.

Cities are laboratories for innovation, where experiments and pilot projects can take place. The circular economy can provide technically innovative solutions for facing and overcoming water risks. Nonetheless, the potential of the circular economy can be unlocked only if the necessary economic and governance conditions will be in place (OECD, forthcoming).

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Notes

1. It is one of the Partnerships created for the implementation of the EU Urban Agenda.
2. Industrial symbiosis allows resources exchanges across companies (waste or by-products from an industry is used as raw material by another) (European Commission, 2019a).
3. There are nine housing associations in Amsterdam. They are responsible for renting or selling accommodation and providing homes for elder people. They are also in charge of building and letting social property (e.g. schools and sports facilities); the maintenance of houses and their immediate surroundings; and selling rented properties to tenants and other house seekers (Government of the Netherlands, 2019).
4. The filter system uses a high-tech shredder to break down waste products in hospital wards. The waste is then transported to a plant where harmful substances in hospital water, such as disease-causing microbes and traces of medications, are filtered out (ozonisation and filtration through activated carbon processes are applied) (OECD, 2016b).
5. After the filtering phase, in the same plant microorganisms through anaerobic digestion break down the solid waste. The plant powers itself from the biogas that results from the breakdown of the solid waste, and any left-over energy is fed back into the hospital grid.
6. Heat is recovered by flowing the wastewater over the surface of a metal plate installed in the part of the system that is in contact with the water. On contact with the metal, the fluid heats up and is fed into a heat pump that recovers heat at temperatures of up to 60°C. This heat is then transported though the district heating network to heat local buildings (Engie Réseaux, 2019).

2

From Waste to Resource: Shifting Paradigms for Smarter Wastewater Interventions in Latin America and the Caribbean

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Abstract

Population and economic growth have driven a rapid rise in demand for water resources. As a result, 36 percent of the world's population already lives in water-scarce regions. Especially in low- and middle-income countries, rapid urbanization has created various water-related challenges. Moreover, by focusing on sustainability, the SDGs are adding a new dimension to the challenges faced in the water supply and sanitation sector. In Latin America and the Caribbean (LAC), only about 60 percent of the population is connected to a sewage system and only about 30–40 percent of the region's wastewater that is collected is treated. These percentages are surprising, given the region's levels of income and urbanization, and have significant implications for public health, environmental sustainability, and social equity. To improve the wastewater situation in the region, countries in LAC are embarking on massive programs to collect and treat wastewater. As cities continue to grow, there is an opportunity to ensure that investments are made in the most sustainable and efficient way possible, embracing the principles of circular economy, considering wastewater a valuable resource. Wastewater can be treated to various qualities to satisfy demand from different sectors, including industry and agriculture, it can be used to maintain the environmental flow, and can even be reused as drinking water. Wastewater treatment for reuse is one solution to the world's water scarcity problem, freeing scarce freshwater resources for other uses. In addition, by-products of wastewater treatment can become valuable for agriculture and energy generation, making wastewater treatment plants more environmentally and financially sustainable. Drawing from case studies and stakeholder consultations, this paper provides a conceptual framework and key policy recommendations for the development of smarter wastewater interventions that adopt circular economy principles. In order to achieve this paradigm shift in the sector, a framework for smarter wastewater interventions has been identified. First, at the country or regional level, wastewater initiatives need to be planned within a river basin framework to ensure that the most cost-optimal and sustainable solution is achieved. Then, at the project level, wastewater treatment plants need to be operated in an efficient and effective way, considering resource recovery opportunities from wastewater. This will make it possible to explore innovative financing and sustainable business models that leverage circular economy principles. Simultaneously, countries need to develop the right policy, institutional, regulatory frameworks to promote the paradigm shift and scale up these solutions.

Keywords

Circular economy, LAC, wastewater, resource recovery, SDGs, reuse

01
Context

1.1. A Growing Global Challenge

Population and economic growth have driven a rapid rise in demand for water resources (WWAP, 2015). As stated by the United Nations and World Bank Group High-Level Panel on Water (HLPW, 2018), 36 percent of the world's population already lives in water-scarce regions and more than 60% of the world's population live in areas that experience water scarcity at least one month in a year (WWAP, 2017). By 2050 more than half the world's population will be at risk due to water stress (HLPW, 2018).

Rapid urbanization, especially in low- and middle-income countries, has created a host of water-related challenges (Reymond, *et al.*, 2016): environmental degradation; water stress accentuated by climate change; infrastructure deficit and need for urban services such as sanitation and wastewater management; and expanding peri-urban and informal settlements. As cities continue to grow rapidly, and climate change impacts water resources' availability and distribution, it will become increasingly difficult and energy intensive to meet the water demands of populations and economies.

Combined, these problems present a challenge for policy makers and municipalities in providing services to their citizens; ensuring that there are enough resources such as food, water, and energy; and protecting public health —all while protecting the environment. In this challenging context, wastewater becomes a valuable resource from which water, energy, and nutrients can be extracted to help meet the demands for water, energy, and food (WWAP, 2017).

1.2. The Sanitation Sector in Latin America and the Caribbean

1.2.1. Population and Sanitation Coverage

In 2017, the population of Latin America and the Caribbean region reached 644 million, 80 percent of which lived in urban areas. Between 2012 and 2017, the population increased by about 34 million, or by approximately 5.4 percent. During the same period, rural populations dropped by 1 percent (WDI, 2019). According to the 2018 Revision of World Urbanization Prospects (UNDESA, 2018), by 2030 the total population in the region will be 718 million with an urban concentration of 84 percent, representing the highest urbanization rate in the developing world.

Regarding access to water supply and sanitation, historically, countries in the region have prioritized investments in water supply, achieving good coverage in recent years. According to WHO & UNICEF (2019) around 97 percent of households had access to an improved source of drinking water in 2017, although this average hides the gap between rural (88 percent) and urban (99 percent) coverage and does not reflect the sustainability and quality of the level of service. The share of the population with access to safely managed water services was only 74 percent.
About 87 percent of the region's population had access to some form of basic sanitation, with an important difference between rural (70 percent) and urban (91 percent) areas. However, only 31 percent had access to safely managed sanitation services. Urban rivers and waterways in the region are among the most polluted in the world, since 70 percent of the wastewater discharged in the region receives no treatment. It is estimated that only about 66 percent of the population is connected to a sewage system (18 percent in rural and 77 percent in urban areas) and only about 30–40 percent of the region's wastewater that is collected is treated (FAO, 2017) - this value, however, does not reflect the quality of the discharged water or whether it complies with discharge standards. This is surprisingly low,

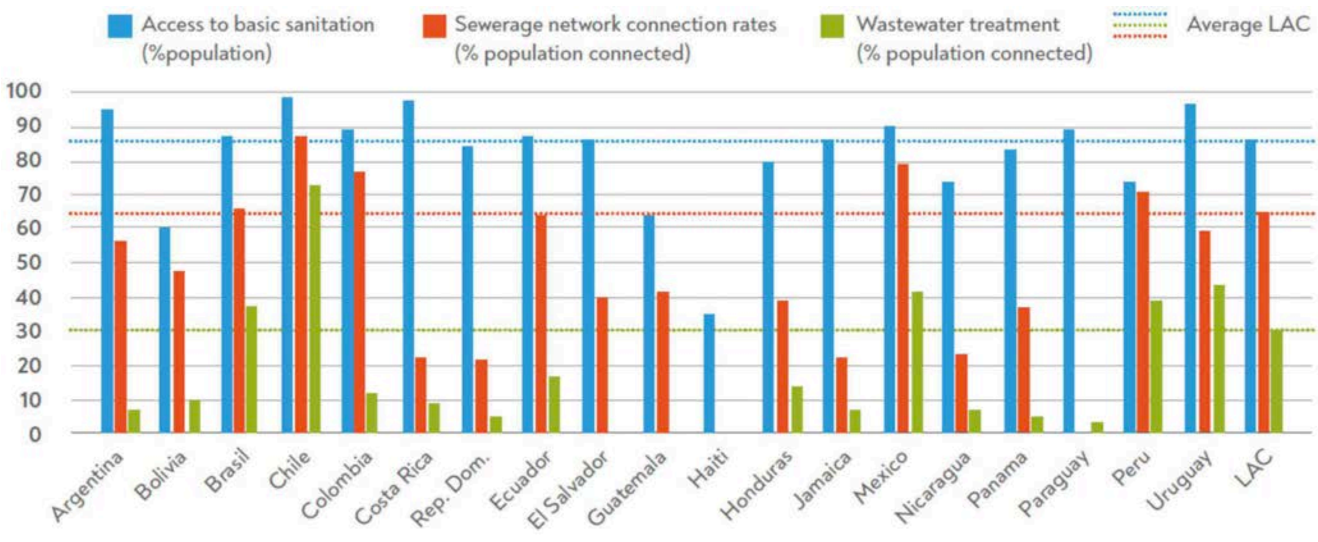

Figure 2-1 *Access to sanitation services in selected countries of Latin America and the Caribbean region, 2017(Source: WHO & UNICEF, 2019)*
Note: LAC = average in Latin America and the Caribbean. Data for Argentina is from WHO & UNICEF, 2017

given the region's levels of income and urbanization, and has significant implications for public health, environmental sustainability, and social equity. As shown in Figure 2-1, wastewater management and treatment levels vary significantly across Latin America and the Caribbean countries, and regional averages mask this significant variation.

Regarding water resources, countries in Latin America and the Caribbean region have a relative abundance of water on a per capita basis compared to other regions of the world (FAO Aquastad). However, water availability is highly seasonal and unevenly distributed in space, with water scarcity already affecting the life of millions in the region (Mejia, 2014). In several countries, there are large asymmetries between the location of water resources availability and population, making many economically dynamic regions water stressed. For example, in Peru, with one of the highest renewable internal freshwater resources per capita in the world (FAO Aquastad), 70 percent of the country's population and 90 percent of the economic output is located along the Pacific Coast, with only one percent of the country's water availability (Mejia, 2014).

1.2.2. Investment Needed to Reach the Sustainable Development Goals in the Region

To reach universal coverage of basic and safety managed sanitation services by 2030, the region will have to reach a total of 307 million as-yet-unserved people.[1] Hutton and Varughese (2016) estimated that the level of investment in the region (excluding Chile, Uruguay, and most of the Caribbean countries) needed to meet the Sustainable Development Goals (SDGs) for sanitation ranged between $3.4 and $11.8 billion per year for the period 2016–30, of which approximately 95 percent would be devoted to urban areas.

The investment needs in the sector are significant, and to improve the wastewater situation in the region, countries are indeed embarking on massive programs to collect and treat wastewater. There is a huge opportunity to ensure that these investments are made in the most sustainable and efficient way. As lessons learned in Latin America and the Caribbean and other regions indicate, investment in technology alone will not guarantee meeting the SDGs. Efficiently investing in wastewater and other sanitation infrastructure to achieve public health benefits and environmental objectives, and to enhance the quality of urban life, is a major challenge for the region. The revalorization of wastewater as part of a circular economy process can contribute to an improved investment efficiency.

1.3. Purpose and Methodology

The purpose of this paper is to raise awareness among decision makers and practitioners involved in wastewater planning, financing, and management (including water utilities, policy makers, basin organizations, and ministries of planning and finance) regarding the potential of wastewater as a resource under the principles of circular economy. The guidelines and policy recommendations provided here aim to encourage a paradigm shift in the sector, resulting in smarter wastewater interventions to be able to meet the SDGs in a more sustainable way.

This paper summarizes the findings and conclusions from six technical background papers (World Bank, 2019a; 2019b; 2019c; 2019d; 2019e; 2019f), from an in-depth analysis of several case studies and from multiple consultations and workshops with key stakeholders working on wastewater management projects in the Latin America and the Caribbean region (World Bank, 2020). The case studies (summarized in appendix A) shed light on best practices to address common challenges and fully leverage the benefits of resource recovery from wastewater and provide examples of projects and programs that promote the implementation of circular economy principles. A key regional workshop was organized in Buenos Aires, Argentina, where government representatives from Argentina, Bolivia, Brazil, Colombia, the Dominican Republic, Ecuador, Honduras, Paraguay, Peru, and Uruguay participated, shared their challenges and ideas (World Bank & CAF, 2018). The initiative's findings have also been presented at several international and regional conferences and events with key stakeholders from governments, international organizations, and the private sector. Feedback from these events and from the workshops enabled to shape the key findings into more practical recommendations.

"Efficiently investing in wastewater and other sanitation infrastructure to achieve public health benefits and environmental objectives, and to enhance the quality of urban life, is a major challenge for the region."

02

The Opportunities Presented by Circular Economy

The challenges of population growth and urbanisation, as well as the water scarcity and security problem, present an opportunity for both developed and developing countries to invest in and develop wastewater and sanitation services that are in line with the circular economy principles. At its core, a circular economy aims to design out waste to achieve sustainability (see Box 2-1). In this context, waste does not exist; products are designed and optimized for a cycle of disassembly and reuse.

Box 2-1 The principles of a circular economy (Sources: Ellen MacArthur Foundation, N.d.; WEF, 2014)

A circular economy is an industrial system that is restorative or regenerative by intention and design. It is an economic system aimed at minimizing waste and making the most of resources. The traditional approach is based on a linear economy with a "make, use, and dispose" model of production. The circular economy approach replaces the end-of-life concept with restoration, shifts toward the use of renewable energy, eliminates the use of toxic chemicals that impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models. Such an economy is based on three main principles: (i) design out waste and pollution, (ii) keep products and materials in use, and (iii) regenerate natural systems.

The long-standing, linear approach of abstracting freshwater from a surface or groundwater source, treating it, using it, collecting it, and disposing of it (most of the time polluted) is unsustainable. However, in most countries of the region, sanitation and wastewater treatment services are still thought out and planned in a linear way. Furthermore, very often water supply is planned first, sewerage systems are planned next, and energy inputs for both are sometimes only considered once the systems have been designed and constructed.

Wastewater and sanitation products and services should not be a burden to governments and society but should be seen as an economic opportunity as it can be transformed into a valuable resource (WWAP, 2017; Otoo & Drechsel, 2018). This change requires a paradigm shift in how we think about and how institutions approach wastewater and sanitation (Andersson *et al.*, 2016; WWAP, 2017; Reymond *et al.*, 2016; Lautze *et al.*, 2014; Otoo & Drechsel, 2018; Allaoui *et al.*, 2015). Wastewater should not be considered a "waste" but a resource.

Wastewater treatment and reuse is one solution to the water scarcity issue, and also to the problem of water security. Wastewater can be treated up to different qualities, to satisfy the demand from different sectors, including industry and agriculture, freeing water resources for household use, to maintain the environmental flow or simply for water for preservation. The diversification of water supply sources is critical for enhanced security and resilience and wastewater should be considered as an additional source when estimating water balances.

Moreover, one of the key advantages of adopting circular economy principles is that resource recovery and reuse could transform sanitation from a costly service to a self-sustaining and value-adding system. Improved wastewater management offers a double-value proposition: in addition to the environmental and health benefits of wastewater treatment, financial returns (Figure 2-2) that partially or fully cover operation and maintenance (O&M) costs are possible. Resource recovery from these facilities in the form of energy, reusable water, biosolids, and other resources (such as nutrients and microplastics) represent an economic and

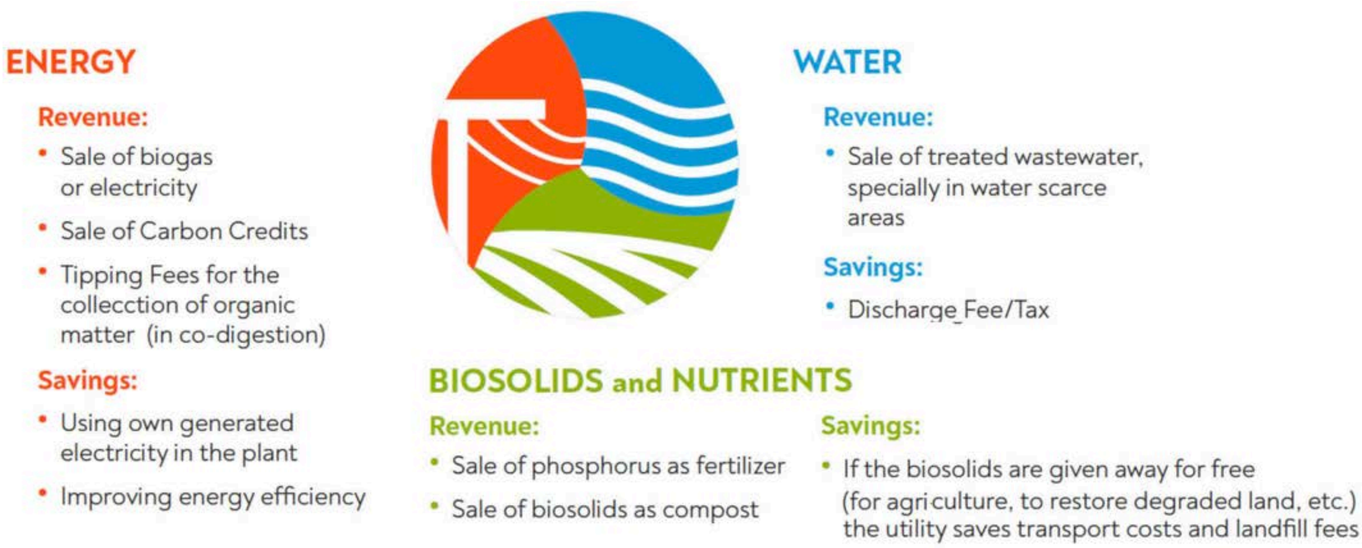

Figure 2-2 Potential revenue streams and savings from implementing resource recovery projects in wastewater treatment plants (Source: Rodriguez et al., 2020)

financial benefit that can contribute to the sustainability of these systems and the utilities operating them.

As documented in the case studies analyzed (Appendix A), applying circular economy principles allow wastewater treatment plants (WWTPs) to: sell treated water for reuse to industry to cover O&M costs, as in the case of San Luis Potosí, Mexico (Box 2-5) or Durban, South Africa (Box 2-7); generate energy for self-consumption to save energy costs as in the case of Ridgewood, United States (Box 2-6) and Atotonilco, Mexico (World Bank, 2018a), or generate revenues by selling energy as in the case of Santiago, Chile (World Bank, 2019g); sell recovered phosphorous for fertilizer, as in the case of Chicago, United States (ASCE, 2013), among others.

Fostering these new business models with additional revenue streams would in turn attract the private sector to close the funding gap. The private sector is often reluctant to invest in the sanitation sector given the low return on investment and the high risks. There is a need for an enabling environment that fosters business models that promote shifting from waste to resource and that enables private investment in infrastructure in tandem with improved efficiency in public financing to promote sustainable service delivery, especially in the poorest countries.

This new approach is also necessary to achieve the SDGs, which are adding a new dimension to the challenges in the sector by considering sustainability. Table 2-1 summarizes the targets and indicators for Sustainable Development Goal (SDG) 6 "Ensure availability and sustainable management of water and sanitation for all".

SDG target 6.3 not only mentions wastewater management but also emphasizes the need to increase wastewater recycling and reuse, and the wording of it places wastewater management firmly in the context of resource efficiency and a circular economy (Andersson *et al.*, 2016). Sustainable wastewater treatment and management, which includes water reuse and resource recovery, will be crucial to achieve SDG 6, and can also contribute toward meeting several other goals. For example, electricity generation in WWTPs, using the biogas produced, can contribute toward SDG 7 (regarding energy) and SDG 13 (climate action); treating wastewater and restoring watersheds also contributes to SDG 3 (good health and well-being), SDG 11 (sustainable cities), and SDG 14 (life below water), among others. The High Level Panel for Water (HLPW – see Section 3.2.1) also acknowledges the importance of water in meeting almost all of the SDG targets: "Water is the common currency which links nearly every SDG, and it will be a critical determinant of success" (HLPW, 2018).

Table 2-1 *SDG 6 targets and indicators (Source: https://sustainabledevelopment.un.org/sdg6)*

	TARGETS	INDICATORS
6.1	By 2030, achieve universal and equitable access to save and affordable drinking water for all	Proportion of population using safely managed drinking water services
6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	Proportion of wastewater safely treated Proportion of bodies of water with good ambient water quality
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	Change in water-use efficiency over time Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	Degree of integrated water resources management implementation Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Change in the extent of water-related ecosystems over time

03

Existing Challenges

The lingering question is: we know that resource recovery and circular economy principles are not new, so why hasn't this approach caught up in the region? Numerous challenges —institutional, economic, regulatory, social, and technological—were identified during the stakeholder consultations (World Bank & CAF, 2018) and also found in relevant literature (OECD, 2018; WWAP, 2017; Trémolet, 2011; HLPW, 2018; Rodriguez *et al.*, 2020). This challenges will need to be overcome to achieve the needed paradigm shift in the sector.

3.1. Institutional Challenges

A knowledge gap and a lack of political will uphold the status quo. There is a general lack of understanding regarding the concept of water resource recovery and how to implement it in practice. Wastewater is still considered a hinderance or a substance to be disposed of, rather than a resource (OECD, 2018). This results in a lack of political will to develop policies and regulations that support and incentivize wastewater reuse and resource recovery.

> *"In most countries in the region, regulations in the water sector are not aligned with the energy, health, industrial."*

Lack of coordination across institutions, legislatures, and sectors. In most countries in the region, regulations in the water sector are not aligned with the energy, health, industrial (including mining), and agriculture sectors, and therefore limit resource recovery and reuse from wastewater (energy, irrigation water, nutrients, preservation, etc.). Moreover, responsibilities for the provision of wastewater services are often fragmented across different levels of governments.
The national government sets policies and targets, while service provision, including investment, operations and maintenance (O&M), and monitoring, is usually delegated to municipal governments, which in many cases lack the technical and financial capacities to adequately provide services (Trémolet, 2011). There is also a lack of coordination between water resource management institutions and those responsible for sanitation service delivery.
As a result, sanitation plans are usually not incorporated in river basin planning efforts, leading to inefficient and costly systems.

3.2. Economic Challenges

Water is undervalued. Unless water resources are properly valued (HLPW, 2018), it will be difficult to promote resource recovery initiatives. The inadequate valuation of water also leads to improper pricing of water resources and water services, which deters resource recovery projects. For example, if industries pay a very low fee to withdraw freshwater, they have limited incentives to pay for treated wastewater unless there is a significant short-term water shortage or a region is facing long-term water scarcity.

There is excessive emphasis on promoting and financing new infrastructure, without sufficiently considering the life cycle of a plant or the sustainability of the system (e.g., coverage of O&M costs) and without evaluating the real capacity of existing infrastructure and optimizing its use.

WWTPs rely on conventional (i.e., public) financing without taking full advantage of market conditions and incentives to enhance sustainability. There is a need for innovative financing mechanisms that can encourage the development of and investment in wastewater systems to promote the sustainability of operations and also the health of local ecosystems.

3.3. Regulatory Challenges

Current regulatory standards are often too restrictive and/ or inconsistent. Countries adopt internationally accepted regulatory standards for water quality that are not tailored to their specific needs. Regulations are often designed without considering the financial implications of their implementation (especially their operational costs). More flexible standards that can be introduced gradually and that are suited to the objective of wastewater investment will encourage innovative solutions needed to provide wastewater services as well as create value from water reuse and resource recovery.

Control over industrial discharge is inadequate. Insufficient legislation, enforcement, regulation, and monitoring of industrial discharge mean that excessive pollutants are released untreated into the environment or left to an already overburdened WWTP. Where untreated industrial discharge is released directly into receiving water bodies, water quality deteriorates, with numerous economic, social, and environmental implications. Where the effluents are left to the WWTP, customers end up paying with their tariffs for industrial treatment.

There is a lack of regulatory frameworks and guidelines for water reuse, beneficial use of biosolids, and energy generation in WWTPs. In Latin America and the Caribbean, there are regulations that limit or forbid resource recovery at WWTPs. For instance, in some countries, the reuse of wastewater might be permitted only for a specific set of activities, such as restricted irrigation, or the use of biosolids might be forbidden in the agriculture sector. Clear regulations and guidelines are needed to ensure the safe use of human-waste-derived products and to widen the market potential. Moreover, a lack of regulation of the pricing of resources recovered from wastewater deters utilities and the private sector from investing in resource recovery projects due to uncertainty regarding the return on their investment. The clear and fair pricing of reclaimed water, biosolids, and energy would foster much-needed innovation and investment.

Incentives for wastewater reuse and resource recovery are absent or insufficient. There is a need for new regulatory mechanisms that specifically provide incentives to all stakeholders to consider wastewater systems as resource recovery facilities. Today, in many countries the benefits and extra revenues reaped from recovery interventions would go only toward tariff reduction. The existence of perverse incentives such as the low price of freshwater abstraction is also a barrier to resource recovery initiatives.

3.4. Social Challenges

Negative perceptions of reclaimed water and reuse products have not been adequately countered. A major challenge to the development of the resource recovery market is the low social acceptance of the use of recycled products from human waste. Also, among farmers already using untreated wastewater, many are against treating it because they have the perception that wastewater nutrients will be removed and that their crop yield will diminish. Public awareness and education campaigns are needed to build trust and change negative perceptions.

3.5. Technological Challenges

Technology selection criteria are biased toward expensive technologies without considering which possibilities best suit local conditions. A challenge related to this point in some countries is a lack of engineers and planners with knowledge of different wastewater treatment technologies.

04

Framework to Promote the Paradigm Shift

Based on the case studies analyzed (See Appendix A), the background reports (World Bank, 2019a; 2019b; 2019c; 2019d; 2019e; 2019f) and the several workshops with the key stakeholders (World Bank, 2020), a framework has been identified (Rodriguez *et al.*, 2020) in order to achieve the paradigm shift in the sector. At the country or regional level, wastewater initiatives need to be planned within a river basin framework to ensure that the most cost optimal and sustainable solution is achieved. Then, at the project level, WWTPs need to be operated in an efficient and effective way, considering resource recovery opportunities.
This will allow the exploration of innovative financing and business models that leverage circular economy principles. Simultaneously, countries need to develop the right policy, institutional and regulatory frameworks that will help promote the paradigm shift.

Develop wastewater initiatives as part of a basin planning framework to maximize benefits, improve efficiency and resource allocation, and engage stakeholders

There is the need to move from ad hoc and isolated wastewater solutions, such as one treatment plant per municipality, to integrated river basin planning approaches that yield more sustainable and resilient systems.
Basin planning offers a coordinating framework for water resources management that focuses public and private sector efforts to address the highest-priority problems within hydrologically defined geographic areas, taking into consideration all sources of water. By planning and analyzing water quality and quantity at the basin level, integrated solutions that are more financially, socially, economically, and environmentally sustainable are possible (Rodriguez *et al.*, 2020; World Bank, 2019b).

Considering an entire river basin can help planners understand different water quality stressors, their interaction in the basin, and can lead to smarter project designs. Impairment of a water body is a result of pollution from various land uses and wastewater discharges that drain into it. Pollution can come from point sources (e.g. from WWTPs, industrial plants, storm water outfalls, sewer overflows, agricultural drains) and nonpoint sources (e.g. illegal dumping and litter, fertilizers and pesticides, agricultural runoff, oil and gas from vehicles).
These different pollution sources exert a cumulative effect on the receiving water bodies, depending on pollutant types, loads, timing, and discharge locations in the basin; therefore, their collective impact must be evaluated when planning wastewater treatment investments.

Despite the widespread use and holistic perspective of river basin planning, it is rarely used in the planning and design of sanitation projects and particularly wastewater treatment plants. However, understanding these cumulative effects at the basin level and their interactions can lead to solutions that target distinct pollution sources, reducing the burden on WWTPs and thus resulting in cost efficiencies and greater environmental benefits. Moreover, river basin planning allows for better treatment processes to be designed as it considers the upstream characteristics of the river basin (existing pollution sources and hydrology) and the characteristics of the downstream users and the receiving water body. The river basin approach can also inform the adaptation of effluent standards to the specifics of a receiving body instead of using a uniform or arbitrary water pollution control standards.

Basin planning allows the identification of the optimal deployment of WWTPs and sanitation programs, including the location, timing, and phasing of treatment infrastructure (Box 2-2). It also enables decision makers to set priorities for investment planning and action (Box 2-3). Basin planning is, therefore, an iterative process that allows decision makers to move from the traditional approach of being reactive to a serious environmental problem to a proactive approach of managing available resources in any given basin through a structured, gradual process.

Moreover, by including wastewater in the hydrological system as a potential water source, it is possible to account and plan for wastewater reuse. Through a basin planning framework, treated wastewater can be included as part of the basin's water balance. Offtakers for treated wastewater can be identified, and its use promoted. A participatory process fosters the identification of synergies across sectors and promotes the development of projects that bring in key offtakers (of biogas, electricity, water, biosolids) from the beginning (i.e. design and conceptualization).

Box 2-2 ***The use of a river basin approach to plan wastewater treatment promotes more efficient outcome and reduces investment needs (Source: Santos, 2018)***

The municipality of Guayaquil, Ecuador, has promoted the creation of a water fund (Fondo de Agua) to clean and preserve the Daule River Basin (Santos, 2018). The action plan includes monitoring and control of water quality, treatment of wastewater, erosion and sediment control, and reforestation, among other actions. The municipality has also developed an integrated plan for wastewater management that includes a hydraulic modelling of the receiving waterbody (Daule Basin) to understand its characteristics and assess the needed level of treatment to meet the existing regulation. The modelling showed that the treatment needed in the wastewater treatment plants to be built was lower than initially designed for since the waterbody had a higher capacity of absorption than thought. This resulted in the more efficient and effective investment in wastewater treatment plants.

Box 2-3 ***Basin plan for the Bogota River, Colombia (Source: World Bank, 2019b)***

A watershed management plan developed for Río Bogotá in Colombia focused not only on wastewater and sanitation but also on general water quality in the river, flood risks, and the supply of water for both potable and nonpotable uses. After a thorough inventory of current conditions, environmental, operational, and ecological goals were defined. With the help of sophisticated water quality, water supply, and flood-risk models, the plan laid out several management alternatives that were consolidated into a detailed investment schedule as well as a monitoring plan to evaluate progress toward the goals.

Build the utility of the future: Move from the concept of wastewater treatment plants to one of water resource recovery facilities, realizing wastewater's value

The practice of waste water treatment continues to evolve, not only technologically but functionally as well. Traditionally, wastewater treatment was focused on removing contaminants and pathogens and safely discharging water back to the environment. Today, wastewater treatment plants should be considered water resource recovery facilities (NSF *et al.*, 2015). This comes with the realization that many components in wastewater can be recovered for beneficial purposes, starting with the water itself (for agriculture, the environment, industry, and even human consumption), followed by nutrients (nitrogen and phosphorus) and energy.

To move toward the ideal utility of the future, first utilities have to be run properly and perform adequately. Wastewater treatment and sanitation projects are designed to provide service for decades. As mentioned in the previous action point, planning wastewater at the basin level is most advantageous because it leads to the best possible solutions under a wide range of situations. However, unless the O&M of the expensive infrastructure laid out in the plan is in the hands of robust water utilities, the benefits of the basin planning approach to sanitation and wastewater treatment will be severely compromised. In Latin America and the Caribbean, as in many regions around the world, poorly operated utilities jeopardize the sustainability of the solutions deployed. There are several examples of very well-run utilities in the region, including in Brazil, Chile, and Colombia.
The issue of utility performance is complex and is not the main purpose of this paper. For further reading, the World Bank has published several documents on the topic (Baietti *et al.*, 2006; Soppe *et al.*, 2018).

Second, treatment facilities need to be designed, planned, managed, and operated effectively and efficiently. When treatment facilities are designed and planned with resource recovery and sustainability in mind, the road to circular economy is paved. Smarter operation and maintenance is then the next natural step to sustainability. Adequate planning, design, and operation entail a series of actions including projecting wastewater influents correctly, setting sustainable targets for effluent quality, selecting an adequate treatment process, using existing infrastructure correctly (Box 2-4) and being energy efficient, among others (described with further detain in Rodriguez *et al.*, 2020 and World Bank, 2019a).

Box 2-4 *Saving costs by utilizing existing infrastructure: Buenos Aires, Argentina (Source: World Bank, 2019a; Rodriguez et al., 2020)*

AySa, the water and wastewater utility in Buenos Aires, had already planned the expansion of its wastewater treatment plants to increase capacity. The expansion costs were around $150 million. However, the application of process audit techniques allowed the utility to use its facilities to the fullest potential, resulting in cancellation of the expansion plans for five years and savings of about $150 million in capital expenditures.

Finally, countries need to recognize the real value of wastewater and the potential resources that can be extracted from it, incorporating resource recovery and circular economy principles in their investment planning and infrastructure design moving forward. The ideal scenario is that utilities would explore the recovery of several resources from wastewater, as exemplified in the case studies analyzed (Appendix A). Infrastructure is a long-term investment that can lock countries into inefficient and unsustainable solutions. This highlights the importance of having resource recovery in mind when planning for wastewater investments. A paradigm shift from treatment plants toward water resource recovery facilities offers new possibilities to create new and more sustainable business models, involve the private sector, and enable new ways of finance, given the potential extra revenue streams (Boxes 2-5, 2-6 and 2-7).

Box 2-5 *Selling wastewater to cover operation and maintenance costs: San Luis Potosi, Mexico (Source: World Bank, 2018b)*

New water reuse regulations and a creative project contract incentivized wastewater reuse in San Luis Potosi. Instead of using fresh water, a power plant uses treated effluent from the nearby wastewater treatment plant (Tenorio) in its cooling towers. This wastewater is 33 percent cheaper for the power plant than groundwater and has resulted in savings of $18 million for the power utility in six years. For the water utility, this extra revenue covers all its operation and maintenance costs. The remaining treated wastewater is used for agricultural purposes. Additionally, the scheme has reduced groundwater extractions by 48 million cubic meters in six years, restoring the aquifer. The extra revenue from water reuse helped attract the private sector to partially fund the capital costs under a public-private partnership agreement (40 percent government grant, 36 percent loan, and 24 percent private equity).

Box 2-6 *The potential of co-digestion: Ridgewood, United States (Source: World Bank, 2018c)*

In the case of Ridgewood, United States, a well-designed public-private partnership between the Village of Ridgewood's water utility and a co-digestion technology provider and engineering company (Ridgewood Green) led to a successful co-digestion project. The Village of Ridgewood leveraged the potential of resource recovery, attracting the private sector to fully finance the retrofitting of their WWTP for co-digestion under a PPP agreement, implying zero investment costs and minimum risk for the village of Ridgewood.

The project allowed the wastewater treatment plant to generate enough biogas to meet all the plant's power needs, becoming energy neutral and decreasing carbon dioxide emissions. Ridgewood Green made all the up-front capital investment needed to retrofit the plan for co-digestion. In return, Ridgewood purchases the electricity generated by Ridgewood Green for the operation of the plant at a lower price than it used to pay for electricity from the grid. The power purchase agreement includes a fixed increase rate of 3 percent per year for inflation, establishing the village's price and Ridgewood Green's revenue for the duration of the contract. Therefore, this agreement benefits both parties. Since Ridgewood Green invested in the co-digestion infrastructure, it owns this new equipment, and the Village of Ridgewood owns and operates the plant with technical support from Ridgewood Green. Ridgewood Green expects to get a reasonable return on its investment through an innovative revenue model that leverages different revenue streams: (i) selling electricity to the Village of Ridgewood; (ii) selling all the renewable energy certificates to 3Degrees, a leader in the renewable energy marketplace under an agreement of several years; and (iii) tipping fees for the organic matter collected for the anaerobic digesters.

Box 2-7 *Reusing wastewater for industrial purposes under a Public-Private Partnership (PPP) agreement: Durban, South Africa (Source: World Bank, 2018d)*

In Durban, South Africa, the private sector provided all the capital needed to implement a wastewater reuse project for industrial purposes under a PPP agreement with the local water utility, which resulted in a sustainable solution with no extra cost for the municipality and the taxpayers. Durban's sanitation capacity was reaching its limits. Instead of increasing the capacity of the existing marine outfall pipeline to discharge primary treated wastewater to the ocean, Durban explored the possibility to further treat it and reuse it for industrial purposes. Mondi, a paper plant, and SAPREF, an oil refinery, expressed interest in receiving the treated wastewater. Given the technical complexity, cost, and risk of the project, the municipal utility opted to implement the project under a public-private partnership. After an international bidding phase, Durban Water Recycling (DWR), a consortium of firms, was chosen to finance, design, construct, and operate the tertiary wastewater treatment plant at SWTW under a 20-year concession contract. The municipal utility would still be in charge of the preliminary and primary wastewater treatment, and the effluent would be sent to the plant operated by DWR to be treated and then be sold to industrial users. The private sector provided the entire funding needed for the project. DWR also undertook the risks of meeting the water quality needs of the two industrial users. The guaranteed demand for treated wastewater from the two industrial users made the project economically attractive and allowed DWR to undertake the investment risks. The sale of treated wastewater to industry has freed enough demand of potable water to supply 400,000 extra people in the city. Moreover, as a result, the need for investment in new infrastructure for water treatment has been postponed.

Explore and support the development of innovative financing and sustainable business models in the sector

Financing sanitation infrastructure and recovering associated costs are challenges throughout the region. Many utilities do not collect adequate sanitation tariffs to cover the costs of O&M, not to mention capital investment or future expansion. Hence, there is considerable agreement that more efficient subsidies are needed for sanitation, at least during a transition period. The existence of subsidies, however, does not mean that the sector has to rely on conventional financing without taking advantage of market conditions and incentives to enhance sustainability (World Bank, 2019e; Box 2-8).

Box 2-8 ***Results-based financing of wastewater infrastructure: PRODES, Brazil(Source: World Bank, 2018e)***

The most prominent incentive-based subsidy example that has been used to finance wastewater is the results-based financing scheme PRODES in Brazil. PRODES is a federal financing scheme set up primarily for depolluting important hydrological basins. PRODES does not directly fund the capital costs of wastewater treatment infrastructure. Instead, PRODES provides clear incentives for efficient investment and operation of wastewater treatment plants, because payments are linked to the quality of treated wastewater based on certified outputs. PRODES did not focus on resource recovery; however, having a plan for the reuse of treated wastewater is one of the criteria for obtaining PRODES support for a wastewater treatment investment. A secondary results-oriented objective of PRODES is to improve the decentralized management of water resources. Criteria for receiving the award includes, for example, the existence of a functioning Basin Committee and evidence of planned implementation of water resource plans and investments.

Resource recovery can help overcome some of the challenges to financing wastewater infrastructure and help to achieve the needed paradigm shift in the sector. Resource recovery can help move away from traditional public financing to innovative financing and new business models that can attract the private sector in the financing of infrastructure. Resource recovery projects can leverage extra revenue streams or cost savings (Figure 2-2) to reduce the financial risk of infrastructure projects, improve the rate of return, and create a more attractive environment for the private sector.

These revenues are not reliant on public sector tariffs. Instead they rely on the market for by-products that are generated during the wastewater treatment process. This requires the identification and development of new markets for reused wastewater, biogas, and biosolids. The rate of return can be high, making these products of interest to operators, private investors, and investment funds.

The case studies analyzed show that most large wastewater projects, particularly those that involve reuse and resource recovery from the onset, have been implemented through various forms of public-private partnerships (PPPs) using a mix of public and private finance (Rodriguez *et al.*, 2020; World Bank, 2019e; 2019f). The private sector can provide not only additional capital but also the new technologies and skills needed to implement and operate the plants.
Reuse and resource recovery projects offer an opportunity to attract the private sector. Reuse and resource recovery projects in wastewater treatment plants can provide a long-term steady financial return, allowing plants to reduce their financial cost, thus attracting those long-term investment funds and investors that are comfortable with long-term regular lower yields. This is shown in several of the cases documented, such as San Luis Potosi, Durban, or Ridgewood, where well-designed contracts secured demand for resource recovery products, ensuring a stable revenue stream and attracting private sector participation.

A specific risk associated with reuse and resource recovery and considered one of the most critical obstacles to private financing and participation is variable demand. The actual volume of by-products that will be eventually used by end users or consumers is uncertain and will decide the project's cost-recovery rate. To mitigate this risk, the case studies show that several approaches are possible but a well-designed contract between the parties is essential.
The financial structure will require a long-term purchase agreement that should provide securities to financial institutions funding the project. Most successful projects involve industries located near the WWTP (case studies of Santiago, Nagpur [World Bank, 2019h], Arequipa [Box 2-9], San Luis Potosi, Ridgewood or Durban) and a contractual structure that mitigates the risk of variable demand. Take-or-pay clauses or a sufficient fixed portion of the payment are common elements in long-term infrastructure contracts and should also be part of reuse and/or resource recovery projects in order to mitigate demand risk.

Box 2-9 ***Collaborating with a mining company to reduce costs: Arequipa, Peru (Source: World Bank, 2019i)***

Cerro Verde, a mining company near Arequipa, Peru, was planning a large-scale expansion that would require access to additional water supplies in a water-scarce area. The mine explored several options such as using desalinated sea water and water from far-away aquifers, but the cheapest option was to build a wastewater treatment plant to treat and use wastewater from Arequipa. Under a PPP agreement, the mining company agreed with SEDAPAR, the municipal water utility, to design, finance, and build the plant, and in exchange, be able to use a part of the treated water for its mining processes. Under this agreement, the industry partner (and end user of treated wastewater), Cerro Verde, provided all the needed investment for capital and operating expenditure not only for the wastewater reuse system but for the entire plant. The municipal authorities provided the land and permits for the plant. After 29 years in private ownership by the mine, the wastewater plant will be transferred to SEDAPAR. Under this PPP agreement SEDAPAR has avoided the cost of construction and operation of the system thus resulting in a net saving of over US$ 335 million. Therefore, this mutually beneficial solution has allowed the mine to expand its operations and has resulted in significant savings for the municipality.

Implement the necessary policy, institutional, and regulatory frameworks to promote the paradigm shift

Finally, for this paradigm shift to happen, policy, institutional, and regulatory (PIR) incentives are needed to encourage sustainable wastewater investments that promote circular economy principles. The case studies analyzed show that such projects are usually developed in an ad hoc fashion and with no national or regional planning, with the enabling factors many times being physical and local: water scarcity, distance to nearest water source, etc. To enable the development of innovative projects at scale, changes in the PIR environment are also needed.
Wastewater treatment technologies for reuse and resource recovery have been progressing much faster than the enabling environment. Weak policy and governmental systems are among the key constraints to the development of resource recovery projects.

“Regulations and standards need to be tailored to the needs of the region and the current trends in the sector.”

Regulations and standards need to be tailored to the needs of the region and the current trends in the sector. The vast majority of the existing legislation in Latin America and the Caribbean was created with the sole purpose of meeting environmental standards and are reflective of instruments from Europe and/or the United States, which have very different capacities and financial means. However, the changes in the sector call for new legislation and regulation that embrace and promote gradual compliance, are flexible, and foster reuse and resource recovery.
Finally, countries in the region need to ensure they have the required institutional capacity to enforce environmental regulations such as water pollution control standards.

Policy, institutional, and regulatory (PIR) initiatives can either trigger or become a barrier to reuse and resource recovery projects. Measures by the government such as pricing freshwater use correctly, especially for industries, could create incentives to switch to using treated wastewater instead (San Luis Potosi case study [World Bank, 2018b]). Economic instruments such as pollution taxes and fees can positively contribute to reducing the treatment burden on the wastewater treatment plant (WWTP), positively impacting capital and operating expenditures.
Governments can also promote energy generation in WWTPs as part of their renewable portfolio, providing WWTP operators the same incentives they would offer to the energy sector. Better regulation of landfill use could also promote the beneficial use of biosolids, for example. On the other hand, banning treated water reuse for agriculture, blocking power generation licenses for biogas producers, or classifying wastewater biosolids as dangerous materials can all pose a barrier to the development of reuse and resource recovery projects.

One of the key factors that can encourage the development of wastewater reuse and resource recovery is having a clear national policy objective. A national policy statement, such as the Brazil National Water Resources Policy, shows the government's commitment to the development of wastewater management that includes reuse and resource recovery. As seen in the case studies, this policy vision is missing in several countries. Policy alone is not enough to generate incentives for wastewater resource recovery; it needs to be supported by a legal and regulatory framework and an adequate institutional arrangement (Rodriguez *et al.*, 2020; World Bank, 2019d).

A key institutional need for the development of resource recovery projects is to foster coordination between different levels of government and between different sectors. Coordination and cooperation among different levels of government help ensure that roles and responsibilities for wastewater management and resource recovery are clearly assigned and fulfilled. In many cases, responsibility for policy development in the wastewater sector lies with the national or state level government, while the planning, investment, and implementation of wastewater services are conducted by local- or municipal-level governments. Various coordination mechanisms can be used to address the institutional disconnect between levels of government: creation of a water/wastewater central institution such as the National Water Commission (CONAGUA) in Mexico, contractual arrangements between levels of government clearly setting out roles and responsibilities as well as key performance indicators and other monitoring mechanisms or the reinforcement or creation of strong river basin institutions.

Moreover, wastewater treatment and reuse and resource recovery also involve stakeholders from different sectors such as water and sanitation, energy, agriculture and food, health, and others. Coordination between these different stakeholders, in addition to an environmental protection mechanism, is needed to create the right incentives for wastewater resource recovery. Some ways to improve coordination among sectors are: alignment of legislation and regulatory frameworks across sectors; contractual agreements between different sectors' stakeholders, *"A robust regulatory framework can also provide incentives for wastewater reuse and resource recovery."*

as in the case of San Luis Potosi (World Bank, 2018b), where a national agreement was signed between the National Water Commission (CONAGUA), the Federal Electricity Commission (CFE), and the state government for the sale of treated wastewater to a thermal power plant for cooling purposes; or collaboration in the development of multisector master plans.

A robust regulatory framework can also provide incentives for wastewater reuse and resource recovery. One of the main obstacles to the recovery of wastewater as a resource is that in most Latin American and Caribbean countries, the by-products (treated wastewater, energy, and biosolids) are not clearly regulated and have no clear value or price. Countries should set clear regulations for the potential by-products. Moreover, it is imperative that regulatory frameworks from different sectors that are relevant to wastewater reuse and resource recovery are aligned (see difficulties in aligning water and energy regulatory frameworks in the SAGUAPAC case study; World Bank, 2018f). The case studies depict different ways of bridging intersectoral regulation, particularly between water and energy. In most cases this was achieved through innovative contracting arrangements, such as in the case of San Luis Potosi.

Finally, the management of wastewater is intrinsically linked to an ability to monitor and enforce water quality standards. Countries in the region should strengthen their enforcement capabilities. Without the right monitoring and enforcement agencies and the right administrative procedures to impose sanctions, it will be difficult to promote wastewater and resource recovery initiatives (Rodriguez *et al.*, 2020).

05

Conclusions and the Way forward for the Region

Wastewater reuse and resource recovery will soon become key aspects of wastewater management strategies worldwide. The scarcity of freshwater in the face of population growth and rapid urbanization, the challenge of meeting the Sustainable Development Goals (SDGs), the impacts of climate change, and the logic of the circular economy have created a compelling incentive to reuse and recover wastewater. The linear approach to wastewater as something to dispose of must give way to a more circular conception of wastewater as a potentially valuable resource. In order to implement the framework outlined above, several actions are needed:

Basin planning efforts in the region need to be strengthened. Governments need to support basin organizations, so they can improve their technical expertise and exert oversight powers to enforce the implementation of basin plans. The sanitation sector—as one of the key beneficiaries of river basin planning—needs to be present in basin organizations and active in promoting basin planning. Instead of fostering one WWTP per municipality, countries should assess the real needs of basins, and work to achieve a water quality standard consistent with the goals established at the basin level (e.g., accounting for the diluting capacity of a local river).

New or improved institutional arrangements may be needed. Such arrangements could universalize basin-level planning and encourage collaboration between different levels of government, as well as between different sectors. Moreover, budgets for government agencies could be linked to river basin plans instead of targeting sector-specific interventions.

Investment priorities need to be unique for each basin. For this reason, a clear methodology to determine investments priorities (in which areas, cities and towns should investment take place), the timing or staging of investments, the levels of treatment required and the technologies to be used must be developed within the basin organization or steering committee. These plans should have legally binding powers and support from the central government to overcome cross-sectorial constraints.

Promote the Utility of the Future. To move toward the ideal utility of the future, utilities first have to be properly run and perform adequately. Second, treatment facilities need to be designed, planned, managed, and operated effectively and efficiently. Finally, countries need to recognize the real value of wastewater and the potential resources that can be extracted from it, incorporating resource recovery and circular economy principles in their strategy, investment planning and infrastructure design. The utility of the future aims for efficient operation and full resource recovery with improved productivity and long-term sustainability. The utility of the future operates under circular economy principles and recognizes the real value of wastewater as a resource: it aims to be net energy neutral or even energy producing, implements beneficial use of biosolids, and reuses water. Ideally, all these elements provide an extra revenue stream or help cover O&M costs, making the utility both more environmentally and financially sustainable. Therefore, the utility of the future does not operate wastewater treatment plants (WWTPs) but water resource recovery facilities (WRRFs). The utility of the future also manages its infrastructure efficiency, while protecting the environment and the health of the population.

Wastewater treatment technology must be adequately understood and used. Adequate guidelines for wastewater treatment process selection are needed in order to avoid unnecessary bias towards expensive technologies such as activated sludge. Technologies that result in lower capital expenditures (CapEx) and operational expenditures (OpEx) must be promoted when possible (UASBs, trickling filters (TFs), and lagoons). A staged or gradual implementation approach in terms of treatment technology, geared towards meeting limits imposed by legislation in the long term, and supported by sound knowledge of wastewater treatment technology and receiving water body capacity, must be promoted.

Private sector involvement in wastewater has proven to be key for the promotion of waste-to-resource projects. Private sector participation brings technical expertise and technology, as well as investment in infrastructure and technology. Moreover, private sector participation early on has led to the successful identification of resource offtakers from wastewater treatment plants. Effective private sector participation, in turn, depends on a conducive, enabling environment for investment as well as a clear policy and regulatory framework. A well-developed and implemented PPP law will therefore be important to attract private operators (Box 2-10).

Box 2-10 Using a public-private partnership (PPP) to increase wastewater coverage and foster wastewater reuse: New Cairo, Egypt (Source: World Bank, 2018g)

As the PPP in Egypt, initially the project faced significant governance issues, since there were no legal or regulatory structures to handle PPPs. The solution was to use the process of the New Cairo wastewater treatment plant to design a model for future PPPs in Egypt and eventually approve a PPP law in 2010. To ensure that the first project was a success, outside advisors were enlisted to assess and evaluate broad options for PPP structuring. The Government of Egypt worked with the International Finance Corporation and the World Bank Group's Public Private Infrastructure Advisory Facility to create a conceptual framework and transaction model. To facilitate the PPP process, a PPP Central Unit was created to act autonomously within the Ministry of Finance. Following the success of the project, the government has created a set of laws and regulations that will govern future PPP projects in the country, drawing on lessons learned from the New Cairo project. The establishment of a PPP central unit enabled co-ordination within the government.

Various forms of public-private partnerships are often needed for the financing of waste-to-resource projects. Blended finance is typically necessary, with subsidies from governments or donors combined with private equity and debt financing that is recovered through user tariffs and resource recovery revenues. The level of subsidy warranted should be determined by economic and financial analysis at the basin level. To provide incentives for efficient performance, subsidies should be disbursed based on achieved results (Box 2-6).

Governments should support the creation of markets for resource recovery products. Technical standards and clear regulations for resource recovery products (treated wastewater, energy, biosolids) are important in building public and private confidence and creating a market that makes resource recovery investments viable. Standards must be flexible and well adapted to local conditions, as standards that are too strict may disincentivize resource recovery. They must also be consistently enforced. Cross-subsidies from tariffs on fresh water may be needed to allow the price of resource recovery byproducts to be set low enough to allow the market to grow. Economic regulation can also be used to stimulate and create competition in the bioresource market. There is also a great need to align regulatory frameworks from other sectors relevant to wastewater resource recovery, as overlapping regulations can create negative incentives.

It is important to align policy, institutional, regulatory, and financing frameworks to encourage and incentivize the development of wastewater resource recovery projects. Although policy and regulatory reforms are context specific and linked to the political economy of each country, a clear policy statement that promotes resource recovery as part of a broad policy on water is a good first step. Around it, commitments from high-level political leaders can coalesce and public support can be built. A set of policies to create incentives for resource recovery from wastewater comes next, accompanied by complementary institutional, regulatory, and financing frameworks that can be improved over time. In fact, flexibility and adaptability may well be most conducive to progressive adoption of resource recovery practices. The policies and frameworks then need to be cascaded down from the national or federal levels to lower levels. Finally, it will be important to raise awareness of the reuse and resource recovery potential and benefits in the region at all levels.

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Appendix A

These case studies illustrate international best practices and provide examples of projects and programs that promote the implementation of one or several circular economy principles (i.e., resource recovery from wastewater treatments plants, efficient plant management and cost savings, innovative financing mechanisms, integrated planning principles, and additional revenue streams from resource recovery). In each case study several project elements were analyzed: (i) circular economy and resource recovery model, (ii) contract arrangements, (iii) financing structure, and (iv) enabling factors (i.e., institutional, regulatory and technical) to be able to draw conclusions. The full published case studies can be found clicking in the hyperlinks (and in the reference list).

Case study	Circular economy model	Contract structure	Financial structure	Enabling factors
Mexico: San Luis Potosí, Tenorio Project	Treated wastewater reused for industry (power plant cooling), agriculture (irrigation of 500 hectares), and environmental conservation (wetland improvement) as part of a wider sanitation and water reuse plan.	Build, own, operate, transfer (BOOT); 20 years Revolving purchase agreement with the Federal Electricity Commission (CFE)	40% government grant from FINFRA funds 36% from Banobras loan; 18-year maturity period 4% equity by risk capital company Federal government guarantee	**Institutional**: Strong leadership of the federal and state water authorities. Cross-sectoral collaboration with CFE. Regulatory: Local water prices at contract signing promoted the use of non-aquifer water. Clarity of payment mechanism and risks well defined and allocated. **Technical**: Scarcity of water resource, multiple quality levels of treated wastewater tailored to different uses.
Mexico: Atotonilco de Tula	Treated wastewater reused for agriculture (irrigation Valle Mezquital). Self-generation of energy with biogas to cover around 60% of energy needs. Biosolids used for fertilizers and soil enhancement.	Design, build, own, operate, transfer (DBOOT); 25 years	49% government grant from El Fondo Nacional de Infraestructura (FONADIN) 20% equity from consortium partner 31% commercial finance	**Institutional**: Strong ownership of experienced water resources management institutions. Strong experience of public funding agency. Regulatory: Clear regulations allowed the reuse of water and biosolids. **Technical**: Multiple quality levels of treated wastewater tailored to different uses, Water Treatment Technology Program (WTTP) adapted to dry seasons.
Bolivia: Santa Cruz de la Sierra	Purchase of certified emission reductions (CERs) from methane gas capture. Electricity for self-consumption.	Emission reduction purchase agreement for biogas capture. First of its kind for low-income countries.	World Bank financing CER but withdrew due to change in legislation	**Regulatory**: Project failed to be implemented due to regulatory limitations in the energy sector. **Technical**: Methane capture technology adapted to anaerobic lagoons.
Egypt: Cairo, New Cairo project	Treated water reused for agriculture. Biosolids used as fertilizers.	First public-private partnership (PPP) in Egypt Design, build, finance, operate, transfer; 20 years	71% public finance 21% nonrecourse finance 8% equity	**Institutional**: Strong leadership of central government (creation of a centralized PPP unit). **Regulatory**: The full potential of the project has not been realized due to ambiguous or no regulatory frameworks. Both the sale of carbon credits and the use of electricity generated have been stalled. **Technical**: Strong external technical support and advising (Public-Private Infrastructure Advisory Facility, PPIAF).
United States: New Jersey, Ridgewood	Plant energy neutrality through the use of biogas generated by the plant (with co-digestion).	20-year power purchase agreement with municipal utility	4 million private finance (Ridgewood Green) Renewable energy certificates	**Institutional**: Strong public support and commitment form the municipality. **Technical**: Innovation used to retrofit existing infrastructure.

Brazil: PRODES	Output-based grants tied to strict environmental and managerial performance standards promoting resource efficiency. Funding eligibility tied to river basin committees promoting a river basin planning approach.	No particular contracting structure is promoted	Results-based financing	**Institutional**: Strong support from the Finance Ministry and the National Water Agency. **Regulatory**: Strict connection between results and financial aid. **Technical**: Strong technical support from ANA during the certifying process.
South Africa: Durban	Treated wastewater sold for industrial purposes: Modi (paper industry) and SAPREF (refinery).	20-year BOOT contract	47% Development Bank of Southern Africa loan 20% equity 33% commercial loan	**Institutional**: Strong coordination mechanisms supported by the local government. **Technical**: Closeness of treated wastewater off takers. Technological innovations to retrofit existing plant.
Chile: Santiago, La Farfana	Generation and sale of biogas to one end user	Joint Venture + Biogas Purchase Agreement (6 renewable years)	Corporate blended funding instruments (green bonds/ debt) Possibility to sell renewable energy certificates	Strong ownership from stakeholders and financially sound partners. **Technical**: Proximity to the Town Gas Plant. Technological innovations to retrofit existing plant. **Regulatory**: Regulated gas market allows using biogas for town gas production. Water regulation that fosters innovation: It provides a grace period of five years during which utilities can keep the profits obtained from an innovation before they are obliged to pass them through to consumers via tariff reductions.
Peru: Arequipa	Treated Wastewater reuse for the mining industry	BOOT 29 years awarded to End user	100% financed by the end user (private mining company)	**Institutional**: Comprehensive PPP legislation, strong support from local and federal government **Technical**: Private partner ensured that the best technology was chosen for the local conditions **Water scarcity**: the cost of tapping the nearest water source was high.
India: Nagpur	Treated wastewater reuse for cooling purposes in thermal power plant	30-year DBOT-PPP End User Model	50% Government Grant 50% Private (sole end user)	**Water scarcity**: the cost of tapping the nearest water source was high. Institutional: Strong Regional and Federal Government support **Technical**: The proximity of the power plant lowered transportation cost

Notes

1. Approximately 233 million people who currently do not have access, plus 74 million additional people.

3

Water Reuse in Singapore: The New Frontier in a Framework of a Circular Economy?

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Abstract

As part of the circular economy, there is increasing interest internationally in water reuse, reclaimed water or recycled wastewater. This interest responds to water scarcity concerns at present and to demands projected for the resource by all sectors in the future, which will surpass freshwater available. It also responds to the incentive to close the water loop and extend the lifetime of water resources through longer use, with the related economic, social and environmental benefits. In this chapter, we discuss water reuse in Singapore where it has been implemented since 2003 for potable and non-potable uses, putting in practice the concept of circular economy. We argue that water reuse is part of a comprehensive framework of water security in the city state that considers long-term policy, planning, management, governance and technological developments. As essential foundations for a reliable water reuse system, we discuss water resources management related institutional and legal frameworks and their evolution over time. We conclude that water reuse is one of the most important pillars for Singapore to provide safe and reliable water sources at present and looking towards the future.

Keywords

Water reuse, recycled wastewater, potable applications, non-domestic users, Singapore

01

Introduction

The circular economy approach seeks to recover and reuse as much as possible of the resources that are used for socio-economic development in any given place. It has the objective to reduce pressure on the use of resources and protect the environment within a framework of sustainability (Byrne *et al.*, 2016). In the case of water resources, when properly planned and implemented, recycling and reuse can produce additional sources of clean water for the increasing number and types of uses. Applications include potable water supplies, urban non-potable applications (e.g. landscape irrigation, street cleaning), irrigation for agriculture production, groundwater storage and recharge, barriers to avoid saltwater intrusion, environmental restoration (e.g. wetland remediation), industrial processes, onsite non-potable use, etc. (USEPA, 2017).

The potential sources of wastewater for water recovery are municipal and industrial. In the case of municipal sources, they are treated to the level required for the intended use, and reused for potable and non-potable applications in the broad economy. In the case of industrial sources, they are reused for on-site purposes. In both cases, drivers for water reuse are related to water quantity and quality concerns and include actual and potential water scarcity risks, and also to the need for discharging wastewater effluents to the environment within certain quality limits with the associated fines and penalties if discharges are above the norms. Instead, by treating wastewater to higher quality standards, resulting water can be reused for different uses increasing the amount of water available (USEPA, 2012).

“In the case of water resources, when properly planned and implemented, recycling and reuse can produce additional sources of clean water for the increasing number and types of uses.”

Water recycling and reuse applications depend on the short and long-term needs and resources of the specific cities, water utility operators and industries. They also depend on the possibility to respond to strict laws and regulations, to be able to cover high-capital expenditure costs in the long-term, and to address potential risks to human health and the environment as well as public perception concerns, among others.

Our analysis focuses on water reuse (recycled wastewater or reclaimed water) from municipal wastewater in Singapore to augment and diversify water resources for all uses. NEWater, as it is known locally, is part of broad, comprehensive water resources policy, planning, management, governance and technological development security framework. Water reuse covers up to 40 percent of the water needs at present and this percentage is expected to increase to 55 percent by 2060. Therefore, the reason for its importance.

We also discuss how Singapore has put in practice the circular economy concept by reusing water for potable and non-potable applications, instead of discharging the wastewater to the sea after treatment. With this, the water loop has been closed and the lifetime of water resources has been extended through longer use, with significant economic, social and environmental benefits.

02

Water Resources Management

Singapore is a city-state of 725.7 km^2 in Southeast Asia situated 137 km north of the equator at the southern end of the Malay Peninsula. It has a total population of 5.7 million and a population density of 7,866 persons per km^2 (Singapore Department of Statistics, 2020). Even though it has an average annual rainfall of around 2,340 mm, it is unable to store it due to the limited land area that can be allocated for reservoirs and the absence of aquifers. Instead, Singapore has to rely on imported water from the state of Johor, Malaysia, and to produe reused and desalinated water.

Total water demand in the city-state is projected to double by 2060 from approximately 1.9 million m^3/d at present. In order to respond to the expected demand, in addition to water conservation strategies, water reuse and desalination capacities are being increased to supply up to 85 percent of the water needs at that time (PUB, 2018d).

Singapore's long-term water security strategy started in 1965 after independence due to physical scarcity of water resources. Throughout the years, it has developed a comprehensive water resources management system that considers catchment management (including land use), infrastructure development, treating and storing local and imported water sources (from Johor, Malaysia), developing pricing and non-pricing mechanisms for conservation purposes for domestic and non-domestic users, wastewater management, production of reused water from municipal sources since 2003 (known as NEWater), and desalinated water since 2005. For both non-conventional sources of water (NEWater and desalination), major investments have been made since the 1970s in research and development to support technological developments such as membrane technology, reverse osmosis, and lower energy-intensive processes, among others.

Fundamental components of water management in Singapore have included long-term planning horizons, effective legal and regulatory frameworks, and strong political will (Tortajada *et al.*, 2013). Following is the analysis of institutional and legal frameworks for water resources management, indispensable for NEWater production.

03

Institutional and Legal Frameworks

The objectives of the Clean Water Policy in the city-state include: ensuring supply of water for all, conserving water resources, and encouraging ownership of waterways. Key targets comprise increasing supply of water from non-conventional sources of water (reused and desalinated water) to cover up to 85 percent of water needs in 2060; reducing daily per capita domestic water consumption to 130 ℓ/capita/day by 2030; and working with the public and private sectors as well as the society as a whole to create greater awareness of the importance of water conservation.

PUB, the National Water Agency, a statutory board under the Ministry of Environment and Water Resources (MEWR), manages water supply, water catchment and wastewater in an integrated way. Two other statutory boards under MEWR are the National Water Agency (NEA), and Singapore Food Authority (SFA). NEA is responsible for ensuring a clean and green environment and the sustainable development of Singapore. Key roles are to protect natural resources (including water resources) from pollution, maintain a high level of public health and provide timely meteorological information (NEA, n.d.). The recently created SFA is responsible for ensuring and securing safe food supply for the city-state (Singapore Food Agency, n.d.).

The Public Utilities Act, The Public Utilities (Water Supply) and the Sewerage and Drainage Act provide the legal framework for the water sector. The following sections present a historic view of some of the legal instruments that support efficient water resources management.

3.1. Public Utilities Act

The Act to reconstitute the Public Utilities Board and matter connected therewith is the Public Utilities Act. This was first enacted in 1963 as the Public Utilities Ordinance, when Singapore was still a British colony. The Ordinance was necessitated by the peculiar structure which the Singapore government inherited from the British administration – Singapore had both a Central Government and a City Council, which existed "side by side and [were] duplicating each other's functions and activities". For efficiency purposes, various functions of the City Council, including streets, sewage, and public health, were absorbed by the Central Government ministries. In the case of water, this was transferred from the water departments of the City Council to the newly created Public Utilities Board (now PUB National Water Agency) (Parliament of Singapore, 1962).

In 1972, the Public Utilities Act (having become an Act upon Singapore's independence in 1965), was amended to

allow PUB to cut off supplies of gas and electricity in case of emergency, fire and in certain other circumstances and also to cut off supply of water in case of misuse or waste (Singapore Government, 1972). Two years later, in 1974, the Act was amended as Singapore began to licence water service workers, e.g., workers who design, install, construct, erect or repair, or carrying out of any other work on pipes, water fittings, apparatus or appliances which supply fresh water (Singapore Government, 1974).
In the same year, electrical workers and contractors were licensed under the Electrical Workers and Contractors Licensing Act (Singapore Government, 1998). This Act would be repealed in 2001, and the licensing scheme brought under section 82 of the Electricity Act (Singapore Government, 2002a).

In 1991, the Public Utilities Act was amended again to implement a licensing scheme for gas service workers, and to provide for a list of water services works that could be done by non-licensed workers (Singapore Government, 1991).
The Act was repealed and re-enacted in 1995 (Singapore Government, 1995) to allow for the Public Utilities Board to transfer its Electricity and Gas Departments to a private company, Singapore Power Pte. Ltd. Privatisation was part of a plan to allow Singaporeans to buy shares of this new company. The PUB would become a regulator for the electricity and gas service industries (Parliament of Singapore, 1995).

In 2001, the Act was again repealed and re-enacted (Singapore Government, 2001a). This time, the PUB took over the Ministry of Environment's Drainage and Sewerage Departments.
The Act gave the Board a mandate, and the resources, to manage the entire water cycle optimally, opening the way for the Board to begin treating and recycling wastewater.

The Act was amended in 2012 to provide for a new function of the PUB in regulating and managing activities in and around reservoirs and waterways, including the management and maintenance of any dam or boat transfer facility in or connecting to a reservoir (Singapore Government, 2012a).
This new regulatory function was required as a prerequisite for the Board to open up water bodies for community and recreational uses. It allowed the Board to draw up rules and regulations for the proper use of water bodies by the public.
The Act was also amended to properly reflect the Sanitary Appliance Fee and the Waterborne Fee as a tax contribution to the sewerage system (Singapore Government, 2012b).
These fees were previously justified as part of the government's general taxation power (Parliament of Singapore, 2012). Additionally, the Act now included a list of costs that may be included in the price of water supplied by the Board (Singapore Government, 2012b).

In 2018, the Act was amended once again. The water service worker licensing regime was reformed to bring sanitary plumbers into the scheme (who were previously not subject to licensing) (Singapore Government, 2018). This was done over concerns of cross-contamination of the drinking water supply and the sewerage systems, citing the case of Alameda City, California, where a cross-connection between the city's drinking water supply and a non-potable irrigation well rendered parts of the city's water supply undrinkable (Parliament of Singapore, 2018).

Institutionally, in 2004, the Ministry of Environment became the current Ministry of the Environment and Water Resources (2019) in charge of law and policy making in the environmental and water fields. Its two statutory boards, the Public Utilities Board and the National Environment, are in charge of implementing its policy directions (Tortajada *et al.*, 2013).

At present, the PUB is the primary statutory agency which manages Singapore's water supply, as well as its sewerage and drainage networks. Its statutory functions include providing, constructing and maintaining water catchment areas, reservoirs and other works; managing and working water installations; securing and providing adequate supply of water at reasonable prices; regulating the supply of piped water for human consumption; collecting and treating used water (as wastewater is known locally); promoting water conservation; regulating the construction, maintenance, improvement, operation and use of sewerage and land drainage systems; regulating the discharge of sewage and trade effluent[1]; and regulating and managing activities in and around reservoirs, waterways, and water catchment areas (Singapore Government, 2002n-v).

3.2. National Environment Agency (NEA)

NEA was created in 2002 under the National Environment Agency Act by the merger of the then-Ministry of Environment's Environmental Public Health and the Environment Policy and Management divisions, and the Meteorological Service Department (Tortajada *et al.*, 2013). This was to prepare for the streamlining of the Ministry of Environment to become a policymaker in 2004, while the NEA and the PUB would implement Ministry of Environment policies (Singapore Government, 2003a).

At present, the NEA is the primary statutory agency which manages Singapore's sanitation facilities, as part of its wider remit to manage and protect the environment. Its statutory functions include, inter alia, monitoring and assessing the water quality of inland and coastal waters, and managing and regulating the discharge of trade effluent, oil, chemicals, sewage and any other polluting matter into water courses or on land; constructing, developing, managing, and regulating refuse treatment and disposal facilities and regulating refuse collection and disposal; controlling land contamination and regulating the remediation of contaminated land; embarking on educational programmes to promote and encourage public awareness of and participation in environmental matters; making regulations on public cleansing, conservancy and the depositing, collection, removal and disposal of dust, dirt, ashes, rubbish, night soil, dung, trade refuse, garden refuse, stable refuse, trade effluent and other filth; and matters relating to the receptacles used or provided in connection therewith; and regulating the provision and maintenance of sanitary conveniences (Singapore Government, 2002m; 2003b-e).

The Public Utilities Act establishes that the PUB is the only entity allowed to supply water, unless the agency gives written approval to another entity (Singapore Government, 2002w). The quality standards of the water supplied are regulated by the NEA under the Environmental Public Health Act (Chapter 95) (Water suitable for drinking) (Part 1) Regulations enacted in March 2019 (NEA, 2019a) and Environmental Public Health (Water Suitable for Drinking) (No. 2) Regulations 2019 enacted in April 2019 (Singapore Government, 2019).

For water quality and safety standards there is a single set of standards stipulated by the National Environment Agency pursuant to the Environmental Public Health Act (Singapore Government, 2002l). These standards are found in the Environmental Public Health (Water Suitable for Drinking) Regulations 2019 (NEA, 2019a).
These Regulations also require piped drinking water quality to be monitored by the supplier (i.e. the PUB). The specific rules are found in the NEA's Code of Practice on Drinking Water Sampling and Safety Plans (NEA, 2019b) under the provisions of the Environmental Public Health (Water Suitable for Drinking) Regulations 2019 (NEA, 2019a). The water safety and water sampling plan, as well as the annual review of these plans, must be approved by the NEA (Singapore Government, 2008a). The laboratory used to test the samples must also be approved by this agency (Singapore Government, 2008b).

Regarding wastewater, the Environment Protection and Management Act provides that "any person who discharges or causes or permits to be discharged any trade effluent, oil, chemical, sewage or other polluting matters into any drain or land", without a written permission from the NEA, is guilty of an offence. Further, it provides for a statutory presumption that "where any trade effluent…[etc.] has been discharged from any premises into any drain or land, it shall be presumed, until the contrary is proved, that the occupier of the premises… had discharged" the trade effluent, etc. Additionally, any trade effluent, etc., which has been allowed to be discharged into any drain or land by the NEA must first be treated to meet the standards in both the Environmental Protection and Management (Trade Effluent) Regulations (for discharge into watercourses) (Singapore Government, 2008c), or the Sewerage and Drainage (Trade Effluent) Regulations (for discharge into sewers) (Singapore Government, 2007a).

Further, in the case of the Sewerage and Drainage (Trade Effluent) Regulations, persons may seek permission from the PUB to discharge trade effluent with a higher amount of TSS, BOD, or COD, subject to a fee in the case of TSS or BOD. Even then, these higher amounts are still subject to absolute caps (Singapore Government, 2007b).

It is the NEA who is responsible for monitoring water pollution through discharge of waste, pursuant to the Environmental Protection and Management Act (Singapore Government, 2002b).

The discharge of effluents into a watercourse or drain or land requires prior permission from the NEA under the Environmental Protection and Management Act (Singapore Government, 2002b). The discharge of effluents into sewerage requires prior permission from the PUB under the Sewerage and Drainage Act (Singapore Government, 2001b).

Permission to discharge effluents may be revoked or suspended at any time, under the Environmental Protection and Management (Trade Effluent) Regulations, or the Sewerage and Drainage (Trade Effluent) Regulations, as may be applicable. The permission can be revoked or invalidated when the relevant Regulation has been breached, or at the discretion of the NEA or PUB (Singapore Government, 2008d).

The NEA is in charge of the administration of penalties for the pollution of watercourses, and the PUB is in charge of the administration of the penalties relating to discharge of effluent into sewerage. Application of fines in Singapore to enforce regulatory measures is very strict. For example, failure to treat effluents before discharging into watercourses, drains or on land results in fines that do not exceed S$20,000 the first conviction and $50,000 the second or subsequent conviction, with possible imprisonment for 3 months.
The damage of any public sewerage system that renders the sewerage system inoperable or severe disruption to the process of treating sewage, trade effluent or the process of water reclamation due to discharging toxic substances or hazardous substance into sewerage systems results in a fine that does not exceed S$200,000 and/or imprisonment not exceeding 2 years. Penalties by both agencies can be seen in tables 1 and 2 in the Appendix.

It is within this legal, regulatory and institutional framework that is continuously adapted to the changing needs, that the PUB, National Water Agency, has produced reused water for potable and non-potable uses since 2003.
This is analysed below.

04

NEWater

Reused water, planned from the 1970s and first produced in 2013, known as NEWater in Singapore, has been successfully implemented due to support from policymakers and the public in general, within a long-term security framework (Tortajada *et al.*, 2013). It has passed more than 150,000 scientific tests and exceeds the World Health Organisation's drinking water quality standards (PUB, 2017a). Tests are supervised by a panel of local and international experts. Table 3 in Appendix shows typical values of NEWater quality.

NEWater is reclaimed municipal water that augments and diversifies water resources for all users. It is supplied directly for non-domestic purposes to wafer fabrication plants (the largest users) and industrial states and commercial buildings, by designated pipes to all users (shown in purple in Figure 3-1). The venture has been highly successful.

NEWater is also used for indirect potable purposes during dry periods by augmenting water sources in the reservoirs. It blends with raw water and is treated by conventional treatment before being distributed as tap water. Its use for indirect potable reuse represents a small proportion of water demand; however, this proportion can increase when and if necessary (Lee & Tan, 2016).

Figure 3-1 shows the water cycle in Singapore, including the NEWater contribution to the circular economy by closing the water loop and extending the lifetime of water resources through longer use (Ng, 2018), with numerous related economic, social and environmental benefits.
Economic benefits include a growing industrial sector that is supplied with NEWater; socially, it is essential because it provides the water for domestic use during dry periods for the population, and because of the jobs it supports in industrial and commercial sectors. Environmentally, its benefits are unquestionably because wastewater is treated properly before being discharged to the sea.

Currently, NEWater meets approximately 40% of Singapore's water demand. It is expected to meet up to 55% of the demand by 2060, mainly by streamlining the water infrastructure to collect 100% of wastewater.
At present, the Deep Tunnel Sewerage System (DTSS) collects and transports wastewater by gravity to centralised water reclamation plants for treatment. Phase One of the DTSS, which covers the eastern and northern areas of Singapore, was completed in 2008, and Phase Two, which will extend to western areas, is projected to be completed by 2025. The expanded system will augment overall water reclamation capacities. Existing intermediate pumping stations will be decommissioned as they will not be necessary any more (PUB, 2017a).

To produce NEWater, clarified secondary effluent from the treatment processes is introduced as feedwater in the NEWater plant. This secondary effluent is micro-screened before passing through microfiltration or ultrafiltration to remove fine solids and particles, and then further purified with reverse osmosis to remove bacteria, viruses and most dissolved salts. The reverse osmosis permeate is finally disinfected by ultraviolet radiation producing a high-grade, ultra-clean reclaimed water end product, NEWater (PUB, 2015). Improving the process and the technology used in its production is one of the key strategies of the PUB for water demand management with S$77.01 million spent in Research and Development for treatment processes since 2002 (PUB, 2018b). For example, in 2018, in the Phase 4 expansion for the management of industrial used water, the treatment capacity the Jurong Water Reclamation Plant was increased from 204,574 to 259,127 m^3/d by implementing a thermal hydrolysis process. Future capacity improvements are projected for other plants such as in the case of the Changi Water Reclamation Plant, the treatment capacity of which is expected to increase from 918,310 to 1 million m^3/d thanks to the use of membrane bioreactors (PUB, 2018a).

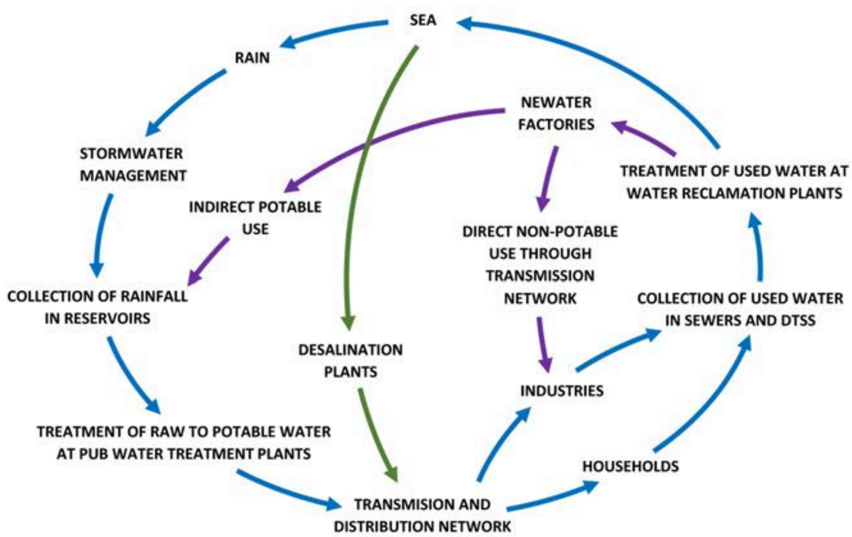

Figure 3-1 Water cycle in Singapore (adapted from PUB, 2018d)

The PUB recognises that urban water resilience is reliant on numerous aspects that include, but are not limited to NEWater. One of the most important aspects is water conservation by domestic and non-domestic sectors (Seah & Lee, 2020), followed by expansion and advancement of water networks, and advance in technological development. As part of resilience building, in 2017 alone, the PUB spent S$733 million in capital expenditure to replace, improve and expand water, wastewater, NEWater, and industrial water infrastructure in the order of S$404.6 million, S$294.6 million, S$13.9 million, and S$19.9 million, respectively. It is important to note that infrastructure is funded from cash generated from revenue collected (net of expenses) and borrowings (PUB, 2018a).

For a circular economy, more efficient use and conservation of (all) water resources is essential. In the case of Singapore, according to the current models used, total water use is expected to more than double by 2060 from 1.9 million m^3/d in 2020 to 4.1 million m^3/d. Approximately 70% of it is expected to be for non-domestic use, for which NEWater and desalinated water are the main water sources. This has enormous implications in terms of energy use as energy requirements to produce NEWater and desalinated water are 5-17 times higher than conventional treatment methods.

With the expected increase in non-domestic water use and, if current technology did not improve, the energy footprint to produce both NEWater and desalinated water would increase from the current 1,000 GWh/year to 4,000 GWh/year in 2060 (PUB, 2018c). PUB's target at present is thus to reduce both water consumption of all users (mainly non-domestic) and energy consumption, mainly of the desalination processes, by more than half from the current 3.5 kWh/m^3 to 1.5 kWh/m^3 in the short term, and to 1 kWh/m^3, as a system, in the long-term. Regarding NEWater, PUB's short-term target is to increase its recovery rate from the current 75% to 90% at the same energy consumption of 0.4 kWh/m^3 for its energy-intensive RO treatment stage. In order to improve technology with the previous objectives, between 2002 and 2018, PUB, research partners, and the Singapore National Research Foundation, have invested S$453 million in over 600 water projects (PUB, 2018b).

With the aim to achieve water use efficiency and conservation, PUB provides technological support to all companies. As a result, there are companies that are now using less potable water; others are replacing potable water use with NEWater use; and some others are using less NEWater and/or replacing it with desalinated water. For example, Systems of Silicon Manufacturing Company (SSMC) reports that their water consumption has reduced, and that water reclamation rates have increased from 50 percent in 2011 to 80 percent in 2015, resulting in an annual reduction of potable water of approximately 1 million m^3 since 2003. Companies like Mitsubishi Heavy Industries-Asia Pacific (MHI-AP) are in the planning stage to reduce consumption of NEWater replacing it with desalinating water for cooling purposes, and diverting surplus NEWater for other uses. The objective is to reduce consumption of potable water, first, and then of NEWater, for efficiency purposes and with the resulting reduction in infrastructure development investment.

There are also companies that are constructing recycling plants to reuse more water in their own processes. In one of the cases, a recycling plant under construction will be able to treat 2,000–2,500 m^3/d, increasing its water recycling rate from the current 18 percent to 41 percent and reducing NEWater consumption by 2,000 m^3/d. A key component of water conservation for non-domestic users has been to understand industries' water needs, which it is done as much as possible.

05

Final Remarks

With the objective to achieve water security, Singapore has diversified its water resource alternatives within a forward-looking, long-term framework, which has ensured it can meet present and estimated future water requirements. These strategies have included support from the highest political level, within institutional and legal frameworks that are modified and improved when and as required.

> *“Water, being fully recyclable, is the archetypical circular economy resource.”*

Singapore implemented water reuse in 2003, at a time when Windhoek, Namibia, and Orange County, California, had already been producing reused water for several decades, in the case of Windhoek for direct potable reuse (Tortajada & van Rensburg, 2020). Singapore studied their experiences and established its own system, achieving industrial large-scale implementation and wide public acceptance for indirect potable use thanks to comprehensive education and communication strategies.

Singapore's framework for water reuse within the concept of a circular economy focuses on implementing a closed system where, instead of discharging treated wastewater into the sea, this resource is treated further to produce NEWater. This water is used then directly for non-potable uses (industrial and commercial uses) and indirectly for potable reuse (domestic use). Behind the circular economy concept, there are robust legal, institutional, managerial frameworks which aim at a mostly successful system that protects human health and protects the environment.

Water, being fully recyclable, is the archetypical circular economy resource. In the city-state, the trigger to develop a “circular water approach” was the realisation, shortly after independence, that water recovery and reuse through unconventional sources of water, was necessary and was possible. This meant incorporation of water resources management tools within a circular economy approach where wastewater is not discharged to the sea after treating it, but further treating it and reusing it for social and economic applications. This will ensure Singapore water security towards the future.

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Notes

1. "Trade effluent" means any liquid, including particles of matter and other substances in suspension in the liquid, which is the outflow from any trade, business or manufacture or of any works of engineering or building construction.

Appendix

Table 3-1 Penalties according to the National Environment Agency

Offence	Penalty
Failure to inform the National Environment Agency of a discharge of effluent into watercourse/drains or on land without permission	Fine not exceeding $5,000 (Singapore Government, 2002c)
Failure to obtain permission from the National Environment Agency prior to discharging effluent into watercourse/drains or on land	First conviction: Fine not exceeding $20,000; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002i) Second or subsequent conviction Fine not exceeding $50,000; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002j) The National Environment Agency may also seek compensation through the courts for amount of any expense in connection with the execution of any work, with interest (Singapore Government, 2002k)
Failure to treat effluent to the standards in the Environmental Protection and Management (Trade Effluent) Regulations	First conviction: Fine not exceeding $10,000; and a further fine not exceeding $300 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2008e) Second or subsequent conviction Fine not exceeding $20,000; and a further fine not exceeding $500 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2008f)
Failure to treat effluent before discharging into watercourse/drains or on land	First conviction: Fine not exceeding $20,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002d) Second or subsequent conviction Fine not exceeding $50,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002e)
Discharging toxic substances or hazardous substances into watercourse/drains or on land	First conviction: Fine not exceeding $50,000 / imprisonment for a term not exceeding 12 months, or both (Singapore Government, 2002f) Second or subsequent conviction Fine not exceeding $100,000 and imprisonment for a term not less than one month and not more than 12 months (Singapore Government, 2002g)
Failure to comply with a notice by the National Environment Agency to remove/clean up toxic substance or trade effluent, oil, chemical, sewage, hazardous substance or other polluting matters which that person has discharged	Fine not exceeding $50,000 (Singapore Government, 2002h)

Table 3-2 Penalties according to the Public Utilities Board

Offence	Penalty
Failure to obtain permission from the Public Utilities Board prior to discharging effluent into sewerage system	Fine not exceeding $20,000; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001b)
Failure to treat effluent to the standards in the Sewerage and Drainage (Trade Effluent) Regulations	Fine not exceeding $15,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $500 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2007c)
Discharging toxic substances or hazardous substances into sewerage system	First conviction: Fine not exceeding $50,000 / imprisonment for a term not exceeding 12 months, or both; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001c) Second or subsequent conviction: Fine not exceeding $100,000 / imprisonment for a term not exceeding 12 months, or both; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001d)
Causing (a) injury or death to any person; (b) damage to any public sewerage system which renders the sewerage system inoperable; or (c) severe disruption to the process of treating sewage or trade effluent or the process of water reclamation, by discharging toxic substances or hazardous substances into sewerage system	Fine not exceeding $200,000 / imprisonment for a term not exceeding 2 years, or both (Singapore Government, 2001e)
Failure to comply with an order by the Public Utilities Board to stop discharge of trade effluent containing dangerous or hazardous substance into sewerage system	Fine not exceeding $40,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001f)

Table 3-3 PUB NEWater Quality (Typical value) (Source: PUB, 2017b)

PUB NEWater Quality (Typical value)			
Characteristics	**Unit**	**WHO 2016 GV** (First Addendum to 4th Edition)	**Typical value**
Microbiological Parameter			
Escherichia coli (E. coli)	cfu/100 mℓ	<1	<1
Heterotrophic Plate Count (HPC)	cfu/mℓ	-	<1
Physical Parameters			
Colour	Hazen	-	<5
Conductivity	uS/cm	-	<250
Chlorine	mg/ℓ	5	<2
pH Value	Units	-	7.0-8.5
Total Dissolved Solids (TDS)	mg/ℓ	-	<150
Turbidity	NTU	5	<5
Chemical Parameters			
Ammonia (as N)	mg/ℓ	-	<1.0
Aluminium	mg/ℓ	-	<0.1
Barium	mg/ℓ	1.3	<0.1
Boron	mg/ℓ	2.4	<0.5
Calcium	mg/ℓ	-	4-20
Chloride	mg/ℓ	-	<20
Copper	mg/ℓ	2	<0.05
Fluoride	mg/ℓ	1.5	<0.5
Iron	mg/ℓ		<0.04
Manganese	mg/ℓ		<0.05
Nitrate (as N)	mg/ℓ	11	<11
Sodium	mg/ℓ		<20
Sulphate	mg/ℓ		<5
Silica (as SiO_2)	mg/ℓ		<3
Strontium	mg/ℓ		<0.1
Total Trihalomethanes Ratio		<1	<0.04
Total Organic Carbon (TOC)	mg/ℓ		<0.5
Total Hardness (as $CaCO_3$)	mg/ℓ		<50
Zinc	mg/ℓ		<0.1

II

Decision-Making for Water Reuse

4

Water Availability and Water Reuse: A New Approach for Water Resources Management

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Abstract

This paper highlight the importance of studying water availability which integrates its quantity, quality and purpose as essential for decision-making regarding the introduction of reuse systems based on the circular economy. Water resources management in Brazil has been developed in a traditional manner (linear model), considering water use by society and returned to the rivers as wastewater. Introducing water reuse systems breaks the linear economy and transforms it into a circular economy model, where the wastewater is no longer a waste product but a resource for potential use. This research aims to evaluate the water availability, including not only the volume of water, but also the variability of water quality, and, additionally, considering treated sewage effluents as available water for industrial use. In order to estimate the importance of a holistic assessment of water resources availability, a case study on the Iguazu river in Brazil was carried out. Due to water quality data scarcity, there were two approaches to permit working with BOD concentration variability. The first strategy consisted in fitting a statistical regression of measured BOD with associated flow, using the statistically established relationship, and then, monthly series of BOD concentrations were generated. The second strategy was to simulate with AcquaNet software the upstream released loads by the water users as, assuming there were no initial concentrations in the river. Eleven scenarios were introduced to assess the impacts on water availability for the user itself, for other users in the region, as well as the availability in the Iguazu River considering: (i) variations in the volume of water abstracted; (ii) the reused water from the WWTP; (iii) the reused water from the industrial wastewater. The average BOD concentration in the river due to upstream releases results 3.2 mg/ℓ.
This means that water abstracted from the river at this point of the Iguazu River is already an indirect reuse process, which concentrations of organic material from released effluents upstream have not fully assimilated until this point.
The result demonstrates, how in regions where the river has experienced degraded water quality, the inclusion of reuse systems may be even more interesting from the point of view of the economics of treatment requirements than of river water abstraction. Finally, this paper presents many concepts that have been previously addressed individually and how to integrate them to subsidise the development of the circular economy in urban water resources management.

Keywords

Water availbility, water reuse, circular economy, water resources management

01

Introduction

This paper reflects on the importance of studying water availability which integrates its quantity, quality and purpose as essential for decision-making regarding the introduction of reuse systems based on the circular economy.In order to understand the relevance of changing the management of the water resources into a circular economy model, this paper reviews the status quo of the water resources management in Brazil.

The next topic considered is the concept of water availability in the world. It was found there is no consensus on the said concept. It is suggested in this paper the concept of water availability based on water quantity, quality and purpose that supports the decision-making of water resources stakeholders.

> *"The water discharged from WWTP is not necessarily returned to the original watershed from which it was withdrawn. The large volume of water transferred to other watersheds impacts the environment and the economy."*

Many guidelines address the introduction of water reuse systems such as EPA's Guidelines for Water Reuse (2012). In Brazil, Hespanhol (2002) approaches the legal and cultural aspects of the introduction of water reuse. However, before this study, it is apparent a lack of scientific literature that approaches the subject of water availability in urban water resources management regarding the circular economy (Stefan, 2019).

In order to estimate the importance of a holistic assessment of water resources availability, a case study on the Iguazu river in Brazil was carried out. This study shows the industrial stakeholder the following possibilities of the river's water availability: an increase in captured volume, reuse of water from a wastewater treatment plant and/or water recycling. This study also shows the point of view of water availability throughout the river, raising arguments concerning the allocation of water resources.

Finally, this paper presents many concepts that have been previously addressed individually and how to integrate them to subsidise the development of the circular economy in urban water resources management.

02

The Current Paradigm of Urban Water Resources Management

Water resources management has been developed with a focus on meeting the human consumption demands and entrenching a linear economy model: water withdrawal, purification, consumption, wastewater treatment and return to the rivers.

Concerning the water withdrawal step, a relevant fact is that water availability is affected by temporal and spatial changes. Additionally, the increasing population density is creating a stressed hydrologic scenario in metropolitan regions. Another factor is water quality conditions as a consequence of anthropic influences. According to the Brazilian Water National Agency (ANA), just 7% of water quality from urban rivers, considering Brazilian Metropolitan areas, are classified as excellent (ANA, 2019).

Brazil, despite having the largest freshwater supply in the world, with 12 per cent of the entire planet's total volume, faced a water crisis between 2012 and 2016. According to ANA(2014), the crisis started because of the increased water demand, poor water quality of local rivers, and a shortage of rainfall, causing hydrologic stress. This crisis required emergency measures, such as water rationing and incentives to save water. Although there was a gradual recovery in 2016 with an increase in rainfall, that alone does not ensure another water crisis will not happen.

Traditionally, the water is treated to meet drinking water standards and it is then distributed to different users. However, the water quality requirements are different among the users: industrial, agriculture and domestic. Using drinking water for purposes for which the high water quality is not required causes a negative impact on economic, energy and environmental aspects (EPA, 2012).

After the water use, in urban centers with sewage infrastructure, once potable water is used, it is conveyed to a wastewater treatment plant (WWTP) and then it is discharged to a river, lake or other surface waterbody. The water discharged from WWTP is not necessarily returned to the original watershed from which it was withdrawn. The large volume of water transferred to other watersheds impacts the environment and the economy (Hespanhol, 2008).

03

Water Availability: The Decision-making Key

Evaluating water availability is paramount to management strategies and plans to make decisions about which source to use, how to allocate water, choice of the best performing process and to ensure water for every user.

Natural processes such as rainfall, evapotranspiration and human interventions such as hydraulic infrastructure, affect water flow, making water availability a complex variable to estimate.

Falkenmark (1989) defined blue water indices based on per capita water resources. Regions with more than 1,700 m^3 per inhabitant per year (/ inhab.year) of water were considered outside the water deficit zone, whereas lower per capita volumes are considered a water stress situation. More critical water deficit conditions, when the water volume is below 1,000 m^3 / inhab.year, are defined as water scarcity, and absolute scarcity occurs when the water volume does not exceed 500 m^3 per inhabitant per year (Xu & Wu, 2017).

On the other hand, Jia *et al.* (2019) points out the necessity to evaluate an indicator of water availability including not only the water volume, but integrating water quantity with quality, and also considering wastewater as a source.

The water quality is also important to determine water availability. Compromised water quality might prevent its immediate use for some purposes, however, it can be used to other ends. In order to attend a specific industrial or agriculture demands, Suspended Solids (SS), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) are relevant water quality parameters to be used as control parameters (JIA *et al.*, 2019).

Figure 4-1 *Water Availability Concept*

Wastewater should be considered a source of water and be included in water availability estimations, since some water might be available depending on its purpose. After all, wastewater has the potential for direct use before undergoing treatment that meets the specific criteria for the intended use as water reuse. In this context, the water purpose concept should not be confused with the concept of water user, since one user at the same site might use water in several distinct processes for different purposes, and each of these purposes may have a particular demand for water quantity and quality. Then, it is also important to partition the demand by quality requirements to evaluate real water availability.

There is no consensus on a definition of water availability and how to estimate it from a perspective of circular economy. There are several indices and indicators that attempt to generate more awareness of the urgency to protect water resources, to mitigate problems related to water scarcity and to promote sustainable use. In order to break the linear logic of water resources management and to develop an integrated system promoting a circular economy, water availability should integrate not only the volume of water available but also the quality and the different water purposes, as summarized in Figure 4-1.

3.1. Urban Water Resources Management and Circular Economy

The assessment of water availability in the triad of quantity, quality and purpose is fundamental for the transformation of water resources management and with the view of closing the loop of water use, as well as closing the loop of the soluble matter that water carries.

Figure 4-2 illustrates the diversity of pathways from water purification (WTP) and wastewater treatment/reuse systems (WRT) that water may follow according to different uses and purposes.

There is this misperception of evaluating water in absolute terms only in volume and not considering the fact that it is normally carrying various compounds, which also have their own natural cycles in the environment. In order to choose the proper pathway water will follow, whether returning to water bodies or being reused, its transport in volumetric terms (quantitive measures) and concentration of environmental relevant chemical elements must be taken into account (qualitative measures). It is relevant to consider the natural hydrological cycle, the cycles of nitrogen, phosphorus and other substances that are normally carried by the water.

The linear model in the use of natural resources is responsible for these contradictions, in which it is possible to observe water bodies polluted and eutrophicated due to nutrient enrichment, while agricultural land is lacking nutrients and making use of fertilizers.

The introduction of reused water into the current water use model transforms the water system from a linear model to a circular model concept. The water reuse system can be either on the micro-scale (e.g. reuse within an industry itself) or macro-scale (among different users). Household wastewater might be reused for irrigation in agriculture or industry, after appropriate treatment for each use.

This systemic approach to water management disrupts the linear model of wastewater disposal and reintroduces water, with a new approach within the context of the water cycle and water carried compounds, establishing a still-developing conceptual challenge that might potentially promote economic and environmental gains.

3.2. What to Expect from the Future of Urban Water Resources Management?

The need for urban model reformulation is required, specially after the latest water crisis events in Brazil (ANA, 2014). The current model has long been developed without regulation for integrating with new strategies and ideas for including circular economy concept. This caused a conservative water resources planning and management plans, focus on achieving effluents regulations. Clearly, there is a very high-level water supply (drinking water) for different uses (such as industry and agriculture), and disjointed from natural resources cycles.

The introduction of reused water systems positively impacts the water availability of the basins, as they act to directly reduce the need for water withdrawal and decrease the volume of effluents returned. This allows a larger volume of water to be available for other uses in the basin. Treated sanitary effluent is no longer a disposal but a water resource with potential use for specific purposes.

Another positive impact is the environmental benefit, whereby water from the wastewater treatment plant is no longer discharged into rivers, which mainly reduces the input of nutrients into recipient bodies, thereby increasing water availability in terms of quality for other uses.

The path that water should take between returning to water bodies and / or recycling for different uses should focus on the development of a sustainable strategy for economy criteria and water quality recovery. In this context, the water availability study of the Iguazu River at MRC, integrates the consideration of effluents as potentially reusable water, thus encouraging users to choose practices such as the introduction of reuse systems, and consequently the transformation of water resource management into a circular economy system.

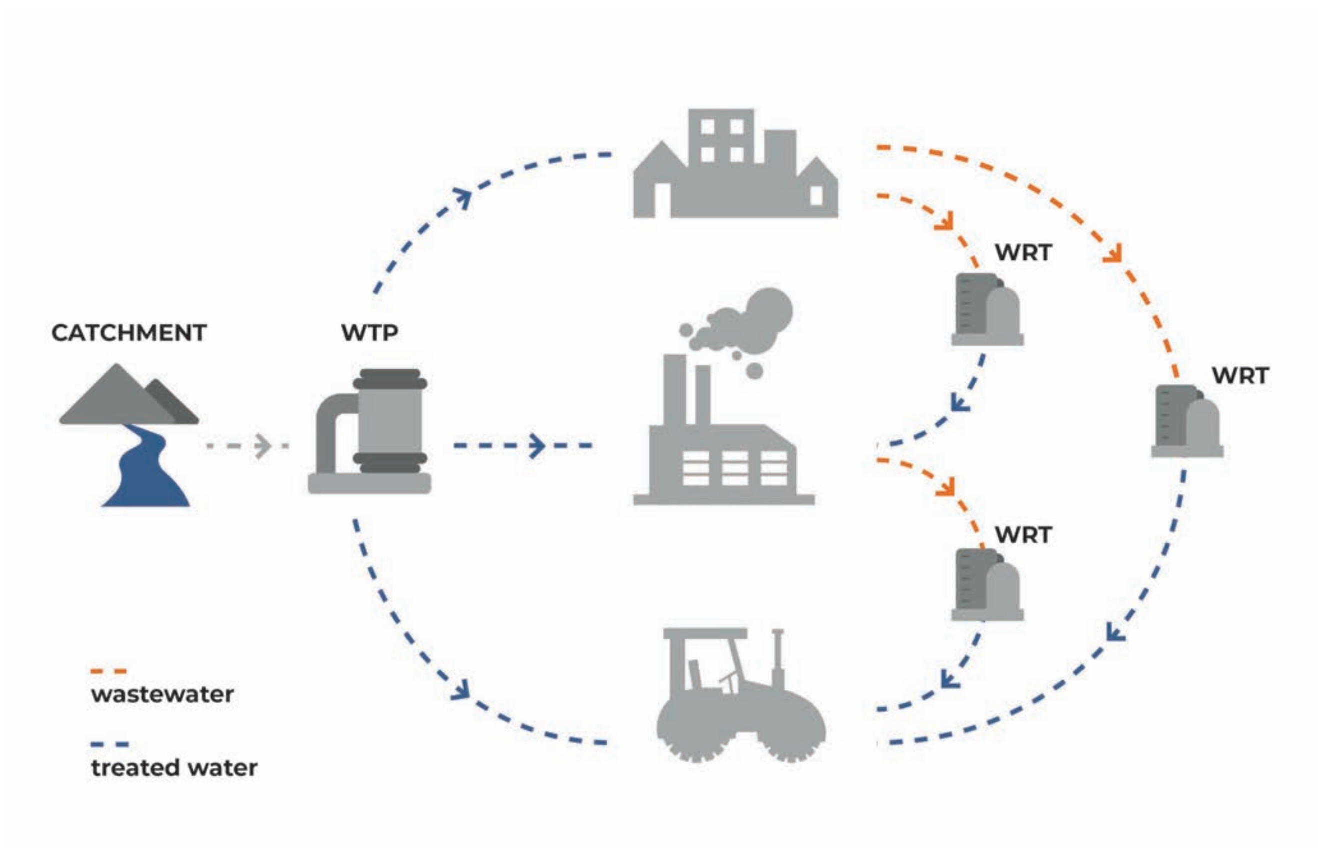


Figure 4-2 *Ilustrated water pathways possibilites*

04

Case-study on Urbanized Brazilian River: Iguazu River at MRC

The Iguazu River is known by the Iguazu Waterfalls, which is the largest waterfall system in the world, in terms of volume and elevation change. Figure 4-3 shown the Iguazu River located. The river headwaters are in the metropolitan region of Curitiba in Brazil, with a population of nearly 3.5 million people (IBGE, 2017), and plays an important role to multiple users in this region. The industrial sector is expanding and water is a limiting factor. Currently, the industry is supplied by a water treatment plant located on the Iguazu River, attending the industrial demands.

From the source of the Iguazu River at MRC to the monitoring point of the study for water availability, there are 4 points for monitoring the water quantity and quality. The river water quality is degraded with measured BOD concentration ranging from 25 to 65 mg/ℓ (Knapik, 2014). The main Iguazu River releases for dilution comes mainly from three sources: wastewater treatment plants, landfills and industry.
The largest portion of BOD load released, comprising 97% of the BOD loading, comes from the WWTPs. Although the effluent volume permitted by the industry is close to those granted for landfill effluents, the BOD load from landfill effluents is four times higher than that released by the industry (Stefan, 2019).

The study area has peculiar characteristics, located in the Araucaria industrial region, after the it passes through a highly urbanized region. Figure 4-4 shows the current framework of the waterways at the study point. Approximately 50 meters upstream from this monitoring point is the industry intake water treatment plant (WTP Ind), which is responsible for the industry's water supply demand. As shown in Figure 4-4, downstream of the monitoring point, also approximately 50 meters away, is the Araucaria wastewater treatment plant (WWTP Cachoeira).

4.1. Methods: Assessing Water Availability

4.1.1. Water Availability: Quantity and Quality

Available water quantity on this interest site was evaluated using historical series with monthly waterflow over 12 years. The chosen quality water parameter was Biochemical Oxygen Demand (BOD). Due to water quality data scarcity, there were two approaches to permit working with BOD concentration variability.

The first strategy is illustrated at Figure 4-5, consisted in fitting a statistical regression of measured BOD with associated flow, using the statistically established relationship, and then, monthly series of BOD concentrations were generated.

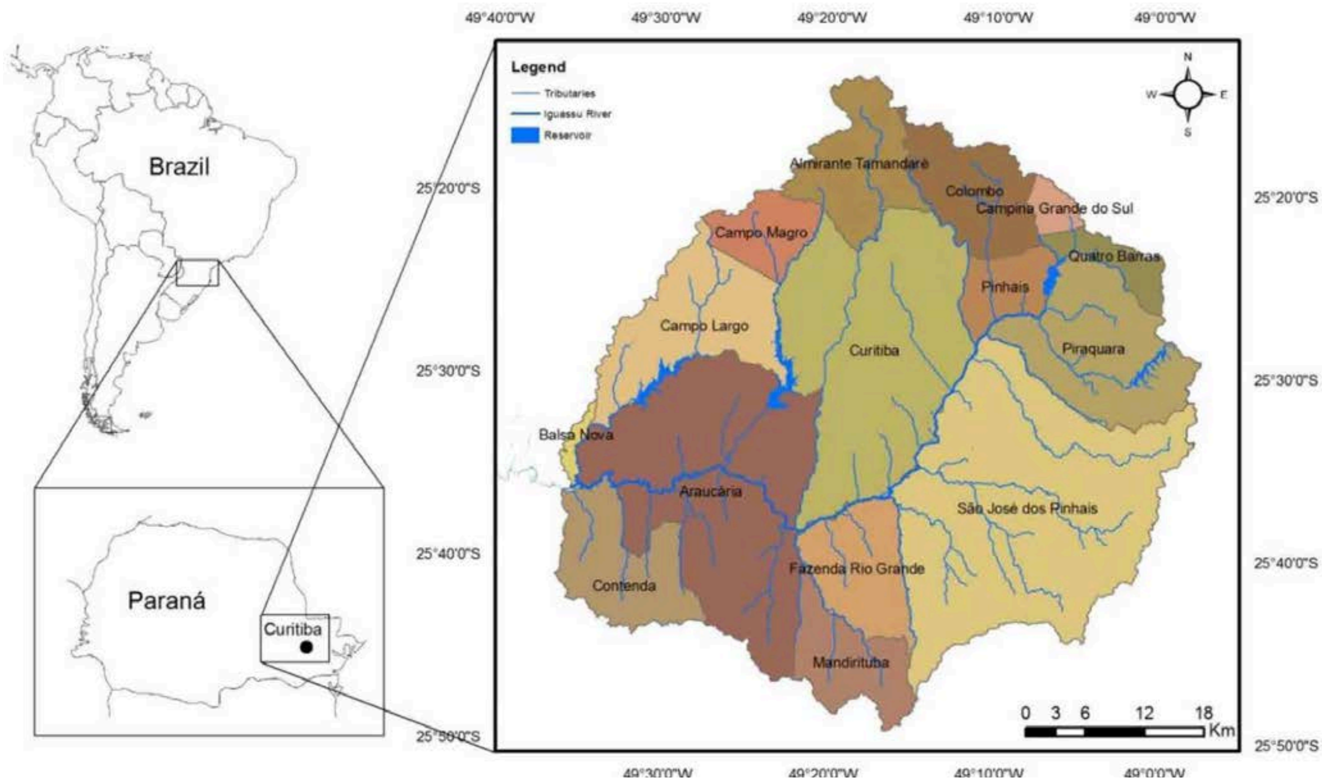


Figure 4-3 Iguazu River Location (Source: Knapik, 2014)

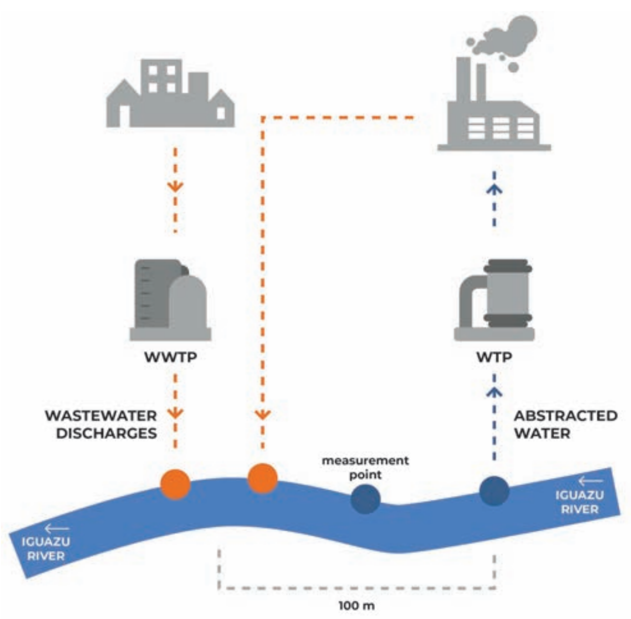


Figure 4-4 *Current framework of the waterways at the study point*

The second strategy was to simulate the upstream released loads by the water users as, assuming there were no initial concentrations in the river. The Figure 4-6 is an illustrative figure of the Iguazu River in the study region showing the locations of wastewater discharge, water withdrawals, and monitoring points on the river is introduced.

To this strategy was simulated using AcquaNet network flow model (AcquaNet, 2013). Acquanet is a Brazlian free software based on the ModSim Model (Labadie, 2006). The components of the water resources system might be represent by nodes (reservoirs, demands, confluences, withdrawals and so forth) and links (stream reaches and canals). The water quality module of AcquaNet allows the simulation of concentrations of: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), total phosphorus, total fecal coliforms, organic nitrogen, ammonia, nitrate and nitrite. To simulate the users BOD loads and water demands on Iguazu River at MCR were obtained on Paraná Water Institute and designed the Iguazu network flow on AcquaNet.

To understand how much water quantity and concentration load is available, a statistical analysis was performed using monthly mean flow and observed concentrations. The frequency analysis adopted is the duration curve, which consists in calculating the percentage of cumulative frequency. The cumulative frequency is interpreted as the percentage of time when the flow or the concentration were exceeded.

4.1.2. Water Reuse Scenarios – Closing the Loop of Water Use

In order to understand the impact on water availability that the closing of water cycles were considered two water reuse systems in the study area. Figure 4-7 illustrates the wastewater from WWTP and from industries that was previously discarded into Iguazu river being reused.

The first system assumed reuse among users, in which the industry user reuses the effluent from the municipal

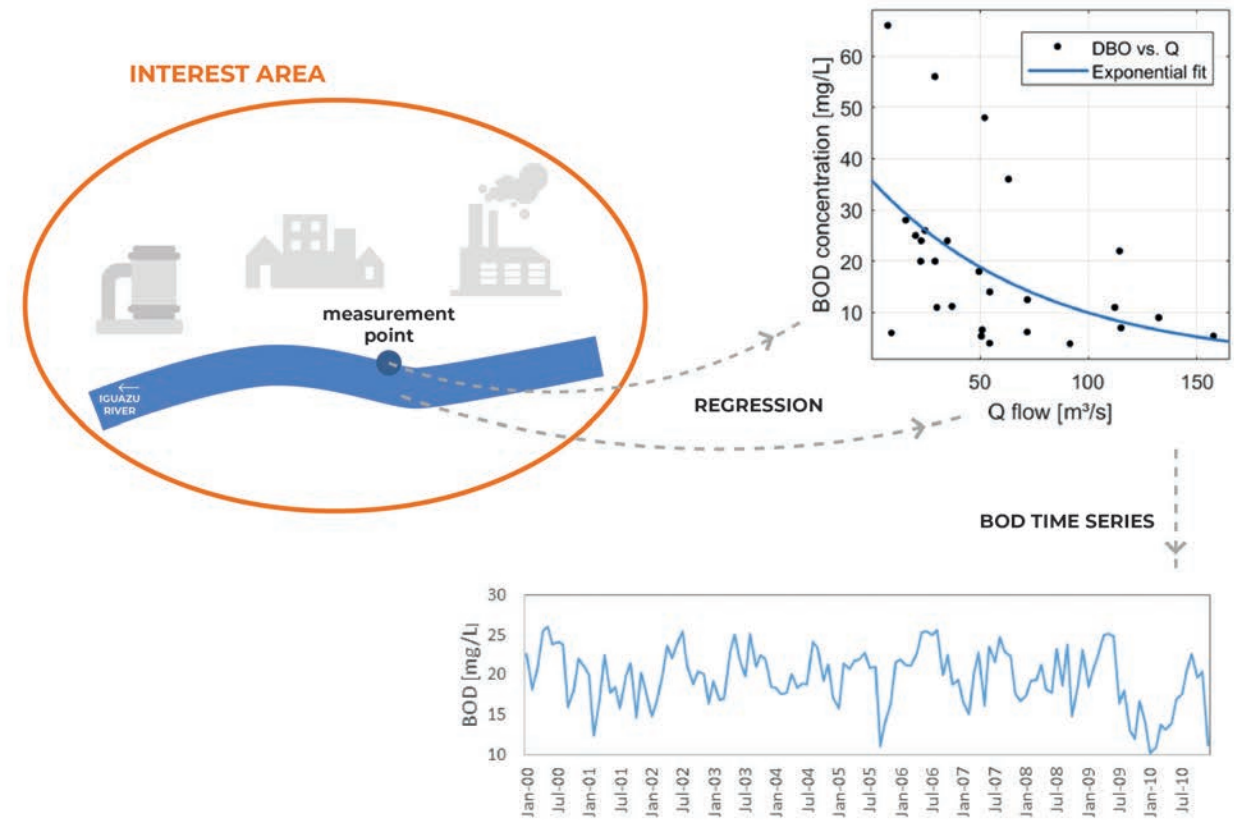


Figure 4-5 *Strategy for obtaining BOD concentration serie by regression*

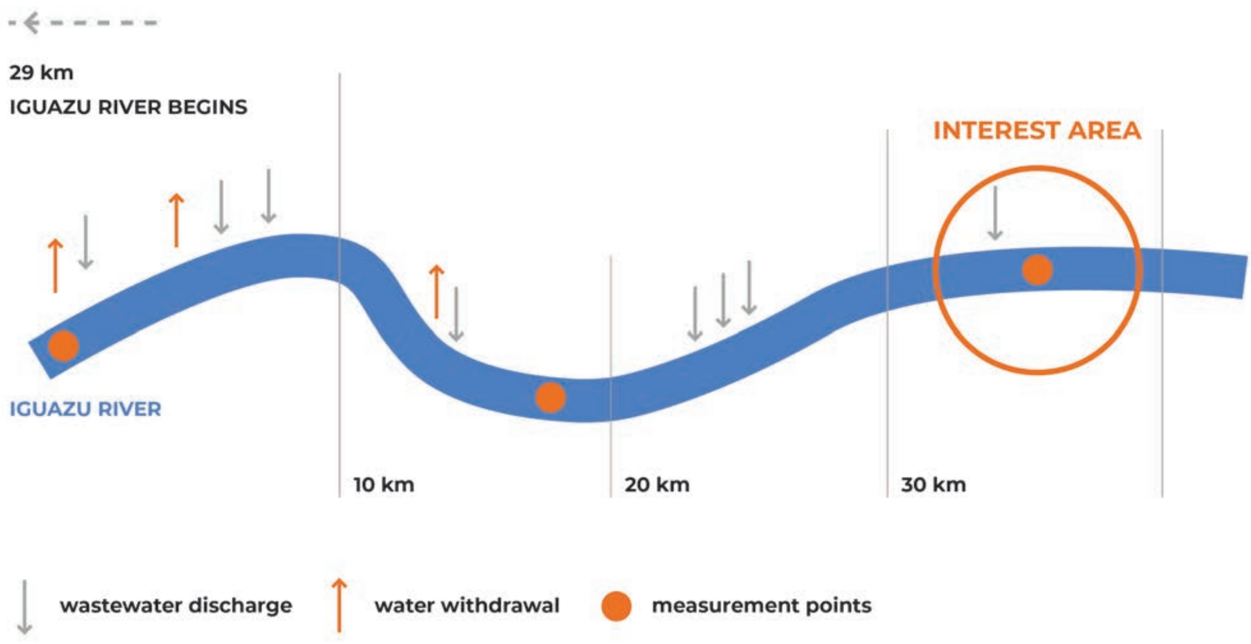


Figure 4-6 Strategy for obtaining BOD concentration serie simulating the upstream released loads

Wastewater Treatment Plant (WWTP). The WWTP treats the effluent from the MRC and releases a volume of 0.16 m^3/s with a concentration of 90 mg/ℓ BOD after treatment into Iguazu river. The second system considered the reuse of water by the industry itself. For this estimation an industry release concentration of 10 mg/ℓ BOD was assumed and the flow rate equal to 80% of the abstracted water volume by the industry. Currently the industrial region abstract a quantity 0.45 m^3/s from the Iguazu river that passes through a water treatment plant (WTP).

Eleven scenarios were introduced that vary from one to another, with variations in the volume of water abstracted, the reused water from the WWTP and the reused water from the industrial wastewater in order to assess the impacts on water availability for the user itself, for other users in the region, as well as the availability in the Iguazu River. The wastewater treatment plant efficiency required to meet an industrial demand for BOD of a maximum concentration of 10 mg/ℓ was calculated. As to calculate its efficiency, it was assumed that the water quality could not under any circumstances be higher than 10 mg/ℓ for use by the industry for limiting release concentration in the river. The amount of annual treated load for each scenario was calculated based on the annual variation of the concentrations present in the river added to the loads from treated water recycling.

The water withdrawal rate was defined as the fraction of the abstracted volume from river in relation to the maximum volume that potentially could be abstracted, that according to bazilian regulations to Iguazu river is 50% from the volume with the frequency of 95% time.The recycle rate of the municipal WWTP is the percentage of water actually reused as a ratio of the total volume that can be reused, which was considered the actually treated effluent volume and concentration realesed into the river, a constant equal to the currently flow rate, 0.16 m^3/s, and also the constant concentration of 90 mg/ℓ BOD.

The industrial effluent water recycling rate is the percentage of the total volume that can be reused, which is variable, since the water returned by the industry is proportional to volume of water withdrawl from the river, which was considered variable among the scenarios.
In this analysis, it was assumed that 80% of the water taken in by the industrial facility's WPP was returned as effluent from the industrial process. With respect to water quality, the concentration of BOD of the industrial effluent was assumed to be constant equal to 10 mg/ℓ, a value adopted under the hypothesis of conservation of the water quality in the industrial use, being the same concentration treated for the use.

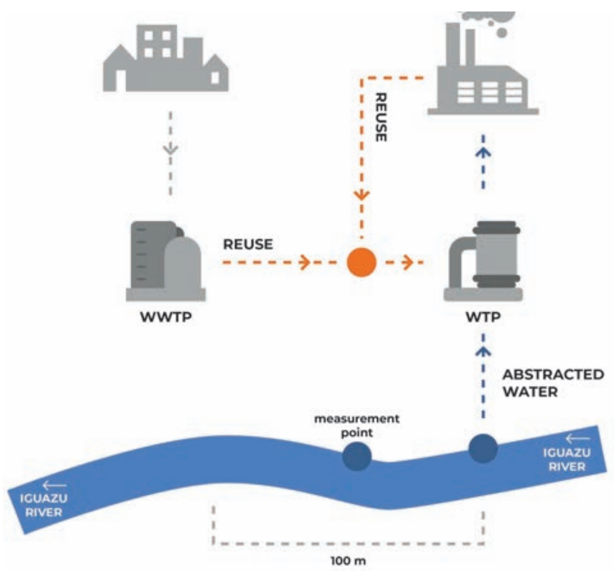


Figure 4-7 Closing Loop with water reuse in the study case. Orange node is an artificial node to illustrated the water reuse system studied.

05
Results

5.1. River Water Availability Results

The results of the water availability analysis for decision making on how to introduce circular economy model and the water reuse systems as water resources planning and management strategy are presented.

The Figure 4-8 shown below results of river water availability:

- **Water Flow**:
  With 12 years of monthly average flow data was calculated month by month the flow that is occurring 95% of the time. The dashed line represents the flow occurring 95% of the time over the years.
- **BOD concentrations from upstream users discharges**:
  With 12 years of monthly average flow data and the concentrations released by users upstream of the study point, the BOD concentration occurring 95% of the time was calculated month by month.
- **BOD concentrations by measured samples regression**:
  With 12 years of monthly average/ flow data and the concentrations measured at the study point, the 12-year BOD concentration series was regressed and the BOD concentration occurring 95% of the time was calculated month by month.

The assessment of water availability in this monitoring point at the Iguazu River at MRC is associated to possible limits of withdrawing water to ensure minimum flow for preservation of the aquatic environment and also for other users.
Analyzing the quantity of water in the Iguazu River, the flow frequency of 95% of the time is at least 15.52 m^3/s (Stefan, 2019). Figure 4-8 is the monthly flow analysis indicating between the months of April to August presented a volume lower than 15.52 m^3/s. This monthly volume difference between and the one with the 12 years of data may lead to a misallocation of water, which would be considered a large amount of water available in times of drought.
It is expected that with this amount of water, especially during drought seasons, one strategy would be consider the potential saved treated water with this potential volume for industrial reuse.

The average BOD concentration in the river due to upstream releases is 3.2 mg/ℓ. This means that water abstracted from the river at this point of the Iguazu River is already an indirect reuse process, which concentrations of organic material from realesed effluents upstream have not fully assimilated until this point. One potential strategy to water management may be the requirement for releases with lower pollutant loads upstream, which would provide the downstream users with better water availability. Thus, the responsibility for handling that load is returned to the polluting user rather than the downstream river water user.

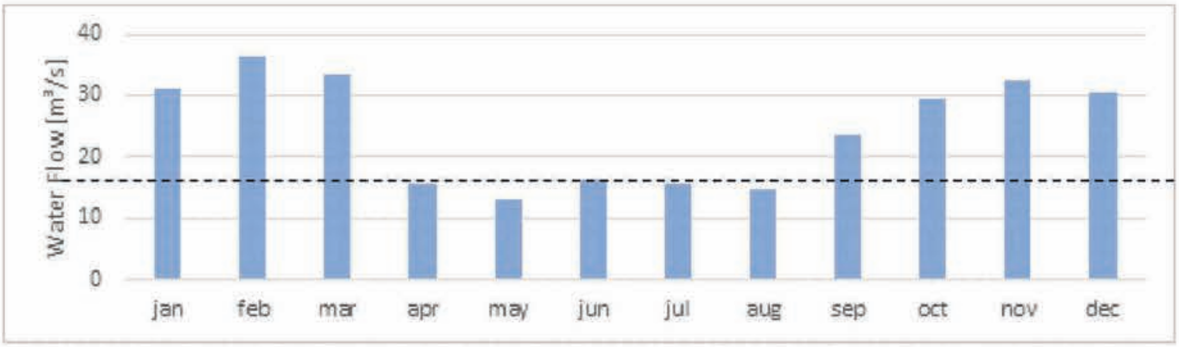
The mean BOD concentration using the regression of the sampled data was 19.53 mg/ℓ. This difference is due to the fact that, in addition to the contribution of the loads released by users, there are several diffuse loads, such as the natural flow from the river beds, from surrounding agricultural areas, and also the possibility of releases that are not legally registered. This result emphasizes the need for constant monitoring of the waterbody's quality.

As verified in terms of the flow between April and August, during a period with less rain, less water is present at the monitoring point in the Iguazu River. Lower river flows negatively affect the BOD concentration levels since there is a smaller volume of water for dilution of effluent releases. Therefore, a higher concentration of BOD might be observed between April and August, during the driest period.
This result allows a conclusion about the water availability of the river in terms of quantity and quality: from September to March it would be possible to optimize the use of water, both for the catchment and for effluent dilution, whereas between the months of April to August water availability is lower.

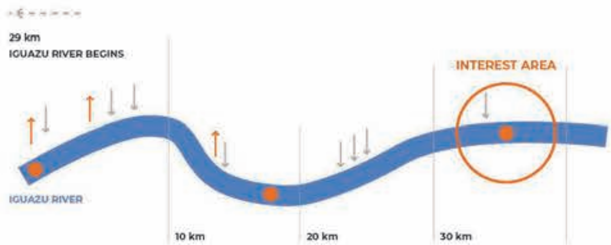
RIVER WATER AVAILABILITY

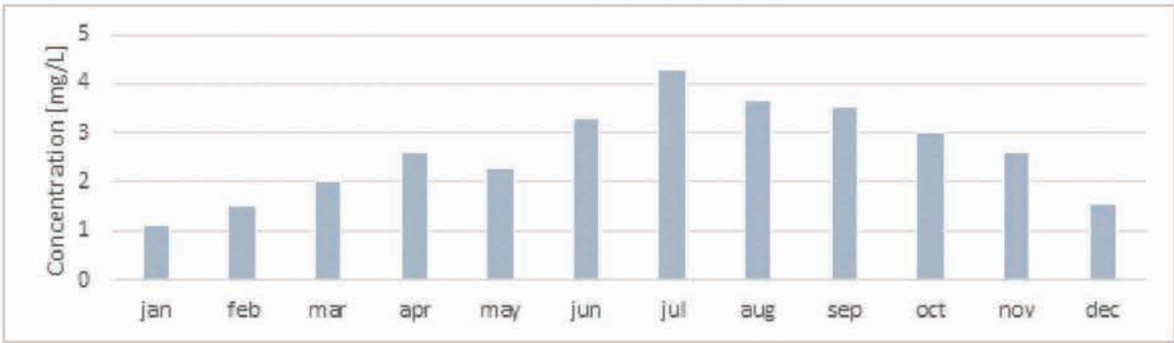
(Below charts show the monthly values with 95% frequency)

WATER FLOW

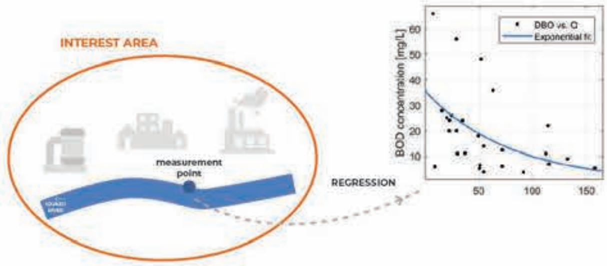


BOD concentrations from upstream users discharges





BOD concentrations by measured samples regression



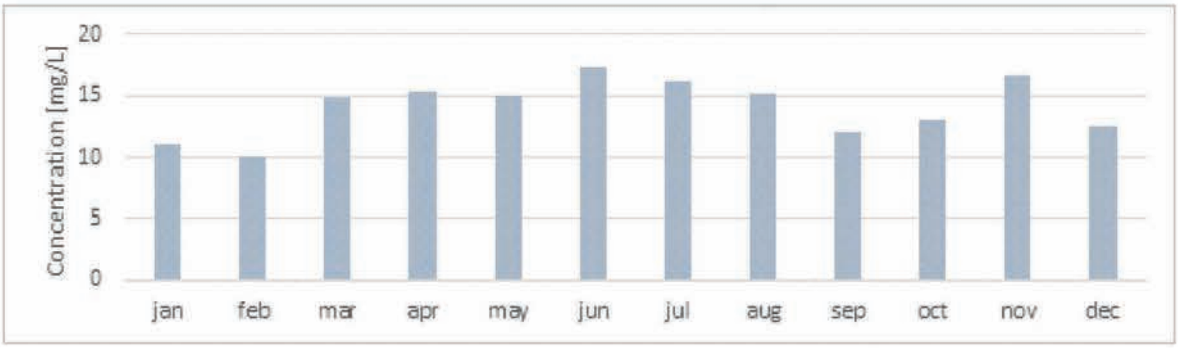


Figure 4-8 River Water Availability (95% frequency monthly flow serie)

5.2. Water Availability with Water Reuse

Table 4-1 describes the water fractions used among the different water sources: river water abstraction, WWTP effluent reuse and industrial effluent reuse. The results presented in Table 4-1 are the water availability for the user and the water availability in the river. The introduction of reuse gives the user the responsibility for water treatment and eases the pressure on the water body, so the results should be analyzed together.

The evaluated results are the water availability for the industrial user and the water availability in the river. Water availability for the industrial user has the following parameters:

Total volume of water available: sum of the volume of water captured with the volumes of water reused.

Total BOD load treated per year: considers the river load (BOD concentration temporal serie by measured samples regression) added the reused effluent loads considering constant concentration (WWTP effluent concentration = 90 mg/ℓ, industrial effluent concentration = 10 mg/ℓ).

Treatment efficiency: Treatment efficiency was calculated according to the river and reuse loads to meet the industrial need considered with the 10 mg/ℓ BOD concentration limit.

Availability of water in the river: was calculated as the released load into the river due to the discharge of treated effluents from the WWTP and industry, and the load that is not released into the river due introduction of water reuse.

Table 4-1 Global Water Availability Analysis

		Abstracted water rate	Reclaimed effluents reuse rate		Industrial water availability			River water avilability	
		[current/river limit]	[current/WWTP limit]	[current /Industry limit]	[total m³/s]	[load to treat tones/year]	[% treatment efficiency]	[load released into river(tones/year)]	[load no longer released into the river(tones/year)]
Without reuse	1	6%	0%	0%	0.45	132.2	62%	567.65	-
Decrease in abstracted water and replacing with reused water	2	4%	100%	0%	0.45	537.9	80%	72.53	454.12
	3	**1%**[a]	100%	100%	0.45	542.7	75%	**0**[c]	526.65
Increase in availability with reuse and maintaining the same abstracted water amount	4	6%	50%	0%	0.53	358.5	72%	340.59	227.06
	5	6%	100%	0%	0.61	584.9	77%	113.53	454.12
	6	6%	100%	50%	0.78	641.5	72%	56.76	510.88
	7	6%	100%	100%	0.96	698.1	67%	**0**[c]	567.65
Increase in availability with reuse and increase in abstracted water	8	25%	100%	100%	3.74	1,537.1	55%	**0**[c]	955.54
	9	50%	100%	100%	7.32	2,621.5	51%	**0**[c]	1,456.96
	10	75%	100%	100%	10.89	3,702.9	100%	**0**[c]	1,958.39
	11	100%	100%	100%	**14.47**[b]	4,787.3	49%	**0**[c]	2,459.81

a *Lowest water abstraction possible to meet industrial demand (with reuse)*
b *Largest volume of water available considering river and reuse water*
c *Zero Effluente Discharge into the river*

1. Current Scenario (without reuse/ scenario 1)

The current abstraction rate by all users is 6% (0.45 m^3/s) of available river volume, following the local policies. Since there are currently no reuse practices, the abstracted water volume represents the total volume available to the user, and is equal to 0.45 m^3 / s. The release is the volume of wastewater discharged into the river that, under the current conditions (scenario 1), is the total volume that comes from two effluents: WWTP and industry, thus resulting in a total effluent release of 0.52 m^3/s.

2. Decrease in Abstracted Water and Replacing with Reused Water

In this strategy, the volume of abstracted water from the river was reduced and replaced by the reuse of effluents.

Scenarios 2 and 3 consist of the reduction of water abstraction currently made by the industries of the region and the introduction of effluent reuse, so that water availability remains the same as currently practised (0.45 m^3/s).

Scenario 2 reuses the effluent from the WWTP, allowing the reduction of water abstraction to 4% of the available river volume. In scenario 3, the maximum possible reuse is made, using the total effluent volume from the WWTP and the industry, which makes it possible to reduce water taken from the river to 1%.

For the industrial user, this change from river water source to reused water would result in an increased need for treatment, from 132.2 tons of organic matter to 542.7 tons per year. The user would need to increase treatment efficiency also to 75% to meet the minimum water quality for industrial process user.

Water availability in the river increases as a smaller volume of water will be abstracted, so a larger volume of water will be available in the river to other downstream users. In addition to a volume available in the river, the decrease of 526.65 tons per year of release of organic matter into the river increases, since the effluent instead of being discharged into the river is treated and reused by industry. Thus, also increasing water availability in terms of water quality for downstream users who will be able to abstracted better quality water.

3. Increase in Availability with Reuse and Maintaining the Same Abstracted Water Amount

In this strategy, the same current water abstracted was maintained and the possibility of an increase in availability for the user was evaluated just by reusing the effluents. Four scenarios were evaluated varying the effluent recycling rates of the WWTP and industry effluents (scenarios 4 to 7 in Table 4-1). The user might double the amount of water available only considering reuse. User-treated load increase to 698.1 tons per year. However, the treatment efficiency of 67% is close to the current treatment without reuse (62%). This is due to the volume of water captured diluting the effluent loads, and thus not impacting the treatment efficiency too much. With the reuse of effluents, the water availability in the river increases in terms of quality, as it reduces the release of 567.65 tons per year of organic matter into the river.

4. Increase in Water Availability with Reuse and Increase in Abstracted Water

In this strategy, the scenarios 8 to 11 was elaborate as the water abstracted was increased until the maximum volume abstracted from the river at this point, in accordance with Brazilian guidelines. The maximum water availability consider this strategy is showed by scenario 11 with a total of 14.47 m^3/s of water available, which considers the maximum water abstracted plus maximum reuse possible in this study case. Under scenario 11, the user would have to handle a load of 4,787.3 tonnes per year of organic matter. Treatment efficiency would decrease to 49%, which is even lower than the efficiency to treat river water only. This is because the river water quality has an average concentration of 19.35 mg/ℓ, and as the industrial effluent concentration used was 10 mg/ℓ BOD, the industrial effluent is diluting the river load and thus reducing the treatment efficiency required. This is possible for industrial uses that do not impact water quality or have little impact, such as the use of water for cooling turbines and others. In this way, reuse helps by reducing the efficiency required to handle river loads.

This result demonstrates how in regions where the river has experienced degraded water quality, the inclusion of reuse systems may be even more interesting from the point of view of the economics of treatment requirements than of river water abstraction. This should not be taken as a premise for not improving and maintaining good river water quality, which should be the basic principle for structuring the water resources management model that is more in line with the planet's natural cycles.

06

Conclusions and Recommendations

Water resources in Brazil and worldwide are under preassure, whether by water scarcity in dry regions, water stress in densely populated areas or/and regions with degraded water quality, or by influences os potential climate changes conditions. Society has developed in a linear way. Nature is cyclical. It is necessary that human use of water resources respects the natural cycles, in order to not cause overloads to the environment as has happened currently and in the past.

> *"The determination of the best economic and environmental efficiency should be made based on the analysis of water availability that includes the quantity, quality and purpose of water."*

This study highlight how water availability analysis is fundamental for transforming water resources management into an integrated and circular economy model. There are several pathways that water may follow among users. The determination of the best economic and environmental efficiency should be made based on the analysis of water availability that includes the quantity, quality and purpose of water.

In the Iguazu River, indirect water reuse already occurs, in which the loads released by upstream users are not totally assimilated. The introduction of reuse in the Iguazu River allows for the improvement of water availability in the river and for several users. The case study results indicate the possibility to evaluate in an integrated way how to develop a circular economy system in the management of urban water resources.

Other scenarios may be studied to evaluate different alternatives for the user. It is possible to simulate scenarios with different flow demand and different water quality criteria and parameters, such as phosphorus heavy metals and nitrogen. The paths that water might follow are diverse and will be different for each reality and region. It is also possible to include other economic variables in order to guarantee the best strategies in this regard. The complexity of best path assessment may necessitate the development of a decision support system that integrates the triad of water availability and the multiple paths that water might have among different users and the return to recipient bodies (and the hydrological cycle) and ensure the best economic efficiency.

The introduction of reuse systems should not be considered as the primary option in water resources management planning. Conscious water use, water loss reduction and other actions that make it possible to reduce water demand must be evaluated as paramount. The reused water must have adequate physical, chemical and biological characteristics for each use. It must also be considered that the concentration of certain contaminants increases as the reuse is applied and offer health risks. Therefore, guidelines such as of main Environmental Agencies (EPA, 2012) are fundamental for the introduction of reuse systems.

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5

Industrial Water Recycling in Australia's Circular Economy

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Highlights

- Industrial water recycling systems provide water intensive industries with greater control over water and wastewater costs and eliminate dependencies on external water supplies.
- Industrial water recycling can be achieved via external "end-of-pipe" and internal systems and use a variety of treatment processes to remove suspended solids, reduce colour and salts and recovery energy.
- The unit cost ($/m^3) of industrial water recycling can exceed the cost of water supply by a factor of 1.5 to 2, however, the recycling schemes can be justified using triple bottom line (TBL) and Life Cycle Assessment (LCA) techniques which account for project externalities.
- Optimising inputs in circular economy in paper production is important as increasing the percentage of recycled paper in the feed stock increases loads in wastewater which results in higher cost of water recycling
- Unlike municipal waste recycling, which has national guidelines for water quality and compliance, industrial water recycling is regulated at a state level. In addition, barriers to water recycling exist in food processing for export markets, particularly red meat exports.

Abstract

Industrial water recycling systems provide water intensive industries in Australia with greater control over water and wastewater costs and eliminate dependencies on external water supplies. This can be achieved via external "end of pipe" or internal recycling systems which use a variety of treatment processes to remove suspended solids, reduce colour and salts and recovery energy. The unit cost ($/m^3) of industrial water recycling can exceed the cost of water supply by a factor of 1.5 to 2, however, the recycling schemes can be justified using triple bottom line (TBL) and Life Cycle Assessment (LCA) techniques which account for project externalities. Unlike municipal waste recycling, which has national guidelines for water quality and compliance, industrial water recycling is regulated at a state level. Various industries accrue their own benefits and have their own pitfalls.
For instance, optimising inputs in the circular economy of paper production is important as increasing the percentage of recycled paper in the feed stock increases loads in wastewater which results in higher cost of water recycling. Barriers to water recycling also exist in food processing for export markets, particularly red meat exports.

Keywords

Food and fibre processing, regulations, treatment, triple bottom line, life cycle assessment

01
Introduction

A key objective of the circular economy is to decouple economic growth from the availability of finite resources (Laurent *et al.*, 2019). Water recycling schemes value waste as a resource and enable water-intensive industries in Australia to realise the benefits of the circular economy.
In particular, the poultry processing, beer brewing, and wood fibre industries have invested in water recycling to increase domestic and export production while balancing the risk of projected declines in water availability due to a warmer and drier climate. The importance of water recycling to these industries is underpinned by a range of geographical limitations including access to climate independent water supplies such as seawater desalination or municipal wastewater recycling.

Three aspects of the water security problem for these water intensive industries are presented in Figure 5-1. First, Australia is a highly urbanised country, however, most water intensive industries are located in regional areas removed from urban centres.
More than 90% of the 24.6 million people reside in 9 major cities occupying less than 0.22% of the total land area (Cress & Murphy, 2017). Additionally, 85% of the population are located within 50 km of the coast. In contrast, the major centres of fibre (pulp, paper, and paperboard), meat, brewing, and vegetable processing are located, on average, 150 km inland from the large coastal cities (Figure 5-1). Although the brewing, poultry, and fibre processing industries collectively account for less than 2% (approximately $23bn) of Australia's Gross Domestic Product (GDP), they are critical to regional towns as sources of direct and indirect employment and local economic activity (Table 5-1). For example, the pulp, paper, and paper board industries, which are mostly located in the south-east of Australia, account for the employment of 12,450 people in production and a further 47,500 in the supply chain, of which 30,000 jobs are located in regional areas (Australian Forest Products Association, 2018). These industries are connected to a network of regional businesses that are linked to the food processing industries, which is the largest overall employer in the manufacturing sector that delivers more than $18 billion in exports to countries such as Japan, China, United States of America, New Zealand, and Korea. Consequently, the viability of towns in regional Australia is dependent on sustaining industries that create jobs and drive local economies.

Second, the majority of brewing, poultry, and fibre processing industries are located in areas where the annual average rainfall has declined between 10 and 30 mm per decade from the long-term average (BOM, 2020) . In some catchments, a 10% decline in rainfall translates to a 30% decline in surface water runoff into rivers and reservoirs (Jones & Brooke, 2005). This decline in water availability exposes water-intensive

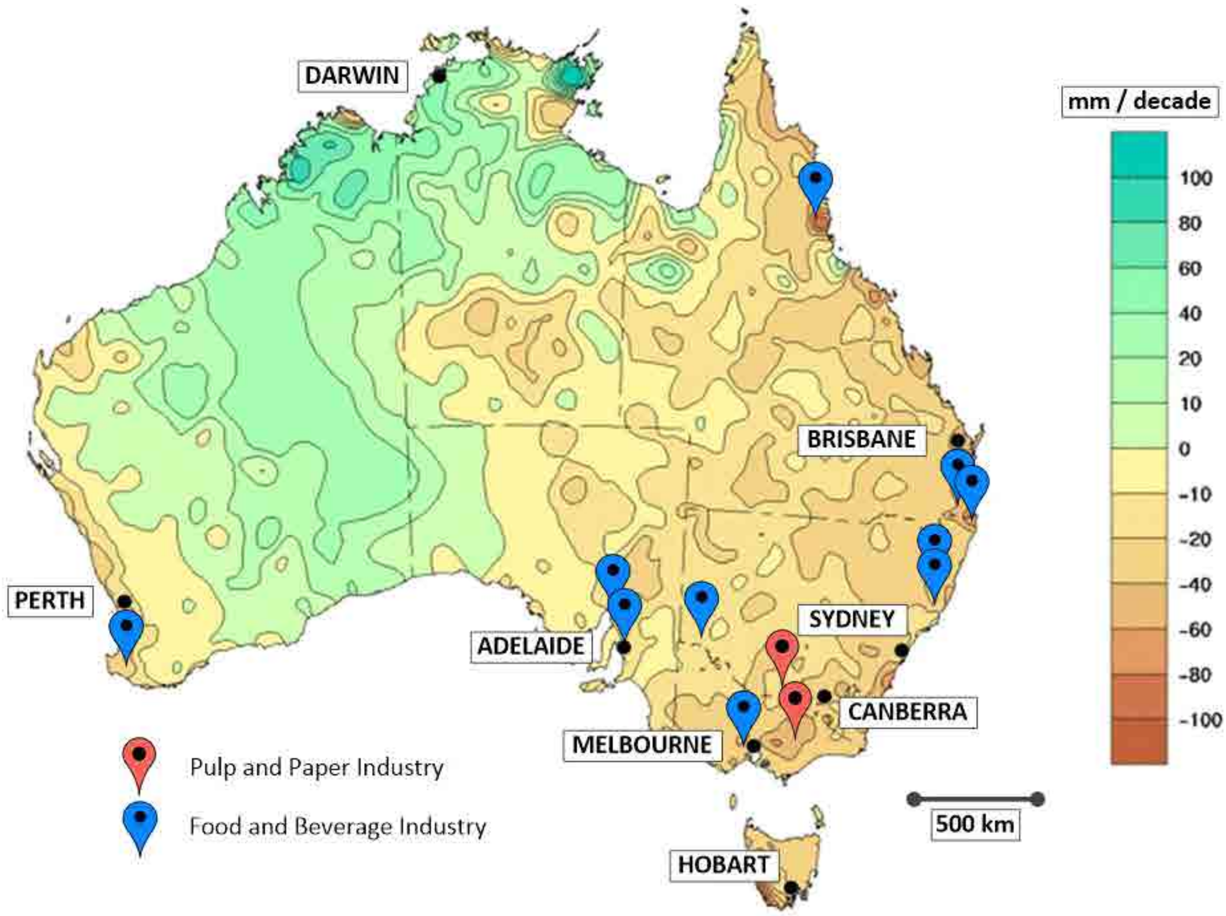

Figure 5-1 *Changes in decade average rainfall patterns and location of water intensive industries in Australia. (Adapted from: "Climate change – trends and extremes", by Bureau of Meteorology (2020). Retrieved from http://www.bom.gov.au/climate/change/#tabs=Tracker&tracker=trend-maps)*

industries to supply chain vulnerabilities and can be a constraint on expansion of production. Beer brewing, poultry processing, and fibre processing are particularly vulnerable to water shortages. Collectively, these industries consume 133 Giga litres per Annum (GLA) (Table 5-1). To put this value in perspective, in 2013-14, the Murray Darling Basin, the largest inland river system in eastern Australia, only allocated 320 GLA out of 8,024 GLA for activities not directly related to agricultural irrigation. The most water-intensive industrial process is fine and high value paper production using the Kraft process, which consumes 20-40 tons (m^3) of water per ton of paper production (Table 5-1). High water consumption in the Kraft process is associated with the batching and application of chemicals used to achieve a high brightness in the final product. In contrast, manufacture of newsprint (10-20 m^3/ton) and paperboard (6-10 m^3/ton) use less water (Table 5-1). Similarly in the poultry industry, the preparation and processing of chickens in broiler abattoirs consumes 22 litres per bird (approximately 20 m^3/ton) while on average, water consumption in beer brewing is 4 litres per litre (4 m^3/ton) (Table 5-1). Each of these industries is expanding production to meet the increased demand. In the paper industry, declines in newspaper production have been offset by the growth in paperboard packaging and high quality paper. In these applications, 70% of recycled paper is used to supplement virgin fibre which increases specific water consumption due to the need to wash ink and other material from the recycled feed stock. In poultry processing, the number of birds processed in Australia has increased from 125 million tons per year in 1995 to 250 million tons per year in 2015. In all industries, this expansion in production in towns in regional eastern Australian is taking place against a background of declining precipitation. Thus, securing water resources in the manufacturing supply chain is critical to the beer, paper, and poultry industries.

The third and final aspect of the geographical challenge for these industries is a of lack access, at scale, to modern water and wastewater infrastructure. In response to the Millennium drought, Australian state and federal governments collectively invested $16billion ($10b USD) to expand the nations desalination capacity from 45 GLA to 500 GLA (Hoang *et al.*, 2009). The expansion of desalination capacity provided the large coastal cities with climate independent water supplies. However, desalination is not viable for the water-intensive industries located away from the coast. In addition, a corollary of high water consumption is high wastewater production. Unlike petrochemical, building products, chemical and other industries located in the cities, paper, poultry, and some breweries are located in towns where discharge to municipal wastewater treatment plants is not feasible. Consequently, expansion of production is attended by an increase in capital and operating costs of wastewater treatment. The problem is compounded when return of the treated waste water to the environment is constrained by lack of hydraulic capacity in the conveyance infrastructure or assimilative capacity in the environment. Consequently, investing in water recycling capacity in lieu of traditional waste treatment and disposal enables water-intensive industries to expand production

Table 5-1 *Market size, employment and water demand of selected water intensive manufacturing industries*

Industry	Brewing[a]	Pulp & Paper[b]	Poultry[c]
Market size	$16.5Bn (1.0% GDP)	$3.7Bn (0.25% GDP)	$2.9Bn (0.19% GDP)
Employment[d]: Production Total	3,700 141,200	12,450 60,800 (30,000 regional)	9,000 58,000
Water Use Total Specific Demand	5.6 GLA 4.0 L/ℓ (Avg)	100 GLA 20-40 m^3/tn Kraft 10-15 m^3/tn Newsprint 6-10 m^3/tn Paperboard	27.7 GLA 22.2 ℓ/Bird (Avg)

a *Brewers Association of Australia (2020)*
b *Australian Forest Products Association (2019)*
c *AgriFutures Australia (2020)*
d *Employment expressed as total contribution including production, supply chain and wholesale/retail*

“A key objective of the circular economy is to decouple economic growth from the availability of finite resources.”

independently of external water and wastewater infrastructure.

In the last 20 years, there has been an exponential growth in urban and regional water recycling projects in Australia. In 1994, the first industrial recycled water scheme was commissioned at the Eraring power station where treated water from the Dora Creek wastewater treatment plant was pumped to the power station for reuse as feedwater to its high pressure boilers. From 2002, which was the start of the millennium drought in eastern Australia, the effects of population growth coupled with less predictable and declining yield from dams and reservoirs accelerated the number of recycled water schemes.
During this period, the motivation has been to develop schemes that offset the need to supply water from the potable distribution system which resulted in an increase in schemes supplying industries such as the petrochemical and paper processing industries. Till date, there has been an increase in water recycling schemes adopted by Australian states (Radcliffe, 2007). A further increase can be expected as the projects currently under construction are completed, reaching a projected 30% by 2030 (Figure 5-2). Industrial wastewater recycling is growing at a comparable rate across Australia, however, the installed capacity is typically less than 10% of the volume of municipal water recycling.

The following chapter provides an overview of features and modalities of industrial water recycling, regulations, water quality, treatment options, and system performance for specific projects in the brewing, paper manufacturing, and poultry processing industries. The central finding is that the unit cost ($/m^3) of industrial water recycling can exceed the cost of water supply by a factor of 1.5 to 2, however, the schemes can be justified using Triple Bottom Line (TBL) and Life Cycle Assessment (LCA) techniques which account for project externalities. Emphasis is placed on providing one key feature from each scheme that articulates the benefits, risks and emerging trends in water recycling in the context of the Australian industries.

Capital City	Recycling 2001-2002 (%)	Recycling 2005-2006 (%)	Recycling 2007-2008 (%)
Sydney	2.3	3.5	4.4
Melbourne	2.0	14.3	23.2
Brisbane	6.0	4.8	6.3
Adelaide	11.1	18.1	30.6
Perth	3.3	5.3	6.4
Total of all State Capitals	3.3	8.4	11.3

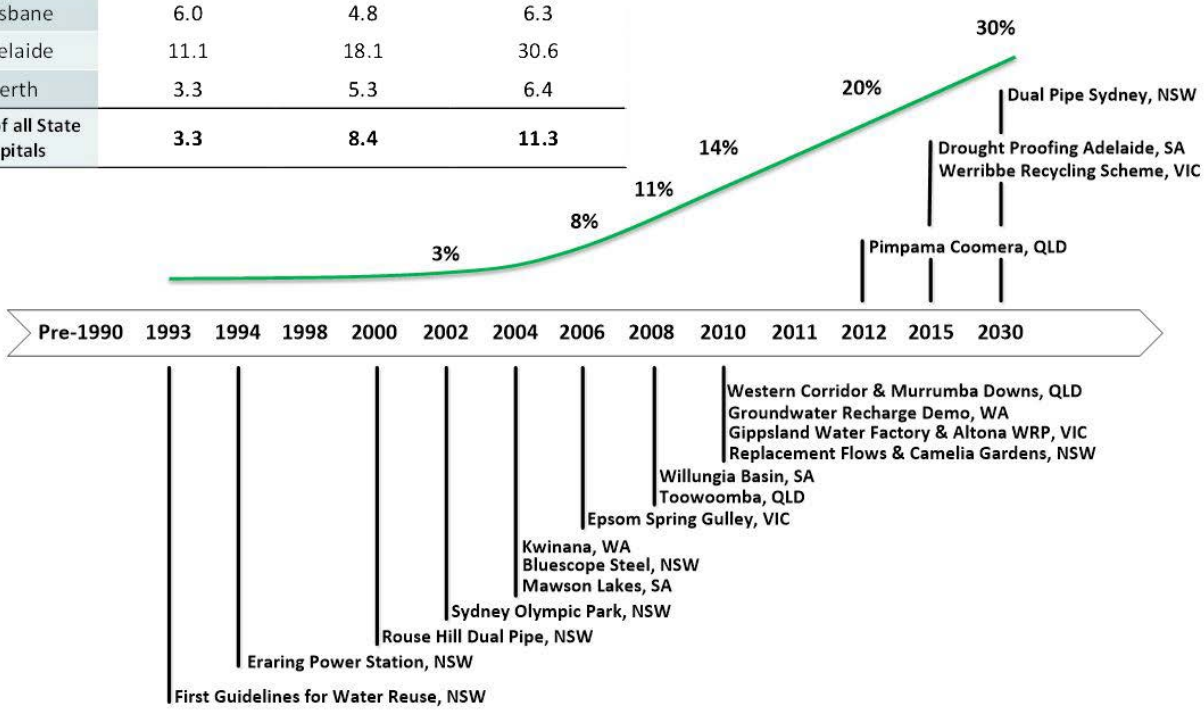

Figure 5-2 Percentage of water recycling in Australia with projection to 2030 (Adapted from: "Water Recycling - Trends, Challenges and Responses", by AWRCoE (2015))

02

Features of Industrial Water Recycling

2.1. Comparison with Municipal Water Recycling

Water recycling is an important component of integrated water resource management (IWRM) strategies used by cities and municipalities to develop water resilient communities (Asano, 2005). Municipal water recycling plants build on existing wastewater collection, treatment and discharge infrastructure. These schemes originally had a public health and environmental protection purpose and were designed to prevent contamination of drinking water and to protect receiving waters such as rivers, lakes, and oceans from nutrients, chemicals, and pathogens (Asano *et al.*, 2007). Wastewater is comingled streams sourced from residential, commercial, and industrial connections to the collection system. Municipal water recycling provides additional treatment prior to diversion of the water for use in lieu of limited drinking water supplies. Increasing the degree of treatment to improve quality accommodates the reuse water in a range of non-potable purposes such as agricultural and landscape irrigation through to application in cooling towers, steam production, and batching of chemicals, and finally through to potable uses such as replenishing groundwater aquifers or direct augmentation of drinking water supplies (Asano *et al.*, 2007, Seah *et al.*, 2003).
The treatment component of the municipal water recycling scheme is referred to as the Advanced Water Treatment Plant (AWTP) because the level of treatment for reuse exceeds the treatment required for discharge to the environment. Emphasis in the design of the AWTP is placed on protection of public health through the reduction in concentration of pathogens in the wastewater. Multiple barriers for pathogens include filtration and disinfection. Additional processes are included to remove dissolved salts and reduce colour depending on the final application. Examples of industries in Australia using water from municipal water recycling plants include oil refineries (Kwinana, WA), steel mills (Wollongong, NSW), and chemical plants (Qenos, Vic). Although these industries are located in a 5 km radius of the wastewater treatment plant the capital cost of conveyance from the AWTP to the point of application can equal or, in some cases, exceed the additional cost of treatment. Consequently, the use of recycled water, sourced from a municipal wastewater treatment plant by industry, is often only viable if the end use customer is located in the vicinity of the AWTP or adjacent to the route of the effluent discharge pipeline if the customer is located near a conventional wastewater treatment plant.

In contrast, industrial water recycling schemes operate on waste generated by unit operations within the production process. Any waste streams containing domestic waste water from showers, toilets, kitchens and offices used by employees is segregated and diverted to the sewer.
Often in smaller industries the inability to segregate the domestic from industrial waste restricts either the ability to recycle water or the use of the recycled water in external uses, often irrigation, that do not feed back into the manufacturing process. For most large scale industries, such as large brewers, pulp and paper mills, and poultry abattoirs, the site provides for separate collection and treatment of the industrial and municipal waste.
In addition to separating waste streams, the larger industries have separate reticulation systems for potable water used by employees and process water used in manufacturing. This separation of both water supply and wastewater collection provides for greater flexibility in industrial water recycling applications that has implications on the development of regulations and guidelines which will be discussed in Section 2.3 and the features of the water recycling scheme including the modality (Section 2.2) and the selection of treatment processes (Section 3.2). Consequently, in contrast to municipal recycling systems, industrial systems do not operate on domestic waste streams and can reuse the water on-site with minimal conveyance costs in multiple applications.

2.2. Modality of Industrial Water Recycling

The provision of separate and segregated water systems enables recycled water to be reused either directly at a specific point in the manufacturing process or recycled back into the overall industrial water supply. The first mode of operation is referred to as “internal” or point of use recycling, while the second mode is referred to as the “end-of-pipe” recycling. Examples of internal use include wash-down of work areas and diversion to heat exchange networks whereas end-of-pipe applications include use in boiler steam production through boiler feed make up, chemical batching and final washing and rinsing of process equipment. Features of each modality including the treatment components and feed water quality are contained in Figure 5-3 and Table 5-2.

The “end-of-pipe” mode is based on traditional approaches to pollution abatement to remove nutrient loads prior to discharge to the environment. Nutrient loads in brewery and poultry waste, measured as Chemical Oxygen Demand (COD), can range from 4 to 15 times greater than the load from domestic waste (COD of 500 mg/ℓ) (Table 5-2). End-of-pipe treatment for brewery (Figure 5-3A) or poultry (Figure 5-3B) waste involves biological nutrient removal to convert soluble carbonaceous, nitrogenous and phosphorous waste to sludge. To comply with wastewater discharge requirements, industries install and operate separate external wastewater treatment plants, which discharge into a dedicated industrial sewer collection pipe. Consequently, increasing production capacity in the brewery and poultry abattoir necessitates upgrade of the end-of-pipe treatment plant and in some cases, expanding the sewer hydraulic capacity.
The capital cost to expand and operate end-of-pipe infrastructure often prevents expansion of plant production

capacity unless a circular economy approach is used to manage water and wastewater (see business outcomes in Section 4). The circular economy approach involves the installation of an industrial form of the AWTP process, usually involving the removal of suspended and dissolved solids, including salts and colour, to enable reuse in applications including high-pressure boilers for steam production, cooling towers, chemical batching, and final cleaning and rinsing of process equipment.

Internal water recycling schemes include the reuse of segregated waste streams that do not require nutrient removal (Table 5-2). Water from internal recycling schemes used directly in the manufacturing process include work area wash-down and use in heat exchange systems. An internal approach is favoured for lightly contaminated hot and cold waste streams (Table 5-2). Examples of waste streams with significant thermal energy include waste from the scald tank (50-60°C), which is the de-feathering step in poultry processing, and from the spin chiller (1-4°C), which is the carcass holding step immediately prior to cutting and packaging (Table 5-2, Figure 5-3B).

Waste from these streams contain minimal nutrients (<30 mg/ℓ COD) and provide opportunities for energy recovery which are lost when the waste is comingled and sent to end-of-pipe treatment systems. Internal recycling schemes offer a number of opportunities for innovation, particularly in food processing applications. Given the varying temperatures of wastewater streams in food processing, the use of ceramic membranes have an advantage over conventional polymeric membranes

Table 5-2 Modality of recycling and typical characteristics wastewater for selected water intensive manufacturing industrie

Recycling Modality	External "end of pipe"				Internal	
Industry	Brewing	Pulp & Paper		Poultry	Poultry	
Product	Beer	Bright paper Kraft[a]	Newsprint TMP[b]	Processed broilers		
Waste stream	Comingled				Scalder	Spin Chiller
Biological treatment	Anaerobic & Aerobic		Aerobic		None	
Temperature (°C)	20-40	15-30	15-30	20	50-60	1-4
pH	8-11	8	8	6	7	6.5
Total suspended solids (mg/ℓ)	300	20	20	250	30	<10
COD (mg/ℓ)	5,000-8,000	600-800	600-800	2,000	<30	<30
DOC (mg/ℓ)	50	70	50	250	20	10
Color (PCU)	450	1,000	370	600	50	10
Total dissolved solid (mg/ℓ)	2,000	2,700	1,000-2,200	2,000	300	350
Sodium (mg/ℓ)	550	770	260 - 800	100	85	100
Chloride (mg/ℓ)	150	490	40	120	195	235
Silica[c] (mg/ℓ)	NA	20	30-120	NA	NA	NA

a *Kraft chemical processing for high brightness specialty paper.*
b *hermomechanical pulping of virgin and recycled fiber content (RFC).*
c *Sodium and Silica content increases with increasing RFC .*

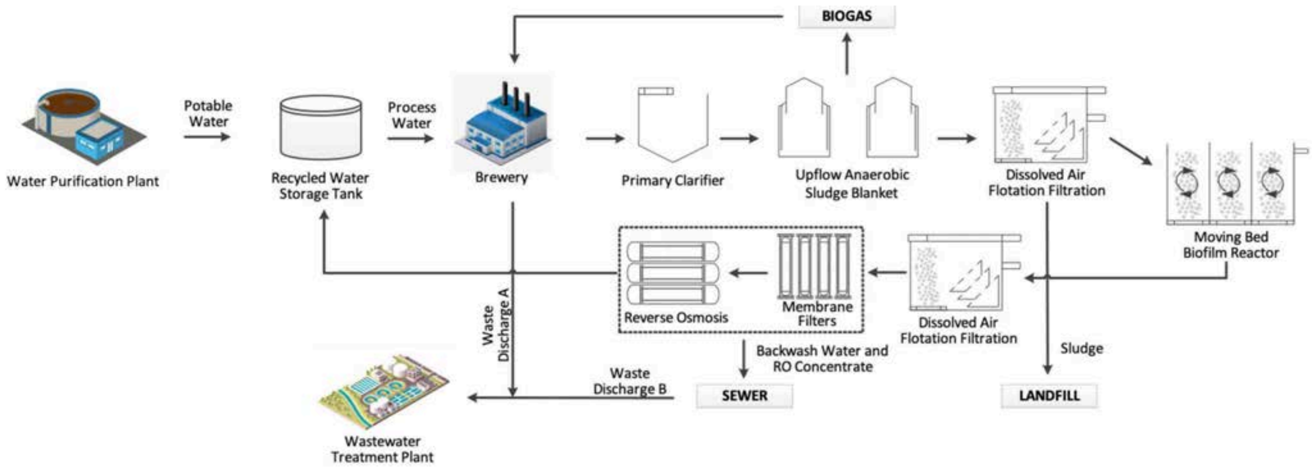

Figure 5-3A *Water Recycling Processes Utilised in the Beer Brewing Industry.*

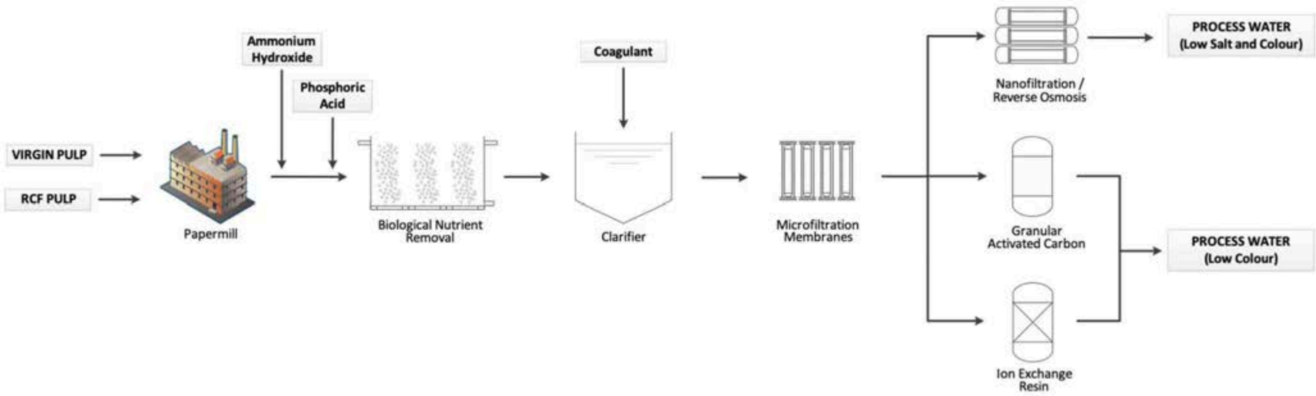

Figure 5-3B *Water Recycling Processes Utilised in the Pulp and Paper Industry.*

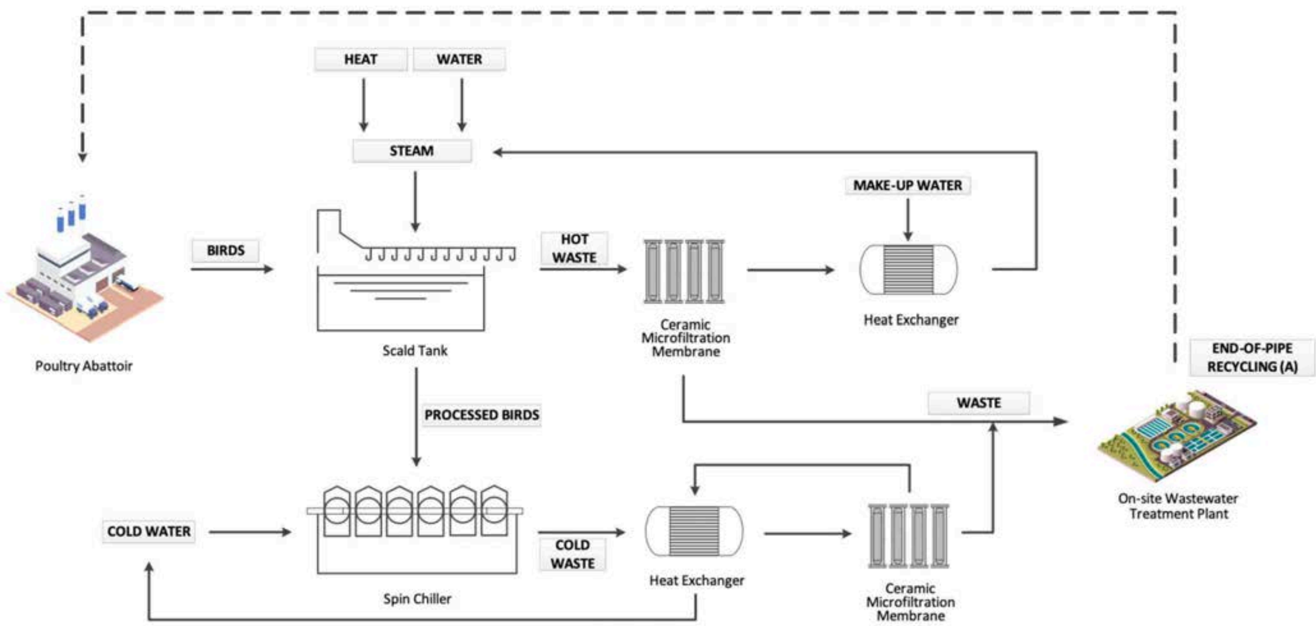

Figure 5-3C *Internal and external water recycling in Poultry processing. Internal recycling operate on segregated waste streams and incorporate energy recovery through heat exchangers. External recycling (A) has similar complexity to brewery applications depicted in Figure 5-2A.*

as they can operate in hot and cold streams due to the ceramic material's high thermal stability. Data on the performance of these membranes is presented in Figure 5-4. In addition, incorporating energy recovery into water recycling allows for the use of project evaluation methods, such as Triple Bottom Line (TBL), Life Cycle Assessment (LCA), and Sankey Diagrams that capture all the benefits of the circular economy and provide an alternative to simple cost of water ($\$/m^3$) metrics to assess water recycling schemes. These aspects are presented in Section 3 and in Figures 5-5, 5-7, and 5-8.

2.3. Regulation of Industrial Water Recycling Schemes

In response to the millennium drought (2003-2008), Australia developed robust guidelines for water recycling schemes to promote diversification of water supplies and to protect public health and provide municipalities and industries with certainty in the planning, construction and operation of recycling projects. Guidelines for water recycling projects are based on a risk management approach which involves; (i) identification of hazard type and concentration, (ii) estimation of exposure and consequence (risk), and (iii) reducing the risk to acceptable levels through the application of treatment barriers and preventive measures. This approach does not prescribe how the wastewater should be treated which allows the use of different treatment technologies to reduce the concentration of biological and chemical hazards to an acceptable level. The guidelines also require proponents of recycling schemes to develop a Recycled Water Management Plan (RWMP) to document the risk management approach through design, construction and operation. One element of the RWMP includes the application of Hazard Analysis and Critical Control Points (HACCP) methods to ensure that appropriate continuous on-line monitoring of performance, particularly for surrogate metrics that ensure the risk associated with microbial pathogens, such as virus, bacteria and protozoa, is reduced to acceptable residual levels.

> *"Internal recycling schemes offer a number of opportunities for innovation, particularly in food processing applications."*

Although there are similarities, there are two key differences between industrial and municipal wastewater recycling guidelines. The first difference is municipal wastewater recycling guidelines have been adopted at the national (federal) level while industrial guidelines differ among states (Table 5-3). Consequently, a company in the same industry, for example brewing or poultry, operating the same manufacturing process but in different states can have different guidelines, water quality testing and reporting requirements. For example, a poultry operating plant in South Australia must comply with the requirements to develop a HACCP plan and establish suitable critical control points (Table 5-3). The same requirement would apply to a poultry plant in NSW with the addition of additional requirements for on-line monitoring of Turbidity, Free Chlorine and pH, and biweekly sampling and testing for Chemical and Biological Oxygen Demand (COD/BOD), Total Suspended Solids (TSS), and total coliform (Escherichia coli).

The second, and the more important, difference is that a separate set of federal regulations governing exported food products are also applied to industrial recycling projects. This requirement limits the development of internal water recycling projects in some industries, particularly in the food and beverage industry, if there is direct contact of the recycled water with the final food product. In these cases, either the use of recycled water is prohibited, or will require additional approval from the Australian Quarantine and Inspection Service (AQIS) as well as the relevant state based food authority before the implementation of any water recycling strategies. An example of how current health and safety regulations have resulted in strong inhibitions when considering water recycling is in the red meat processing industry, due to export market requirements in the meat industry. To receive accreditation as a meat processor at Tier 1 or 2 Export Registered Australian Standard Meat Establishment, recycled water cannot be a direct ingredient in meat products. These standards prohibit meat processors from exporting to overseas markets if they use recycled potable water inside processing plants that comes in contact with meat products. Hence, it is difficult for red meat processors to become more water resilient to alleviate the water demand experienced in drought-affected communities.

2.4. Water Quality and Treatment Technologies

Industrial wastewaters generally contain higher levels of carbonaceous nutrients and dissolved solids than municipal wastewater, but lower levels of microbial pathogens, urea and phosphorous due to the segregation of domestic waste from toilets, laundries and showers. A selection of water quality data for external end-of-pipe and internal industrial water recycling schemes in brewery, paper and poultry applications is presented in Table 5-2.

External water recycling systems operate on comingled wastes. The temperature of the waste ranges from 15 to 30ºC due to mixing of hot and cold streams in the production process which enables the waste to equilibrate with atmospheric conditions. Treatment processes for these streams are based on a biological treatment component followed by clarification, filtration and processes to remove residual salts and colour so that the product water can be returned to the general process water feed tank (Figure 5-3A, 5-3B, and 5-3C).
Brewery waste presents the highest nutrient load expressed as COD which can range from 5,000 to 8,000 mg/ℓ (Table 5-3).

Brewery waste consists of complex sugars and proteins from the spent fermentation tanks. Biological treatment of brewery waste consists of anaerobic treatment to reduce the COD from >5,000 mg/ℓ to approximately 2,000 mg/ℓ followed by aerobic treatment to further reduce the COD to approximately 500–600 mg/ℓ which is acceptable for discharge to municipal wastewater treatment plants (Figure 5-3A).
The use of anaerobic treatment in external recycling schemes presents an opportunity to generate energy via the production of methane which offsets the cost of additional treatment prior to reuse. Comingled waste from poultry processing has a COD of approximately 2,000 mg/ℓ while waste from pulp and paper typically ranges from 500-600 mg/ℓ COD due to dilution associated with the high water use at 20-40 m^3/ton for Kraft and 10-15 m^3/ton for TMP (Table 5-2).

Effluent from the biological treatment stage is treated to reduce total suspended solids, recalcitrant organics and salts. Removing the suspended solids prevents blocking of sprays, nozzles and other fixtures used in the industrial water systems. Tertiary unit operations such as reverse osmosis and ion exchange are often utilised for the removal of dissolved salts, whilst nanofiltration and granular activated carbon are usually used to remove colour and dissolved organics (Bassandeh *et al.*, 2013, Ciputra *et al.*, 2010), however, all these processes require a pretreatment step for suspended solids removal with external water recycling schemes using a range of solid/liquid separation processes to reduce the concentration of suspended solids. External recycling schemes in brewing applications have the most rigorous solids removal process post biological treatment due to the high concentration (300-400 mg/ℓ) and neutral buoyancy of the suspended biological materials. An external water recycling plant at a brewery in Queensland employs dissolved air floatation and filtration to remove fine biological flocs after the anaerobic and aerobic nutrient removal stages (Figure 5-3A). Because space is a premium in industrial systems, breweries, pulp and paper and poultry use membrane filtration (microfiltration or ultrafiltration) as the final solids removal step prior to final processing to remove colour and salts (Figure 5-3A, 5-3B, and 5-3C). Membrane filtration is the de-facto industry standard for pretreatment to reverse osmosis in municipal wastewater recycling (Seah *et al.*, 2003) and this trend has continued in industrial applications. Membrane filtration is preferred by industry due to the ease of operation (pressure filtration), small footprint, and minimal chemical use.
External water recycling systems use 0.01 to 0.2 micron polymeric membranes which are suitable for the ambient temperature streams. These systems are very reliable and have a long track record in both municipal and industrial applications. In internal water recycling schemes, where it is necessary to handle both hot and cold streams, the use of ceramic membranes that have higher mechanical strength and thermal tolerance than polymeric membranes are evaluated (Grant *et al.*, 2011) (Figure 5-3B).

> *“It is difficult for red meat processors to become more water resilient to alleviate the water demand experienced in drought-affected communities.”*

The removal of salts and colour is particularly important for fine paper production which produces a paper product with high brightness. The Kraft process is designed to separate lignin and organic acids from the cellulosic fibre to produce a high brightness (white) paper. The efficiency of the colour removal coupled with the high chemical use produces a waste that typically contains 1,000 colour units (PCU), 70 mg/ℓ of Dissolved Organic Carbon (DOC), 700-800 mg/ℓ of sodium and 2,700 mg/ℓ of Total Dissolved Solids (TDS).
The production of newsprint does not require the same brightness levels as fine paper so a chemical free thermo-mechanical process (TMP) employing steam and shear is used to remove cellulose fibres from virgin pulp. Consequently, the colour (370 PCU), DOC (50 mg/ℓ), TDS (1,000 mg/ℓ) and sodium (260 mg/ℓ) of TMP effluent is lower than Kraft effluent (Table 5-3). Another significant characteristic of TMP effluent is the effects of a trend to replace virgin pulp with recycled fibres from used papers and magazines. In some applications, such as paper board, 100% of the feedstock is Recycled Fibre Content (RFC). In newsprint, RFC can vary from 20 to 70%. As the RFC percentage increases the effluent will contain more silica (up to 120 mg/ℓ) and sodium (up to 800 mg/ℓ) (Table 5-2). Increasing RCF content to 50% decreased reverse osmosis water recovery from 80% to 22%. This reduction was due to the increase in silica and sodium associated with the use of surfactants and caustic soda to remove inks and dyes from the recycled fibre before pulping and use in the paper machine. It is also noteworthy that increased sodium increases the osmotic potential of the waste that increases the operating pressure of the reverse osmosis, while increased silica limits the recovery of the reverse osmosis process (Negaresh *et al.*, 2013). Studies on wastewater from TMP processes with high RFC found that additional chemical with lime and magnesium hydroxide upstream of microfiltration was required to remove residual silica (Figure 5-3C). Consequently, treatment processes such as ion exchange or granular activated carbon have been evaluated for colour removal in TMP applications (Antony *et al.*, 2012) (Figure 5-3C).

Table 5-3 Summary of features of legislation governing internal industrial water recycling in food and beverage applications at national and state level

Jurisdiction	Relevant Legislation/Regulation
National	No testing parameters are defined in national legislation or standards. A risk assessment, including HACCP and food safety plan, must be developed and implemented. Risks identified in the HACCP and safety plan must be monitored acceptably to ensure food safety and quality is not compromised (FSANZ (Food Standards Australia & New Zealand), 2011)
New South Wales	As per national requirements for risk assessment and risk monitoring. Testing criteria provided for validation of recycled water meeting potable standards by NSWFA WRG which also states the minimum testing limits and frequency of monitoring for reused water in direct contact with food or food contact surfaces, which are: online for Turbidity, Free Chlorine and pH, and biweekly for BOD, TSS and E. coli (NSWFA (New South Wales Food Authority), 2008)
Australian Capital Territory	No testing parameters are specified. Identified risks by mandatory HACCP and safety plan must be monitored acceptably. The ACT Environment & Health – Wastewater Reuse Guidelines 1997 recommends that an application to the Department of Health include plant effluent information on thermos-tolerant coliforms, Total Phosphorus, Total Nitrogen, Sodium Absorption Ratio, Acidity (pH), Total Dissolved Solids, Turbidity and Biological Oxygen Demand (Australian Capital Territory (ACT) Government, 1997).
Victoria	Victorian legislators do not specify testing parameters. Identified risks by mandatory HACCP and safety plan must be monitored acceptably. The minimum testing limits and monitoring frequency for Class A recycled water are outlined, but this is not mandatory in a food setting (EPA Victoria, 2003). HACCP may require more or less stringent limits and should be used as the compliance value.
South Australia	South Australia legislators do not specify testing parameters. Identified risks by mandatory HACCP and safety plan must be monitored in an acceptable manner (South Australian Government, 2001)
Tasmania	No testing parameters are specified. Identified risks by mandatory HACCP and safety plan must be monitored acceptably. The *Environmental Guidelines for the Use of Recycled Water in Tasmania* specify that microbiological, chemical and physical risks should be minimised; however, the guideline stops short of setting a specific limit to be maintained for use with recycled water for use in food. The guidelines provide testing criteria for Class A recycled water and may apply to treatment systems in food processing plants (Tasmanian Department of Primary Industries, 2002).
Western Australia	No testing parameters are specified. Identified risks by mandatory HACCP and safety plan must be monitored acceptably. The *Guidelines for the non-potable uses of Recycled Water in Western Australia* provide testing criteria for treated water that has a high risk of human contact (Western Australian Department of Health, 2011). These guidelines may apply to treatment systems in food processing plants but are not explicitly addressed in the document.

03

Performance and System Evaluation

3.1. Performance

3.1.1. Use of Ceramic Membranes in Internal Recycling Schemes

End-of-pipe water recycling in poultry processing, while feasible, is capital and energy intensive. The alternative is to process internal waste streams that are lightly contaminated (<30 mg/ℓ COD) and do not require biological treatment prior to reuse. In poultry processing, the best candidate streams are the waste from the scald tank and the spin chiller, which collectively account for 70% of total energy demand. Reuse of these streams generally requires membrane filtration to remove suspended solids and coliforms and reduce the turbidity to allow the product to be reused. In these applications, ceramic membranes are preferred over polymeric membranes due to the wide temperature range of the chiller (<4°C) and scalder (>60°C) waste streams.

Recently, a poultry processing plant in the state of New South Wales evaluated the performance of a pilot-scale (2,500 ℓ/day) membrane filtration system fitted an alumina (Al_2O_3) coated, 0.2μm (micron) Ceramic Microfiltration (CMF) membrane in an internal water recycling scheme. The ceramic membrane was operated at a sub-critical flux (no cleaning required) of 48 ℓ/m^2/h on scald tank waste and a sub-critical flux of 100 ℓ/m^2/h on spin chill water. The higher fluxes on the spin chill waste were possible because of the lower suspended solids concentration (Table 5-2). Turbidity was selected as an appropriate Critical Control Point (CCP) based on NSW legislation and was measured upstream and downstream of the ceramic membrane in both applications. When connecting the CMF to both the scald tank and spin chiller, all permeate turbidity values satisfied the NSWFA WRG 95% compliance limit for turbidity of 1.00 NTU (Figure 5-4). When connected to the scald tank, CMF permeates turbidity varied from 0.01 to 0.98 NTU with an average of 0.31 NTU (n = 29). CMF permeate turbidity from spin chiller feed water had a range from 0.04 to 0.77 NTU with an average of 0.27 NTU (n = 17). Despite the different quality of the scald tank and spin chiller wastewater, the average turbidity of the CMF permeates from both trials was relatively similar. As suspended particles predominantly cause turbidity in the wastewater, the membrane pore size used in the trials (0.2 μm) is sufficient to remove all suspended solids from the wastewater. Permeate quality for both streams complied with NSW Food Authority Water Reuse Guidelines for fit for purpose reuse in both unit operations (Table 5-3).

However, the main advantage of using a ceramic membrane over a polymeric membrane was the ability to operate directly on the hot and cold streams and to incorporate energy recovery through heat exchangers. In this application, the heat exchanger was located on the filtrate from the ceramic membrane on the scald tank water (hot stream) and upstream of the ceramic membrane on the spin chill water (cold stream) (Figure 5-3C). This arrangement provided a modest (approximately 5ºC) increase in feed temperature on the cold stream which reduced viscosity and lowered membrane operating pressure. A Sankey diagram analysis was used to compare energy flows for the internal versus the end-of-pipe water recycling options (Figure 5-5). This analysis indicated that recovering both energy and water directly from the scalders and chillers would reduce the gas supply inputs used to run the scalders and chillers by 52% (431 to 208 kW) and reduce the energy associated with producing water for the scalders and chillers by 60% (91 to 36 kW) (Figure 5-5).
This illustrates the importance of introducing circular economy externalities, such as energy, when evaluating water recycling schemes in industrial applications. For example, while it is not possible to justify the installation of the ceramic membranes on a cost of water basis due to differences in the amortized cost of water produced by ceramic membranes (1.5-2 times higher than cost of potable water), the energy savings associated with the internal recycling system offset the cost of installing and operating the membranes over the same period.

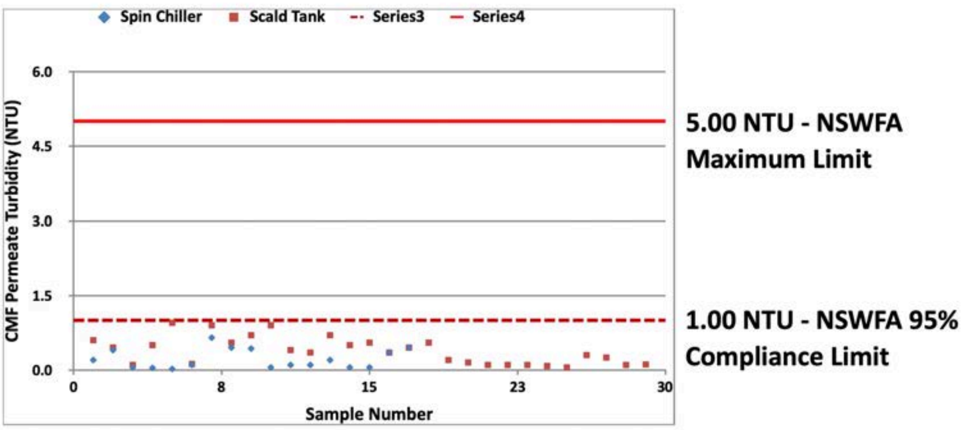

Figure 5-4 *Membrane Filter Permeate Turbidity for Scald Tank and Spin Chiller in Poultry Abattoir over 30-Day Performance Test (Source: Grant et al., 2011)*

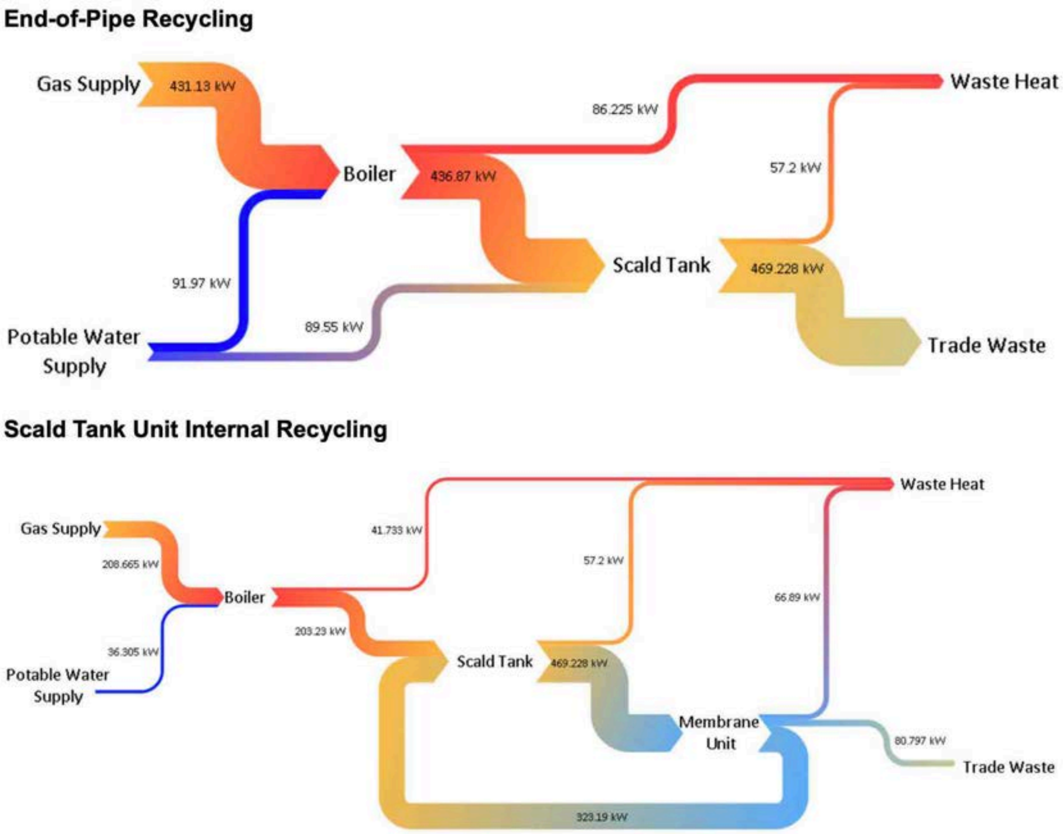

Figure 5-5 *Sankey Diagram Comparison of Energy Consumption for End-of-Pipe and Internal Recycling in Poultry Abattoir (Source: Grant et al., 2014)*

3.1.2. Salt and Organic Removal in the Pulp and Paper Industry

Recycling paper mill effluent by conventional water treatment is difficult due to the persistence of salt and recalcitrant organics. Recently a Kraft paper mill in Victoria and a TMP mill in New South Wales evaluated the performance of a range of systems to remove dissolved organic matter (DOM) from mill effluent including Ion Exchange Resin (IER), Granular Activated Carbon (GAC), and Nanofiltration (NF) (Ciputra *et al.*, 2010). The removal efficiency of each treatment process was analysed based on hydrophobicity, molecular weight, and fluorogenic origin of the DOM fractions. The overall removal of DOM for IER, GAC and NF treatments were 72%, 76%, and 91%, respectively (Figure 5-6). While all three treatment methods significantly removed the hydrophobic acid fractions, IER removed a proportion of all fractions with 57% removal of hydrophobic acids, 44% of transphilic acids, and 18% of hydrophilic acids. Removal based on the molecular weight of the DOM, IER, and GAC treatments removed the majority of the high molecular weight fractions, whereas NF effectively removed all molecular weight fractions. Qualitative analysis of fluorescence excitation-emission matrices showed that the fulvic acid-like fluorophores were more recalcitrant among the various DOM fractions with a considerable amount retained after undergoing all the three treatment methods. The three treatment methods differed considerably in terms of removing different DOM fractions; however, a broad-spectrum process like NF would be the most effective for maximal removal. However, the deployment of nanofiltration and reverse osmosis in paper production should be evaluated cautiously as the trend towards using more recycled fibre from used papers and magazines as a replacement to virgin wood pulp comes with its own inherent risk (see Section 4.2 on risk below).

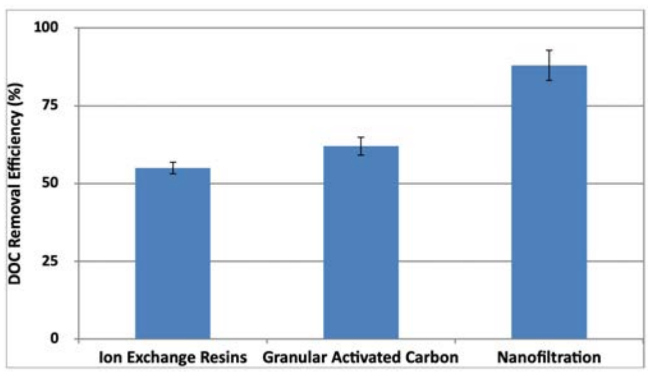

Figure 5-6 *Dissolved Organic Removal Efficiency in Paper Mill Recycling by Ion Exchange, Activated Carbon and Nanofiltration (Source: Antony et al., 2012)*

3.2. System Evaluation

The example of using energy analysis to evaluate the merits of internal water recycling in a poultry processing application illustrates the need to adopt a broad range of measures and analysis to assess the benefits of a circular economy approach. In almost all cases, the unit cost of water from the main potable supply is less than the unit cost of recycled water. For example, the average water tariff in Australia is \$1.10 (0.7USD)/m^3 while fully amortized treatment costs of recycled water range from \$1.50 to \$2.00/m^3. Consequently, it is necessary to factor in externalities through techniques such as Triple Bottom Line (TBL) or Life Cycle Assessment (LCA) techniques to capture additional advantages of water recycling in the circular economy.

3.2.1. Triple Bottom Line (TBL) Evaluation of Socio-Environmental-Financial Factors

Triple Bottom Line (TBL) analysis is a set of full cost accounting techniques and sustainability reporting guidelines developed by the Global Reporting Initiative (GRI), designed for businesses and governments to undertake a holistic assessment of operations across economic, environmental and social criteria (Foran *et al.*, 2005; GRI, 2013).
While TBL can be used as a tool to compare industries or sectors of an economy (Foran *et al.*, 2005), it can also be used as a specific comparative modelling tool, to quantify the impact of a range of changes made in an individual operator, company, industry or sector.

TBL analysis is a comparative tool and as such, a suitable benchmark needs to be established before comparison can be undertaken. Benchmark values were based on selected criteria obtained from data collected from abattoirs, following normalisation to a per bird basis. TBL analysis was conducted, and abattoirs were compared to the national average of each evaluated criterion to observe trends (Grant *et al.*, 2014). The analysis used water and power consumption data from 7 plants located in 4 states, representing 28% of total national production.
The results of the analysis are presented in Figure 5-7.

> *"It is necessary to factor in externalities through techniques such as TBL or LCA techniques to capture additional advantages of water recycling in the circular economy."*

The TBL analysis indicated that the benefits across 6 of the evaluated criteria increased as the percentage of water recovered increased (Figure 5-7). Internal recycling resulted in an overall improvement in energy use across the average of all sites from 6.6% at 50% water recovery up to 15.2% at 90% water recovery, while equivalent greenhouse gas emission (eGHG) were reduced by 1.7% at 50% water recovery to 6.5% at 90% water recovery. Overall water consumption was reduced by 13.5% at 50% recovery to 24.3%

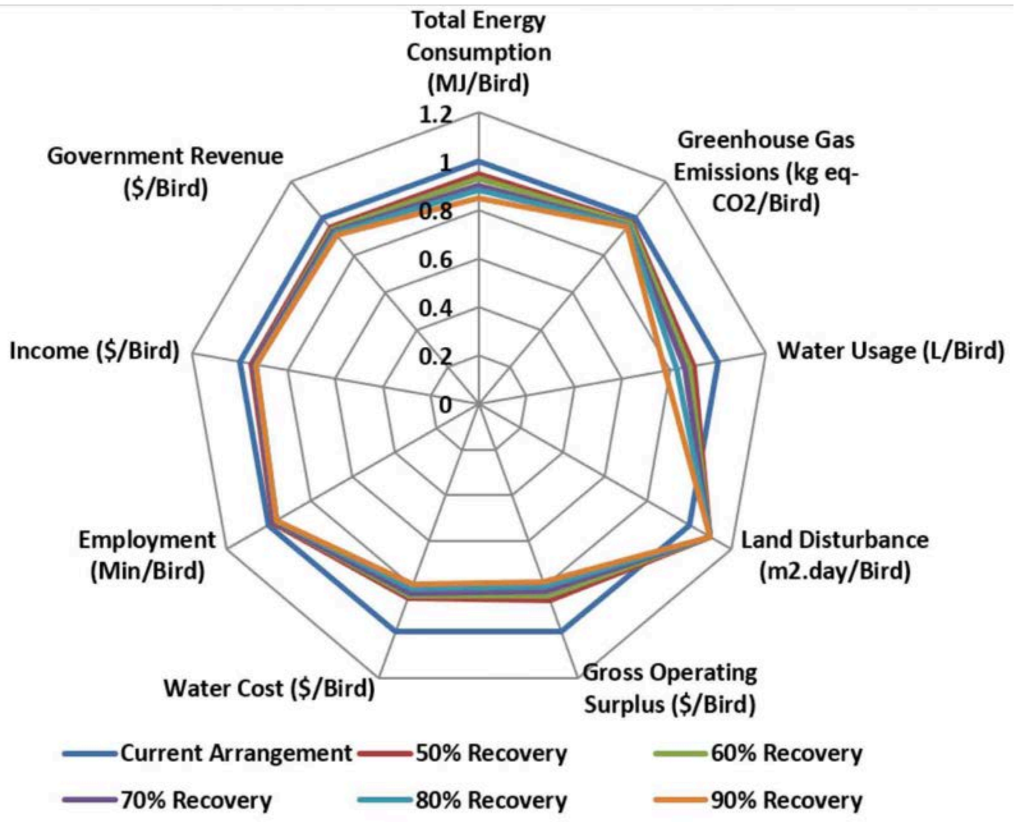

Figure 5-7 Triple Bottom Line (TBL) Analysis of Water and Energy Recovery Technology Implementation (Source: Grant et al., 2014)

at 90% recovery. Economic criteria showed an improvement for all recoveries tested which was due to the cost savings associated with a reduction in energy consumption in boilers and ammonia chillers due to the water and energy recovery technologies. Water costs were reduced due to the reduced demand on potable water and minimisation of wastewater disposal charges. This translated into improvements in gross operating surplus and water cost between 13.1% and 12.8% at 50% recovery and 24.3% and 23.8% at 90% recovery, respectively. Social factors such as employment and income increased by 1.5% and 2.6% respectively while Government revenue declined by 4.3% at 50% water recovery, up to 12.5% at 90% water recovery, due to the savings made on water and energy usage reductions (Figure 5-7).

3.2.2. Life Cycle Analysis (LCA) of Greenhouse Gas Emissions (GHG) in Recycling Options

For a more detailed assessment of the environmental impacts of water recycling technologies, a Life Cycle Analysis (LCA) is an established tool that can be used to quantify the environmental impact of plants, processes, businesses, industries, or sectors. However, in order to ensure an accurate and meaningful LCA, data from relevant operational data from either pilot or actual operations in the industry are necessary. LCA is governed by the ISO 14040-44 guidelines (ISO, 2006), and is comprised of four major steps:

1. Goal and scope definition, which identifies the purpose and objectives of the study, including the objects and processes to be studied, and their system boundaries;
2. Life cycle inventory (LCI), which involves the systematic collection of all relevant inputs and outputs of all process included within the system boundaries;
3. Life cycle impact assessment (LCIA), where collected data are grouped and assigned to specific impact categories and characterized using a suitable LCIA model that allows for comparison; and
4. Life cycle interpretation, where the LCIA model is used to draw conclusions and make recommendations in the context of the original study goal, functional unit and system boundaries.

Results from an LCA can be used to demonstrate the impact of implementing new technologies and compare that to the current technologies implemented. Reductions signify an environmental benefit, whereas increases signify an environmental cost.

In poultry abattoirs, an LCA was used to compare three scenarios at a single poultry abattoir (Figure 5-8). The scenarios included, business as usual (no recycling), deployment of an internal recycling system with energy recovery, and an external end-of-pipe recycling plant operating on comingled streams. The external plant was based on a standard advanced wastewater treatment plant consisting of biological and dual membrane treatment. A single impact factor, greenhouse gas emissions expressed as kg CO_2 eq/kℓ of water recovered, was used to account for inputs across 10 inventories. Water use in the scald tank for broiler processing results in a greenhouse gas emission of 10.4 kg CO_2 eq/kℓ for the current arrangement compared to 7.4 kg CO_2 eq/kℓ and 14.2 kg CO_2 eq/kℓ for internal recycling using ceramic membranes and external end-of-pipe water recycling options respectively (Figure 5-8). The increased electricity use in internal recycling was due

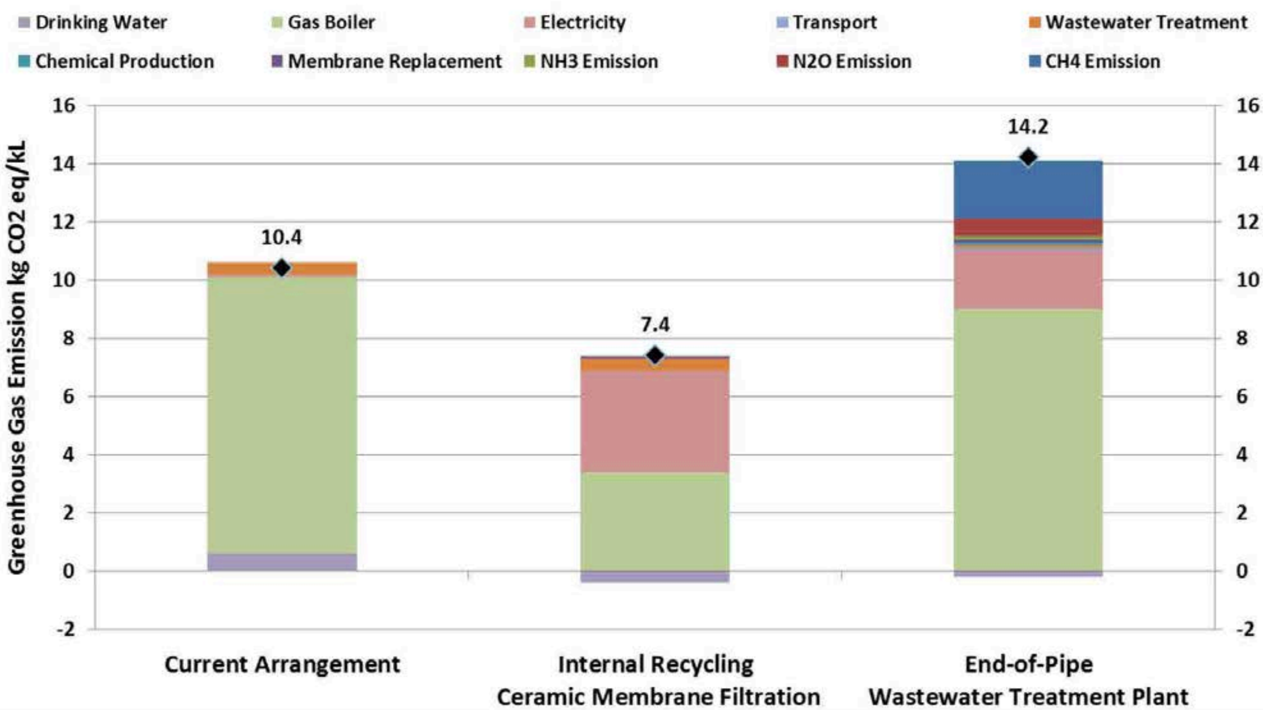

Figure 5-8 Life Cycle Assessment Comparison of Greenhouse Gas Emission for End-of-Pipe and Internal Recycling in Poultry Abattoir (Source: Grant et al., 2014)

to the process requiring the use of recirculation pumping, however, the energy consumption is partly offset by heat recovery, reducing overall energy use. External water recycling at an "end-of-pipe" advanced wastewater treatment plant resulted in an increase in greenhouse gas emissions compared to the current arrangement due to higher electricity use and fugitive emissions of methane and nitrous oxide from the biological nutrient removal process.

LCA comparison between internal water recycling technology and external "end-of-pipe" water treatment plants showed that while the potable water savings did provide an environmental benefit, the energy savings associated with energy recovery for the internal water recycling option were more significant compared to that of "end-of-pipe" treatment. Water and energy recycling internally using the ceramic membrane treatment was environmentally beneficial in most impact categories compared to the current arrangement, particularly when applied to water recovery from specific unit processes.

The external water recycling option did not provide any environmental benefit compared to the current arrangement but this option may still be considered due to other factors that do yield some benefits despite its longer Return on Investment (ROI) period.

04
Discussion

Although the cost of water, TBL, and LCA are important justifications for developing industrial water recycling, another important externality is the level of autonomy the schemes can provide to businesses. In particular, the circular economy enables business to decouple growth from finite resources. However, the circular economy also decouples growth from constraints of finite capacity of infrastructure and can encourage innovative uses of waste products. The following section examines how water recycling enabled a significant expansion of capacity at an Australian brewery and enabled a vegetable processing company to develop a new high margin product from a waste stream. However, business risks do exist, particularly when the use of one waste product, in this case recycled fibre in paper production, can have a negative impact on the performance of water recycling systems.

> *"The circular economy also decouples growth from constraints of finite capacity of infrastructure and can encourage innovative uses of waste products."*

4.1. Business Outcomes

A beer brewery in Yatala, Queensland is one of the largest breweries in the country, with a production capacity of 450 mℓ per annum. In under two decades, the brewery has more than doubled its production (140 mℓ/year in 1993 to 330 mℓ/year in 2001), quadrupling its share of the Australian market (5% to 21%) and halving its water requirements per litre of product (5.5 ℓ to 2.3 ℓ per litre of product), which is among the lowest globally (ISF, 2013). Unprecedented expansion and resource optimisation were possible even during the Millennium Drought of 2002 – 2008 with the use of on-site wastewater treatment and recycling.

Upon expansion to the current capacity, the brewery faced a costly dilemma. The local wastewater treatment plant was only optimised for a residential load of 30,000-40,000 people, while the brewery alone would produce an equivalent load of 60,000 people in wastewater. The extra load from the brewery on the municipal plant would render the brewery liable to pay the local government to increase the treatment capacity of its treatment plant to accommodate the brewery's effluent. Alternatively, the brewery could install an on-site treatment plant at Yatala. The local government was broadly supportive of the brewery's expansion to Yatala but the wastewater treatment infrastructure was unable to process such a scale of industrial waste. An upgrade to the municipal plant would have also accommodated a growing population in the region, however, there were still two potential setbacks. First, the expected municipal plant expansion time would likely have been at least five years, in tandem with the projected trends of population growth and second, despite fronting much of the expense for the upgrade, the brewery would not be guaranteed reception of all of its treatment waste. Given these constraints, the brewery opted for an on-site treatment plant, which granted them full autonomy and discretion concerning the timing of upgrades and treatment capacity. The plant went ahead with a budget that was approximately similar to the contribution the brewery would have made for the municipal plant upgrade of 3-4 million AUD in 1993 (5.5-7.5 million adjusted for inflation to 2018 dollars) (ISF, 2013).

In 2005, the brewery made another stride towards water use optimisation in response to the Millennium Drought and the closure of one of its breweries in Sydney. The closure meant that Yatala would soon have to double its production. Doubling production also meant doubling water usage and waste production. During a time of intense drought, this would leave the brewery liable to increasing water prices and wastewater disposal charges, as well as headworks charges if they opted to expand the municipal wastewater treatment plant to accommodate the increased waste. Taking another calculated risk to avoid these extra costs, the brewery opted for on-site water recycling in addition to on-site wastewater treatment Avoiding the increased cost of water, wastewater disposal, and installation of headworks, the brewery was able to offset offset the bulk of the expense of building the new recycling facility (the plant cost $6.5 million but saved the brewery $5.7 million in headworks charges). The recycling plant, in turn, diffused any potential political sensitivity regarding water use in a time of immense tension over the ongoing drought and spared the brewery from water restrictions that would have been a hindrance to production. Furthermore, on-site wastewater treatment and recycling minimised the greenhouse gas emissions by eliminating the need for transport of wastewater before processing (ISF, 2013).

Other benefits of having on-site recycling processes in breweries include the ability to treat feed water for quality control purposes. For example, it is not uncommon to treat town potable water before use in the brewery to ensure that the taste influencing, mineral quality of the process water is kept consistent throughout the yearly production cycle. Often, reverse osmosis is used to treat the potable water, which creates a residual stream of concentrate that needs to be disposed to the sewer. However, alternative technologies such as electrodialysis can also be used to increase the water recovery of existing on-site systems.

Ultimately, taking calculated, research-backed risks, in both 1993 with the installation of the WWTP and in 2005 with the addition of a water recycling plant, has led to unprecedented growth for the brewery, all while increasing its autonomy from the government in a time of increasing water restrictions.

4.2. Risks to Specific Industries

There exist specific industries for which careful considerations of water recycling practices need to be made. For instance, using recycled fibre (RCF) in newsprint production reduces the requirement for virgin fibres as well as the waste products sent to landfill and cuts costs. RCF use allows production to maintain profitability amid an increase in electronic news consumption, which caused demand for newsprint quality paper to decline. Measures to incorporate RCF also substantially decrease greenhouse gas emissions per tonne of paper, from 6.5 tonnes to 5.5 tonnes when mills operate with 30% RCF content, with a further decrease to 4.4 tonnes when they operate at 60%.

However, recycling fibres is not as unambiguously environmentally benign as it may appear, as the incorporation of RCF at an industrial scale requires the use of chemicals to brighten and de-ink the fibres. Such chemicals include sodium hydroxide, sodium silicate, and surfactants. The inclusion of these compounds means that the wastewater that remains at the end of the paper recycling process accrues massive amounts of sodium and silica, hindering its treatability by membrane filtration. Thus, the recycling of paper impedes the treatment of remaining wastewater after brightening and de-inking processes. As the paper industry is the third-largest industrial consumer of water in Australia, operating in a time of increasing water shortages and restrictions emphasises the paramount need to reduce water requirements. Balancing these two environmental and economic interests ought to be carefully considered by businesses in the paper and pulp industry. One solution is to use a lime coagulation pretreatment for the removal of excess sodium and silica, before treatment by reverse osmosis and nanofiltration.

Recycling and treating recovered materials as part of an industrial operation offers reduced costs for virgin materials and lower greenhouse gas emissions, which economically entices producers. However, in water-intensive industries like pulp and paper, wherein equal or more significant incentives to reduce water consumption exist, careful evaluation of how these processes may affect one another is critical. As in the case of using RCF in newsprint production, often a solution can be found.

4.3. Future Trends and Innovation

The proximity of Australia to the growing population centres of South and South East Asia, particularly India, Indonesia, and China, creates an opportunity for expanded export markets, especially for food and beverages. Meeting this demand with finite resources, including water, will necessitate the use of a circular economy approach to the management of raw material inputs and waste outputs. Consequently, brewing, packaging, and food processing industries looking to expand output without stretching demand on water supplies beyond sustainable levels will look to both internal water recycling and end-of-pipe recycling solutions.

This trend will result in increased use of compact treatment solutions, such as moving bed bioreactors, membrane bioreactors, reverse osmosis, and ultraviolet disinfection, that have become common place in municipal water recycling. Also, because the strength of industrial wastewaters is greater than municipal wastewaters, there will be an increase in the use of anaerobic processes, such as upflow anaerobic sludge blanket combined energy co-generation to either reduce or produce surplus power. The challenge for both industrial end users and equipment manufacturers will be to continue to innovate in the areas of process monitoring and control to ensure comparable reliability and resilience in the water recycling operation as well as the main processing lines. Again, it will be critical to capture all data, particularly power and water consumption across the integrated plant to validate the whole of life benefits to justify the project.

Other aspects of the circular economy that will become more important will be the valorisation of waste. An example of this comes from one Australian processor of canned fruits and vegetables that has developed an innovative approach to producing and marketing of a new premium product out of its wastewater. Specifically, when fruit and vegetable juices are reduced to concentrates to be exported and used to make bottled, shelf-stable juices, most extracted and separated water content becomes surplus to the process.

In most instances, the fruit and vegetable processors discharge the surplus water, however, in one facility, the waste is filtered, partially demineralised, and pasteurised to produce treated water that meets drinking standards. The treated water is packaged and marketed as a premium water product called AquaBotanical, which is now served in fine dining restaurants and lauded for its unique flavour notes. It is an excellent example of innovation in industries that are water-intensive but do not include processed potable water as part of the core business. Given the increased demand for processed fruit and vegetables, it is likely that more value will be extracted from the wastewater streams in order to manage limited supplies of water and minimise the impact of wastewater discharge on the environment.

In the case of AquaBotanical, the valorisation of the waste stream provides a new source of revenue to build into the business case for its industrial water recycling system.

05

Conclusions

Many water-intensive industries, such as pulp and paper, brewing and vegetable and meat processing are located in regions where both water availability and wastewater disposal options impose constraints on expansion and create vulnerabilities in supply chain logistics.

The impact of these constraints on regional economies and employment were highlighted during the 2002 to 2008 Millennium drought. In response, many businesses began to explore water recycling options. Before the drought, the prevailing regulatory environment governing both public health and third party private sector participation in water services was fragmented and not conducive to water recycling. In the absence of a national approach to establishing guidelines and performance standards for internal industrial water recycling, particularly in the food industry, businesses operating in two different states were subject to different standards and permits for projects with comparable uses of treated water. The situation was compounded if the industry had an export focus which involved federal as well as state regulations.

In response, policy, laws and guidelines covering pricing, investment and the protection of public health were gradually revised to encourage investment in water recycling and the adoption of a suite of technologies that enabled an expansion of production capacity with reduced freshwater demand and waste generation.

“Policy, laws and guidelines covering pricing, investment and the protection of public health were gradually revised to encourage investment in water recycling.”

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6

Wastewater Treatment and Reuse Best Practices in Morocco: Targeting Circular Economy

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Abstract

Many factors will challenge water users and stakeholders in the new millennium. Water shortage is not a new phenomenon in the African countries; but the problem resides in interference from other environmental challenges (climate change, population growth, droughts, desertification…) that are rising every day, which can result in difficult situations all over the world.
Morocco, as the North African country of the Maghreb, is suffering from water stress. This water shortage has important implications for the management of water and explains the current Moroccan policy of seeking new unconventional resources (wastewater reuse and desalination of brackish or marine sources waters). Moroccan water resources are unevenly distributed over its regions and heavily dependent on climatic variations. Pollution from households, industry, and agriculture poses an ever-greater threat. Increased demand for drinking water for tourism, industry and above all agriculture has led to the overuse of water resources, with major implications for the country's socio-economic development. In this respect, new technological capabilities and innovative solutions to increase water sources are required. Many countries such as Morocco have included treated wastewater reuse as an important dimension of water resource planning, using high-cost technology for urban areas (activated sludge, membrane reactor…) and low-cost ones for the rural areas (natural lagoon, constructed wetlands…), taking into consideration the eco-friendly vision. This governmental strategy has a target to cover agricultural needs (45%), green spaces and golf courses (43%). A total of about 730 Million euros in investment will serve to increase the wastewater reuse capacity from 38 Mm^3/year to 325 Mm^3 /year by 2030.
In this context, the present work is a review focusing on the best practices of treated wastewater reuse in Morocco, which targets a circular economy concept and serves as a key tool to mitigate climate change impacts in the region.

Keywords

Wastewater treatment, reuse, agriculture, policies, circular economy

01

Introduction

Morocco, a country known for its rapid population growth, urbanization and increasing economic growth, is suffering from water deficit and pressure on water resources.
One of the best alternatives to deal with this problem is treated wastewater reuse especially in agriculture. Wastewater contains some macro and micronutrients in different quantities, but cannot cover all plant needs. Wastewater reuse has been a benefit strategy in the last 30 years in the large urban areas and cities (Casablanca, Rabat, Fez…), because of the arid climate of Morocco (Aziz & Farissi, 2014). Generally, the entire Mediterranean basin is considered the most water-scarce region in terms of water availability in the world (Ezbakhe *et al.*, 2019).

> *“Reuse of wastewater in agriculture, or in other economic sectors could protect our natural resources from depletion and overuse.”*

Reuse of wastewater in agriculture, or in other economic sectors could protect our natural resources from depletion and overuse. Currently, the quality of the wastewater is rarely taken into consideration, because almost 90% of this wastewater is discharged and dumped directly into natural receivers (rivers, basins, open lands…) without any treatment. Only a small quantity is reused in agriculture. Several authors worked on the reuse of wastewater in irrigation in different parts of Morocco, and reported that many kinds of cultivated plants and crops can benefit from this practice (vegetables, forage and grain crops) (Aziz & Farissi, 2014). Forty-five percent (45%) of the total quantity of wastewater issued from wastewater treatment plants (WWTP) is now reused for agriculture in Morocco, which is a volume of 80M m^3 and could irrigate 4,000 hectares in 2020. Wastewater has several reuse applications as well, such as golf areas and green zones, recycling and cleaning in industry.
Even with the interest and the efforts presented by the Department of Agriculture for wastewater reuse in agriculture, results are still insufficient regarding the gap between experimentation and real field application in Morocco. Therefore, there is a delay in acceptability and realization of this concept within Moroccan society.
The implementation of the reuse of wastewater will certainly benefit the entire suite of involved actors in Morocco (farmers, scientists, policy makers and stakeholders) (Aziz & Farissi, 2014; Salama *et al.*, 2014). The reuse of treated wastewater in irrigation, instead of dumping it into to open lands, protects water resources, especially in arid and semi-arid regions such as Morocco where any water deficit could result in dramatic damage. Treated wastewater reuse also mitigates and reduces the high presence of different substances in wastewater (macro and micronutrients) absorbed by plants. However, reuse of wastewater without any treatment presents several risks for environment and human safety (Chaoua *et al.*, 2018). At the same time, organizations and suppliers of wastewater could invest in this direction and create positions for unemployed people and obtain additional financial revenues.

For these reasons, government should guarantee treatment of wastewater before any reuse, especially in agriculture. Treatment should be in accordance with international standards, for all types of treatment, to suit the nature of wastewater and its components in terms of substances, heavy metals, pathogens etc. The national water strategy (NWS), adopted by the Moroccan government in 2010, considers treated wastewater to have great potential in terms of facing water scarcity and facing the increasing demand for water, food and energy (WFE nexus) (Aziz & Farissi, 2014).

02

Water Scarcity and Climate Change Impact on Africa

The succession of periods of drought, the rapid increase in population, rapid urbanization and megacity development, increasing competition among water users, and growing concerns for health and environmental protection are examples of real challenges to overcoming water scarcity. According to the International Report of the Food and Agriculture Organization of the United Nations (FAO), by 2025, 1.8 billion people will live in countries or regions with absolute water scarcity (FAO, 2012). The term "absolute water scarcity" means water availability of less than the 1,000 m^3/inhabitant/year that is necessary for domestic and industrial use. This level of water availability is not sufficient to maintain the current level of per capita food production from irrigated agriculture (Lazarova & Bahri, 2005). Today, most countries of the southern Mediterranean basin (the Middle East and North Africa) can be classified as having absolute water scarcity because of their arid and semi-arid climate.
These data suggest that many countries will have to manage water resources far more efficiently than they do now if they are to meet their future needs.

In addition, interactions and interference between climate change and other environmental problems is now a significant challenge for Morocco as well as for African counries (Aziz *et al.*, 2020). Among the variables of interest are environmental degradation, agricultural productivity, food security, population growth and economic and societal instability. So far, the majority of research articles have focused on climate change and its interrelation with one or two of the aforementioned variables (Bekkoussa *et al.*, 2008; Thomas, 2008; Lhomme *et al.*, 2009; Sowers *et al.*, 2011).

Water for agriculture is critical for food security. Agriculture remains the largest water user, with about 70% of the world's freshwater consumption. According to recent FAO data (FAO, 2012), only 30 to 40% of the world's food comes from irrigated land, comprising 17% of the total cultivated land. In the future, water availability for agriculture will be threatened by increasing domestic and industrial demand. The demand and pressure for irrigation are increasing to satisfy the required growth of food production, because there is little growth in cultivated areas worldwide (0.1%/year). Between 1961 and 1999, a two fold increase of the total irrigated area in the world was observed, up to 274 million ha, whereas irrigated area per capita remained almost constant at 460.7 ha/1,000 inhabitants (Lazarova & Bahri, 2005).

Against this background, (Schilling *et al.*, 2012) gave an overview of the vulnerability to climatic changes of the five North African states Algeria, Egypt, Libya, Morocco and Tunisia (Figure 6-1). The overview serves two purposes: first, it allows us to discuss security concerns of climate change which have been raised even prior to the Arab spring in Tunisia, Egypt and Libya in 2011 (WBGU, 2008; Smith & Vivekananda, 2009; Iglesias *et al.*, 2010). Second, the overview enables us to identify countries that are the most vulnerable to climate change. Morocco's water resources are especially vulnerable, particularly surface water as it is the important water resource in the country,

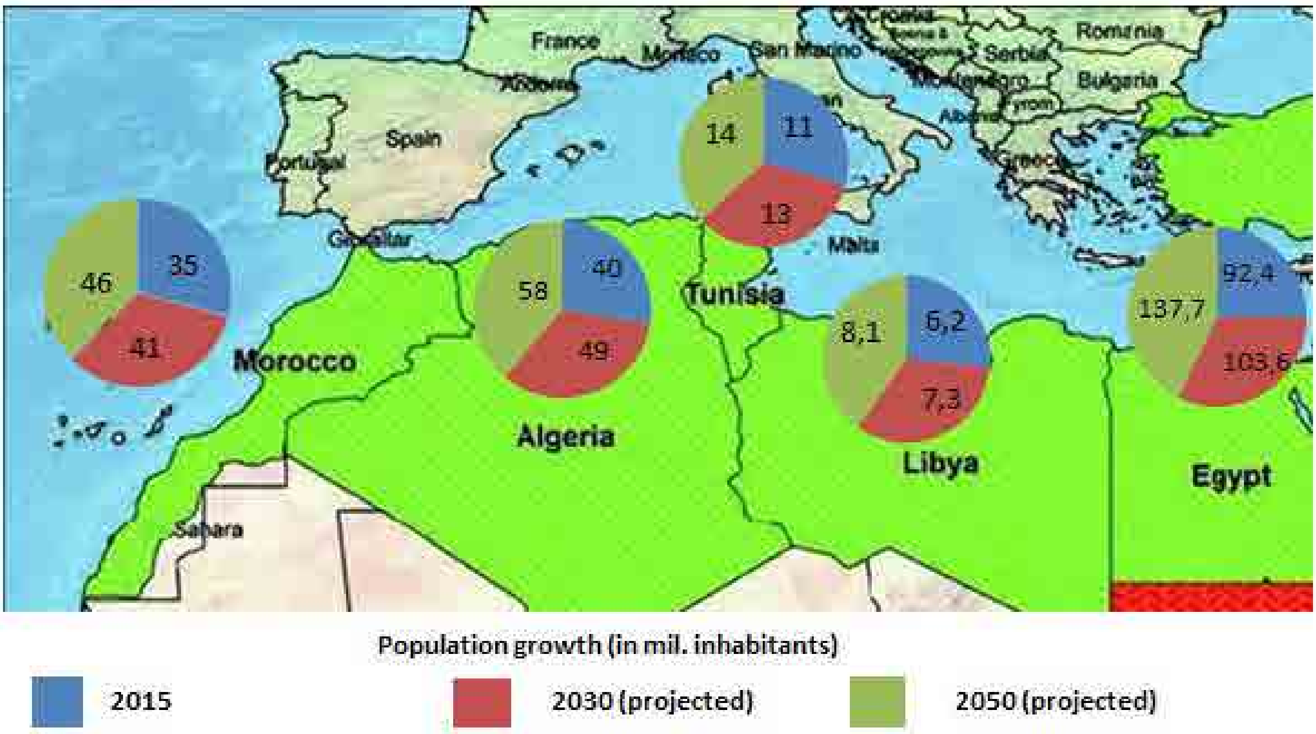

Figure 6-1 *Land use and population growth in North Africa.*

due to its sensitivity to climatic changes (low rainfall, and high evaporation).

Morocco, which is characterized by arid to semi-arid climate, is among the countries where water is scarce. In fact, the situation of its water resources is already critical and the risk of it becoming a problem hindering any further development is real. Precipitation in Morocco averaged 27.18 mm annually from 1901 until 2015. The annual volume of precipitation is highly variable over the entire territory, ranging between 50 to 400 billion m^3, and estimated to average 150 billion m^3. Water availability is expected to decrease due to climate change, creating a projected decrease in rainfall (Abdelfadel & Driouech, 2008). Current per capita availability is 760,000 ℓ/year, but that availability is expected to fall to 560,000 ℓ/year by 2030 (Kurtze *et al.*, 2015).

The renewable water resources are estimated in an average year to be some 30 billion m^3, of which only 20 billion m^3 are accessible (FAO, 2005). The volume of renewable water per capita is currently about 1,000 m^3 per capita, situating Morocco at the limit of poverty in water. Morocco's water availability is considered to be at the limit from which pressures on water resources begin to manifest (World Bank, 2017). Water availability in Morocco has decreased from 3,500 m^3 per person per year in 1960 to 645 m^3 per person in 2015. Even without any change in the available water resources, an estimated population of about 44 million inhabitants by 2050 would enhance a ratio of 510 m^3 per person per year by 2050, which is near to the "extreme water scarcity" level of 500 m^3 per capita (World Bank, 2017).

2.1. Irregularity of Rainfall and Inadequate Water Surface Resources

Precipitation in Morocco is characterized by a wet season in winter and dry conditions in summer. The rainy season, which starts in October and lasts until April, has its maximum in the months from December to February (Endlicher, 2000; Lionello *et al.*, 2006). Additionally the whole region is characterized by high inter-annual precipitation variability. Precipitation in the southern region is irregular in space and time and does not exceed 200 mm per year, which indicates a significant water deficit both in terms of surface and groundwater resources (DRSM, 2015).

2.2. Depletion and Overexploitation of Groundwater Resources and Degradation of Its Quality

Morocco is a predominantly arid and desert country despite its Atlantic coast. The weather conditions make irrigation a key technical requirement, from which economic and social benefits are undeniable. The day after the country's independence, irrigation was a privileged way of agricultural development and has received special attention from the authorities (Doukkali, 2005).

Today, the irrigation sector is the largest consumer of water in Morocco. Indeed, it consumes nearly 88% of the volume of water. Morocco has a total area of 446,500 km^2; the cultivable area is 8 million ha or 18% of the total land area.
The area for potential of perennial irrigation is currently estimated at 1,364,250 ha, or nearly 16% of the utilized agricultural area. Added to this perennial area, about 300,000 ha of seasonally irrigable land is available.
This large water deficit on the one hand, and increasing demand for agricultural products on the other, are two factors among others that are behind the development of irrigation in all regions of Morocco. Scarcity and the limited potential of natural water resources are limiting factors for the development of irrigated crops. The national water demand was estimated by 5.823 km^3/an, but the water withdrawal for irrigation was 11.010 km^3/an (Frenken & Gillet, 2012). Considerable efforts are being made in the monotoring, the mobilization and management of water resources (Aziz & Farissi, 2014).

Chronic water scarcity is thus becoming a permanent situation that can no longer be ignored when developing the strategies and policies concerning the management of water resources in Morocco. In this context and to support the development of the country, Morocco has long been committed to mastery of these water resources through the implementation of 128 large dams with a total capacity of around 17 billion m^3 and thousands of boreholes and wells capturing groundwater (Doukkali, 2005).

To face this serious situation, we have to tackle the following questions:

- What are the challenges to be addressed to satisfy irrigation demand under conditions of increasing water scarcity in both developed and emerging countries?
- What are the strategies to be developed to improve the efficiency of water use through better water management and policy reforms?

03

Reuse of Treated Wastewater as an Alternative, Moroccan Situation

This critical situation of water resources has increased the interest in reuse of treated wastewater in agriculture as an alternative and the integration of non conventional water in a planning and mobilization strategy and water resources management within the river basin.
Indeed, the water deficit can be filled mainly by treated wastewater; this resource is abundantly and continuously available. It has many advantages, notably a reasonable cost compared to desalinating seawater or digging wells.

The direct benefits for the inhabitants of the cities and centres that will be rehabilitated by this program are estimated at 1.7 million € per medium-sized centre for access to an efficient service. Indirect benefits to the health of the population and the Moroccan economy will be converted into improving the quality of surface water and groundwater impacting economic activities, in particular tourism, agriculture and also the production of drinking water or water-using industries.
A summary economic evaluation thus made it possible to calculate an Economic Internal Profitability Rate of 9%.
In addition to these benefits, treatment and reuse of wastewater contribute to the protection of the receiving environment (Aziz & Farissi, 2014).

3.1. Wastewater Potential in Morocco

During the 20th century, Morocco has experienced a very high population growth resulting in the increasing of demand for potable water in urban areas and, subsequently, the rate of connections to the drinking water system and therefore to the wastewater system as well. With the expansion of urban areas and the expansion of sewerage networks, the annual volume of wastewater discharged has increased (Jemali & Kefati, 2002). According to the environment minestry, in Morocco, the annual volumes of wastewater discharge have risen sharply over the last three decades. They increased from 48 million to 600 million m^3 between 1960 and 2005, reaching 700 million by the year 2010. These releases will continue to grow rapidly, and are expected to reach 900 million m^3 in the year 2020 (Figure 6-2).

3.2. Wastewater Treatment in Morocco

The National Liquid Sanitation and Wastewater Treatment Program (PNA 2005 – 2030) is targeting general access to the sanitation and wastewater treatment network.
Also, the PNA contributes to communicate and to reuse wastewater after treatment in Morocco. The main objectives of the PNA are: 1) implementing and promoting the circular economy concept in Morocco that could enhance the sustainable development rate by protecting natural resources, 2) identifying best management of wastewater, which is available in large quantities, and 3) capacity state improvement of basins, dams and water preservation systems. In addition, this program aims to create new job positions and opportunities in water engineering, management and treatment in order to reduce wastewater pollution by 60% and to improve the implementation of wastewater treatment plants in the country by 80% in 2030. It is also programmed to realize more than 300 wastewater treatment plant projects in order to reuse a total volume of 325 Mm^3 of wastewater by 2025 (World Bank, 2017).
The PNA is a very ambitious, real action strategy to control and to manage wastewater in Morocco. Multiple projects have been, and are currently being, implemented, including 18 projects to reuse wastewater in agriculture.

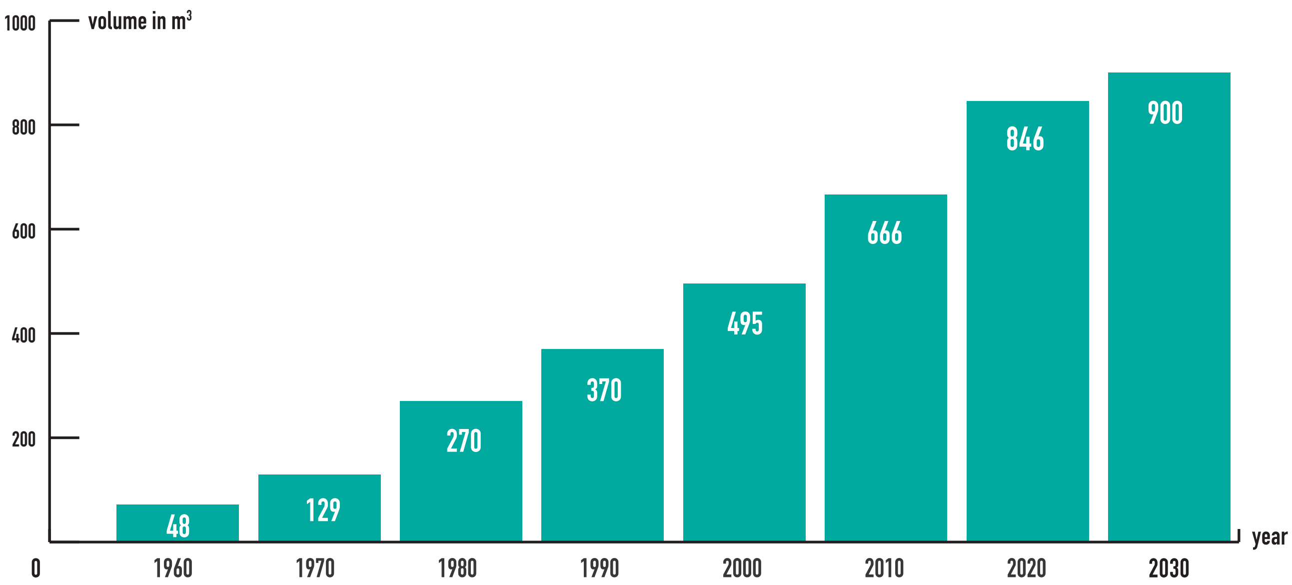

Figure 6-2 Trend of urban wastewater volume produced in Morocco

These projects have resulted in 38 Mm^3 total production every year, and are now monitored and in operation. They provide good wastewater quality to municipalities in order to be used in parks and green spaces, a use that accounts for 69.3%, followed by agricultural use at 13%, and finally for transportation in the phosphate industry at 16.6% (extraction of phosphate mineral consumes large quantities of water for pipeline transportation and in the purification process) (Alhamed *et al.*, 2018).

The Green Morocco Plan was launched in 2008 by the Moroccan government. It aims to face the environmental challenges, especially water scarcity which a serious threat to Mediterranean countries. The priority of the Green Morocco Plan and the National Water Strategy (PNA) is to manage water resources, to reduce pressure on freshwater and to conduct new strategies in wastewater reuse in agriculture. In this context, new technologies are also improved and supported as well as desalination of seawater, reuse of wastewater, biological, chemical and physical methods to treat wastewater and to reduce pollution, coastal and maritime strategy to preserve the water ecosystem and to mitigate water scarcity (Aziz & Farissi, 2014; MAPM, 2011).

According to (Aziz and Farissi, 2014), wastewater treatment processes require a consistent set of treatments performed after pretreatment, such as screening and degreasing. There are both intensive processes, including activated sludge, biological drives and trickling filters, and extensive processes with lagoons and infiltration-percolation beds. Since 1958, sixty wastewater treatment plants (WWTP) were built in Morocco, but in 1994 the vast majority were down or not connected to the network for various reasons: inadequacy of the treatment system to meet local conditions, faulty

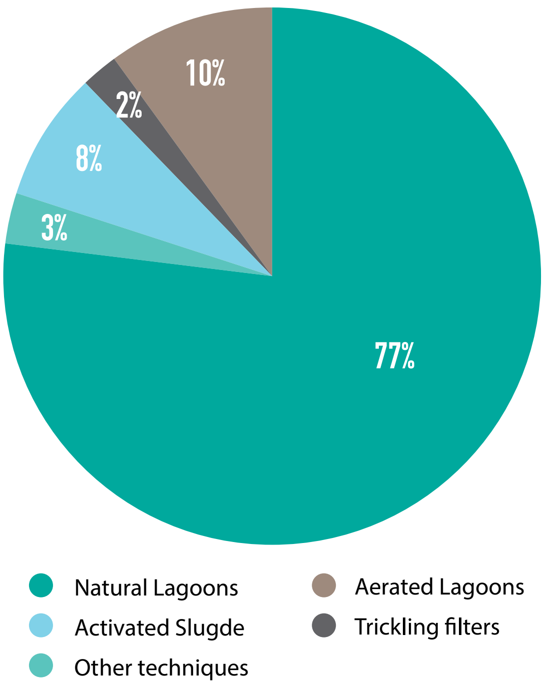

Figure 6-3 *Distribution of different kinds of wastewater treatment technologies existing in Morocco (Source: AZIZ & Farissi, 2014)*

design of structures, lack of maintenance, management problems (e.g. lack of budget, lack of competent technical staff), lack of planning in the short and long term. In 2004, only 8% of wastewater was treated, the rest was discharged directly into the sea (52%), the surface freshwater system (32%) and septic systems, causing serious pollution of the coastline, rivers and groundwater. This wastewater treatment rate was increased in 2012 to 28% (Rifki, 2013). By 2009, over 100 WWTPs are installed, mainly in small and medium size towns in the interior of the Moroccan country. They used a variety of technologies such as activated sludge, ponds, drainage and stabilization ponds and infiltration filters (Figure 6-3). But the lagoon technology remains the most used in the country due to their low cost, simple maintenance and adaptation to climate conditions of the area (Mandi, 2012). For these 100 WWTPs, more than half are not functional for many reasons: technical, financial and human (Mandi, 2012). This situation shows not only a delay that the country has experienced in successful wastewater technology deployment, but also contamination risks for the receiver environment in general and water resources in particular. Therefore, to protect water resources and reduce pollution, a PNA has been developed to improve sewerage collection, including the treatment of both industrial and domestic wastewater, and to increase wastewater reuse.

Twenty-six WWTPs are equipped with tertiary wastewater treatment (disinfection step using chloride and UV irradiation), allowing the reuse of treated water. The largest WWTP in Morocco, which was built within the framework of the PNA, is that of Fez which can treat 130,000 m^3/day and has a tertiary treatment process similar to that of the WWTP of Marrakech (120,000 m^3/day). The latter, inaugurated at the end of 2011, makes it possible to meet the needs of 7 golf courses in addition to the various green spaces. The WWTP manager (Autonomous Agency of Distribution of Water and Electricity of Marrakech, RADEEMA) has been able to conclude very specific commercial agreements with existing and future golf courses (for house garden's and the golf grass), i.e 18 golf courses in total. with the aim of providing them with a perennial water supply of around 39 million m^3/year (RADEEMA, 2009).

At the end of 2014, the total annual treatment throughput of the constructed WWTPs reached 292 million m^3. The wastewater flow in 2015 was estimated at around 780 million m^3. The treatment rate of collected water is thus estimated at around 50%, with a connection rate to the sewerage network set at 75% of the building in the country. This rate coincides with the specific objectives set by the program in 2015. In 2014, 6 pretreatment steps prior to release via marine outfall were completed, for an annual pretreatment volume of 321.24 Mm^3. These units are built in Tangier (82,000 m^3/day), Tetouan (43,400 m^3/day), Casablanca El Hank (500,000 m^3/day), Rabat (110,000 m^3/day), El Jadida (95,040 m^3/day) and Agadir Anza (49,680 m^3/day). Three other pre-treatment units are scheduled from 2015 to pre-treat the wastewater from Salé, Casablanca (North) and Laarache. This resource is only pretreated which cannot be used for irrigation.

04

Impact of Wastewater Reuse on the Soil, on Plants on the Water Ressources and Consumer Health

Wastewater reuse is not a new strategy, but generally, a lack of data, interference of several factors, differences in the nature and composition of wastewater make the understanding and elaboration of a typical and unified prototype for treating wastewater very difficult. It has been reported that 7% of agricultural lands are irrigated with untreated water and 10 % used treated wastewater. Several authors used wastewater for crop irrigation, and the results were highly positive in terms of crop production yield and fruit quality, but the wastewater was applied only after treatment, in order to avoid pathogenic contamination and high concentration of heavy metals (Intriago *et al.*, 2018; Nicolás *et al.*, 2016; Pedrero *et al.*, 2013).

The quality of wastewater is influenced by the type of treatment technology (membrane filtration, electrochemical methods, anaerobic digestion, adsorption, ion exchange method, etc.) and can cover the crop needs (water and nutrition) or even exceed it. Therefore, treating wastewater should always be controlled and evaluated especially before use as irrigation water (Sarode *et al.*, 2019; Tallou *et al.*, 2020). Generally, all treatment methods lead to positive results in terms of reducing phytotoxicity and pathogenic contamination, and the wastewater can be used in agriculture taking into consideration that it can meet over 75% of plant nutrition needs. In Morocco, the majority of wastewater treatment methods and technologies are not available everywhere in the country. However, there are current efforts at all levels of society to implement new technologies and strategies (Aziz *et al.*, 2019; Aziz & Farissi, 2014; Salama *et al.*, 2014). On the other hand, exceeding the macro and micronutrients limits could negatively influence crop production. Therefore, managing nutrients and choosing the adequate type of treatment is essential.

Reuse of domestic water must be considered as a new water resource and especially for irrigation but its use must also consider the health risk, soil contamination and the effect of those waters on crop growth. For example the chemical risks of using reclaimed water for agricultural irrigation might occur by consuming polluted crops and livestock, or by drinking or being in contact with reclaimed water (Chiou, 2008).

4.1. Impact on the Soil

As compared to conventional irrigated soils, the results revealed that wastewater could be a source of fertilizer since it contributes potassium oxide (K_2O) and phosphorus organic matter (Castro *et al.*, 2011).

The problem of soil contamination is a threat resulting from wastewater reuse in agriculture, due to the presence of some toxic constituents including high nutrients, heavy metals and chemical fertilizers. The accumulation of these substances in the soil leads to not only soil degradation, but also to a decrease in crop productivity, an increase in plants disease, and an increase in salinity which causes soil and groundwater pollution (Salama *et al.*, 2014). Several factors, such as the wastewater source and constituents, crop characteristics and soil properties, can influence the effectiveness of irrigation using wastewater. There are many differences between industrial, municipal, farm and commercial wastewater, which can also differ in economic value and environment impact.

Unfortunately, potential problems associated with recycled wastewater in irrigation do exist. These problems include increased salinity and relatively high sodium (Na) and boron (B) accumulation in the soil. Especially problematic is the significantly higher soil sodium adsorption ratio (SAR) in recycled wastewater irrigated sites compared with surface water irrigated sites. Sodium levels provide reason for concern about possible long-term reductions in soil hydraulic conductivity and infiltration rates in soils with high clay content, although these levels were not high enough to result in short-term soil deterioration (Abd-Elwahed, 2019). Salt leaching becomes less effective when soil hydraulic conductivity and infiltration rates are reduced. These chemical changes may in part contribute to the stress symptoms and die-off observed in some crops (Chaoua *et al.*, 2018).

Wastewater reuse in agriculture has now become common in Morocco, but it has resulted in soil contamination in some cases. A previous study has reported on the accumulation of heavy metals (Copper (Cu), Lead (Pb), Cadmium (Cd) and Zinc (Zn)) in wastewater reused for irrigation in the Marrakech region (Chaoua *et al.*, 2018) and that the problem of wastewater contamination is serious and could have negative impacts on natural resources and human health. In this research paper (Chaoua *et al.*, 2018), the authors investigated and evaluated the transfer of heavy metals from soil to crop, and they also calculate a health index based on the concentration of heavy metals. The results obtained show high contamination by heavy metals and a health risk index (HRI) above the acceptable limit. Therefore, the population that works on this farm, and consumers of this crop product, are highly exposed to contamination and pathogens. The authors highlighted exceeded values for toxic elements and cautioned that prevention should be taken in this case in order to avoid human health risk and environment degradation (Chaoua *et al.*, 2018).

Best management practices, such as application of soil amendments that provide calcium (Ca) to replace sodium (Na); periodic leaching to reduce salt accumulation; frequent aeration to maintain infiltration, percolation, and drainage; regular soil and plant monitoring; and, selection and use salt-tolerant crops, will be helpful in mitigating the negative impact of wastwater irrigation to ensure success in using recycled wastewater for irrigation (Qian & Mecham, 2005).

4.2. Impact on the Water Resources

Wastewater application has the potential to affect the quality of groundwater resources in the long run through excess nutrients and salts leaching below the plant root zone. Groundwater constitutes a major source of potable water for many developing country communities. Hence the potential of groundwater contamination needs to be evaluated before embarking on a major wastewater irrigation program. In addition to the accumulation of salts and nitrates, under certain conditions, wastewater irrigation has the potential to translocate pathogenic bacteria and viruses to groundwater. However, the actual impact depends on a host of factors including the depth of the water table, the quality of groundwater, soil drainage, and the scale of wastewater irrigation (Hussain *et al.*, 2002).

> *"It is clear that the impact of wastewater on water resources and aquatic ecosystems is very negative."*

Wastewater reuse in Morocco could affect the quality of available freshwater over the long term, for example by accumulation of macro and micronutrient quantities. Hence, more precautions and evaluations need to be done in order to confirm the safety and quality of wastewater for reuse in irrigation. In addition, pathogenic bacteria and viruses can be transported by wastewater if not highly treated. In fact, the complexity of this concept resides in interference among several factors (e.g. soil parameters, soil contamination rate, wastewater parameters and safety, climate of the region). Eutrophication is another serious problem that can be caused by drainage runoff after irrigation with wastewater. Eutrophication can affect the ecosystem and human safety due to the presence of an excessive quantity of nutrients in the water. It is clear that the impact of wastewater on water resources and aquatic ecosystems is very negative (e.g. impacts on the food chain). In addition, soil could be also affected by an accumulation of heavy metals year after year due to illegal dumping of wastewater to open spaces and natural resources. There are several factors that can affect the relationship between wastewater and the ecosystem, including soil parameters, rate of land use (yield production), type of wastewater, the type of irrigation system and climate (Hussain *et al.*, 2002).

4.3. Impact on plants

Wastewater irrigation affects not only physical and chemical properties of the soils but also plant yield and mineral content. According to (Choukr-Allah & Hamdy, 2005), irrigation using treated wastewater has given similar results, and sometimes better results, than fresh water irrigation in terms of yield. Table 6-1 shows some examples. Wastewater has a high nutritive value that may improve plant growth, reduce fertilizer-application rates, and increase productivity of poor-fertility soils. It is suggested that treated wastewater can be used to irrigate vegetables that are eaten cooked, with continuous control of the effluent quality to avoid contamination (Kiziloglu *et al.*, 2007).

Reported results have shown that the growers can find a long-term advantage in wastewater irrigation and, at the same time, satisfy consumer demands for food safety with continuous monitoring of wastewater irrigation. Meanwhile, questions of the long-term effects on soil fertility and protection of food chain are raised.

Table 6-1 Comparison of the yield obtained by irrigation using treated wastewater and that obtained by using fresh water (Source: Choukr-Allah & Hamdy, 2005)

Treatment	Crop						
	Chrysanthemum	Melon	Zucchini	Eggplant	Maize	Bread wheat	Durum Wheat
	Flower/plant	T/ha	Kg/plant	Kg/m^2	Qx/ha	Qx/ha	Qx/ha
Fresh water	69	26.2	1.29	3.17	12.43	5.11	0
Treated wastewater	80	34.6	2.18	3.41	12.62	48.69	31.83

4.4. Solute Accumulation from Irrigation with Treated Wastewater

In arid regions, the low input of fresh water due to limited precipitation means that accumulated ions are rarely removed naturally from the soil profile by flushing or leaching. Significant long-term problems for soil productivity can occur if irrigation with slightly saline water continues without additional water being applied to leach the solutes (Carr *et al.*, 2008). Irrigation by wastewater, with its large load of salts and nitrates, confronts us with a quandary: to apply just the water quantity necessary for cultivation (and thus to increase the salinity of the soil) or to apply a leaching fraction that will enable percolation of the nitrates at depth, thus risking contamination of the groundwater. It was hypothesized that, to meet 100% of the crop water requirements, irrigation with treated wastewater would lead to an increase in the solute concentration in the soil solution as the number of years of irrigation with reclaimed water increased. (Carr, 2011) indicated that the soil analysis results suggest that irrigation does lead to the accumulation of plant-toxic solutes, but soil analysis from farms which have been irrigated with reclaimed water for several decades reveals that solute accumulations have been avoided through water management strategies on the farm.

The challenge will be to design and operate a new generation of water management systems that are able to meet the demand for food in a context of water scarcity, while respecting the requirements of the environment (Choukr-Allah, 2005). The role of leaching in maintaining low soil salinity has been investigated at research sites by comparing the salinity of the soils irrigated with 100% and 120% of the crop water requirement. It was expected that the soils irrigated with 120% of the water demand would have lower soil salinity than the soil irrigated with 100%, which means that irrigation using more than the demanded quantity would reduce the salinity of the soil, providing a good strategy to overcome the soil salinity issue (Carr, 2011).

4.5. Impact on the Consumer Health

A research study in the Beni Mellal region in the center of Morocco was done in order to assess the possible risk of using wastewater without treatment in agriculture.
The study was conducted on 1,343 randomly selected children from this region, where 603 children provided a reference condition for communities that don't use wastewater in irrigation, compared to 740 children who consume products irrigated with wastewater without treatment or who are exposed and interact daily with raw wastewater. The objective was to evaluate the rate of geohelminthic infections. After analysis, using questionnaires and interviews with parents and children, they found that people exposed to wastewater reuse were affected by intestinal infection caused by two parasites; Ascaris lum-Žbricoides and Trichuris trichiura. In contrast, people who do not use wastewater nor consume crops irrigated with wastewater were 5 times less contaminated. The study highlighted that 20.3% of children were contaminated with Ascaris lum-Žbricoides parasite in are as that use wastewater in their daily life, while only 3.8% were reported for the control. In contrast, no significant result for Trichuris trichiura was found between the control and children in areas exposed to wastewater.
The authors of this study reported that wastewater reused in any field could present serious risk to the population, and therefore wastewater must be treated before any approved uses. In addition, demographic and social factors (gender, age, education level and profession) had no impact on the results obtained (Habbari *et al.*, 2000).

05

Wastewater Reuse and Acceptance Challenges from Moroccan Society

The implementation of wastewater treatment plants should also take into consideration economic and social aspects. For example, the location, proximity to population habitations, roads and natural resources, agricultural lands and agroforestry are very important to reduce the impact of wastewater. These factors could increase the cost of wastewater valorization in agriculture and the quality can be evaluated easily and the persisting risks can be avoided (Hussain *et al.*, 2002). Some best practices for treated wastewater reuse as a model of a circular economy are described following.

In the last decade, Moroccan society, including scientists, farmers, policy makers and stakeholders, have been aware of the current situation of Morocco in terms of water scarcity, climate change, rapid population growth, pressure on food, the energy-water sector and other environmental challenges that the country is facing today. This is reflected by the new strategies and action plan that Morocco is leading and establishing, and the Green Morocco Plan and the National Wastewater Strategy for example.
Theoretically, the country will face extreme water scarcity in the near future, while Morocco is depending on agriculture. For this reason, wastewater treatment reuse in agriculture seems to be the best alternative strategy to face water scarcity and to reduce pressure on available freshwater.
On the other hand, there are many new projects to support and to promote innovative ideas for water solutions in agriculture. For example, the Center for International Cooperation on Agronomic Research for Development (CIRAD), financed the Massire Project, which is a project for supporting farmers and new solutions and ideas in agriculture. The project funding is 1.7 million € financed by the UN International Fund for Agricultural Development (IFAD). It aims to identify and support small-scale innovations in the water management sector in rural areas, focusing on successful small-scale farming irrigation applications, for example, wastewater treatment technologies, drip irrigation, new solar water pump technology and innovative water governance metrics. The project objective is also to identify any other agricultural practices with the potential to improve Morocco's mitigation efforts towards water scarcity (Eliason, 2019).

It has been reported that the Massire project will help small scale farmers with the main actors in sustainable development such as agricultural cooperatives, international organizations, irrigation companies, scientists and local stakeholders in order to facilitate for them access to new technologies for sustainable farming.
Water management is the key issue for Morocco as the country regularly faces extreme environmental events (droughts, desertification, water scarcity…). In 2016, a sudden severe drought negatively impacted agricultural activity and production, during which the country's GDP decreased by 3.3%. According to the FAO, 83% of agricultural lands are not irrigated in Morocco, which is a percentage that needs to be reduced in the future. In addition, the country is suffering from significant variations in rainfall and droughts.
This vulnerability will rise as the rainfall is projected to be reduced by 30% by 2050, which puts Morocco in an alarming position (Eliason, 2019).

A wastewater treatment and reuse project is currently being carried out under the PREM (Sustainability of Water Resources in Morocco) Global Project funded by USAID in partnership with the Secretariat State in Charge of Water and Environment in Morocco. The various stages of the project are established in collaboration with the Wilaya of Greater Agadir, the rural municipality of Drarga, the Al Amal Association and in on-going consultation with the regional and multi-institutional committee for wastewater treatment and reuse. The population concerned was also asked at all stages to participate in the choice of scenarios concerning the site of the treatment plant and those relating to reuse options. This consultation is a good initiative to involve people who certainly have gained great experience in this field.
The feasibility study, concerning the installation of a wastewater treatment and recovery system in the municipality of Drarga, demonstrated the positive economic and environmental impacts of this action.
The location of the project in the municipality of Drarga is justified by the presence of a sewerage network, by the fact that this municipality does not belong to the Grand Agadir Sanitation Network and by the existing supportive community framework. The community framework has proven its worth in other very significant ways, including the provision of drinking water and the organization of various water raising awareness campaigns. The municipality of Drarga is located on the right bank of the Oued Souss (Souss River). The area is generally suffering from extreme water scarcity with very low rainfall and high evaporative capacity of the air and the soil.

The economic gain generated by the reuse of treated wastewater compared to irrigation with conventional water is reported to be very positive and attractive. This gain is due to the supply of treated water as an alternative water resource and to the nutrients provided by these waters.
A 100 mm clean water slide (1,000 m^3/ha) would provide crops with a fertigation equivalent of 40 kg of mineral nitrogen/ha, 11 kg of assimilable phosphorus/ha and 28 kg potassium/ha. In addition, the yield production will be at least doubled or tripled for all crops to be promoted. The current low crop yields are attributed to the lack of water, the high cost of pumping water and the low rate of technical supervision of farmers. Thus, it can be deduced that the project for the reuse of reclaimed water, coupled with technical support from the ORMVA of Souss Massa, will allow the farmers to achieve yields much higher than those previously obtained (Institut Agronomique et Vétérinaire Hassane II, 2000).

In Ouarzazate city, the committee that manages the wastewater treatment plant is called the Local Technical Committee of the Project Supervision (CTLSP). This committee was created in collaboration with the local authorities and the Provincial Technical Department (DPA). Its role is to bring the members together to make decisions and to release some of the effluent from the wastewater treatment plant to farmers who request it. In the event of an emergency related to a failure of the sewage system, committee members are also asked to solve the problem.

The rural municipality of Tidili Mesfioua is located in the province of El Haouz-Marrakech. Three of these villages, or douars as they are called in Morocco, were the target of a call for projects launched by the “Association Tissilte pour le Développement (ATD)” itself supported by the expertise of the “Centre National d’Etudes et de Recherche sur l’Eau et l’Energie (CNEREE)” of Cadi Ayyad University. The objective was then to acquire funds in order to improve the health conditions of 2,100 inhabitants and to preserve natural resources in this region. In 2011, funding was provided by the American Cooperation Agency (USAID). The agency thus financed most of the project in collaboration with the municipality, which also had to contribute financially to its implementation by the company INOVAR.
Today, the first four phases have been successfully completed. The fifth phase was the subject of a late feasibility study carried out by the CNEREE and aimed at providing different possibilities for reuse scenarios in irrigation. It therefore now aims to establish an experimental phase as well as to study the prospects for the sustainability of the project (Legros, 2017).

Wastewater treatment plants funded by OCP Group for phosphate extraction (Khouribga, Benguerir and Youssoufia cities) in Morocco are using microfiltration and disinfection of tertiary treatment and they are also using biogas technology to produce electricity from sludge treatment (World Bank, 2017). It has been reported (Mandi & Ouazzani, 2013) that wastewater treatment plants in Morocco can meet 45% of the needs of the agricultural sector, while allocating 43% of irrigation water to green spaces in cities and golf courses, and also 6% for aquifer recharge. In order to increase the wastewater reuse capacity from 38 Mm^3 /year to 325 Mm^3 / year by 2030, a total of about 71 million € should be provided.

The new wastewater treatment plant (WWTP) of Marrakech city, which started in 2011, is considered to be the first WWTP in North Africa to integrate in its system tertiary wastewater treatment, biogas technology, electricity and heat cogeneration, air treatment and wastewater reuse.
In this plant, a total of about 120,000 m^3/day of wastewater are treated in four steps (pre-treatment, primary treatment, secondary treatment with activated sludge, and tertiary treatment using microfiltration by sand filter and disinfection by ultraviolet lamp units). The tertiary process increases the quality of the final effluent that will be reused for irrigation of golf courses. The annual electricity consumed by the wastewater treatment plant of Marrakech is about 30 GWh/year, while the electricity generated by the cogeneration units is in total about 10.5 GWh/year.

The wastewater treatment plant of Marrakech city is one of the best plants that made great progress in terms of reaching a circular economy concept in order that Morocco could treat 60% of wastewater generated in all of the country (Mandi & Ouazzani, 2013). The cost of primary and secondary treatment for the WWTPs of Marrakech is 0.2 €/m^3, while the cost of tertiary treatment, including costs for pumping and transporting to the customers for reuse in irrigation, is 0.3 €/m^3 (Mandi & Ouazzani, 2013). In general, treatment and reuse of locally available wastewater can be a sustainable economic strategy to address water scarcity, which contributes to environmental protection, natural resources preservation and an important economic gain (World Bank, 2017).

5.1. M’Zar WWTP as a Case Study

The water master plan developed by the Souss Massa hydraulic Basin Agency responds to the framework directive of the integrated water resource management in Morocco. The driving forces are strong population growth and urbanization; tourism and industrialization; globalization; and climate variability and change leading to decreasing precipitation and increasing frequency of droughts. This situation has increased interest in recycling of treated wastewater in agriculture and the integration of non conventional water in a planning and mobilization strategy, and water resources management within the river basin.

The river basin of Souss-Massa in Southern of Morocco is the source of irrigation in this area, which is considered an arid region. Intensive agriculture is stressing the available water supply, especially the culture of growing some crops that consume water in large quantities (e.g. watermelon). However, pollution of water, extreme drought events and the overuse of water by the local population are the main challenges that threaten human safety and environment resources. (Malki *et al.*, 2017) investigated the impact of wastewater reuse in agriculture in the Tiznit region (in southern Morocco), where they reported that wastewater is reused after biological treatment based on anaerobic digestion of organic substances by microorganisms in anaerobic conditions and open lagoons. This treatment is declared to be an effective technology that result in good quality of wastewater (Malki *et al.*, 2017; Tallou *et al.*, 2020). In this region, cereals, vegetables, fruits are the major crop cultured and irrigated with treated wastewater.
The authors reported positive results obtained in terms of safety, production yield, and fruit quality. In addition, this concept of wastewater reuse presented several benefits such as low-cost for installation, and preservation of natural resources especially in this scarce region where 430 ha of different crops were irrigated with wastewater from the wastewater treatment plant in Tiznit, Morocco.

Many studies have focused on wastewater treatment and the reuse in agriculture and green spaces in order to decrease the use of conventionnal water and save it for drinking water. Unfortunately, just a few studies have been carried out in Agadir city (Mimouni *et al.*, 2002; Alla *et al.*, 2006; Eddabra *et al.*, 2011). Agadir region is situted in the southern part of Morocco, and is characterized by an arid climate, and high industrial and agricultural activities. The wastewater of the greater Agadir region is currently being released differently in different regions:

- For the northern sector of Anza, on the coast, north of the port of Agadir: without treatment;
- For the port area by the sea, at the main jetty of the Agadir port: without treatment;
- For the rest of Greater Metropolitan Agadir: primary effluent treatment by anaerobic lagoon (up to 75,000 m^3/day) and by secondary treatment using a sand infiltration process with a capacity of 30,000 m^3/day then tertiary treatment using UV lamps (RAMSA, 2016).

Despite the collection and treatment of much of the wastewater in Greater Agadir, major problems remain to be solved:

- Collection and treatment of wastewater from the northern area of Agadir (port, urban and industrial Anza).
- Storm water: The threat posed by storm waters that flow from external outlying areas to the urban perimeter, and have consequences in terms of overflow to urbanized areas and saturation of collectors and storm drains.
- Wastewater: discharges of water overloaded with organic matter and brine from many industrialists in the agri-food sector, promoting the emanation of hydrogen sulphide (H_2S) in the network with release of foul odors and high salinity at the exit of M’Zar WWTP (RAMSA, 2016).

5.2. Description of M’Zar Treatment plant

Currently, treated water, including UV disinfection, from the M’Zar WWTP is used to water a golf course in Agadir city. The M’Zar treatment plant is located in the south of Agadir, Morocco (30°20’28.1"N, 9°35’35.0"W). It was built in 2002 inside the Souss Massa national park. The purification mode includes three successive treatment stages, as summarized in Table 6-2 following.

During the first stage of watewater treatment, the raw water is sedimented for 3 days in the settling basins, with a treatment capacity of 75,000 m^3/day; during a second treatment stage, decanted water is percolated in the sand basins, which provide a treatment capacity of 30,000 m^3/ day; and the third stage, which has a treatment capacity of 30,000 m^3/day. Finally, the infiltrated water is disinfected by UV exposure (RAMSA, 2002).

The total landscape area of Agadir city covers around 600 ha with a need for irrigation water reaching 10 million m^3/year. With a daily flow of 50,000 m^3/day, the treated wastewater of the M’ZAR plant will completely fulfill this need. The golf courses alone occupy 30.5% of the total area of landscape in Agadir, with water consumption estimated to be 3,216,103 m^3/year (Mouhanni *et al.*, 2011).

Table 6-2 Physical and geometrical characteristics of the wastewater treatment process of the M’Zar WWTP (Source: RAMSA, 2002)

Primary Treatment: anaerobic decantation		**Secondary treatment: infiltration percolation**		**Tertiary treatment: UV disinfection**	
Flow	75,000 m^3/day	Flow	10,000 m^3/day	Flow	30,000 m^3/day
Number of decanters	13	Number of filters	24	Pumps (number and unit capacity)	6 + 1 Pumps— 270 m^3/h
Length of decanter	115 m	Filter surface	5,000 m^2	Reactors (number and unit capacity)	6 Reactors— 5,000 m^3/day
Width of decanter	35 m	Sand thickness	2 m	UV lamps: Number per reactor	14 lamps
Depth of the decanter at the deposit area	6.59 m	Gravel thickness	0.5 m	Wavelength	254 nm
Depth of decanter at lagoon area	4.24 m	Infiltration speed	1 m/day	Exposure dose	50 mJ/cm^2
Total Volume of decanter	210,000 m^3	Filter bottom sealing material	1 mm thick of HDPE eomembrane	Service life Contact time	16,000 h 4 s

06

Wastewater Reuse Policy in Morocco

National data for Morocco reports the presence of 17 wastewater offices and services (public and private) in all municipalities. Generally, these specialist services manage 112 networks in both large cities and small ones.
The population that benefit from these facilities is estimated to reach 20 million and will continue to increase due to the development of the country. Those centers are managed by multiple authorities and offices (Ministry of Interior, secretaries, National Office of Electricity and Water (ONEE) and some private companies) (see Table 6-3). These offices and companies' missions are the formulation of policy and rules that organize the water sector, manage water resources in Morocco, and provide and regulate services of the communities (Alhamed *et al.*, 2018).

The Ministry of Interior manages the different municipalities and oversees water and sanitation facilities through its water and wastewater direction (DEA). This direction plays a crucial role in establishment, implementation, support and organization of wastewater treatment plants and water network infrastructure. The communal law chart indicates that the responsibility of water and wastewater treatment and management is a task for municipalities under the supervision the Ministry of Interior. The Office of water and wastewater (DEA) provides financial support and technical knowledge.

In the National Program of Wastewater (PNA) framework, planning and financial support are provided by the Office of Water and Wastewater Network (DEA). In addition, the Ministry of Finance and the Secretariat of State in charge on Environment are also main actors and decision makers for the national wastewater program in Morocco. DEA is also responsible for monitoring of the sanitation network and to fix the price for wastewater, while the Secretariat of State in charge on Environment is responsible for policy development and execution in the environmental field. The tasks are the following:

Table 6-3 *Principal Authorities and offices managing water sector and resources in Morocco (Mandi & Ouazzani, 2013)*

Authorities managing water sector	Role
River Basins Agencies	9 agencies are managing the main hydraulic basins of Morocco.
ONEP (national office of drinkable water)	Principal producer of potable water in Morocco.
Distribution offices	Private organizations responsible for drinkable water distribution in some big cities in the country.
Municipalities	Responsible for irrigation of gardens and green spaces.
Rural Towns	Providing drinkable water to rural populations.
ORMVA (agricultural offices)	Responsible for the management of the big irrigated perimeters in the country.
DPA (provincial delegations of agriculture)	Management of the small hydraulic resources.
ONEE (national office of electricity)	Principal producer of electric energy including energy of hydraulic origin (merged with ONEP).
Waters and forests administration	Responsible for water resources management.
The provincial health delegations	Health responsibility, hygiene and diseases especially from water.

- In coordination with the different ministries responsible for policy making in Morocco, they prepare and update the national strategy of sustainable development according to the national needs and new international standards.
- Suggestions for new laws and policies in the wastewater treatment reuse sector in order to preserve natural resources and to valorize wastewater.
- Representation of the Moroccan government in international events to follow the updates and import experiences.
- Contribution in climate change and water scarcity mitigation by adoption of the circular economy concept.
- Establishing and building new wastewater treatment plants with good performance regarding location, climate, wastewater properties, new applications and technologies.
- Environmental data collection especially in Morocco where there is insufficient information about wastewater treatment and reuse.
- New water resources prospects and assessment, as well as seawater desalination, biological technologies for wastewater treatment.
- Control of wastewater quality especially in agriculture.

The directors of the secretariat of state in charge of water (local municipalities, water associations, academic and stakeholders) administers the Morocco's river basin agencies which are semi-public and independent financially.
The responsibilities of water basin agencies are the following:

- Developing, a new plan for collecting water, especially the collection of rainfall over a natural drainage area.
- Ensuring the control and monitoring of the water discharge in convenable area and providing good quality of wastewater.
- Elaboration of new techniques and technologies of wastewater treatment in order to improve the treated wastewater quality.

The communal charter of 1976 in Morocco gives the municipalities responsibility of managing and distributing freshwater and sanitation network. However, municipalities assign the management of water and sanitation to some private and public utilities. For example, ONEE is the main actor in different Moroccan cities, in Casablanca, the private concessionaire LYDEC, in Rabat (REDAL), in El Jadida (RADEEJ), Tangier and Tetouan (AMENDIS), and Marrakech (RADEEMA) etc. are the main providers and managers of water and sanitation services (Alhamed *et al.*, 2018).

In Morocco, the main legislative framework and articles that manage and organize working in the water and wastewater sector are:

- Article (84): It is prohibited to reuse wastewater in agriculture if not treated and in accordance with international standards and limits for nutrient and heavy metals composition.
- Article (57): good and precise conditions of wastewater reuse are imposed. Authorization to treat and reuse wastewater can be supported financially and technically from the government and national administration to preserve water resources against environmental challenges and pollution.
- Article (51): The establishment of standards and values of wastewater quality for irrigation are updated every ten years by the Norms and Standards Committee.
- Article (54): Prohibition of discharging wastewater into the open environment, agricultural lands and different natural resources.
- Article (52): Discharging wastewater needs an authorization from the Agency responsible after investigation of the receiving areas.

In Morocco, the problem of construction of wastewater treatment plants refers to the financial funding required for realization of these kinds of projects. The majority of wastewater treatment plants are financed by credit or partnerships within municipalities. The international contribution also has a part in building these projects in some cities but it is not enough to meet the needs of increasing population and the quantity of wastewater generated. Another difficulty of providing wastewater treatment services resides in the installation of the sewerage network, which requires huge funding. The cost of establishing a WWTP depends on the technology used (e.g. the treatment process), the source and type of wastewater, the quality targeted and the final disposal method. For example, if the wastewater will be reused directly, authorities require high quality for the final product. In Morocco, there are no models or details outlined for creating wastewater treatment plants because the cost depends on several factors. However, some experience could provide a general overview for the cost, for instance where one m^3 of wastewater treated by lagoon or filtration and percolation technology costs 1 Euro (10 Moroccan Dirham). For example, in Benslimane region in Morocco, wastewater is sold after treatment for golf irrigation at a cost of 0.18 €/m^3, while for the farmers the cost is 0.045 €/m^3 which is a suitable price. In addition, offices of agricultural development sold treated wastewater to farmers for agriculture at an average cost of 0.045 €/m^3, while the cost of drinkable water is between 0.18 and 0.72 €/m^3. This is a positive solution for farmers instead of paying the fees for pumping groundwater at 0.13 €/m^3 especially in water-scarce regions, such as Souss-Massa in Southern Morocco. The price is always an obstacle for farmers, especially in arid regions, therefore this problem should be taken into consideration when establishing wastewater treatment plants in order to implement low cost and effective technology (Alhamed *et al.*, 2018; Salama *et al.*, 2014).

According the law on water 10-95 (see below), the use of untreated wastewater is banned. However, policy makers should facilitate scientific research on wastewater treatment, especially since very large volumes of water could be made available through wastewater reuse.
Therefore, treatment and good management practices are the right decision due to the fertilizing value of this by-product. It has been reported also that the main problem in world now is the gap between policy makers and scientists, and this is due to the interference of different factors and drivers

(economic, environmental, social and political).
Some authors worked on epistemological problems and limitations or conceptual challenges, but only few ones presented the institutional metrics that could limit the adoption of the wastewater reuse. Therefore, the complexity could be visible and clear when using institutional and academic way of thinking that makes environmental challenges relevant. These metrics can establish new governance legality in terms of effectiveness.
The wastewater reuse in agriculture should be considered as a problem of legitimate policy objective if we want to be precise within the institutional culture of the international commissions and policymaking. Therefore, the orientation of the global awareness should be in this direction of giving the opportunities to the new strategies of mitigating the climate change impact (Voelker *et al.*, 2019).

In general, the policies and laws that organize the wastewater sector in Morocco are illustrated below (Haité, 2011; Legros, 2017):

Law 10-95 on water

The Water Act 10-95 brought together the various existing water laws and supplemented them in order to make them as coherent and simple, and in a comprehensive legal text taking up the different facets of sustainable water management.
The principles of this Act are:

- Ownership of water resources.
- Integrated and decentralised management at a basin agency level.
- Authorisations for different water and wastewater reuse.
- Managing fees for the use of water resources and their discharge.

Law Project on water 36-15

The aim of the proposed new Water Act is to eliminate identified weaknesses and problems over the years in the 1995 Water Act. These weaknesses include:

- Complexity in the demarcation and allocation of water available in the public domain
- Few provisions on stormwater and wastewater.
- Lack of provisions on flood protection metrics and measurement.
- Lack of provisions on seawater desalination.

Due to the current situation for Morocco and the new climate change challenges, these laws need to be updated.

Decree n°2-97-875 of 6 Chaoual 1418 (04 February 1998) for the wastewater reuse

The objectives of this Decree are the regulation of the application for authorization to use wastewater and the conditions proposal for financial assistance available for investments in wastewater treatment and for the installation of pumping and supply systems.

Decree n°2-07-96 of 19 Moharrem 1430 (16 January 2009) that fix excising procedures for authorizations and concessions relative to public water sector.

It is forbidden for anyone to use water resources available in his land without permission from authorities. In cases of non-compliance, the water police have the power to intervene.

Joint Decree of the Minister of Equipment and of the Minister in charge of Spatial Planning, Urbanism, Habitat and the Environment No. 1276-01 of 10 Chaabane 1423 (17 October 2002) laying down standards for the quality of water intended for irrigation

This Order consists here of a summary document of the standards quality for water destined for irrigation. These standards are collected and reproduced in a document of the SEEE (State Secretariat of State in Charge of Water and the Environment) in order to make them accessible to all public.

Joint Decree of the Minister of Economy and Finance, of the Minister of Equipment and of the Minister of Agriculture, Rural Development and Maritime Fisheries No. 548-98 of 21 August 1998 on water use charges for public water supply for irrigation

The fees are calculated by consumption band using a mark-up coefficient. For example, this coefficient will be 0.3 when the intake is carried out directly by the user downstream of a dam, while it will be 0.8 when the secondary or tertiary channels in the land have been carried out by the state (the fees are raised due to the charges of investment in channel construction). Additional costs may also be added to cover the costs of pumping stations from which certain users benefit, such as: pumping costs for gravity irrigation (0.03 and 0.07 Dh/m^3) and pumping costs for sprinkler irrigation (0.26 and 0.3 Dh/m^3). The tax collector is the Minister of Finance. Nevertheless, the task can be carried out by delegating it either to the wastewater treatment plants, to the ONEP, to the Boards or to private dealers.

Dahir n°1-87-12 of 3 Joumada II 1411 (21 December 1990) Promulgating law n°02-84 relation to agricultural water user associations of wastewater reused in agriculture.

This Dahir aims to codify the functioning of wastewater treatment plants. First, it focuses on defining the tasks assigned to them which include: carrying out works related to the use of agricultural water, the maintenance of these works in order to ensure its sustainability and the organisation of water distribution for agricultural irrigation, and pay the recovery of taxes and fees.

07
Conclusion

In this world, water is extremely important for our life, but that precious resource is very limited in terms of availability. Water is used in agriculture to produce food, where 70% of the available water and 30% of energy are used in agriculture. In addition, the global population is increasing (9 billion estimated in 2050), which implies continued pressure and high demand for water, energy and food.

“The reuse of treated wastewater can be an important alternative to the use of potable and freshwater in the agricultural sector, especially in a country like Morocco where irrigation uses up to 90% of the water consumed.”

Therefore, there is a need for new strategies and methods to manage water in international and national governance. In the last ten years, due to water scarcity and climate change impact, this concept has become very interesting to scientists and policymakers. The large quantities of wastewater illegally dumped year after year into natural resources could represent valuable opportunities if the resource is, instead, managed well.

The reuse of treated wastewater can be an important alternative to the use of potable and freshwater in the agricultural sector, especially in a country like Morocco where irrigation uses up to 90% of the water consumed. Performance studies of wastewater treatment plants in Morocco show that the microbiological quality of water treated by the majority of functional wastewater treatment plants does not meet the irrigation standard, as is the case for most North African countries. This failure gives rise to treated water presenting significant health and environmental risks, which becomes an impediment to the strategy of reuse of wastewater as the only way to overcome water scarcity in the region.

Wastewater is known to contain different microorganisms that could be pathogenic (viruses, bacteria…) and it is difficult to remove them after the treatment process.
For this reason, wastewater reuse in agriculture can result in dramatic scenarios, such as human health risk (diarrheal and parasitic infections) and environmental degradation (microbial water contamination and salinity effects on soil... etc), especially in developing countries.
The complexity of the problem is not only in microbiological contamination, but also chemicals present in wastewater that come from industrial effluents or from the accumulation of substances in soil after using chemical fertilizers and pesticides above the limits and standard values. Contamination and the risk of intestinal nematode infections can threaten human safety, including not only farmers but also consumers of commercial produce (Salama *et al.*, 2014). Factors influencing the vulnerability of populations could, firstly be the level awareness and consciousness of people and their behaviors, in addition to wastewater quality, harvesting and irrigation systems, the nature of the crop and type of soil. But for protection of human health from pathogenic microorganisms, pathogenic removal technologies are required, which are in some cases expensive and need daily control, since are high and advanced technologies, such as nanofiltration and UV irradiation.

Therefore, scientists and policy makers must work together in order to change our behaviours with respect to water, energy and food consumption. Morocco, an arid region, is continuing to develop its natural resources management by establishing new strategies and technologies to reuse wastewater in agriculture in the context of the Green Morocco Plan and the National wastewater program.
Even though there has been progress in natural resources management and wastewater reuse, Moroccan governance should elaborate precise and clear instructions and laws that organize and legalize wastewater treatment and reuse.

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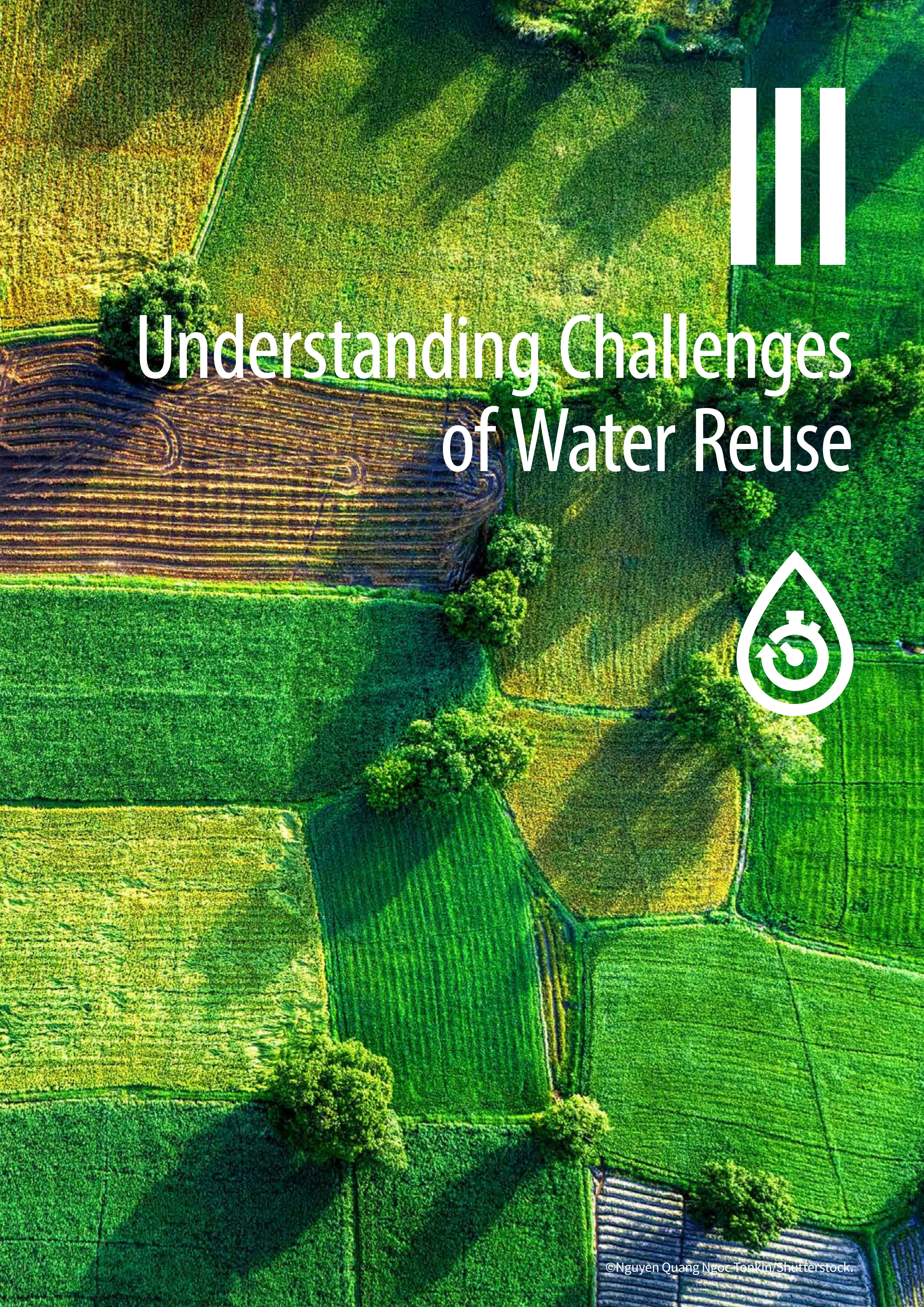
III

Understanding Challenges of Water Reuse



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7

Marginal Water Resources for Food Production –Challenges for Enhancing De-growth and Circular Economy in the Gulf Cooperation Council Countries and Iran

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Abstract

This contribution reviews current efforts in the region, and compares reuse trends in Iran and Gulf Cooperation Council countries. Agricultural production in the Gulf region is naturally constrained by water scarcity and alternative water sources are therefore highly needed. The impacts of unsustainable water use on the limited, non-renewable groundwater resources are disastrous in terms of declining groundwater table, increased salinity and farm closures. In Iran, water is more available but water scarcity is increasing due to the rapid growth of economy and population, but also due to waste and overuse. Marginal water resources – unutilized water of lower quality - such as urban wastewater, stormwater, as well as saline water, can provide important options for sustainable local food production. Although some new water sources, such as treated wastewater, are being increasingly used, the use in agriculture or other close-to-person uses are still not common. At the same time, different water sources can be used or combined for food production, e.g. marine-terrestrial agriculture or the utilization of harvested or drained water. In this context, this comparative review analyses the use of these marginal resources for food production as a way to enhance de-growth and a circular economy in urban areas of the region. It first highlights the available marginal resources and conceptualizes the use of these resources in the context of sustainability paradigms, such as de-growth and circular production. At the same time, policy challenges are highlighted and this paper advocates the use and potential of new resources such as treated municipal wastewater. For a wide use to happen, such new water sources need to be appropriately identified, treated, delivered and accepted by society and end-users.

Keywords

Marginal water resources, treated wastewater, water reuse, de-growth, circular economy, Gulf Cooperation Council, Iran

01
Introduction

Water scarcity is a constraining factor for food production in most riparian countries of the Persian/Arabian Gulf. This is particularity true for the hyper-arid region of the Gulf Cooperation Council countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates). These countries, which have a small cultivated land ratio of between 2-4% in comparison to the global average of around 10%, are increasingly importing most of their food supplies due to rising populations and increasing food consumption per capita (Al-Saidi & Saliba, 2019). Both the GCC region and Iran face a similar challenge with regard to water supply security threats due to growth, waste and ineffective policies. Further, all countries have a high rate of urban population of more than 85% for the GCC region, and around 74% for Iran in 2017 – both above the global average of around 55% (World Bank, 2019). Supplying the growing, and increasingly urban, population with sufficient amounts of food in decent quality without causing a deterioration of water resources availability and quality is an important challenge.
In Iran, water is more available but water scarcity is increasing due to the rapid growth of economy and population, but also due to other combined factors such as mismanagement, overuse, economic sanctions, expansion of the cultivation area in the context of the food sufficiency policies (Madani *et al.*, 2016; Pirani & Arafat, 2016).

The high rate of food imports is expected to continue due to local population growth, constraints of land, and the presence of large numbers of expats who fuel markets for international food (Kodithuwakku *et al.*, 2016). At the same time, local food markets are increasingly finding more attraction due to societal demands for healthier food and political initiatives to decrease the dependence on food imports (Alpen Capital, 2017). In addition, wastage by households and in the tourism sector is also a major concern (Pirani & Arafat, 2016). However, the environmental impact of local food production is significant. Groundwater resources are largely used for agriculture, which consumed 67-93% of total annual water used in GCC countries in 2010, and have witnessed a steep decline, leading to water quality problems, seawater intrusion and many farm closures (Saif *et al.*, 2014). Similarly in Iran, the local agricultural sector, which consumes around 92% of water, has been heavily subsidised, and, particularly after the Islamic Revolution in 1979, has achieved higher rates of sufficiency of more than 90% which also resulted cheap food prices, increased food demands and the promotion of consumerism culture (Amid, 2007; Saatsaz, 2019).

The water demands for agricultural in the Gulf region can be partially met through the use of marginal water resources (World Bank, 2019). These resources are defined here as unutilised water resources of typically lower quality. Marginal water resources such as urban wastewater from domestic, commercial and industrial effluents, stormwater, as well as saline water, can provide important options for sustainable local food production. At the same time, the use of these resources can reduce the need to desalinate more water. The desalination increase to meet future demands has raised several concerns about the future of the Gulf water body, e.g. the deterioration of water quality (e.g. through increased salinity) and an increase of supply risks in the case of failures of mega desalination plants (Al-Saidi & Saliba, 2019). Although some marginal water resources such as treated sewerage effluents are increasingly being used, mostly for non-edible agriculture (i.e. uses and products not directly for human consumption such as landscaping or forage cultivation), there are many other unused resources. For example, treated wastewater is an important emerging source of reused water for urban areas due to the closeness of wastewater treatment plants to urban areas. If these plants were to become more integrated with urban agriculture, the beneficial uses of this water source are numerous as it can replace earlier mentioned freshwater use for non-edible agriculture. Further, saline water and wastewater can be used for combined marine-terrestrial agriculture, while water harvested or drained water is often suitable for vertical farming.

In this context, this contribution aims to analyse the use of these marginal resources for food production as a way to enhance de-growth (a food economy characterized by low-metabolism and high-reuse rates) in the cities of the region, with a particular focus on challenges facing the emerging use of treated wastewater. This study uses recent academic reviews, primary literature as well as policy documents to highlight directions for marginal water use in the Gulf region. It does not provide detailed national-level analysis of technologies, projects or trends in marginal water use per type and region since such data are largely not available and/or consistent. In fact, academic research on reuse trends, policies and constraints in the region is limited, with only a handful of papers mainly on wastewater treatment either in the GCC region or in Iran. We assume that the comparison between Iran and GCC countries can provide valuable insights. Both Iran and the GCC region have similar economic characteristics (middle and upper-middle income carbon economies with strong state involvement) as well as water scarcity pressures (due to natural scarcity and/or growing populations and economies).
At the same time, they differ in terms of hydrological conditions as well as the technological advancement and policies with regard to water reuse. The chapter first briefly conceptualises the use of these resources in the context of the sustainability paradigms such de-growth and circular economy. Here, marginal water resources are seen as more sustainable alternatives to the use of freshwater. Therefore, they constitute an instrument to curb waste of water, energy and produce through the use of local production. This contribution also outlines current efforts in the GCC countries and in Iran to utilise these resources. Later, the main policy challenges are analysed in more detail in order to outline recommendations for the potential use of these resources for urban food production.

02

Marginal Water Resources, Circular Economy and Degrowth – Conceptual Remarks

2.1. Linking De-growth to Reuse and the Circularity Idea

The need for, and benefits from, the utilization of marginal water resources can be derived from broader sustainability paradigms that offer generic recommendations for a better (more sustainable) production, consumption and resource utilization. Here, we are not concerned about these paradigms as precise scientific ideas or political economic propositions, but more as general, but useful, sustainability frameworks and entry points for debates.

For example, we do not understand the de-growth idea as in contrast to growth per se. In fact, de-growth resembles a "banner" that rallies critics of uncontrolled growth – more production and more consumption – that is evidently crossing important planetary or environmental boundaries, thus becoming destructive and unsustainable (Latouche, 2009). In fact, although the idea of de-growth has been around for a while, it has gained much attention in recent years as a common demand by some scholars, activists and policymakers for a transformative change towards a new era in which growth is not an ultimate and absolute objective (D'Alisa *et al.*, 2015). The concrete implications of this concept are often captured in principles such as re-conceptualizing (redefining desirable growth and development ideas), restructuring (e.g. through structural change of industries), re-localizing (e.g. local food), reducing (e.g. minimization of waste), recycling or reusing (e.g. reuse of water) (Latouche, 2009). This is done through a downscaling of the physical throughput in order to achieve a sustainable steady-state (Büchs & Koch, 2019). We use this understanding of de-growth and define it in the food sector as a steady-state in which the food value chain (production, distribution, consumption and disposal) is characterized by low-metabolism and reuse is widely practiced in the food economy (e.g. water reuse for agriculture, food sharing or donations). In this sense, the de-growth idea cannot be effectively separate, nor should it be, from other concepts such as the circular economy narrative since both address the narrowing and slowing of material flows and the importance of increasing circulation of materials (Schröder *et al.*, 2019). In fact, the core of circular economy's definition lies in the ideas of reduction, reuse and recycling (3R framework) (Kirchherr *et al.*, 2017), while most of the concrete applications of such a concept are driven by the business community or pioneer countries (e.g. Germany, China) advocating low-metabolism economies and reuse systems for valuable/scarce resources (Korhonen *et al.*, 2018; Geissdoerfer *et al.*, 2017).

Sustainable production and utilisation of food/land as well as water are prerequisites, as well as a means, for the fulfilment of the de-growth premise while circularity of resource utilization helps achieve this premise. De-growth, and some circular economy concepts, can be closely associated with the idea of strong sustainability which postulates that one capital type should not be substituted by another one to generate growth. Here, water and food policies are evolving to incorporate strong sustainability ideas through the use of ecosystems services, natural infrastructure and community-based management approaches that utilise and protect both water and land resources (Al-Saidi & Buriti, 2018). Furthermore, both water and food are non-substitutable and satiable, basic needs whose satisfaction should not be traded against each other in a way that jeopardises the sustainability and the long-term availability of the underlying resources, e.g. destroying arable land or polluting/overusing water resources (Büchs & Koch, 2019). In this context, the transformation of the agricultural sector requires rethinking current practices and their potential to contribute to a low metabolism in line with the de-growth idea. Gomiero (2018) explored de-growth criteria for the agricultural sector, namely the availability of an "appropriate technology" for creating jobs as well as the use of "convivial tools" such as do-it-yourself tools and tools that increase productivity and have an open-access character. Using these criteria, some current practices, such as bio-tech agriculture or organic farming, face limitations such as the lack of conviviality for a large-scale and user-driven practice. Therefore, more experimentation is needed to identify food practices that correspond to the proclamations of de-growth in the agricultural sector in terms of increasing local food self-sufficiency, reducing waste, recycling, using renewables, and eliminating environmental damage caused by products such as agrochemicals (Gomiero, 2018).

2.2. Marginal Water: Content and Examples

In order to implement better agricultural practices that produce more local, healthy and environmentally friendly food, water needs to be analyzed as the constraining input in arid or water-scarce regions. In this contribution, we regard marginal water resources as a key solution for such regions. We define marginal water as water which is neglected or underutilized in comparison to other water resource types. Therefore, the marginality refers to the relational use pattern of marginal water of often lower quality (e.g. unutilized saline, brackish, treated or storm water) in comparison to higher quality water (e.g. to freshwater or desalinated water). In this sense, the types of these marginal water resources are site-specific, e.g. treated wastewater can be widely used in some areas (e.g. Singapore) and therefore not considered of marginal use there.

Utilizing commonly neglected water of lower quality can be seen as an entry point and a means for the dissemination of de-growth ideas in the agricultural sector. For this to happen, such marginal water resources need to be appropriately identified, analyzed, treated, delivered and accepted by the producers and the end consumers. These steps represent serious challenges in the Gulf region. At the same time, marginal water resources are being discovered as a valuable and viable option, particularly for rapidly growing urban areas of the region. In fact, the potential use of a particular type of marginal water resource differs from a region to another. Table 7-1 gives some examples of the current uses of non-conventional water resource types in the Gulf region, including some sources having marginal use, namely treated, produced and brackish water. This simplification applies specifically for GCC countries, although the use pattern is very similar in Iran expect for the fact that treated wastewater is not yet systematically (e.g. through large public investments) used for purposes such as groundwater recharge. This use in Iran is rather bottom-up in certain regions as we will explain later.

Detailed analyses of the use/reuse patterns countries are provided in other studies, e.g. (Brown *et al.*, 2018; Aleisa & Al-Zubari 2017; Zubari *et al.*, 2017) for GCC countries, and (Abulof, 2014; Charkhestani *et al.*, 2016; Tajrishy, 2012) for Iran. In GCC example in Table 7-1, it is noticeable that desalination water is commonly accepted and widely used for many purposes. In contrast, the use of treated wastewater is confined to use purposes that are not close to persons due to the relative novelty and concerns about the quality of this marginal water type. The use of treated wastewater for forage production and groundwater recharge is currently promoted on a wide scale in the region (Aleisa & Al-Zubari, 2017). Further, produced water – water as a by-product from oil and gas productions – is largely not utilized despite the huge amounts produced in the Gulf.

Table 7-1 Water reuse sources for different reuse purposes in the Gulf region

Water type / Use type	Industrial Use	Non-edible agriculture	Recreational	Indirect potable Reuse	Edible Agriculture	Direct potable Reuse
Treated Wastewater	uses in district cooling; road projects	use for forage cultivation	landscaping; small artificial lakes	recharge of groundwater aquifers		
Produced Water	reinjection into oil and gas fields					
Brackish Water			mangroves parks; natural reserves		aquaculture; growth of fish food	
Desalinated Water	high quality water used in industry	use generally in agriculture in the absence of groundwater	aqua parks; swimming pools		livestock and agricultural production	Domestic drinking water

BLUE *commonly not used* CYAN *some uses exist* GRAY *widely used*

03

Beneficial (Re)Use of Marginal Water in Iran and the GCC Region - Wastewater Reuse as a Case

3.1. Iran

3.1.1. Potential and Use Patterns

Unconventional water resources of marginal utilisation (marginal water resources) are being considered as a part of the solutions to the increasing scarcities and recurrent shortages. In Iran, the use of these water types has only started recently, but is still not sufficiently highlighted as in comparison to other water management problems, e.g. the high leakage of water from potable water distribution networks (unaccounted for water or UFW) of around 32% (Saatsaz, 2019). The (re)use of marginal water resources in Iran is beginning to emerge but is still far from its full potential. The potential has been explored by Charkhestani, Ziri, and Rad (2016) who reviewed reuse potential for agriculture, industry and municipal consumption. Accordingly, the most important reuse option in agriculture in Iran is related to drainage water from irrigation, which can amount to around 30 billion cubic meters by 2021. This type of water can be used in conventional or saline agriculture (e.g. irrigation of halophytes which grow in low and moderate salinity levels) as well as for livestock and restoring or sustaining wetlands. However, the reuse of such water requires careful management to match the cropping pattern to the quality of the water, and also to introduce practices of integrated drainage management that considers the overall drainage system design together with the soil and water quality aspects (Charkhestani *et al.*, 2016). Other water reuse options are related to the use of water provided by municipal wastewater treatment plants for industrial parks, landscaping in cities, construction of lagoons or even as indirect potable water reuse if the reused water is mixed with other water of better quality (Karandish & Hoekstra, 2017; Ministry of Energy, 2016; Ministry of Energy, 2010; Kayhanian & Tchobanoglous, 2016).

Table 7-2 provides some key data on water use and reuse patterns in Iran, with a focus on treated wastewater. According to official numbers by the NWWEC (National Water and Wastewater Engineering Company, 2018), in 2017, 74% of the collected sewage was treated in 194 wastewater treatment plants. The number of wastewater treatment plants in 2017 was 4.97 times higher than 2001. Another 109 plants are under construction. The wastewater treatment plants serve about 27% of cities and 48.90% of the urban population in Iran. The cost for connecting the remaining population is anticipated to be higher. Considering the total amount of produced sewage in urban areas, full urban wastewater treatment in Iran would create a potential of about 4.5 billion cubic meters of treated wastewater per year for reuse.

In 2010, around 0.33 billion cubic meters of treated municipal wastewater (this number was around 0.86 billion cubic meters in 2012) was used for irrigation (AQUASTAT, 2019). However, according to Tajrishy (2012), over 90% of the treated wastewater in Iran is reused in some way although such reuse is not systematically done, i.e. due to a lack of considerations of adequate quality and reuse purposes. Further, while a high amount of collected municipal water is treated, the collection rate remains quite low (see Table 7-2). The treated wastewater is mostly mixed with storm water or water in tributaries of

Table 7-2 Key water use and reuse statistics for Iran, in million cubic meters (MCM)

	Groundwater abstracted[a]	Surface water[a]	Desalinated Water[b]	Municipal wastewater Produced[d]	Municipal Wastewater Collected[a]	Municipal Wastewater Treated[a]	Treated Wastewater as % of Collected Wastewater	Reused Water for irrigation purposes[c]
Iran	3,375	2,786	730	4,500	1,785	1,785	74%	328

a. Data for the Iranian year between 21st March 2017 to 20th March 2018, retrieved from (National Water and Wastewater Engineering Company, 2018).
b. Exact year for this figure unknown, however published in 2019 and retrieved from (Tansim News Agency, 2019).
c. Reused water is defined here as the direct use of treated municipal wastewater for irrigation purposes. It includes treated municipal wastewater applied artificially (irrigation) and directly (i.e. with no or little prior dilution with freshwater during most of the year) on land to assist the growth of crops and fruit trees. Treated municipal wastewater applied artificially and directly for landscaping and forestry also falls under this category. This figure is for the year 2010 from the (AQUASTAT, 2019).
d. Data for the year 2010 retrieved from (Charkhestani *et al.*, 2016).

large water bodies before use mostly for irrigation of low-value crops, particularly in the suburban areas.

In such a case, wastewater treatment plants would discharge water to the environment, where it mixes with freshwater, and is then withdrawn by unregulated users downstream (Tajrishy, 2012). In the same process, intentional groundwater recharge happens around the major cities. In this case, the plants release the effluent to recharge brackish water aquifers, and then it is later used through springs and qanats by downstream farmers for irrigation purposes (Tajrishy, 2012). Moreover, transportation of treated wastewater directly to the point of use is becoming more common. Farmers can negotiate the right for direct use of treated wastewater through special contracts. Different literature reports direct use of partially treated or untreated wastewater for agricultural purposes (Jimenez & Asano, 2008; Tajrishy, 2012; WHO, 2005). This raises concerns about monitoring of treated wastewater quality for irrigation and health or soil related problems. The untreated wastewater mixed with storm water or small streams or tributaries of larger water bodies – in order to allow for self-purification – is used for irrigation, especially downstream of urban centers where wastewater treatment facilities are inadequate. Increasing the capacities for wastewater treatment and reuse could reduce the amount of indirect use of untreated wastewater for agricultural purposes.

3.1.2. Policies, Options and Constrains

Recently, the periodic development plans of Iran have considered the use of marginal water resources, particularly wastewater, although most of the current use for agricultural purposes is unplanned and uncontrolled (Karandish & Hoekstra, 2017). With regard to the use of wastewater, the central government assumes the lead role for the development of this water source. In Iran, water and wastewater supply are highly centralised with the Ministry of Energy and the National Water and Wastewater Engineering Company (NWWEC) (under the latter ministry) supervising a number of provincial urban, municipal and provincial rural Water and Wastewater Companies (WWC). As most wastewater effluents are currently not treated, the NWWEC Vision 2021 foresees the increase of wastewater treatment to 60% in urban areas, and 30% in suburban areas by 2021 (Ministry of Energy, 2016). Alongside wastewater use, there are other types of marginal water that can be used in Iran such as stormwater runoff, rainwater harvested from rooftops, greywater (e.g. for uses in households e.g. for toilet flushing) or saline water. However, up until now, most of these types are not systematically used.

Environmental guidance for reuse of treated wastewater was developed by the Ministry of Environment in 2011 stipulating the quality standards for different uses of the treated wastewater. The main sectors that take in the treated municipal waterare those of irrigation, landscaping and forestry near to urban areas. The use of treated wastewater for aquifer recharge is a second priority (Ministry of Energy, 2010). In some major cities, seepage pits and effluents from wastewater treatment plants are used to recharge groundwater aquifers. The long-term goal is to use water from these recharged aquifers and underground strata for irrigation in some urban communities. At the same time, despite concerns about water quality, treated wastewater can be used directly for irrigation, to augment water supply and reduce pressures in the case of droughts (e.g. in the city of Mashhad) (Kayhanian & Tchobanoglous, 2016).

In fact, the options for incorporating marginal water resources as a part of the sustainable water management in urban settings are plenty, but they are largely not systematically approached in Iran. For example, the integration of treatment plants in closed loop systems with the water users – i.e. water consumption sites lined directly to treatment plants producing water for use again - can help deliver water at different qualities for different purposes, and effluents can be treated after the use. The users can produce edible agriculture, forage, or mix the water with other water types, such as harvested water from rain or saline water, in order to provide other products.

In order to encourage a wide use of treated wastewater in Iran (i.e. higher collection, treatment and reuse rates), there is a need to overcome the obstacles by creating appropriate technologies for different reuse purposes, decentralized wastewater treatment systems as well as enhancing social acceptance (Rezaee & Sarrafzadeh, 2017). For example, a study by (Hamidi & Yaghubi, 2018) shows that the availability of high quality potable water for irrigation purposes is the main constraint to the use of treated wastewater in urban agriculture. Reuse of treated wastewater could foster the use of the right water quality for the right agricultural purpose. Furthermore, considering that 7,505 hectares for urban and industrial landscaping area exist in Iran, expanding the reuse of treated wastewater for landscaping purposes could reduce the pressure on water resources. In order to encourage water reuse, the Expediency Discernment Council of Iran (an administrative body appointed by Iran's Supreme Leader) has outlined some plans for recycling water nationwide. The proposed policies and strategies include replacement of the agricultural water right for fresh water with treated effluents, promoting reuse of treated effluents, use of low quality water instead of high quality urban water to create green spaces, and expand relevant research projects (Tajrishy, 2012).

3.2. GCC Region

3.2.1. Wastewater Reuse as a Primary Option

In recent years, water reuse has been a key item in the water strategies of GCC countries, with the reuse of treated municipal wastewater expected to increase significantly. Other marginal water types, such as drainage water, treated industrial wastewater, produced water, or harvested water, are much less used. While only around 50% of total domestic wastewater is collected in the GCC region, and around 40% of the volume collected is treated, the reused wastewater was used to satisfy only 3% of water requirements in 2010/2012 (Zubari *et al.*, 2017). At the same time, treated wastewater is largely used for gardening, parks, highway landscaping and fodder production (Saif *et al.*, 2014). For all member countries collectively, the GCC targets, by 2030, to collect 60% of municipal water and, by 2035, to reuse 90% of treated wastewater (Zubari *et al.*, 2017).
The efforts of the GCC countries regarding wastewater treatment and reuse have been reviewed by Aleisa and Al-Zubari (2017). The main sectors that take in the reused wastewater are landscaping and for the irrigation of livestock feed crops.
In some exceptional cases, the treated wastewater is used for aquifer recharge through reinjections and the irrigation of edible crops if higher water quality is produced (e.g. through the use of reverse osmosis wastewater treatment).
Currently, treatment plants have units for primary, secondary and tertiary treatment, while some plants, e.g. in Kuwait, also use reverse osmosis (RO) and ultrafiltration (UF) (Aleisa & Al-Zubari, 2017). Other uses of treated wastewater such as toilet flushing, firefighting, recreational purposes and crop or fish production have been limited in the GCC region.
At the same time, the reuse of treated wastewater (largely of good quality) has been lower than the policy aspirations, with some of the excess treated wastewater stored in lakes or discharged into the sea (Aleisa & Al-Zubari, 2017).

Considering the large per capita water use footprints in GCC countries, the use of treated wastewater is expected to generate important quantities of additional water.
Table 7-3 indicates current use patterns. Although much of the collected municipal water is treated, large amounts are not used – note that the indicated reuse quantities in Table 7-3 do not exclusively originate from municipal wastewater.
At the same time, the treatment quality in some GCC countries is quite high, i.e. at least tertiary levels of treatment. Therefore, treated wastewater is used for agriculture but not on a large scale. While some GCC countries have reported some agriculture use for irrigating date palms and forage crops or watering livestock, the wide-scale utilization of treated wastewater is still hindered by the lack of integrated and connected infrastructure for delivery, the heavy subsidization of other water sources, the weak appreciation of treated wastewater benefits, the need for strict regulation and monitoring of water quality, and the potential impact on public health (Jasim *et al.*, 2016; Jaffar Abdul Khaliq *et al.*, 2017; Ouda, 2016). It is therefore not surprising that some of the treated wastewater is collected in small lakes awaiting customers willing to utilize it. More recent wastewater reuse or food security strategies envision locating livestock or forage projects in close proximity to wastewater plants in order to benefit from the high-quality water.

Table 7-3 Key water use and reuse statistics for GCC countries for the year 2016, in million cubic meters (MCM)[a]

GCC country	Groundwater abstracted	Desalinated Water	Wastewater Collected	Wastewater Treated	Treated Waste Water as % of Collected Wastewater	Reused Water[b]	Reused Water as % of Collected Wastewater
Bahrain	144	242	158	69	44%	39	25%
Kuwait	85	712	319	247	77%	96[c]	-
Oman	1,084	280	68	67	99%	33	49%
Qatar	250[d]	535	198	194	98%	97	49%
Saudi Arabia	21,595	1,947	2,503	1,604	64%	216	9%
UAE	3,536	2,005	724	711	98%	452	62%

a *All figures are for the year 2016 from the source (GCC-STAT, 2016), except for figures with the notes c and d.*
b *Reused water is defined as any water received from another user with or without treatment. It includes treated wastewater for further use, excludes water discharged into watercourses and recycling within industrial sites.*
c *Figure from the year 2010 from the source (Zubari et al., 2017).*
d *Figure from the 2012 from the source (Zubari et al., 2017).*

3.2.2. Reuse Constrains and Other Reuse Options

It is not only treated wastewater that constitutes a marginal water source that can be utilised. Brown, Das, and Al-Saidi (2018) reviewed several types of marginal water resources that enhance sustainable agriculture in the Gulf region, namely domestic wastewater, produced water, saline water, marginal water for the production of microalgae, marine aquaculture, and integrated seawater agriculture. The main insights from this review can be summarised briefly here. With regard to wastewater, it can be used for the production of drought-tolerant plants (xerophytes) or other native species that do not require much water, while irrigation and on-farm monitoring strategies (e.g. high leaching fraction, monitoring of heavy metals and salts) need to be deployed in order to ensure safe use. Produced water is generated during the extraction of oil and gas and represents an important water type in the Gulf region. This water might require more sophisticated treatment due to high content of salt, chemicals and hydrocarbons, but it can be utilised for the production of salt-tolerant crops or algae. Further, a promising option for sustainable agriculture in the region is the use of saline water for terrestrial agriculture through the production of halophytes. Halophyte species can be used in many products, e.g. firewood, fresh vegetables, oilseeds, grains, medicine, forage, biofuels etc. Similarly, saline water can be used for the production of microalgae which, due to its high protein content, is a component of aqua-feeds for aquaculture. Marine agriculture is another promising alternative to counteract the overfishing problem by producing high value products such as finfish, shellfish, crustaceans or shrimps. Aquaculture projects are spreading across the GCC countries in close proximity to coastal cities, while these projects are trying to solve problems such as a lack the local knowledge and capacities, high temperature and salinity of the Gulf seawater and the selection of appropriate species. Finally, aquaculture can be integrated with high salinity agriculture where wastewater from aquaculture can be enriched with nutrients and used to irrigate halophytes or produce microalgae to be reused later as fish feed.

3.3. Comparative Insights

Both Iran and the GCC region are increasingly interested in developing marginal water resources for domestic, industrial and agricultural uses as well as for other purposes such as recreation and landscaping. However, some difference exists with regard to geography and the type of available marginal water. First, despite the similar water scarcity pressures (water availability in relation to current use) to the GCC region, Iran has a higher rainfall and thus a higher natural water availability, with annual rainfall ranging between 50 and 2,275 mm (the national average annual rainfall is 228 mm) and the total renewable water resources per capita was estimated at around 1,700 cubic meter in 2014 (AQUASTAT, 2019). In contrast, GCC countries are hyper-arid with an average rainfall of less than 100 mm, almost no surface water and shallow groundwater aquifers as the only renewable water source (Saif *et al.*, 2014). Therefore, Iran possesses higher quantities of certain marginal water resources, such as stormwater, brackish water and water harvested from rain. Second, with most of the major cities in the GCC cities located in close proximity to the Gulf water body, saline water is a convenient resource under consideration for utilisation for the production of halophytes, fish or feed. Conversely, the major cities in Iran are in the inner lands while the bulk of aquaculture projects in Iran are concentrated in the southern coastal parts of the country (Hadipour *et al.*, 2015). For the major urban areas in Iran, the reuse of wastewater and the recovery of drainage water constitute the primary marginal water utilisation forms under consideration, while other sources such as stormwater and rain water have not been systematically explored.

“Wastewater treatment plants with higher capacities and more advanced technologies are producing more treated water than the current capacities to use this water.”

Another difference is with regard to the reliance on high technologies by GCC countries to expand the reuse potential. In the GCC region, the reuse industry seems to have gained strong momentum and to be supported by ambitious government goals for collection, treatment and reuse. Wastewater treatment plants with higher capacities and more advanced technologies are producing more treated water than the current capacities to use this water, i.e. some high quality treated water is not used due to the lack of demand, delivery infrastructure and/or acceptance one can argue that the water treatment and reuse industry in GCC countries exhibits higher levels of planning and control while policymakers are still reluctant to use the high-quality water for sensitive purposes, such as aquifer recharge, edible agriculture or (indirect) potable use. For example, in GCC states, the establishment of treatment plants is carried out through public works authorities, while the operators of the plants are in charge of finding suitable users for the treated water in the short run (e.g. for landscaping companies, district cooling plants or farmers). Further, national water supply providers can engage in major projects for aquifer recharge and infrastructure development (e.g. construction of pipelines) for the transfer of treated water for recharge sites. Despite this national-level involvement, some quantities of treated wastewater are left unused in treatment plants. This is due to acceptability problems and safety concerns that are not necessarily supported by evidence related to water quality (Aleisa & Al-Zubari, 2017). Solving these issues can help advance the current ambitious reuse policy goals. In contrast, some of the treated wastewater in Iran is used spontaneously by farmers in semi-urban areas or is used, in case of droughts, to augment irrigation supply (Charkhestani *et al.*, 2016;

Kayhanian & Tchobanoglous, 2016). In the GCC region, farmers might be reluctant to use treated wastewater since they enjoy an easy and universal access to good quality and free groundwater or desalinated water at highly subsidised prices. In fact, the issue of the low water prices is a common problem in the region and is a major impediment to efficient and sustainable use of the scarce water resource in both the urban and agricultural sectors (Al-Saidi & Dehnavi, 2019). Since low water tariffs fuel high water consumption rates in the Gulf region, such issues of pricing and demand management need to be considered in any de-growth discussion of a low metabolism society.

04

Directions and Common Challenges for Urban Food Production

The common challenges for marginal water utilisation extend from a lack of comprehensive strategies, inadequate infrastructure, concerns about quality aspects, to public acceptance and awareness. Some recommendations exist for the GCC region and Iran in order to advance the use of marginal water resources. For example, for wastewater reuse in the GCC region, Aleisa and Al-Zubari (2017) stressed the importance of adopting adequate legal frameworks, reducing water consumption, awareness raising, finding uses for sludge from sewerage plants and advancing the research and development of wastewater treatment technologies. Further, most GCC countries do not have national water strategies that include clear investment targets (including wastewater treatment), water reuse plans, or explanations of roles and responsibilities. While some regulations on wastewater quality exist, they are not specific with regard to the different reuse purposes and processes. In fact, it is important that the role of governments in setting up the institutional frameworks for regulating wastewater reuse goes beyond partial regulations (e.g. focusing only on safety and quality regulations) or the simple incorporation of wastewater in sectoral policies (e.g. wastewater reuse as a sub-target in food and environmental protection policies). This has been the current practice so far. For example, in Oman, the government has created regulations for the protection of environment and public health and the use of sewage wastewater for agricultural use and landscaping (Jaffar Abdul Khaliq *et al.*, 2017). In Saudi Arabia, the government has encouraged several initiatives for the utilization of the large quantities of treated wastewater produced through the National Water Company which promotes the production, marketing and utilization of this water (Ouda, 2016). In fact, similar initiatives exist in other GCC countries, e.g. in Qatar where elements from its food security plan are linked to the use of water from wastewater treatment plants.

In Iran, various studies recommend an increase in the number and quality of treatment plants, improvements to collection networks, expansion of seawater desalination – to accommodate additional potable water use demands, improved monitoring networks, enhanced drainage systems in irrigation, removal of regulatory barriers and increased public acceptance through (religious) education (Kayhanian & Tchobanoglous, 2016; Charkhestani *et al.*, 2016). Some of these regulatory barriers include the absence of guidelines for the construction and operation of wastewater treatment plants, the need for clear water quality standards for various uses of marginal water including potable use, and the lack of environmental monitoring regarding wastewater quality and suitable uses of this water. Further, there are conflicting responsibilities with multiple agencies working on water reuse issues and no clear national guidance for mainstreaming roles and enhancing cooperation (Kayhanian & Tchobanoglous, 2016).

At the same time, the use of marginal water for food production brings along additional challenges related to quality, infrastructure, cost and acceptance.
Some of these challenges lie in the ability to upscale the food production using treated or saline water despite the low cost of desalination and freshwater, i.e. low or non-existent volumetric prices of water for domestic use and agriculture. This low-cost water has been the norm in Gulf countries as a part of the rentier states' ideologies of providing free benefits to citizens – a political-economic strategy towards increasing regime legitimacy. In recent years, water tariffs have been reformed in some GCC countries (Krane, 2018). However, water (and electricity) tariffs remained significant, especially if the total water costs, including environmental externalities, are calculated. Other challenges can only be solved if public trust and the perception of wastewater quality improves, e.g. through concerted campaigns by public authorities.
At the same time, some alternative agricultural production systems, e.g. the use of saline water or the cultivation of microalgae, need some initial subsidisation while some practices, such as microalgae, are still not considered as a part of agriculture (Brown *et al.*, 2018).
Further, it is important to consider integrating treatment plants with accompanying networks to deliver the right water amounts with the right quality to the right place.

“It is important to consider integrating treatment plants with accompanying networks to deliver the right water amounts with the right quality to the right place.”

However, since much of the treated wastewater is not done for potable use, it would be difficult to create dual distribution networks and deliver treated wastewater everywhere. Instead, the sites for use of treated wastewater need to be carefully chosen – e.g. in the vicinity of wastewater treatment plants, while some new distribution networks can be constructed. This is especially important for the (re)use of marginal water resources for urban food production since such practice demands careful design with regard to space as well as energy and nutrient supply.

International experience with the utilisation of marginal water resources for urban food agriculture emphasises multiple benefits of, and the need for, more integrated systems.
For example, with wastewater reuse in urban agriculture, there is a good potential for nutrient recycling and the reduction of carbon emissions (Miller-Robbie *et al.*, 2017).
Further, integrating water and nutrient reuse systems (i.e. reuse of nutrient-rich water in sanitation) with crop production sites can be a viable resource recovery system that enhances sustainable sanitation and urban agriculture in arid regions (Woltersdorf *et al.*, 2018).
Such coupled systems of wastewater and nutrients needs also to monitor the salt flow in order avoid soil salinization (Woltersdorf *et al.*, 2016). While these systems seem plausible and technically feasible for other regions, they might face difficulties in the Gulf region due to the problem of poor acceptance and the cautious approach of decision makers regarding the water quality. In order to ensure high quality water supply for urban agriculture, countries can invest in advanced wastewater treatment technologies using membranes as these tend to minimise unwanted constituents in treated wastewater for urban irrigation (Bunani *et al.*, 2015). Furthermore, the utilisation of saline water for fisheries through aquaculture has been expanding in urban and peri-urban areas, for example in African cities exhibiting high population growth rates (Miller & Atanda, 2011).
Aquaculture can also be developed using wastewater and this specific use is rising globally (Bunting & Edwards, 2018). Finally, renewable energy is increasing in the region for desalination – in order to face the rising energy cost of high-quality desalinated water – and other applications in the water-energy-food supply infrastructure (Gorjian & Ghobadian, 2015; Al-Saidi & Elagib, 2018; Al-Saidi & Saliba, 2019). This advancement, together with the energy recovery capacity from treatment plants, can open up more cost-effective ways to reuse water for urban agriculture.

05
Conclusions

Iran and the GCC region share major concerns related to increasing incidents of water resources overuse, the deterioration of groundwater resources, and the health of the Gulf water body. Realizing the potential of water reuse in augmenting supply and providing needed water to cities facing rapid growth, Gulf countries are investing in their capacities to utilise previously neglected water sources. Marginal water resources for food production serve as a useful instrument for sustainable agriculture in urban areas and can help achieve the de-growth idea of a low metabolism society. The bulk of efforts for the utilisation of marginal water resources have concentrated on the expansion of wastewater treatment and reuse capacities. Wastewater treatment is capitalizing on the large footprints of water used in urban areas. The set-up of treatment technologies able to process water to advanced levels in terms of produced water quality opens up several potential uses including irrigation of certain crops such as forage or date palms.

While the reuse levels are still far from achieving the ambitious future targets for municipal wastewater, large water quantities are already produced. In light of the lack of infrastructure, monitoring and regulations to ensure that treated wastewater is delivered to the desired use and users at the right time and quality, most current uses are confined to landscaping or industrial uses (e.g. district cooling, roads construction, firefighting etc.).

Other uses such as the recharge of vulnerable aquifers or a wide-scale use in urban agriculture, or even for drinking water, are contingent on public acceptance and the commitment of public authorities to move beyond experimentation and single reuse initiatives to full utilization.

> *"Marginal water resources for food production serve as a useful instrument for sustainable agriculture in urban areas and can help achieve the de-growth idea of a low metabolism society."*

While wastewater reuse is a potentially significant new water source, other sources such as saline water, greywater, rainwater, storm water, or produced water are not adequately considered. Iran exhibits higher water availability and a significant potential for utilizing runoff water or drainage water for irrigation. In contrast, water reuse in the GCC region is more ambitious, technologically-driven and planned, while water reuse in agriculture is still limited to some forage production activities. At the same time, there is a big potential for food production using aquaculture, algae, and combined marine-terrestrial systems that can supply the coastal cities of the GCC region with high-value fish products. For wide utilisation of marginal water resources in Iran and the GCC region, coherent regulatory and investment policies, as well as the right economic and pricing incentives, are needed alongside better public engagement and awareness. As this study did not compare current national-level legal, regulatory and policy frameworks for (marginal) water use/reuse in the region, future research in this area is needed. Further, urban planning systems that provide integrated infrastructure between the treated water and nutrient sources to the suitable agricultural production sites are needed. Finally, the practice of utilizing marginal water resources for urban food production needs a high degree of experimentation. A future research agenda can include more site-specific analysis regarding the right integrated system design, the quality and health impacts, the acceptability of the end products by the consumers and the integration of renewables components, such solar energy and bioenergy, in order to minimise the costs and negative environmental impacts.

Glossary of Terms

- **Vertical farming**: The practice of growing crops in a vertical manner in order to optimize plant growth, minimize the need for soil and save place. This include growing plants in not used cites, e.g. buildings or tunnels, or in controlled-environments such as hydroponics, aquaponics and aeroponics.
- **Produced Water**: Water produced as a by-product in the hydrocarbon industry.
- **Greywater**: Water produced from any household sources other than toilets.
- **Halophytes**: A category of salt-tolerant plants that grow in soils or water of highly levels of salinity.

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8

SWOT Analysis of Reclaimed Water Use for Irrigation in Southern Spain

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Abstract

The EU project 'Network for effective knowledge transfer on safe and economic wastewater reuse in agriculture in Europe (SUWANU-Europe)' aims to identify the limitations and factors of success in fostering the use of reclaimed water by the agricultural sector in different European regions. This study shows the results of a SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis in the case of Andalusia (Southern region in Spain). The goal is to define a regional strategic plan to promote the use of urban reclaimed water for irrigation purposes. The SWOT analysis carried out in this study has identified barriers and challenges that still exist in the implementation of irrigation systems with reclaimed water. Among the main threats identified, stakeholders' perceptions and the higher cost of reclaimed water for irrigators (compared to alternative sources) play a relevant role. Additionally, the excessive bureaucracy and long administrative processes are significant weaknesses to be considered. On the other hand, technology availability and the increasing scarcity of conventional sources are seen as strength and opportunity factors for the expansion of reclaimed water use for irrigation purposes.

Keywords

SWOT analysis, reclaimed water, water reuse, irrigation

01
Introduction

Water scarcity is a critical economic and environmental problem in many regions of the world, as it is the case of southern European countries. Water scarcity is a 'long term' imbalance between supply and demand where available sources cannot satisfy the increasing economic and societal priorities. Additionally, according to the European Commission (2012), during the last forty years, drought episodes in the EU have increased dramatically in frequency and intensity. The number of areas and people affected by drought events increased by almost 20% between 1976 and 2006. In that period, the economic cost of droughts recorded in Europe was estimated at around € 100,000M and all this in a context where water scarcity affects 11% of the European population and 17% of the territory of the EU (European Commission, 2012). In southern Europe, the phenomenon of climate change has increased temperatures, reduced precipitation and changed the rainfall regime (Valdes-Abellan *et al.*, 2017). Consequently, climate conditions have become unpredictable, creating water availability tensions (Morote *et al.*, 2019).

Supply-side mechanisms have been implemented by governments to avoid drought effects and associated economic loses (Berbel & Esteban, 2019). In some cases, like in the Segura river basin, employing re-use water for agricultural or urban irrigation allowed the region to reduce the pressure on freshwater resources and achieve a more sustainable use of water (Morote *et al.*, 2019). Specifically, the study of Morote *et al.* (2019) concludes that the mixed-use of water resources (e.g. by using reclaimed water) could improve water availability in certain regions of the world suffering from critical water scarcity.

“Reclaimed water offers a more environmentally friendly water source alternative than other non-conventional water sources, capable of improving supply reliability and mitigating climate change impacts on the irrigation sector.”

Andalusia (in southern Spain) is a region with severe water scarcity that leads to increasing conflicts among different users (Expósito & Berbel, 2017, 2019). The region is technologically prepared to offer tertiary treatment that enables the reuse of reclaimed water for irrigation (urban and/or agricultural) purposes. In fact, 33% of the 2000 wastewater treatment plants (WWTP) operating in Spain are located in Andalusia. Spain already reuses more than 492 cubic hectometres of urban wastewater per year (10.4 % of total treated urban wastewater). In the EU context, the case of Cyprus constitutes a benchmark example of water reuse for agricultural irrigation, where this water source has a long tradition.

This research aims to identify and evaluate the relevance of barriers and factors of success in implementing reclaimed water as an alternative water source for the Andalusian agricultural sector. To achieve this objective, a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis has been conducted in the frame of the “Network for effective knowledge transfer on safe and economic wastewater reuse in agriculture in Europe” project (SUWANU-Europe).
The SWOT analysis can support further development of a strategic management policy (Pickton & Wright, 1998). Specifically, our analysis studies perceptions regarding the strengths, weaknesses, opportunities and threats related to the use of reclaimed water for irrigation, as expressed by an interviewed group of experts and stakeholders involved in the water and agricultural sectors, as well as from other societal groups (e.g. consumers associations, public institutions). With this aim, the analysis addresses a wide range of aspects influencing and determining strengths, weaknesses, opportunities and threats for reclaimed water reuse for irrigation purposes, including market-related, product-related, social and governance aspects.
The SWOT analysis highlights the main challenges to focus on future research to facilitate the acceptance of reclaimed water as an alternative water source for irrigation purposes in Andalusia. In doing so, external and internal barriers and challenges are identified. Identified economic, social and environmental benefits may also be significant, thus facilitating the use of reclaimed water. In fact, the cost of reclaimed water supported by local agents is close to 0.4 €/m^3, which is significantly lower than the cost of desalinated water (0.6-0.8 €/m^3) (Cabrera *et al.*, 2019), thus helping the economic viability of small farms in coastal areas of Andalusia. Further, water reclamation in coastal areas could provide a net water contribution to southern water basins by avoiding discharges to the sea, thus improving water availability during drought periods. Therefore, reclaimed water offers a more environmentally friendly water source alternative than other non-conventional water sources (i.e. desalination), capable of improving supply reliability and mitigating climate change impacts on the irrigation sector.

This paper is structured as follows. The next section describes the Andalusian contextual characteristics in relation to wastewater reuse. The SWOT methodology used in this study is explained in Section 3. Results are explained in Section 4. Finally, a brief discussion and some concluding remarks are offered in Section 5.

02

Background and Case Study Description

This research is based on previous work done within the framework of the EU funded project "Sustainable water treatment and nutrient reuse options" (acronym: SUWANU[1]) in 2012, where different aspects related to water reuse and nutrient treatment were identified and evaluated in the EU context (Michailidis *et al.*, 2015). Further, the current project SUWANU-Europe seeks to identify barriers and factors of success in the implementation of reclaimed water use for irrigation purposes, with special focus on certain EU regions, such as Andalusia (southern Spain), with significant potential benefits.

The use of reclaimed water is seen by many scholars and policy makers as a means to implement a circular economy and resource efficiency in the water sector, both by reusing water and recycling nutrients embedded in the effluents, as declared by the implementation of the Circular Economy Action Plan by the EU. That Plan includes the implementation of measures for waste water reuse as an essential part of the global strategy (European Commission, 2015). Recently, the EU published the "Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse" (European Commission, 2018). Its aim is to foster the use of reclaimed water in agriculture irrigation to reduce the use of common water sources (surface freshwater and groundwater). For that reason, the final Proposal for a Regulation of the European Parliament and of the Council (European Commission, 2018) aims to increase the confidence in this type of water and minimise potential risks through the establishment of high-quality requirements in the whole EU. In the same sense, different studies agreed about the suitability of reclaimed water as an alternative water source to replace common water sources use (Morote *et al.*, 2019; Navarro, 2018). Areas with water scarcity like Israel, California or Australia have already implemented projects to reuse wastewater for different uses, such as golf course irrigation, industrial uses or even tap water uses (Mainali *et al.*, 2011a). In the EU, the use of reclaimed water is more common in the Mediterranean countries.
The case of Cyprus is the keystone, but also Greece, or some regions in Spain are implementing the use of reclaimed water as an alternative water resource (Berbel & Esteban, 2019; Morote *et al.*, 2019; Navarro, 2018; Terrados *et al.*, 2007).

Table 8-1 Percentage of wastewater according to the point of discharge (Source: INE, 2016. Authors' elaboration)

	Sea	River	Reuse	Groundwater
Spain	33.5	55.8	10.4	0.2
Andalusia	58.0	36.1	5.9	0.0
Aragón	0.0	99.2	0.8	0.0
Asturias	21.7	74.5	3.8	0.0
Balearic Islands	59.6	7.3	33.0	0.0
Canarias	77.9	2.1	19.8	0.2
Cantabria	79.5	18.8	1.7	0.0
Castilla y León	0.0	99.1	0.9	0.0
Castilla-La Mancha	0.0	96.2	3.8	0.0
Cataluña	66.3	28.7	4.9	0.1
Comunidad Valenciana	16.5	33.6	47.5	2.4
Extremadura	0.0	100.0	0.0	0.0
Galicia	30.5	60.7	8.8	0.0
Madrid	0.0	97.7	2.3	0.0
Murcia	11.5	16.7	71.8	0.0
Navarra	0.0	100.0	0.0	0.0
País Vasco	67.7	31.4	0.9	0.0
La Rioja	0.0	100.0	0.0	0.0
Ceuta y Melilla	100.0	0.0	0.0	0.0

The study of Mainali *et al.* (2011a) followed a SWOT analysis to investigate which factors determine the success or failure of different implementation processes of water reuse. They concluded that public acceptance is essential to success in the implementation of reclaimed water for potable, irrigation, environmental restoration or industrial uses. Moreover, societal agreement among all involved groups and stakeholders constitutes a prerequisite for success, and not allaying stakeholders' doubts about health risks, public opposition, political disinterest, and information manipulation constitute the main causes of failure of reclaimed water projects.

The region of Andalusia has an area of 87,268 km^2. Its Mediterranean climate is characterised by dry and hot summers, warm winters and irregular rainfall. The total annual rainfall varies according to the climate area of the region. Average rainfall is 750 mm/year, though the mountainous areas of Aracena, Cazorla-Segura and Grazalema reach a higher average of 2,000 mm/year. The main water sources in Andalusia are surface water (76.6%) and groundwater (28.2%) (INE, 2016). Other alternative sources, such as reclaimed water, do not register significant figures (1.2% in 2016). Despite this fact, wastewater treatment has followed a very positive evolution in Andalusia since 1984, from 55 up to 695 WWTPs in 2017 (Junta de Andalucía, 2017). The total population served is 7.2 million inhabitants, although 12.40% of the total population of Andalusia still remains without an appropriate wastewater treatment service. The total volume of wastewater treated in Andalusian amounts to 698 hm^3/year, thus representing a significant water source to reuse.

The use of reclaimed wastewater in Spain is regulated by the Royal Decree 1620/2007 'Wastewater reuse standards'. This Decree was approved at the national level during the long drought event, which occurred in the period 2005-2008, as a measure to facilitate the use of alternative water resources. The Decree was based on existing regulations in similar regions, for example in California (Berbel & Esteban, 2019). Despite regional differences, Royal Decree 1620/2007 has represented an important advance to standardize wastewater reuse practices (Iglesias *et al.*, 2010). As shown in Table 8-1, in 2016, Mediterranean regions like Murcia, Comunidad Valenciana and the Balearic Islands reused 71.8%, 47.5% and 33.0% of the total treated urban wastewater, respectively. These three regions represent 90% of total water reused in Spain (INE, 2016). Andalusia, although located in the southern Mediterranean area and with serious water scarcity problems, only reuses 5.90% of the treated urban wastewater.

The percentage of treated water reused represents 5.90% in 2016, while in 2014 it was 7.83% and in 2013, it was 8.31% (INE, 2016). Through an in-depth analysis about the uses of reclaimed water, we found that in 2016, 69.20% of treated water was used for gardens and golf courses, while only 2.50% of the reclaimed water was used for agricultural irrigation (INE, 2016).

03

Material and Methods

Existing literature concludes that SWOT is an adequate method for strategic analysis in fields related to resource management, such as water reuse (Mainali *et al.*, 2011b), solid waste management (Srivastava *et al.*, 2005) or regional energy planning (Terrados *et al.*, 2007). This methodological tool allows the identification of factors influencing the development of a management initiative (Pickton & Wright, 1998). In doing so, the SWOT analysis tool applied in this study allows the identification of strategic factors that should receive attention for the development of a regional strategy for the use of reclaimed water (Houben *et al.*, 1999).

This research takes the aspects identified by Michailidis *et al.* (2015) to focus on all kinds of aspects influencing/determining strengths, weaknesses, opportunities and threats for reclaimed water reuse, including market related (economic, availability and market aspects), product-related (technical and technological transfer aspects), and social and governance (social awareness, regulation, management, institutional, environmental) aspects. With the objective of updating these aspects, a four-step process has been followed: Firstly, in order to update the information, existing aspects from SUWANU (2012) were analysed by ten Spanish experts, who reconsidered their suitability and identified new factors/aspects to take into account. This group of experts comprised distinguished scholars, policy-makers and business practitioners in the Spanish water sector. They also evaluated if the roles assigned to the different aspects was right, e.g. whether an aspect that was evaluated as an opportunity actually represented an opportunity in the current context or not. Secondly, once their comments were received, the aspects identified were discussed individually by the Spanish partners of the SUWANU-Europe (2019) consortium in a working session, with the aim to contrast all received information and decide whether the different aspects included in each group (strengths, opportunities, weaknesses and threats) were adequate to ensure water reuse in Andalusia. Considering the comments received from the 10 independent experts and those of the members of the project consortium, the list of aspects to be evaluated in each group was selected. The third step was the development of a questionnaire to evaluate the relevance of identified aspects in each group (see Appendix for a link to the questionnaire in Spanish). The questionnaire was tested by two external experts and the consortium partners in order to produce the final version. The questionnaire uses a Likert scale from 1 (not relevant) to 5 (very relevant) to assess the relevance of the SWOT factors/aspects identified. The questionnaire permits respondents to rank the different aspects within each group according to the average relevance given by the consulted experts. Finally, the fourth step consisted in sending the questionnaire to a group of national experts and stakeholders.

The potential respondents were identified from the state-of-the-art review made by all participants in the SUWANU-Europe project (SUWANU-Europe Deliverable 1.1, available on the project's website[2]) where relevant actors with an active role in water reuse were identified. Selected respondents were involved in a wide variety of organizations, both public and private, representing different interests and views regarding water reuse in Spain. Furthermore, relevant actors and institutions (e.g. Spanish Ministry of Agriculture, Spanish Ministry for Ecological Transition, Consumers organizations), which have an active role in decision making, were also invited to participate.

04
Results

Twenty-two responses were received to the questionnaire sent to a group of national experts. Among these 22 responses, the key actors that answered the questionnaire belong to the following groups: researchers (7), members of NGOs (5), members of utilities (4), users (2), public administration (2) and agri-food firms (2). The following tables show the classification of the different aspects on a scale from 1 (not relevant) to 5 (very relevant), as assessed by the group of Spanish experts responding the questionnaire.
The reported results combine both the new aspects or factors and those identified by the former SUWANU project (2012).

Results of the SWOT analysis are presented in a step-by-step manner in order to facilitate its comprehension.

“SWOT is an adequate method for strategic analysis in fields related to resource management, such as water reuse.”

4.1. Strength

A total of eleven strengths were identified in the questionnaire following the process described in Section 3. According to the experts' evaluation, the most relevant aspects to consider are (Table 8-2): "Water availability guaranteed even in drought periods"; "National and European regulations are available to ensure the sanitary and environmental quality of reclaimed water for agricultural irrigation"; "The quality and safety of food crops irrigated with reclaimed water has been scientifically documented by numerous international projects"; and "Reclaimed water use mixed with other water resources (surface water, groundwater, etc.)".

These aspects show how the use of reclaimed water for irrigation allows access to a water resource despite the existence of drought periods or climate change effects. This aspect is supported by the European Union and the Spanish national legislation to promote the gradual use of this water for irrigation, although it also requires strict quality controls to avoid potential health risks.

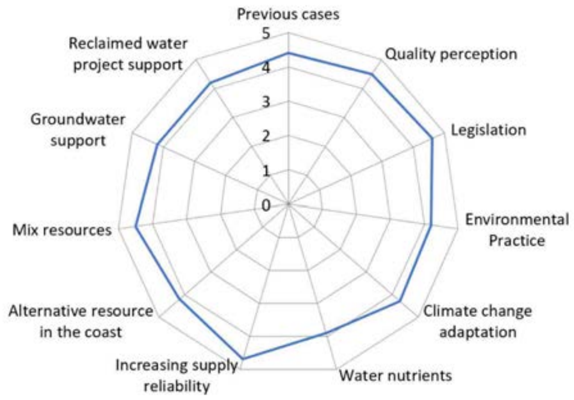

Figure 8-1 *Strengths relevance*

The average evaluation of most items has received an average score of 4.3, as can be also observed in Figure 8-1. This result shows the high relevance assigned by the consulted experts to these strength aspects to promote the use of reclaimed water for irrigation purposes.

Table 8-2 *Strength aspects*

No	Strengths Item	Explanation	Score
F7	Increasing supply reliability	Water availability guaranteed even in drought periods	4.7
F3	Legislation	National and European regulations are available to ensure the sanitary and environmental quality of reclaimed water for agricultural irrigation	4.6
F2	Quality perception	The quality and safety of food crops irrigated with reclaimed water has been scientifically documented by numerous international projects	4.5
F9	Mixed resources	Reclaimed water use mixed with other water resources (surface water, groundwater, etc.)	4.5
F1	Previous cases	Numerous success stories are available on local water reuse projects for agricultural irrigation	4.4
F5	Climate change adaptation	Reclaimed water offers a more environmentally friendly water source alternative, capable of mitigating climate change effects, than other conventional or sophisticated water sources such as desalination	4.3
F4	Environmental Practice	Irrigating with reclaimed water is considered as an environmental practice	4.2
F8	Alternative resource in the coast	Water reclamation in coastal areas provides a net water contribution to water basins, by preventing the irrecoverable loss of freshwater discharged to the sea	4.2
F10	Groundwater support	Reclaimed water can be used as an alternative source (no mix at the source)	4.2
F11	Reclaimed water project support	Existence of projects that promote a better perception of using reclaimed water with the support of the health systems authorities	4.2
F6	Water nutrients	Reclaimed water provides a natural supply of nutrients (nitrogen and phosphorus), in a very similar way to fertirrigation .	3.9
	Total average score		**4.3**

4.2. Weaknesses

As shown by Table 8-3, weaknesses related to "Wholesalers and vendors of agricultural food crops have a very limited knowledge about the implications and public health and safety impacts of using reclaimed water for irrigation" and "The quality of the wastewater treated effluents (inflows to the water reclamation facility) does not comply with applicable regulatory limits" are identified as relevant. This last aspect refers to the WWTPs which do not comply with the defined standards (EU Directive 91/271) before this treated water enters the reclamation facility. Special attention should be paid to the situation explained in Section 2, since 12% of Andalusian population still lacks adequate wastewater treatment service. Due to this fact, the European Court of Justice in Luxembourg sanctioned Spain at the end of July 2018. Despite the relevance of the quality dimension of reused water, the most relevant aspect identified by the respondents is the lack of interest in the food-chain industry about the quality standards of reclaimed water and the system of quality assurance (i.e. risk assessment and quality monitoring plan) needed to secure a high-quality water source.

Additionally, it is worth noting that the aspect "Reclaimed water is too expensive for a significant part of the agricultural sector" is highlighted as the second most relevant weakness. Though the production of reclaimed water is less expensive than desalinated water (0.4 vs 0.6 €/m^3), this costs must

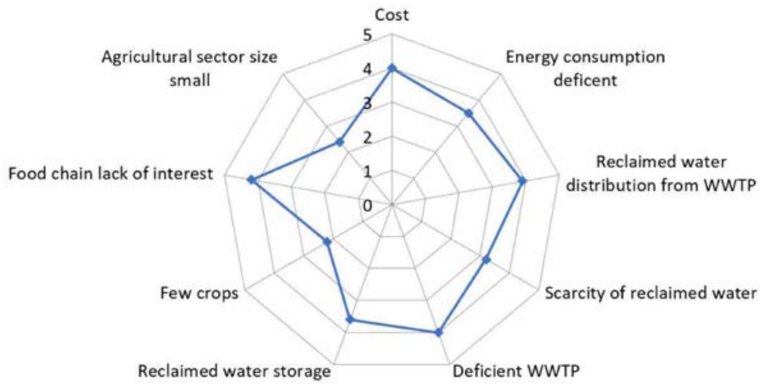

Figure 8-2 *Weaknesses relevance*

be supplemented with transport and storage costs, thus discouraging its use by irrigators.

Finally, it seems interesting that several weaknesses have been considered as less relevant (Figure 8-2), such as the small size of many irrigation districts and the limited supply of reclaimed water in certain irrigation areas. This analysis has shown that main challenges to be addressed by a future regional strategy would be: the promotion of information among food-chain agents, the guarantee of quality standards of reclaimed water, and cost affordability by irrigators.

Table 8-3 *Weaknesses aspects*

No	Weaknesses Item	Explanation	Score
D19	Food chain lack of interest	Wholesalers and vendors of agricultural food crops have very limited knowledge about the implications and public health safety of using reclaimed water for irrigation	4.2
D12	Cost	Reclaimed water is too expensive for a significant part of the agricultural sector	4.0
D16	Deficient WWTP	The quality of the wastewater treated effluents (inflows to the water reclamation facility) does not comply with applicable regulatory limits	4.0
D14	Reclaimed water distribution from WWTP	The distance between the water reclamation facility (normally in an urban setting) and the irrigation areas requires pumping of reclaimed water	3.9
D17	Reclaimed water storage	Reclaimed water needs to be collected for seasonal irrigation	3.6
D13	Energy consumption deficient	Control of the energy costs involved in water reclamation is very difficult	3.5
D15	Scarcity of reclaimed water	Reclaimed water is limited in numerous agricultural areas/ zones	3.2
D20	Agricultural sector size small	Agricultural irrigation with reclaimed water is a small activity sector, unable to feel motivated for participating in large innovation projects	2.4
D18	Few crops	Irrigation Districts are small, made up of a limited number of users	2.2
	Total average score		**3.8**

4.3. Opportunities

In the case of opportunity aspects, the most relevant seem to be (Table 8-4): “The Royal Decree 1620/2007 (Spanish legislation) offers assurance to farmers and consumers on the potential public health impacts associated with the consumption of food crops irrigated with reclaimed water”; and “There is growing social concern about the effects of future water droughts and scarcity episodes, associated with the weather irregularity resulting from climate change”.

The existence of a European regulation (European Commission, 2018) offering clear rules for irrigating with reclaimed water and bringing security to stakeholders is identified as the most relevant opportunity aspect. Therefore, the development of European and national regulations to guarantee quality standards represent a powerful means to promote confidence on the use of reclaimed water among irrigators and general public. However, the EU regulation on minimum requirements for water reuse, although it was favourably voted by the EU Parliament in February 2019, is not yet in force and needs to complete the full legislative process[3]. This situation might explain the contradictory perception of respondents, who consider the existing policy framework as an opportunity though the lack of compliance with the regulatory limits also constitutes a relevant weakness. In this sense, the development of an ecolabel and clear quality standards at European level for reclaimed water, as a result of being considered an ecological product, might also represent a potential opportunity to foster its use. Other aspects, such as water scarcity concerns, the limits to use surface water for irrigation, as well as the occurrence of more frequent and long drought periods, were identified as especially relevant opportunity sources. Experts seem to agree on the opportunity that the use of reclaimed water represents for a region such as Andalusia in terms of higher water supply reliability in a context of climate change with increasing water scarcity.

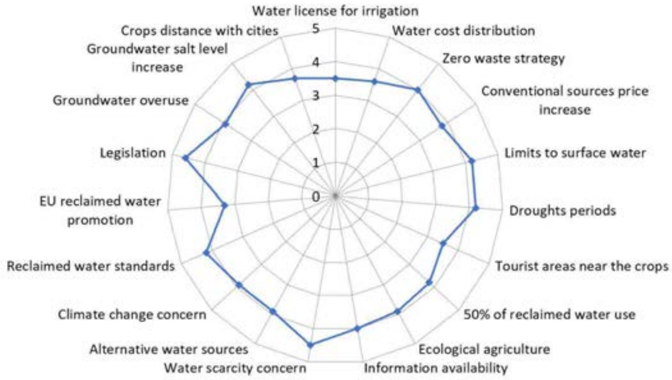

Figure 8-3 Opportunities relevance

Table 8-4 Opportunities aspects

No	Opportunities Item	Explanation	Score
O36	Legislation	The RD 1620/2007 offers assurance to farmers and consumers on the potential public health impacts associated to the consumption of food crops irrigated with reclaimed water	4.6
O31	Water scarcity concern	There is growing social concern about the effects of future water droughts and scarcity episodes, associated to the weather irregularity resulting from climate change	4.5
O25	Limits to surface water	Limitations in surface water supplies for agricultural irrigation (4,500 m^3/ha-year) can be compensated by using reclaimed water flows	4.2
O26	Droughts periods	Increased urban water abstractions during drought periods may limit the availability of water for irrigation	4.2
O34	Reclaimed water standards	The new European regulation offers clear rules for irrigating with reclaimed water, on a European context, bringing security to growers and consumers	4.2
O38	Groundwater salt level increase	Reclaimed water offers a favourable option to counteract increased salinity of groundwater	4.2
O23	Zero waste strategy	The growing interest in the "Zero Waste" option within the circular and green economy is stimulating the consideration of alternative water sources into the political debate	4

O30	Information availability	Successful studies are available on the positive effects of reclaimed water on cultivation of food crops	4
O29	Ecological agriculture	The use of reclaimed water is a potential favourable feature of organic farming	3.9
O32	Alternative water sources	Social concern for future water resources is promoting the development of alternative sources of water, such as reclaimed water	3.9
O33	Climate change concern	There is a growing social awareness of the need to seek alternative sources of water in view of the irregular rainfall associated to climate change	3.9
O37	Groundwater overuse	The use of reclaimed water can significantly help in mitigating over-exploitation of aquifers	3.9
O24	Conventional sources price increase	The cost of water reclamation may be lower than water abstraction from other natural water sources, such as groundwater	3.8
O28	50% of reclaimed water use	How possible do you consider the possibility to reuse the 50% of water in agriculture	3.8
O39	Crops distance from cities	The proximity of agricultural areas to population centres (source of reclaimed water) considerably helps in promoting irrigation with reclaimed water	3.7
O22	Water cost distribution	The cost of reclaimed water can be jointly covered by water reclamation agencies and agricultural irrigation users	3.6
O21	Water license for irrigation	Possibility to exchange freshwater license for reclaimed water ones	3.5
O27	Tourist areas near the crops	Higher water consumption in tourist areas during the peak season may limit the availability of water for agricultural irrigation	3.5
O35	EU reclaimed water promotion	The EU is definitely interested in promoting the use of reclaimed water (Directive 91/271/ECC, art. 12, and new Regulation on irrigation with reclaimed water)	3.3
	Total average score		**3.9**

4.4. Threats

Within the identified threats, (Table 8-5): "Wholesalers of food crops reject agricultural products irrigated with reclaimed water"; "Irrigation with reclaimed water lacks public acceptance in Andalusia"; and "Excessive bureaucracy needed for irrigating with reclaimed water" were identified as main threats for the promotion of the use of reclaimed water for irrigation in Andalusia. With excessive bureaucracy, we refer to the long administrative process needed to obtain the final use entitlement, including municipal and regional permissions, as well as environmental impact assessments. This result seems paradoxical, since the existing legislation is also understood as a strength (referred to the national Royal Decree 1620/2007) by providing confidence to farmers and general public on public health impacts, though the long administrative process and complexities set by existing legislation are perceived as a serious threat.
Two of the most important threats are related to the lack of acceptance of products irrigated with reclaimed water by the food chain agents and the general public.
This result is related to one of the main weaknesses identified previously, the lack of public acceptance. These findings are similar to those found by Mainali *et al.* (2011a) in previous reclaimed water implementation projects, where the lack of public acceptance and participation in the reclaimed water implementation process were considered the main cause of failure. In this line, the quality standards (at European level) and potential impacts on public health should be clearly specified in order to promote public acceptance of reclaimed water as a safe water source.

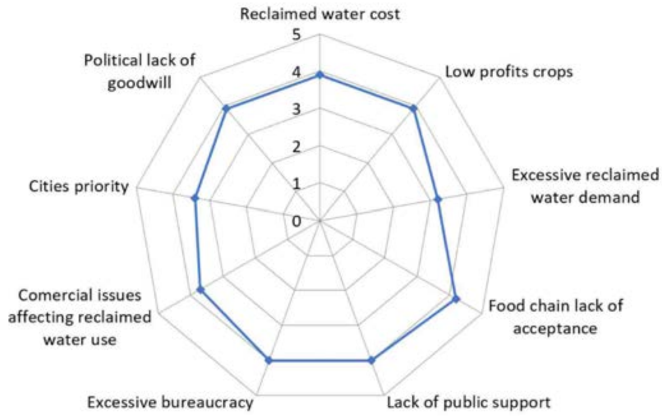

Figure 8-4 *Threats relevance*

Threats received the lowest average score within the different categories of aspects evaluated by the respondents. Similar to the weaknesses group, this average score may reflect that consulted experts consider that there are more positive than negative aspects in fostering the implementation of reclaimed water as an alternative water source for irrigation in Andalusia.

Table 8-5 *Threats items*

No	Threats Item	Explanation	Score
A43	Food chain lack of acceptance	Wholesalers of food crops reject agricultural products irrigated with reclaimed water	4.2
A44	Lack of public support	Irrigation with reclaimed water lacks public acceptance in Andalusia	4
A45	Excessive bureaucracy	Excessive bureaucracy needed for irrigating with reclaimed water	4
A41	Low profits crops	The low value of agricultural products in certain areas prevents the use of reclaimed water	3.9
A48	Political lack of goodwill	Lack of political goodwill to make reforms to promote reclaimed water	3.9
A40	Reclaimed water cost	Reclaimed water use in irrigation has an high cost for a significant part of the Spanish agricultural sector (low value crops)	3.9
A46	Commercial issues affecting reclaimed water use	The use of reclaimed water can be an excuse for unfair trading of agricultural food crops	3.7
A47	Cities priority	Urban and industrial uses will become priorities for allocating available supplies of reclaimed water	3.4
A42	Excessive reclaimed water demand	Water flows required for irrigation exceed reclaimed water flows	3.2
	Total average score		**3.8**

05

Discussion and Concluding Remarks

This research aims to identify the barriers and factors of success that determine the use of reclaimed water as an alternative water source. The SWOT analysis performed is part of a more ambitious planning process and constitutes a step further in the regional diagnosis of the Andalusian water reuse sector. This analysis leads to structuring and prioritizing of the most relevant aspects identified in the characterization of the Andalusian water reuse sector. The SWOT analysis constitute the prior step to define specific objectives and priority actions for Andalusia.
The participation of the different actors in the consulting process has been essential to guarantee the co-creation of strategies and consequently, to increase further acceptance of reclaimed water as an alternative source. Therefore, the knowledge gained in the SWOT analysis will culminate in the preparation of a Regional Strategic Plan to promote reclaimed water for irrigation purposes in Andalusia.

Previous research has concluded that this alternative water source facilitates climate change adaptation in a context of increasing water scarcity and drought events, as it is the case in other parts of southern Spain and in the Mediterranean region. Successful initiatives in other regions of the world (e.g. Cyprus and Israel) seem to confirm that the use of reclaimed water might become an adequate strategy to achieve higher supply reliability for irrigation and mitigate water scarcity conflicts. Nevertheless, special attention should be paid to the weaknesses and threats identified in the specific case of Andalusia.

The SWOT analysis carried out by SUWANU Europe and the subsequent research analysis conducted above, have shown that three main groups of aspects should receive special attention: water scarcity, stakeholders' perception and administrative or legislative issues. Key consulted actors mostly agreed on the relevance of these issues, thus expressing the need to be considered in the design of the regional strategy. Our SWOT analysis highlights the main issues identified. Firstly, legislation is perceived as a strength (existing norms), as well as an opportunity (future legislation), since the awareness of increasing resource scarcity is growing in society and the existence of strict quality requirements could increase trust in this alternative water source. On the other hand, the lack of interest by the food distribution system is seen as a weakness, as well as a threat (i.e. the non-acceptance of reused water in food production). Similarly, the high cost of reclaimed water for irrigators, compared to the current low cost of surface and groundwater resources, is seen as a weakness that needs to be addressed. Nevertheless, reclaimed water is less expensive than desalinated water, which constitutes an opportunity to decrease water cost for irrigators in the arid areas of eastern Andalusia (e.g. greenhouse crops in Almeria). Additionally, the excessive bureaucracy and long administrative processes to obtain a water use entitlement are considered a threat to be addressed. Reclaimed water licenses in Andalusia are mostly focused in irrigating gardens and golf courses. As previously explained in the region background section, only 2.5% of total reclaimed water is used for agricultural irrigation in Andalusia. In 2017 the Andalusian government set the goal of 20 hm^3 of reclaimed water to be allocated to the agricultural irrigation sector though this goal has not be fulfilled by the end of 2019. Lack of political will in the facilitation of new reclaimed water entitlements and long administrative processes could explain this delay.

Groundwater over-abstraction and the poor status of some waterbodies can be eased with the introduction of alternative water sources, such as reclaimed water. As previous literature has shown, public awareness is a key factor to successfully implement the use of reclaimed water in agriculture. Information campaigns about the use of reclaimed water and the quality assurance schemes for the products irrigated with this water seem crucial to increase interest and acceptance by the food industry and general public. Moreover, it is worth noting the relevance of integrating reclaimed water into general resources management. New supply sources should not increase demand through larger irrigated areas, but should reduce the pressure on existing water resources under stress, both surface and groundwater bodies. With this aim, water management institutions should guarantee an adequate control of water abstractions and limitation of irrigated areas as prerequisites to avoid the increase of water consumption. The use of diversified sources (e.g. reclaimed, groundwater, surface and desalinated water) should result in more reliable and sustainable water use. Additionally, the use of nutrients contained in reclaimed water should be considered as an example of a circular economy in practice.

> *"Public awareness is a key factor to successfully implement the use of reclaimed water in agriculture."*

In summary, the low level achieved in the use of reclaimed water in Andalusia, as deduced from the SWOT analysis carried out in this study, can be explained by certain aspects. Among them, the following aspects need to be highlighted: lack of clear quality standards to guarantee acceptance among food-chain agents and general public, deficient performance of WWTPs, higher costs for irrigators (including production, transportation and storage) and the bureaucratic process to obtain use entitlements.

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Appendix

Online questionnaire can be found in the following link: https://forms.gle/PJqAYXRNEuGogYDa8 (In Spanish)

Notes

1. Grant Agreement number 319998.
2. Available at the SUWANU-Europe project website: https://suwanu-europe.eu/wp-content/uploads/2019/11/D1.1_Regional-state-of-play-analyses.pdf.
3. European Commission press release, 3 December 2019. "Water reuse: Commission welcomes the provisional agreement on minimum requirements for water reuse in agriculture". Retrieved December 18, 2019 from https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6652.

9

Wastewater Production, Reuse and Management Practices in Nigeria

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Abstract

This paper explores wastewater production, reuse and management practices in Nigeria through a systematic review of literature. Findings note that wastewater production in Nigeria comes from the residential, commercial, industrial and institutional places as well as storm water run-off. Reuse is found in agricultural irrigation, landscaping irrigation, building and construction, industrial recycling and reuse, and non-potable urban uses. Reuse has been useful as coping mechanisms against inadequate freshwater supplies occasioned by population pressures, increased socio-economic activities and a corresponding rise in urbanization, as well as climate change impacts. Most Nigerians in the low income category use untreated wastewater, and this is likely to constitute environmental and public health risks. This lack of treatment calls for urgent organizational and regulatory frameworks to guarantee environmental and public health and safety arising from wastewater reuse. This paper is expected to raise public understanding of the public health perspectives of informal wastewater reuse, guide any future development of comprehensive wastewater reuse policies and plans for Nigeria, as well as enhance further research.

Keywords

Wastewater market, wastewater economy, informal wastewater reuse, Nigeria, sub-Saharan Africa

01

Introduction

The practice of reusing wastewater (treated or untreated) to complement the water resources needs for domestic, agriculture, industry and other purposes has intensified since the beginning of the 21st century. This trend is a result of competition for the use of freshwater resources, as well as the growing demand for an alternative economic vision built around sustainable development and zero waste tolerance. Wastewater production and discharge are experienced at residential, commercial and institutional places as blackwater (excreta, urine and faecal sludge) and greywater (wastewater produced in bath tubs, showers, handwashing basins, laundry machines and kitchen sinks in household, offices, schools and commercial buildings etc). Relatively large-scale production and discharge of wastewater come in forms of industrial effluent, storm water and other urban run-off; and discharge from agricultural, horticultural and aquacultural activities (Corcoran *et al.*, 2010 p. 7). Their reuse is found in agricultural irrigation, landscaping irrigation, industrial recycling and reuse, groundwater recharge, recreational/environmental uses, non-portable urban and potable urban uses (see Adewumi & Oguntuase, 2016) (Table 9-1).

> *“Wastewater recovery and reuse will not only ensure wastage is minimised, it has the potential of complementing the goal of guaranteeing water security for human wellbeing and socioeconomic development.”*

The rise in urbanisation and population growth leads to a corresponding rise in demands for food, water, shelter, energy, employment and pleasure, etc., which are all dependent on availability and stable supplies of water. But freshwater availability is becoming increasingly threatened due largely to pressure from competing uses as well as the impact of climate change. Wastewater reuse holds the prospect of complementing freshwater needs, and aligns well with the sustainable development and circular economy principles, which aim to secure intra- and inter-generational equity in access and development benefits with minimal tolerance for waste.

The UN sustainable development goal (SDG) 6 aims to ‘ensure availability and sustainable management of water and sanitation for all’ by 2030. The sustainable management of water resources is central to addressing the growing threats to freshwater water security. It resonates with other goals including poverty elimination, zero hunger, and good health and wellbeing (Goals 1, 2 and 3 respectively). It equally seeks

Table 9-1 Wastewater reuse categories (Source: Adewumi & Oguntuase, 2016)

Domains of wastewater	Possible uses	Remarks
Agricultural irrigation	Crop irrigation; commercial nurseries	Widely used for urban farming and to complement irrigation sources in drought-prone areas.
Landscape irrigation	Parks, school yards, freeway medians, golf courses, cemeteries, greenbelts and residence	Complements landscape irrigation in contexts of competitive freshwater demands
Industrial recycling and reuse	Cooling, boiler feed, process water and heavy construction	Treated, they are widely and commercially used in the building/construction industry (block moulding and brick laying), reinforcement of concrete structures.
Groundwater recharge	Groundwater replenishment, salt water intrusion control	This is a widespread practice in arid and semi-arid regions
Recreational/ environmental uses	Lakes and ponds, marsh enhancement, stream flow augmentation, fisheries, snowmaking	This is a widespread practice in arid and semi-arid regions
Non potable urban uses	Fire protection, air conditioning, toilet flushing, irrigation	Reuse of treated/untreated wastewater in toilet flushing is widespread in domestic and commercial places mostly among low income population. They are also available for use in areas experiencing water scarcity
Potable reuse	Blending in water supply reservoir, pipe to pipe water supply	A major source for augmenting water supply in water scarce regions

to: improve the quality of education for the children (by minimising the average time involved in securing daily water supplies-Goal 4); secure gender equality (by reducing the burden on women, often saddled with the responsibility of securing access to water for domestic use in developing countries-Goal 5); guarantee sustainable economic growth and cities (Goals 8 and 11); and secure life on land (Goal 15), among others.

Securing adequate supplies of water in quantity and quality is crucial to the SDGs agenda. Wastewater recovery and reuse will not only ensure wastage is minimised, it has the potential of complementing the goal of guaranteeing water security for human wellbeing and socioeconomic development, in addition to loosening excessive pressure on the available freshwater resources necessary for ecological protection. Global statistics on wastewater reuse is growing and partly facilitated by technological innovation (see Adewumi & Oguntuase 2016 for a review). Rough estimates put one-tenth of the world's population as consuming food produced through wastewater irrigation, and about 200 million hectares of land in 50 countries are irrigated with raw or partially treated wastewater (Abegunrin *et al.*, 2016; UNESCO-WWAP, 2003; Kauser, 2007). At the country level, it is reported that 80% of the inhabitants in Pakistan are using untreated wastewater for irrigation, and countries in arid regions (e.g. Israel, Jordan, Australia, etc.) optimise their wastewater reuse through innovative technological solutions.

How much wastewater is recovered and utilised in sub-Saharan Africa? Literature is surprisingly mute on this. Given the impact of climate change and the rising population, the pressure on freshwater resources has been growing and its withdrawal is estimated to increase by 50% before 2025 (Alade, 2019). Nigeria, in particular, is said to have the potential to irrigate about 3.1 million hectares of farmland were wastewater incorporated in the supply mix (Alade, 2019, p. 29). This practice has, however, not been the case as the country has no realistic policy plans or the capacity for wastewater recovery and reuse. Without appropriate reuse plans, wastewater is likely to be mismanaged by corporate organisations and private individuals. This paper explores the situation in Nigeria with the aim of improving awareness, informing a policy agenda and influencing further research.

02

Nigeria's Water Resources Availability and Utilization Practices

Nigeria's water resources availability naturally varies in space and time relative to rainfall incident and the underlying hydrogeology. The yearly mean rainfall ranges between 250 mm in the north and could rise as high as 4,000 mm in the south, concentrating between March and October. Nigeria is credited with about 267 billion m^3 annual surface water and an estimated 52 billion m^3 groundwater resources (see Akpabio & Udom, 2018, p. 1033; FGN, 2000). Of these potential sources, only 15% of the surface water is estimated to be utilized, with no available statistics for groundwater use (ADB, 2007).

Over the years, Nigeria's water resources system has witnessed enormous pressure due to rising population growth (over 200 million people), climate change impacts and the absence of adaptive policy practices to harness the available water resources to strengthen access for meeting human, industrial, agricultural and recreational needs. Currently, the country's needs for daily water supplies come from natural sources (rainfall, streams, ponds, rivers, wells, etc.), private and commercial supply sources and limited public water services (urban and rural potable water schemes) as well as occasional charitable water supply projects from the non-governmental organizations. The total cultivable land for Nigeria is estimated at 39,200,000 hectares (Alade, 2019, p. 28) and depends on water supply from direct rainfall, private and commercial supplies (borehole, hand-dug wells, mobile tanks) or untreated wastewater from domestic settlements and industrial discharges. The lack of capacity to harness and secure the available water resources for the population is likely to affect our capacity to guarantee basic sanitation and food security for the citizens.

Uncertainties in seasonal rainfall patterns over the years have imposed excessive financial costs on access to water for human domestic, agricultural and other needs. As a form of coping, a large proportion of the population resorts to all possible means to gain access to water to satisfy their diverse needs. Wastewater becomes readily available. According to the UN World Water Development Report (UNESCO-WWAP, 2017, p. 10), globally about 5 to 20 million hectares of land is irrigated with raw and diluted wastewater, with China probably being the largest contributor in the range of between 2 to 7%. The report noted that Sub-Sahara African countries lack the financial resources to support wastewater treatment and management facilities, in addition to the absence of necessary data: '…32 out of 48 sub-Sahara African countries have no data available on wastewater generation and treatment' (p.11). Absence of wastewater facilities means the main mining, oil and gas, and manufacturing industries in the sub-region discharge wastewater into the environment with minimal or no treatment. The UNESCO-WWAP (2017, p. 11) observed that less than 10% of industries in Nigeria treat their effluents before discharging into the environment. In southern Nigeria with relatively heavy presence of oil and gas, and other manufacturing industries, Alade (2019, p. 29) noted that, apart from Port Harcourt city (serving only one percent of its population), no other wastewater treatment facility is available for the entire region. Similar observations have been reported for other major regions of Nigeria including the southwest and north west.

Urbanization and industrial activities have contributed to the volume of wastewater produced in Nigeria: the annual wastewater production estimate is conservatively put at over 500,000 m^3 (Olonade, 2016, p. 235). Wastewater from domestic dwellings, commercial places and offices is disposed through channel pipes or concrete sewers into soakaway pits, septic tanks and open drains; and stored in containers (for subsequent reuse or discharge on open surfaces) without treatment. Industrial wastewater discharges into open surfaces and bodies of water are common among bigger industrial establishments.

Interest in wastewater reuse in Nigeria is the outcome of institutional factors. These factors are specifically related to the privatization and commercialization of public water services, and the consequent marginalisation of the poor and low income households who find the cost of access to potable water services increasingly unaffordable.
Nigeria started the process of privatizing its public services in the late 1980s (through Decree No. 25 of 1988) as a consequence of the pressure from the international financial institutions led by the World Bank and the International Monetary Fund (IMF). This Decree was implemented through the structural adjustment programme (SAP). In 1999, the government enacted the Public Enterprise (privatization and commercialization) Act which created the National Council on Privatization to evolve comprehensive privatization policies and programmes for the country. According to Estrin and Pelletier (2018, p. 70) although Nigeria's privatization plan had been one of the most successful in sub-Saharan Africa in the 1990s, it was however suspended in early 1995 in preference for a mass programme of commercialization.

The World Bank has been at the forefront in promoting the policy through financial assistance. According to Babalobi (2005): "....so far, the World Bank has extended a loan facility of US$173.2 million guaranteed by the Federal Government of Nigeria (FGN) with a maturity period of 14.5 years (from 1st August, 2008) with repayment dates on 15th October and April at a rate of 5.59%. The World Bank also approved a project called 'privatization support project' in 2000 worth US$114.29 million. These two World Bank loans prepare the necessary conditions to attract foreign multinational water corporations through promotion of cost recovery tariffs and promotion of private sector involvement.......so, we have a right to ask questions because if the loan is not judiciously expended and properly managed, our children and grand children will repay the World Bank loan."

The commercialization of public utilities effectively affected the water services sector. The public water services landscape was restructured with the transformation of public water corporations to joint venture companies with the private sector, with no clear operational legal framework.
The restructuring and transformation processes effectively limited the activities of the existing water companies to cities to enhance the full-scale commercialization of water services to city dwellers. Public water taps have disappeared from the urban streets over the past three decades, paving way for the emergence of various forms of private and commercial water services entrepreneurs (supplying water in tanks, sachets, bottles, and other containers in addition to private/commercial supplies from boreholes). This imposes high economic cost on low income earners, creating the necessity for unregulated and untreated wastewater reuse.

03

Methods

This paper is a product of a systematic review of literature and previous research experiences on water, sanitation and hygiene (Akpabio & Udom, 2018; Akpabio & Udofia, 2016; Akpabio, 2012; Akpabio *et al.*, 2017). The review process was conducted through google scholar. Three search topics were inputted in google scholar as follows: 'wastewater reuse in Nigeria', 'institutional framework and wastewater management in Nigeria', and 'regulatory and legal framework for wastewater management in Nigeria'. The first search topic: 'wastewater reuse in Nigeria' (through 10 pages of google scholar) returned 16 relevant articles after careful screening of the abstracts with interest on reuse practices. The second, 'institutional framework and wastewater management in Nigeria', and third, 'regulatory and legal framework for wastewater management in Nigeria', search topics, respectively did not return any new and relevant article after 10 pages of google search and had to be discontinued. References of the printed articles were further scrutinized, which made it possible to generate another set of relevant articles on the topic. Overall, over 30 useful publications were generated and reviewed between December 2019 and February 2020. Besides looking through the abstracts and results, the body of each publication was carefully scanned for relevant information and data. Some articles carried almost similar information on the subject matter, and selection decisions were based on the criteria of depth, rigour and originality of study and report. The paper equally benefitted from my almost two decades of research on water, sanitation and hygiene in Nigeria in particular and sub-Saharan Africa in general.

"Wastewater reuse is an everyday experience of slum dwellers in Nigeria's urban areas and communities experiencing severe scarcity of freshwater supplies."

04

Urban settlements and wastewater

Nigeria's annual urbanization rate is projected at 4.4%, with 50.34% urban population as at 2018 (Plecher, 2020). The majority of the urban settlements enjoy very limited planning visible at public residential and adminsitrative quarters, with limited supplies of public sanitary infrastructure. Settlements located outside the reach of public planning face difficult problems due to the inability to access public water and sanitation infrastructure. Currently, no city in Nigeria has a coordinated sewerage system except for limited areas of Abuja and Lagos; and that about 42% of the urban and semi-urban population has access to safe water supplies and adequate sanitation (FGN, 2000; Akpabio & Udofia, 2016). Urban public water services are carefully and, to a large extent, commercially designed to serve high income citizens found in high quality residential locations, and on demand responsive arrangements. This long-standing public policy practice emerged since the late 1980s in line with the IMF/World Bank Structural Adjustment Programme (SAP), and the consequence has reflected significantly on access and management of basic services at homes including sanitation. Akpabio and Udom (2018) reported for instance that the majority of citizens in the low income category commit, on average, 20% of their monthly income for water and water-related storage facilities to support basic household activities such as cooking, laundry, bathing and dishwashing, among others.

Wastewater produced from the domestic sources are stored and reused for other household services such as for disposing human excreta, cleaning of domestic features including windows and doors, floor mopping, watering of plants, among others. Kitchen and bath wastewater are regularly stored in big containers (mixed or separate for different purposes), and can be reused for flushing the toilet, cleaning the floor, initial cleaning of some food items (depending on quality) as well as watering outside plants. Wastewater reuse is not only common in unplanned residential places, public estates with access to public water and sanitation systems regularly reuse untreated wastewater for toilet flushing and other domestic services to cope with irregular public water supply.

Wastewater reuse is an everyday experience of slum dwellers in Nigeria's urban areas and communities experiencing severe scarcity of freshwater supplies. Houses equipped with in-house flush toilet systems run regular toilet flushing time tables corresponding to calculations of daily wastewater availability. Every member in the household is allowed to use the toilet before flush. Two things are involved: a) such a toilet is often flushed once (at night) or twice in a day (mid-morning and night) depending on the amount and availability of wastewater generated for the day; b) as wastewater is constantly produced, it is captured in big containers, where it is stored for many hours to be used when needed.

In a typical Nigerian city, it is reported that about 35% of domestic wastewater empties into the septic tank while the remaining (65%) is channelled onto open ground surfaces to contribute to the building up of stagnant pools (Idris-Ndah *et al.*, 2013).

05

Wastewater and Irrigation Agriculture

Wastewater from commercial, public and domestic places, as well as stormwater generated from run-off, are important sources of supply for agricultural and landscape irrigation in rural, urban and peri-urban areas over the past decades. Salad crop irrigation farming in northern Nigeria depends on the reuse of untreated wastewater (Okafo *et al.*, 2003) as scarcity of freshwater supply severely imposes difficulties for irrigation farming. Regular demand for water to support irrigation activities has led to the emergence of commercial market opportunities for untreated wastewater to supplement household incomes. Commercial trade in untreated wastewater has been a longstanding and popular business and livelihood support for low income earners in big Nigerian cities including Lagos, Kano, Kaduna and Katsina, etc. In a study on reuse of wastewater in urban farming in Katsina Metropolis, Ruma and Sheikh (2010) observed that a number of the urban inhabitants earn their living from wastewater trade to meet farmers' demand for crop irrigation in the context of rainfall uncertainty. Recently, there have been reported instances of human urine for crop fertilizations within the framework of ecological sanitation.
Though not widely used, ecological sanitation enables source-separation of urine from faeces, with the urine used as a source of organic fertilizer for crops e.g., the UNICEF pioneered an ecological sanitation initiative in the riverine communities of Odukpani, south-south Nigeria (Akpan-Idiok *et al.*, 2012).

06

Wastewater and Industries

Wastewater discharges from industrial and commercial places are sources of pollution to water bodies, groundwater and urban landscapes. Although very few industrial establishments in Nigeria are credited with functional wastewater treatment facilities, none has wastewater reuse plans that are coordinated and functional (Adewumi & Oguntuase, 2016; Adesogan, 2013; Mustapha, 2013; Odurukwe, 2012). The major petroleum refining companies in Nigeria not only lack wastewater reuse plans, their wastewater treatment and handling processes hardly meet regulatory standards (Osin *et al.*, 2017). The refineries make use of water for distillation, hydotreating, desalting, steaming and cooling processes (Osin *et al.*, 2017). While these processes eventually lead to wastewater production, studies demonstrate that the liquid waste from the oil and gas companies did not meet the necessary regulatory standard (see Al-Suhaili & Abed, 2008; Yu *et al.*, 2017).

It is also reported that most of the wastewater treatment plants of the oil and gas industries are less than optimal in treatment effectiveness. A study from Nkwocha *et al.* (2013), on the performance effectiveness of a wastewater treatment plant of a petroleum refinery located in Nigeria's Niger Delta region, concluded that the plant's average treatment effectiveness was about 30-70% below the minimum required treatment effectiveness of 50-90%. On a spatial note, Odurukwe (2012), in a study on the absence of wastewater management practices in Aba city, had documented the growing incident of channelling and emptying untreated wastewater from the sewers serving big, medium and small-scale industries into the Aba river, posing existential public health risk to the city population. Generally, the absence of effective, coordinated and functioning wastewater treatment facilities and reuse plans means that untreated wastewater produced from industrial and commercial establishments is discharged into available water bodies, drains and open grounds.

Wastewater reuse in industries is largely at the informal and small scale levels in the construction/building industries. Reservoirs and blocked drains are receiving sites for wastewater discharges from domestic and storm sources. The stored wastewater is used in moulding blocks, laying bricks and other concrete works to minimise the high cost of freshwater supplies from mobile trucks and other sources. The rise in urbanisation and small scale industrial activities in Nigeria has engendered a rise in private and public construction activities, with heavy demands on available freshwater resources. Areas experiencing acute freshwater scarcity are likely to witness a surge in wastewater demand and reuse, providing market opportunities for low income urban citizens who depend on wastewater trade to supplement income.

07

Practical and Institutional Challenges of Wastewater Reuse in Nigeria

Over 95% of wastewater reused for various purposes in Nigeria is untreated, and originates from domestic, commercial and institutional sources as well as from the chemical, petroleum and brewery industries, among several others. The typical composition of wastewater according to Metcalf and Eddy (2004, cited in Adewumi & Oguntuase, 2016, p. 21) includes a range of potential contaminants, including conventional (i.e. total suspended solids, colloidal solids, biochemical oxygen demand, total organic carbon, ammonia, nitrate, nitrite, total nitrogen, phosphorus, bacteria, protozoa and viruses), non-conventional (e.g. refractory organics, volatile organic compound, surfactants, metals, total dissolved solids) and emerging (e.g. prescription and non-prescription drugs, home care products, veterinary and human antibiotics, industrial and household products, sex and steroidal hormones and other endocrine disrupters). Olonade (2016, p. 236) has categorized some contaminating and harmful chemical and biological agents contained in wastewater produced from different sources (Table 9-2).

Nigeria has no clear legal and regulatory framework for managing/reusing wastewater. However, relevant institutional authorities exist for waste management which, in almost all cases, boils down to solid waste management (Table 9-3).

Several legislations broadly touching on environmental management, impact assessments and river basin management provide guidelines, standards, duties and responsibilities for managing the environment, of which water resources are a sub-set. Specific legislations on water resources focus on pollution control, which aim to protect the sources of water supplies mostly from streams and rivers, with no provision for wastewater reuse. Legislative provisions as detailed in Table 9-3 are not significantly different from the colonial legislative instruments, framed to protect available water bodies from polluting substances in the interest of public health.

Public health protection was the cardinal motive of the colonial laws related to water resources management, which was mostly to serve the interest of the colonial officials resident in cities. Few legislative additions and modifications during the postcolonial period happened in the context of petroleum resources exploration (e.g. the petroleum, effluent limitations, EIA and related legislations). These and related laws only sought to control pollution and regulate effluent discharges into open waters. For instance the national guidelines and standards for environmental pollution control issued by the Department of Petroleum Resources (DPR) and revised in 2002 approved the prohibition of the discharge of wastewater from crude oil extraction activities onto onshore environment designated as 'zero discharge zones' in preference for offshore locations (about 12 nautical miles away from the shoreline and of depth not less than 200 ft). There was an alternative provision for the re-injection of the produced water into reservoirs. But Osin *et al.* (2017) has observed that these prohibitions are commonly breached by the petroleum resource industries since treated wastewater is still being discharged in the surrounding environment.
In all these instances, there are no specific legal instruments and standard for wastewater reuse.

> *“Nigeria has no clear legal and regulatory framework for managing/reusing wastewater. However, relevant institutional authorities exist for waste management.”*

Table 9-2 Wastewater sources and possible contaminating elements (Source: Olonade, 2016, p. 236)

Sources	Possible contaminants
Domestic/kitchens (households) and offices	Decomposable and indecomposable organic materials
Pharmaceutical industry	Anti-biotics, lipid regulators, anti-inflamatories, anti-epileptics, tranquilizers and cosmetic ingredients with significant amount of oil and grease
Soap and detergent	Heavy metals including lead, zinc and manganese. They are contaminated with organic compounds which contain significant amount of oil and grease
Paper mill	Sugars and lignocellulose
Fertilizer plant	Toxic waste rich in ammonia-nitrogen, urea, nitrate-nitrogen orthophosphate-phosphorus
Textile mill effluent	Heavy metals, starch, waxes, carboxymethyl cellulose (CMC), polyvinyl alcohol (PVA), wetting agents, sodium hypochlorite, NaOH, H_2O_2, acids, surfactants, ($NaSiO_2$ sodium phosphate, sodium hydroxide, cotton wax, reducing agents, oxidizing agents, acetic acid, detergents, wetting agents, pastes, urea, starches, gums, oils, binders, cross-linkers, reducing agents, alkali
Brewery industry	High in carbohydrates, ammonia
Tannery industrial effluent	Chromium
Soft drink effluent	Acidity with a pH of 6.6 ±1.2
Chemical industry	Hydroxylbenzene (phenol), chlorobenzene, methylbenzene (toluene) and dimethylbenzene (xylene)
Palm oil mill	Organic carbon, nitrogen content (0.2 g/ℓ) as ammonia nitrogen and 0.5 g/ℓ total nitrogen, various suspended components including cell walls, organelles, short fibres, a spectrum of carbohydrates ranging from hemicellulose to simple sugars, a range of nitrogenous compounds from proteins to amino acids, free organic acids and an assembly of minor organic and mineral constituents, dark colours

Table 9-3 Institutional authorities for wastewater management (Source: Adapted from Akpabio & Udom, 2018)

Institutional authorities	Provisions	Remarks
National Policy on Environment, 1989	This was launched to provide guidelines and strategies for achieving the Policy Goal of Sustainable Development	This policy has not been revised to account for norms of zero waste tolerance and reuse of wastewater. A substantial aspect of this policy is reproduced from the provisions contained in colonial and some post-colonial regulations.
The Environmental Impact Assessment (EIA) decree/Act 1992 & 2004	EIA covers a broad range of issues including the disposal of wastes	Nigeria lacks the necessary institutional capacity and transparency to address a wide range of environmental and public health issues (including wastewater treatment and reuse) in every EIA document
National Guidelines and standards for Environmental pollution control (1991); National environmental standards and regulations enforcement agency Act 2007 (NESREA ACT); National Environmental Sanitation and Wastes Control Regulations, 2009	Specified duties also cover enforcement of standards on waste disposal procedures and practices	Same comments as above
National Effluent Limitation Regulation 1991	Regulated duties include prescribing a maximum limit of effluent parameters allowed for discharge and penalties for contravention	This has no provision on how treated wastewater should be managed. No reported cases of punishment for breach of regulation.

08

Discussion and Concluding Remarks

Wastewater reuse is widely embraced by the Nigerian populace and, through largely informal mechanisms, serves to cope against inadequate freshwater supplies occasioned by population pressures, increased socio-economic activities and a corresponding rise in urbanization, as well as climate change impacts. The capacities of available freshwater resources and public infrastructure to address the competing needs of water for human, energy, industrial, agricultural and other socio-economic activities becomes inadequate. Costly private and commercial supplies do not equitably fill the gap between supply and demand. Reclaiming and reusing untreated wastewater to complement supplies becomes a viable alternative for a large segment of the Nigerian population in the low income category. Greywater from domestic, commercial and institutional buildings is stored in containers in cities and used for various purposes, including urinal and toilet flushing. Wastewater from the bathroom and laundry machines is occasionally used for cleaning floors and other household items. Outdoor use of greywater is common in irrigation, washing of windows, doors, vehicles, block moulding and other concrete works. Storm water in puddles, ponds, and drains have also been used in toilet flushing, outdoor cleaning, irrigation and concrete work.

The intensity and frequency of wastewater reuse vary relative to socio-economic capacities, seasonal changes and spatial/ecological circumstances. Drought-prone northern Nigeria depends on untreated wastewater to complement domestic, agriculture and other supply needs. Urban, semi-urban and rural areas depend on wastewater reuse to mitigate the social and economic costs of accessing limited freshwater. Southern Nigeria, with a relative abundance of freshwater resources, faces relative scarcity during the dry season, necessitating frequent indoor and outdoor use of untreated wastewater for toilet flushing, irrigation of compound farms, cleaning and building/concrete works, among others.

Well over 95% of wastewater reused is untreated, which raises important environmental and public health questions related to food safety, the potential for the spread of infectious diseases and contamination of the soils, water and air, among others. Nigeria does not have organized and coordinated wastewater reclamation, treatment and reuse policies and plans. Available legislative frameworks on wastewater are old, not comprehensive and do not address the question of reuse. More so, enforcement of available laws on wastewater production and discharge remains weak. Consequently, industries have taken advantage of weak regulations to discharge untreated or partially treated wastewater to the environment.

With growing population pressure and the possible impact of climate change, as well as a lack of necessary technological and institutional capacities to harness and optimize the utilization of available freshwater resources, the use of alternative sources of supplies is likely to intensify, with wastewater reuse becoming a crucial necessity.

“Reusing wastewater not only fits with the circular economy principles of optimising resource use with zero waste production; it has become a natural response available for cushioning the effect of climate change and costly neoliberal policies on freshwater availability and access for low income citizens.”

In most African countries, freshwater withdrawals are projected to increase by 50 percent before 2025 to meet the current challenges imposed by excessive demand (Alade, 2019). Intensified freshwater withdrawal will impose enormous pressure on available sources of supply. Reusing wastewater not only fits with the circular economy principles of optimising resource use with zero waste production; it has become a natural response available for cushioning the effect of climate change and costly neoliberal policies on freshwater availability and access for low income citizens.

In conclusion, wastewater reuse has contributed to a reduction in the demand for freshwater in rural, urban and semi-urban areas of Nigeria as well as reducing water shortages during the dry season. Wastewater reuse has sustained urban farming, landscape irrigation, concrete works and a range of other socio-economic activities. It is equally a potential alternative for coping with the anticipated consequences of climate change-induced water scarcity for Nigeria. As the review has demonstrated, most Nigerians in the low income category use untreated wastewater, and this is likely to constitute environmental and public health risks (Abegunrin *et al.*, 2016; Adewumi & Oguntuase, 2016). This lack of treatment calls for urgent organizational and regulatory frameworks to guarantee environmental and public health and safety arising from wastewater reuse. This paper is expected to raise public understanding of the public health perspectives of informal wastewater reuse, guide any future development of comprehensive wastewater reuse policies and plans for Nigeria, as well as enhance further research.

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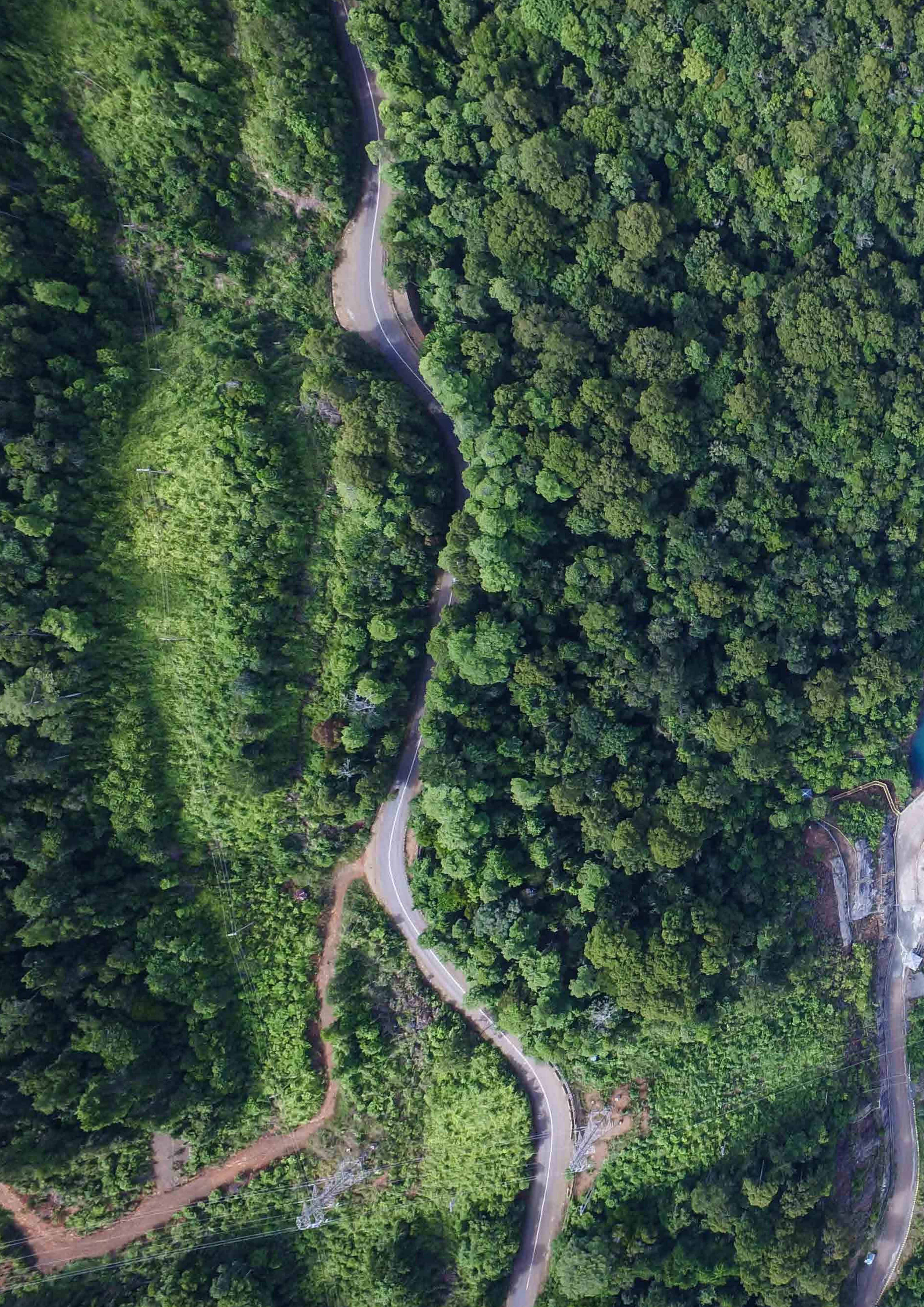
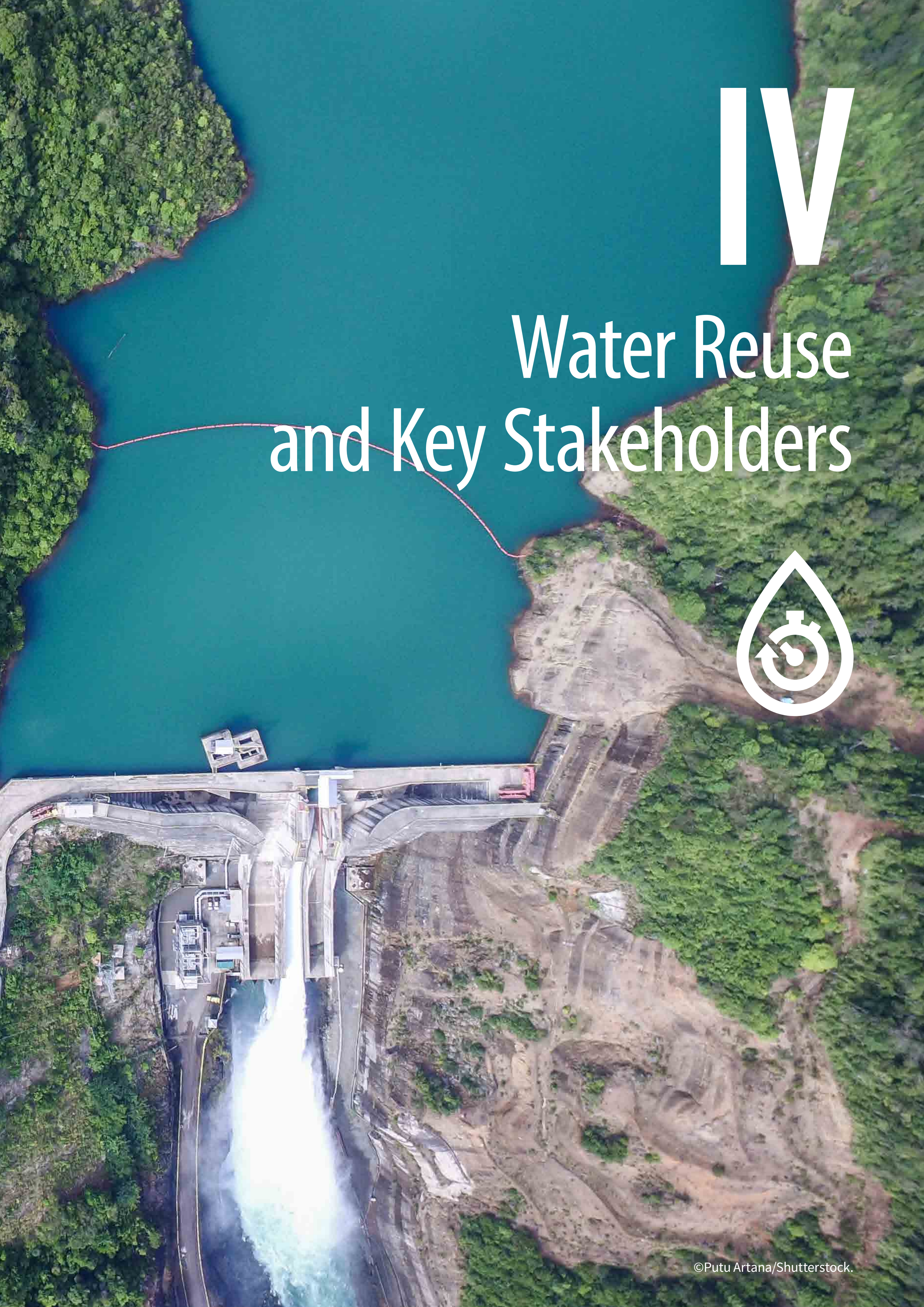


IV

Water Reuse and Key Stakeholders



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10

Market for Reclaimed Water through Private Water Tankers – Sustainable Service Provision in Peri-urban Areas

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Abstract

Bengaluru's urban peripheries have a dual challenge. One is over abstraction of ground water resources for non-potable uses by residential dwellings and small commercial units. The second is disposal of excess treated water from private Sewage Treatment Plants (STP), which remains even after reusing some of it for toilet flushing and gardening by apartments. The study proposed addressing this challenge through formalizing private water tanker supply of the treated water from apartments to individual residential dwellings and commercial units for non-potable purposes, thereby reducing groundwater consumption and ensuring efficient and reliable allocation of water through a circular economic model from source to user and user to source and giving water true value.

Tankers are currently supplying 2.5 million litres per day of fresh water. The tanker operators were interviewed to understand their motivation to sell reclaimed water. Out of 25 tanker suppliers interviewed, 15 are willing to invest in new tankers to supply reclaimed water, provided their revenue is not affected. From the 350 end users surveyed, 1.9 million litres per day is used for non-potable purposes. This non-potable demand could be met through supply from tanker vendors while not raising challenges posed by other conventional interventions, such as dual piping or distribution system and storage.

Keywords

Reclaimed water, water tanker, non-potable demand, water use behaviour

01

Introduction

1.1. Background of the Study

The 2030 Agenda's Sustainable Development Goal (SDG) 6 for 'Water and Sanitation' comprehensively looks at drinking water quality, sanitation and hygiene, scarcity and water use efficiency to promote environmentally sustainable and healthy communities. The target of goal 6.3 under SDG 6 aims specifically at improved wastewater treatment and an increase in water reuse. For creating liveable cities, a long-term vision and need for rethinking the approach are essential to augment water resources, not only from conventional sources (i.e. surface water and groundwater) but treated sewage (reclaimed water) use. This non-conventional source is an important solution to solve water scarcity issues across the globe (Tortajada & Ong, 2016) and has been put into practice successfully in many cities like Singapore (Lee & Pin Tan, 2016); Namibia (Lahnsteiner *et al.*, 2016); and Israel (Friedler *et al.*, 2006). There is enormous growth in the body of literature and case studies demonstrating reclaimed water as a viable alternative source, even for drinking purposes (UN Water, 2017; Khan & Roser, 2007). Rethinking sewage treatment plants more as 'resource factories' requires transforming a linear model of water management, which takes water from source, to supply and discharge, often rendering it unfit for use by subsequent users and society. Instead a circular economy approach closes the loop from source to user, and user to source, by giving it true value. Water by nature follows a circular path; hence human intervention should aid in regenerative practices and circulate water back at its highest value by eliminating the concept of waste (Ellen MacArthur Foundation, 2015). With this backdrop, this paper focuses on a peri-urban area in Bengaluru, India. The paper is structured as follows: the next section identifies challenges related to water; a rationale for choosing the study location is discussed next, along with the methodology to assess water demand; findings from the survey and recommendations are then presented.

Table 10-1 Water related challenges (Author's compilation)

No	Challenges	Global	India	Peri-urban areas and Bengaluru periphery
1	Water scarcity	By 2025, two-thirds of the world's population could live under water stressed conditions (UN water scarcity, 2014).	Per capita water availability is 1,720 m^3 in 2007; < 1,700 m^3 is water stressed. India estimates a forecast of about 1,340 m^3 per capita in the year 2025.	Farmers find it lucrative to sell groundwater from their own borewells, using tankers changing the occupational characteristics of farmers to water sellers
2	Distance of water withdrawals and augmenting water supply to meet the growing demand	Cities moved 504 billion litres/day a distance of 27,000 ± 3,800 km. (Mc Donald *et al* 2014)	The distance between a city and its water source (in km) are: Delhi (320 km), Mumbai (120), Chennai (200), Hyderabad (100), Bhopal (70)	Using groundwater as the main source of water to quench urban thirst increases water insecurity. Bangalore withdraws water from Cauvery River, which is at a distance of 120 km
3	Unaccounted water loss	Worldwide, leakage loss rates of up to 50% are seen in urban potable water distribution systems. Some 250 to 500 million m^3 of drinking water is lost in many mega cities each year.	Losses in metropolitan cities (percent): Kolkata (50%), Chennai (20%), Delhi (26%) and Mumbai (18%).	There is no accounting for water demand, or metering. Bangalore ranks fourth with 30% (Raj, 2015). Revenue losses of 90 crores
4	Ground-water stress		India abstracts about 245 billion cubic meters (BCM) of groundwater per year, which represents about 25% of the total global groundwater abstraction making it the largest user globally.	There are approximately one lakh or more bore wells dug, which includes private and government bore wells. 7,000 borewells are dug by Bengaluru Water Supply Sewerage Board (BWSSB) drawing water to supply 35 – 70 million litres per Day (MLD) through 22 water tankers in the core area of the city.

1.2 Water in peri-urban areas

The water-related challenges in context of peri-urban areas can be classified into the six challenges listed in Table 10-1. These challenges are interlinked and specifically in the peri-urban region, the water and sanitation challenges are more complex to address due to a lack of institutional frameworks. To identify entities and factors to be included in the circular economy, it is vital to think of peri-urban developments as ecosystems in such a way that good quality freshwater is equitably distributed and pragmatic solutions are implemented to treat wastewater as a valuable resource for water, energy, and nutrients.

1.3. Rationale for the Study

Bengaluru city is chosen for this study. Greater Bengaluru formed in 2007 when 110 villages in the periphery were added to the Bruhat Bengaluru Mahanagara Palike (BBMP). The core city is 245 km^2 and the 110 villages are an additional 225 km^2, referred to as the peri-urban areas in this paper. These villages have emerged as major urban regions accommodating the workforce population who have migrated from other cities. This has led to the creation of a middle income neighborhood but the infrastructure development did not take place at the same pace as the housing and commercial establishments. Water and sewerage infrastructure in these localities are poor to almost nil.

Figure 10-1 depicts the development stages of the only surface water source, the Cauvery River, to meet the demand of growing Bengaluru since 1974. The Cauvery water supply scheme (CWSS) stage-I was commissioned in the year 1974 to augment the supply by 135 MLD. Consequent CWSS Stages-II, III, and IV followed in the years depicted in brackets in Figure 10-1. CWSS Stage- IV Phase II was commissioned in 2012 to further augment supply by 400 MLD. Currently the Bengaluru Water Supply and Sewerage Board (BWSSB) is withdrawing about 1,470 MLD water from the Cauvery River to meet the city's demand.

These schemes have not met the complete demand of the population. The water utility is planning to augment the supply through Cauvery Stage V to the 110 villages for which connections are being laid under funding from the Japan International Cooperation Agency (JICA). Will this linear model of augmenting Cauvery through Stage VI for rapidly growing 110 villages be reliable?

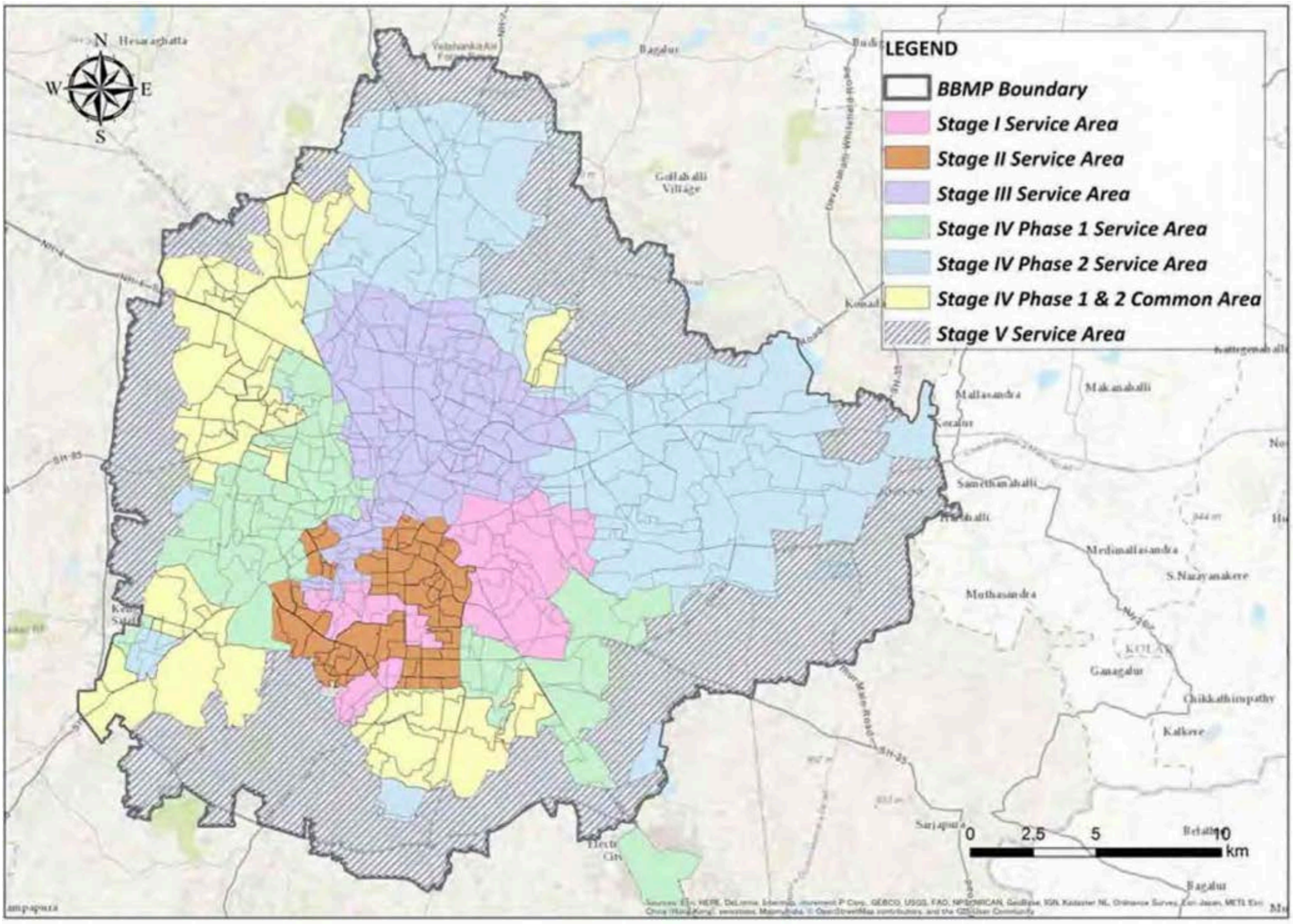

Figure 10-1 *Cauvery Water Supply services in the BBMP area (in MLD) (Source: BWSSB, 2017)*

Table 10-2 *Water supply and groundwater withdrawal (as of year 2013) by Water Supply Zone (Source: BWSSB, 2017)*

Water Supply zone	River water (MLD)	No. of Deep wells	Groundwater Withdrawal (MLD)
Central	69	7,206	39
North	210	16,126	87
West	185	27,625	149
East	169	9,346	50
South	133	32,593	176
South-east	105	12,555	68
Total	**869**	**105,451**	**569**

As we see from the Table 10-2, groundwater abstraction has been excessive and unsustainable, leading to many bore wells drying up. Forty percent of the Bengaluru population is dependent on groundwater. Water consumption by Bengaluru (based on metered connections as of March 2015 for each division) shows that the Southern Division of the city consumes 133 lpcd which is equivalent to the Ministry of Urban Development (MoUD) norms, while the rest of the city seems to be either under-supplied with water or dependent on other sources, primarily groundwater. Moreover in the 110 villages, bore wells installed by the BBMP are going dry in the wake of increasing demand for informal water (through tankers). This demand for tanker water has not only made their business lucrative but is also creating unrest in the public as these tanker operators are taking advantage of the situation causing delays in making water available to users and charging higher rates due to the higher demand.

Bengaluru takes credit for being a proactive city by setting up centralized sewage treatment plants. Table 10-3 depicts the sewage treatment plant (STP) infrastructure developed and planned until 2031 as per a Revised Master Plan (RMP) for 2031 for Bangalore. We notice there is a gap of 475 MLD of untreated water at present and by 2031 it will only be reduced to 378 MLD in spite of so many STPs being constructed. However, only three fourth of the installed capacity is being utilized to date to treat the waste water of the city.

In addition to existing STPs, there are 11 STPs with an overall capacity of 339 MLD under construction and another 8 STPs with an overall capacity of 550 MLD under tendering process. To meet projected demand for 2049, BWSSB has proposed to construct another 207 MLD capacity of STPs at 16 locations. Overall, once these systems are built, about 1,817 MLD of treated waste water will be available for reuse.

In addition to central municipal sewage treatment plants, the Zero Liquid Discharge law was enacted in 2006 by the Karnataka State Pollution Control Board (KSPCB) to control water pollution and encourage fresh water savings. The rules mandate that apartments with more than 50 units, or a total constructed area greater than 5,000 m² in the unsewered areas of BWSSB, must have their own STP. The legislation has been successful in the city, at least in terms of the number of installed STPs in apartments. Bengaluru possibly has the highest number of STPs for any Indian city, with a total treatment capacity of about 141 MLD (Evans *et al.*, 2014), which is about 10% of the total wastewater generated in the city. Figure 10-2 shows the growth in capacity of treatment in private STPs in apartments. A vast majority treat their wastewater to tertiary levels and about 70% employ activated sludge process (ASP) for secondary treatment.

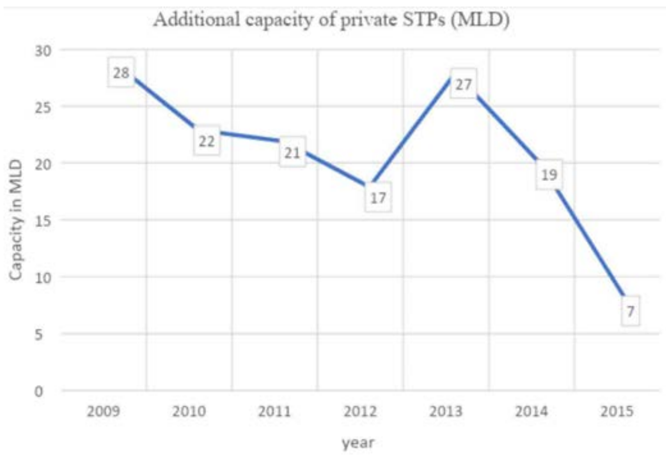

Figure 10-2 *Figure 10-2 Capacity of Private Sewage Treatment Plants installed from 2009 to 2015 (Source: BWSSB, 2017)*

Table 10-3 *Sewage Treatment infrastructure gaps for domestic sector (Source: BWSSB and RMP 2031 Analysis as cited in Revised BDA Master plan 2031)*

Sl.No	Head	Units	2011	2016	2021	2026	2031
1	Population	No.	9,044,664	11,071,055	13,551,445	16,594,465	20,320,805
2	Water Supply @135 lpcd	MLD	1,221	1,495	1,829	2,240	2,743
3	Sewage	MLD	977	1,196	1,464	1,792	2,195
4	Treatment capacity	MLD	721	721	1,060	1,610	1,817
5	Gap in Treatment infra	MLD	256	475	404	182	378

Table 10-4 *Quantity of reclaimed water sold (Source: survey response by BWSSB official, Note that the table reports the only months of data that were available from government sources)*

Month - Year	Quantity (MLD)
Nov-15	0.20
Dec-15	2.30
Jan-16	6.33
Feb-16	6.25
Mar-16	6.44
Apr-16	7.76
May-16	7.23
Total	**36.51**

A formal market is established to sell reclaimed water to industries and to the international airport of Bengaluru.
The following tables provide details of the quantity of water sold (Table 10-4) and the major recycling units with sale price.

Accelerating and scaling up this market to 110 villages in the peri-urban areas of Bengaluru will aid in reducing ground water abstraction and to assess if the communities will accept reclaimed water use to implement allocation of fit-for-purpose water. Since, these peri-urban areas do not have formal water supply coverage by the BWSSB, there is no data to assess the water demand. Hence, primary surveys were administered to assess the actual demand for water, as discussed in Section 5 following.

In 2019, a similar initiative was extended to residential areas in core area of Bengaluru through tankers as shown in Figure 10-3. However, this study was conducted specifically for peri-urban areas in 2016 and 2017 and the findings were presented as part of the author's Ph.D. research.

The research had two stages – stage 1 was to examine the feasibility of having a formal market for provision of reclaimed water service through tankers for non-potable water uses. Further, in stage 2, we examined how formal provisions can be made if there is social acceptance for tankers to deliver reclaimed water.

ಬೆಂಗಳೂರು ನೀರು ಸರಬರಾಜು ಮತ್ತು ಒಳಚರಂಡಿ ಮಂಡಳಿ

BANGALORE WATER SUPPLY & SEWERAGE BOARD
5th Floor, Cauvery Bhavan, K.G.Road, Bangalore-560009.

No. BWSSB/CE(WWM)/ACE(WWM)-1&2/DCE(WWM)/1202 /2019 Date: 5/8/19

Notification

Sub : Sale of Tertiary treated waste water of BWSSB through tankers – Regarding publishing of notification in News Dailies and Website.

Ref : U.O. note approved by Hon'ble Chairman at 20-07-2019

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With reference to above approval has been obtained to sell the tertiary treated waste water through tankers to the public for non potable purposes . The details of the place of availability of this water, rates prescribd and the contact details are shown in the following table.

Sl. No	Place of availability of Treated Waste Water	Areas which can make use of the facilities (within a radius of 5 Kms)	Rates of treated water	Contact details
1	Cubbon Park Waste Water Treatment plant – Kasturbha Road	CBD, UB City, MG Road, Halasuru,Richmond Town, Shanthi Nagar,Old Airport Road,Domlur,EGL Surounding areas	Rs.360/- per 6000 litre tanker load.	Sri. Rajesh (AE) Mobile 9886619737
2	Lalbagh Waste Water Treatment plant- Lalbagh	Jayanagar, Basavanagudi Surrounding areas	Rs.360/- per 6000 litre tanker load.	Sri. Rajesh (AE) Mobile 9886619737
3	Vrishabhavathi Waste Water Treatment plant- Nayandanahalli	Mysore Road, Vijayanagar, Global Village Tec Park, R.R.Nagar, Nagarabhavi, B.D.A. Surrounding areas	Rs.360/- per 6000 litre tanker load.	Sri.Girivas, (JE) Mobile 9940061797 Landline 28600907

Figure 10-3 *Source BWSSB portal, https://www.bwssb.gov.in/images/upload/pdfs/Notification06-08-19.pdf*

02

Research Objectives

2.1. Research Objectives

The research embarked on an empirical investigation in a groundwater dependent peri-urban ward of Bengaluru city in India with the following objectives:

i. To evaluate actual water demand for different uses within the ward
ii. To identify non consumptive uses which can be catered with reclaimed water through tankers (fit for purpose mapping)
iii. To determine if private water tankers are willing to supply reclaimed water to the identified non potable demands (allocative efficiency mapping).

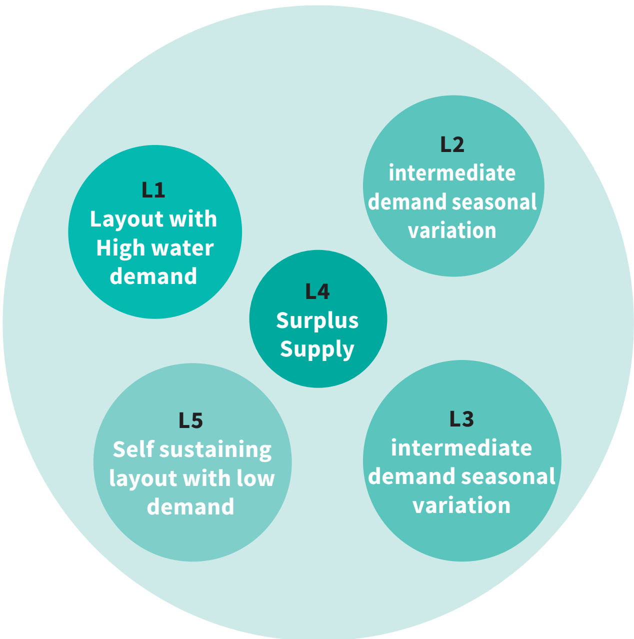

Figure 10-4 *Schematic representation of a Ward with localities of varying demands*

2.2. Conceptual Framework for Blue Circular Economy

The framework for the study is embedded in the fundamental principle of circular economy comprising of four pillars: demand quantification; assess allocative efficiency for non-potable uses; social acceptance and formalizing private water vendors through policy modifications. The approach used to arrive at the circular economy principle was through the System of Environmental and Economic Accounting (SEEA) which comprises of accounting for water and wastewater flows within a system boundary. The system boundary is a spatial extent in which the economy and environment interact in three stages. The system boundary chosen here is a ward which is an administrative region and the level of geographical disaggregation within this ward for water accounting can be done for each locality (L) as shown in the schematic Figure 10-4.

Within each system boundary, L, we have considered the groundwater resource flow in 3 stages using SEEA. Each of these stages has a demand component (D), uses (U) of required quality (Q) which can be supplied back by reclaimed water (R) from the last stage i.e., flows from the economy to the environment as depicted in Figure 10-5.

Allocative efficiency will be achieved when apartments with STPs and the centralized STPs supply the desired quality of water for respective end users in a reliable and sustainable manner.

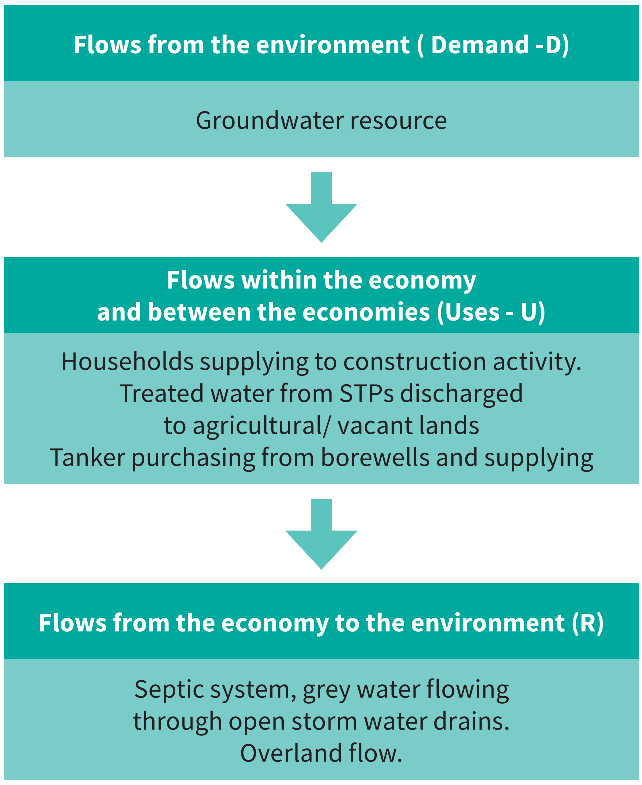

Figure 10-5 *Stages and Processes for attaining blue circular economy*

2.3. Study Area

Out of the 110 villages, the study area Bellandur ward is the second largest ward in the city and is comprised of 10 villages, which have been the unit of analysis. From Census 2001 to Census 2011 we see population growth rate of 11% and using standard projection methods, we can observe that in the year 2051, Bellandur ward will have a population of 0.15 million and consequent water demand.

The piped supply of surface water (from the Cauvery River) is only supplied to 11% of the household connections of the ward's residential population. There are three modes of supply for groundwater, namely BBMP borewells, tankers, and private (own) borewells. The largest mode of supply is through tankers (around 25%), followed by 24% through own borewells dug by residents, followed by BBMP borewells servicing 18% of the residential units. The remaining 21% of supply is through a combination of Cauvery plus tanker; tanker plus borewell; Cauvery plus own borewell.

03 Methodology

As seen in the map (Figure 10-6) of Bellandur ward, there are 14 localities in this ward. With practical considerations of time and budget, systematic random sampling was used. A map was used to identify streets, housing density, high to low income areas, source of water supply and geographical features like lakes in each of these localities.
The population in each locality was obtained from BBMP property tax collection records for the year 2015 and Census 2011 was used with the size of each locality to come up with a sampling strategy. Larger localities were broken down to smaller clusters which were segmented further based on the source of water supply and presence of informal settlements to encompass a range of socio- economic and environmental conditions that is broadly representative of the total ward.

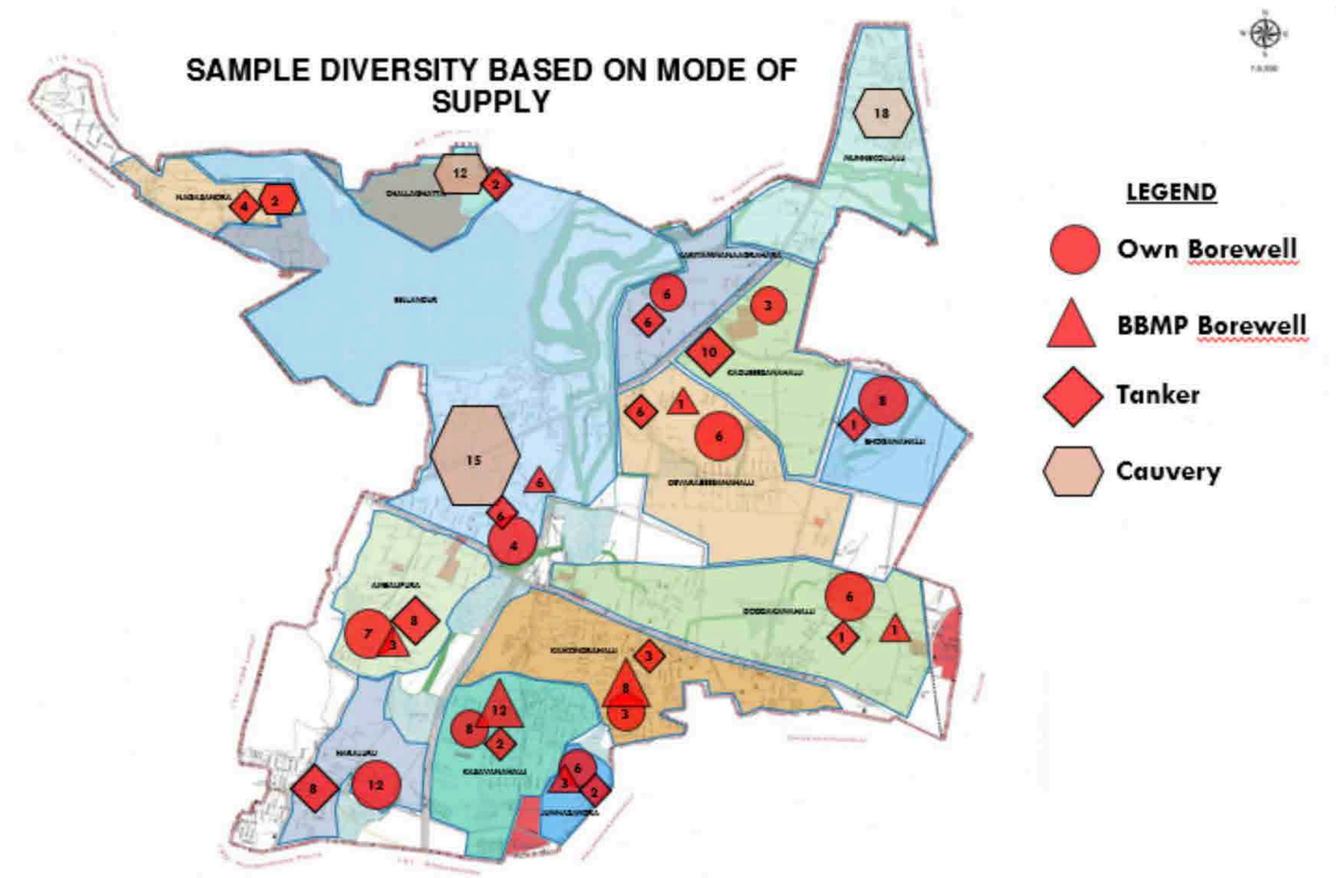

Figure 10-6 Sample distribution based on the mode of supply of water (Source: BBMP map, modified by author)

3.1. Survey Tools

The determination of sampling size for the implementation of research was based on commonly utilized statistical equations (Walpole & Myers, 1985). Practical considerations of time and budget limited the survey to 350 samples spread across 14 localities.

The questionnaire was designed considering the three consumer groups of different sources of water supply: 1) public water utility dependent communities i.e. Cauvery water; 2) bore wells – both public and private; 3) private informal water supply (i.e. tankers). Two questionnaires were developed for the study: one to collect the household-level and commercial unit data and another to collect the Tanker vendor data. (See Appendix A for questionnaire used for tanker vendors).

The month preceding the field work was used to identify these consumer groups. The questionnaires were also field tested and revised after confirming the different housing types, tenure of housing, income groups and source of water supply.

During the survey, an advertisement issued by BWSSB in February 2015 (Figure 10-7) was used to create a hypothetical market for residential users and tanker vendors to assess if they were aware of this provision and willing to buy at a quoted price of 15 INR/KL. A wide range of socio-economic variables and environmental conditions such as age, family size, education level, income, access to water supply, quantity of household wastewater generated and discharged, etc., were considered.

The ward was analyzed by considering different types of end uses, such as commercial or residential, which were further classified as shown in Table 10-5. From Table 10-5, we can see that end uses are not very uniform. BBMP provided the data for all types of properties except commercial units.

Table 10-5 Percentage distribution of different water users within the Survey Sample (Source: Author's calculation)

		No in the ward (BBMP)	Sample size	Percent of survey sample
Residential	Individual homes	22,795	162	46%
	Apartments	281	77	22%
	PG	112	44	13%
Commercial	IT	23	5	1%
	Recreational Center/ Malls	4	2	1%
	Slum	2	2	1%
	Shops	NA	38	11%
	Hospitals	6	6	2%
	Hotels	17	14	4%

Hence these commercial units were randomly picked to represent all types which require water and the type of source they depend upon.

The survey was carried out for 162 individual households, 44 Paying Guests[1] (PG), 2 slums (refer Table 10-5), 38 commercial establishments were chosen, of which 18 have their own bore wells and 10 depend on BBMP. A door to door interview was carried out with a response rate of 90%.

3.1.1. Selection of Water Tanker Operators as Respondents

The study findings are based on a primary survey carried out with tanker operators. Survey and discussions with Tanker owners were conducted to understand the dynamics of supply versus demand in terms of areas of operations, delivery schedule and delays, demand assessment by different types of end users (largely domestic and construction) and seasonal variations.

The tanker operators were interviewed for various aspects like the motivation to start their business, how they operate in terms of distance covered, localities they cater to, source of water supply, quality issues, customer complaints and satisfaction with respect to the delivery time, operation and maintenance and economics of investment.

3.1.2 Findings

During the survey, it was observed that not all apartments are 100% dependent on tanker supply. Individual apartments had groundwater wells which catered to some percentage of actual demand, while the balance was being met by tankers with varying capacities. Generally, for sampled apartments within each locality, tankers with capacities of 6,000 litres and 12,000 litres supplied water. The average tanker capacity was determined based on these two tanker volumes and the number of apartments sampled within each locality, to arrive at an estimate of water demand met by tankers alone. This average tanker capacity was multiplied by the supply gap encountered due to insufficient supply through groundwater wells, to arrive at the approximate total number of tankers that are required/supplying water to all the existing apartments in each locality within Bellandur ward.

3.2. Allocative Efficiency Mapping

Allocative efficiency is an economic concept as defined in a technical brief by Global Water Partnership (GWP Technical Brief 4) that relates to the distribution of factors of production (i.e. the resources used to produce particular goods and services) and to the distribution of the goods and services produced within an economy. From a water perspective, in this study, the concept covers the allocation of the available water resources among competing “uses” within domestic use i.e., potable versus non potable uses. The allocation is considered to be “efficient” when the net benefits gained from the use of water in these various ways are maximized. Improving allocative efficiency therefore means examining how water can best be allocated and used to achieve, in a balanced way, a multitude of society’s goals.

Allocative efficiency mapping is a method to quantify input water, essentially freshwater coming out as black and grey water which, after treatment, can be appropriately used for non-potable uses that are competing now for freshwater use. The survey included such apartments where their own STPs are recycling water for toilet flushing, landscaping or gardening. Excess treated water, which is a disposal problem, can be allocated or supplied to nearby dwellings and commercial units for the same non potable uses.

Figure 10-7 *BWSSB Advertisement for selling reclaimed water (Source: The Hindu Newspaper)*

04
Findings

4.1. Actual Water Demand

The Phase I survey responses indicated a lack of knowledge among the respondents about their actual water usage levels as their usage is not metered at the household level. Quantification of the actual water demand for potable and non-potable uses are tabulated in Table 10-6.

The 38 commercial units that were administered with the water demand questionnaire are categorized in Table 10-7. The drinking water was purchased in the form of water cans. The tankers supplied water which would be collected in the sump or Overhead Tank (OHT) and used for toilet flushing and washing. The drinking water accounts only for 6% of the demand. Auto garage and salons/ spa facilities require approximately 5,000 litres of water per day and are the largest users of water.

The demand estimation also posed certain challenges which were overcome by using certain approaches tabulated in Table 10-8.

4.2. Fit for Purpose Allocation of Reclaimed Water

After accounting the total non-potable uses, our study accounted for specific non -potable uses relevant to study region and southern India, which are few in the literature.

Every household has a cultural practice of washing the front yard every day to put Rangoli[2]. Washing is extended to streets for dust suppression. As seen in Figure 10-8, the surveyed sample in the ward uses 296.5 kilo litres per day for street washing.

Table 10-6 Water demand and wastewater generated by different end users (Source: Author's calculation)

No	End users	Water demand (lpd)	Wastewater generated	% treated	Volume requiring treatment (lpd)
1	Residential Units	171,000	136,800	0	136,800
2	Apartments	8,764,000	7,011,200	95	350,560
3	Hospitals	638,100	510,480	20	408,384
4	Hotels	93,780	75,024	20	60,019
5	Restaurants	57,750	46,200	0	46,200
6	IT parks	1,863,000	1,490,400	70	447,120
	Total	**11,587,630**	**9,270,104**		**1,449,083**

Table 10-7 Total water demand in the sampled commercial units (Source: Author's survey)

		Type of supply per day		Total demand in lpd
Type of Commercial unit in each Locality	**Total number of shops/units**	**Water can**	**Tankers**	
Stationery				0
Hardware	1	30	0	30
Bakery	8	240	0	1,920
Auto garage	7	210	500	4,970
Supermarket	6	180	100	1,680
veg and fruit vending shop	6	180	0	1,080
Parlor/Salon	7	210	500	4,970
Garments	1	30	0	30
Fancy/Novelty	2	60	0	120
Total	**38**	**1,140**	**1,100**	**14,800**

Table 10-8 Challenges for estimating demand of non-consumptive uses (Source: Author's construction based on survey)

No	Activity	Challenges to quantify exact demand	Our approach for demand estimation
1	Car washing	Number of cars - owned cars could be obtained by survey but taxi cars or private cars could not be assessed.	Questionnaire survey of 285 households, with no. of cars. The property tax information collected from BBMP gives us the car parking area details from which we could work out an estimated number of cars.
		Frequency of washing.	Survey interaction included car owners, cleaners to identify method, frequency of cleaning.
		No uniform method for car washing.	For bucket wash, 25 litres of water quantity is assumed. For spray wash, mechanic shops have air spray.
2	SStreet washing	Mode of washing used varies. Some users use a hose pipe and others use buckets. The purpose also varies, either for dust suppression alone or for application of Rangoli. (see footnote next page)	Observations were recorded during early morning when commercial and residential establishments use/spray water to suppress dust.
		Spatial factor: the area washed cannot be limited to the surrounding space and cannot be demarcated or measured.	
		Seasonal variations	
		Cultural factors: During festivities, washing is more periodical	People were asked to come out with the motive behind this; responses claimed that it was mainly for one of the following three reasons: i. Religious practices ii. Dust suppression iii. Habitual reasons or the influence of others who practice it.
3	OHT overflow	Period of overflow varies. The sampled households show the period of overflow ranging from 15 mins to 2 hours. Some residences have overflow throughout the night. This issue is primarily behavioural and negligence as water is a free good for them.	Whenever overflow was observed, we requested respondents to permit us to measure the flow rate. The time taken to fill one bucket was noted and that gave us the flow rate.

Figure 10-8 Every day, mud streets are washed to suppress dust using a hosepipe from own borewell (Source: Author, photo captured in study area)

Figure 10-9 To the extreme left of the image, we see a lady drawing Rangoli and another lady washing the front yard of her house. The entire street ahead will be washed every day to suppress dust using at least 20 to 30 litres per day using a hosepipe (Source: Author, photo captured in study area)

4.3. Analysis of Tanker Water Supply

There are various dimensions of anonymity observed while estimating the number of private tankers getting into the business as there is no formal registration or licensing in place to trade the right quality and quantity of water.
First it was observed that the tankers can be classified based on the end users they cater to and sources of supply, as shown in Table 10-9.

Table 10-9 Classification of tankers catering to different consumers (Source: Author's computation based on survey data)

Types of consumers	No of tanker suppliers	Total volume of water supplied per day (in Litres)
Apartments	3	744,000
Independent villas	3	186,000
Commercial establishments	2	150,000
Office/IT parks	11	1,801,000
Construction sites	3	354,000
Colleges/ Recreation center	2	132,000
Slums	2	156,000
Total	**25**	**3,391,000**

Tankers withdraw water from borewells. Borewells can be further classified as: i. borewells owned by tanker companies; ii. Borewells dug by BBMP; iii, purchase from borewells owned by individual property occupants. Table 10-10 shows the estimate of water withdrawn from own borewells is largest quantity of 23 lakh litres.

Table 10-10 Classification of tankers based on source of water supply (Source: Author's calculation / survey findings)

Types of supply	No of tankers	Quantity supplied (lakh litres per day)
Own borewells	34	2,397,000
Purchase from private borewells	11	1,558,000
BBMP Bore wells	4	228,000

To understand the growth of this business in this ward, Table 10-11 shows the number of companies which have got into this trade over the past 15 years and has flourished since the advent of Special Economic Zones (SEZ) and residential development over a decade.

There are 423 tankers supplying for the sample size of 350 dwellings of which 336 tankers (79%) cater to apartments,

Table 10-11 Classification based on years of starting the business (Source: Author's survey findings)

No	Years of operation	No of sampled tanker companies	No of tankers
1	1 year	2	4
2	2-5 years	14	9
3	5-10 years	8	5
4	10 – 15 years	1	2

108 (26%) cater to the households and 15 (4%) tankers were supplying to the shops. The total volume of supply is 25 lakh litres per day. The different capacities of tankers are listed in Table 10-12. The price for supplying one load of full capacity depends on the radius of operation and type of land use tabulated in Table 10-14. The price increases with every 10 km increase in radius of operation. The apartments and IT parks get into annual contracts with the tanker vendors with an agreement on a fixed price and number of loads of supply throughout the year (Table 10-13).

Table 10-12 Classification based on type of capacities or volume of water (Source: Author's survey findings)

No	No of tanker companies	Capacities (in Litres)	No of tankers	No of loads	Quantity supplied (per day)
1	2	3,000	2	8	24,000
2	2	4,400	3	5	22,000
3	6	6,000	12	111	1,716,000
4	1	7,500	11	23	405,000
5	3	12,000	22	53	1,224,000
	Total		**50**	**200**	

Thirty-six percent of tanker suppliers do not check the quality of water nor do the consumers ask about the quality. But respondents of household have acknowledged that the water is not of the same quality with respect to the color. At times it is muddy brown in color and has a lot of particles which they simply accept as there is no other option.

Table 10-13 Cost per tanker load supplied to different land use types (Source: Author's survey findings)

Type of land use	Selling price (Rs) per load
Apartments	600-1,000
Commercial	800
Construction	800-900
Coorporate firms	1,000-1,250
Slums	200
Independent houses	500

4.4. Willingness of Tanker Vendors to Supply Reclaimed Water

To recommend tankers as a formal reclaimed water service provider, tanker operators were asked if they were willing to supply reclaimed water, as tabulated in Table 10-14 and Table 10-15. Four factors were considered that might influence the tankers to operate the business of reclaimed water supply, i.e. revenue, quality assurance, consumer willingness to buy, pro-environment. A combination of factors influenced the responses by tanker operators and the factors presumed by tanker operators for not buying water (Table 10-15).

Table 10-14 Willingness of Tanker vendors to buy reclaimed water (Source: Author's survey)

Factors for buying BWSSB water at 15Rs per KL	Percentage of Tankers supplying from their own borewells. Sample size indicated within brackets	Tankers supplying by purchasing from borewells. Sample size indicated within brackets
Revenue	33% (4)	17% (1)
Revenue, BWSSB giving quality assurance	17% (2)	0%
Consumer willingness to buy	33% (4)	50% (3)
pro-Environment, revenue	17% (2)	33% (2)
Total	**48% (12)**	**24% (6)**

Table 10-15 Reasons for not buying reclaimed water by Tanker vendors (Source: Author's survey)

Factors for not buying	Tankers supplying from their own borewells	Tankers supplying by purchasing from borewells
Consumer won't accept buying reclaimed water	13%	50%
No provision for people to store	13%	17%
Quality Concern	50%	0%
Tanker investment and maintenance	25%	33%
Total	**32%**	**24%**

Question number 12 of the Questionnaire for private water supply tanker vendors (see Appendix A) asked, "Do you think that the taker business will be sustainable in the long run?" All the vendors admitted that water is scarce and they will soon run out of business. Then they were shown the advertisement (Figure 10-8) and informed about the alternative arrangement they could make.
They were asked, with BWSSB selling non-potable water as an alternative, would they be able to invest in a separate tanker just to supply reclaimed water and sell it to the same customers who buy freshwater from them. The responses were as shown in Table 10-14 and Table 10-15.

Behavioural, economic and operational challenges have been identified in this study that hinder the development of mechanisms that incentivize the reduction of fresh water usage for non-consumptive uses and promote reuse. (Ravishankar *et al.*, 2018a)

4.5. Associations between Water Demand and End User

Water demand is influenced by the type of end user due to the presence or absence of a kitchen and bathrooms and, in commercial units, demand depends on the type of toilet facilities (either urinals or toilets). The current water use in apartments and IT parks constitutes 92% of the Ward's demand. The non-potable demand for commercial units ranges between 40% to 70%.

The survey response indicates a lack of knowledge among respondents about their actual water usage levels if their usage is not metered at the household level and not a priced commodity. Twenty-four percent (24%) of the sample surveyed have water as a free good.

Other major determinants which have shown a positive and significant impact on water usage are household size and income level. Ownership of the house also increased the water usage, more for non-potable usage due to cleaning their front yard and street to suppress dust. In addition to these determinants, the attitudinal variables, like having concern for environment and cultural habits of street washing, significantly impact the usage. Water scarcity in the ward is influencing the demand by reducing the usage during non-supply hours. The influence of water demand for all outdoor uses is not a function of income, with one exception. This exception pertains to high end apartments that irrigate turfgrass and keep gardens.

"The understanding of user behavior, financial incentives and allocation of best fit water are essential, hence the recommendations following can be scaled up to any peri-urban area."

4.6. Awareness of Treatment and Reuse

Out of 38% of residents who were aware of treatment, 47% were willing to use reclaimed water as they reside in apartments with STPs and are currently using it for flushing. The remaining 52% were not willing to use reclaimed water. These residents reside in independent houses and water is a free good for them through their own dug borewells. The 23% of tenants who are dependent on tankers were ready to buy reclaimed water as they found it to be economical compared to the purchase of tanker water.

4.7. Precedence of Mode of Supply for Community Acceptance

The mode of water supply influences the attitude for acceptance. In particular, one of the modes, own borewell, is free, reliable, and has a regular alternative source of supply. The mode of supply also brings in an element of disparity with respect to affordability. BBMP borewell users are using water as a free good and those using tanker supplied water are paying a price for water. Tanker users were more aware and receptive to the idea of the use of reclaimed water. Acceptance of reclaimed water use was lower among the BBMP borewell users and Cauvery users. Tanker communities and communities using Public Stand Posts would be early adaptors for reclaimed water use. BBMP borewell and Cauvery dependent communities should be a separate target group to be educated and informed about the reuse concept and options.

Three aspects emerged out of this study that position the results in the context of previous studies and explore inferences in accounting for water use and improving efficiency in groundwater-dependent peri-urban areas: firstly, how water demand fluctuates amidst various socio-economic and land use typologies by conducting a primary survey of actual water demand; secondly, bifurcating the demand to potable and non-potable uses and looking into the feasibility of use of reclaimed water; and third, drawing relations between community acceptance to use reclaimed water with the present modes of supply (which is more significant than the socio-economic characteristics of the sample). The understanding of user behavior, financial incentives and allocation of best fit water are essential, hence the recommendations following can be scaled up to any peri-urban area.

05

Recommendations

5.1. Rigorous Categorization of Outdoor Uses

There is need for detailed categorization of outdoor uses as there are several practices where reclaimed water can be used.

It was observed in this study that 15 litres per day is used on average for car washing alone. This volume is less than the usage restrictions in Netherlands which is 60 to 70 litres per car. An average of 30 litres per day is used for washing streets using hose pipe. Commercial shops use 10 litres per day for dust suppression on streets among the sampled data. The auto garages sampled in the study area exhibited 5,000 litres per day of demand supplied by tankers which could be potentially supplied with reclaimed water.

The demand assessment revealed that the land use planning is an overlooked factor which needs to be of paramount importance. For efficient allocation of reclaimed water, metering the water usage is to be mandated for all residential and commercial dwellings.

Table 10-16 *Feasibility of public private partnership for formalizing reclaimed water supply through tankers (Source: Author's compilation)*

Support from BWSSB and Central Pollution Control Board (CPCB)	Mandates to be followed by tanker vendors
Train and upgrade skills of workers.	Utilizing the skills and education will create awareness and efficiency in maintaining water supply and quality.
Provide flexibility to tankers for operation and logistics.	
Give authority to collect penalties or inspect and complain if they find systems not working.	Build a sense of ownership by empowering them might ensure larger health and safety compliance.
Extend facilities like labs to check quality and accreditation system. The charges may be included in the water supply	Registering, licensing and paying tax will give them a branding and ensure to adhere to quality.

5.2. Regulating Tanker Supply for Reclaimed Water - A Reliable Supply Provision

There is a formalized process already in this informal water provision, as noted by Ranganathan (2014). The groundwater abstraction and water supply through tankers is not going to be eliminated even after commissioning Stage V of Cauvery in 2023. Hence addressing the groundwater withdrawal and regulating tankers should be the first step to address the issues. Rao, Hanjra, Drechsel, and Danso (2015) propose aquifer recharge as a business model which can be beneficial to tanker operators. This study recommends a similar business model approach to supply reclaimed water. Rao *et al.* (2015) suggests the process of formalization is to emphasize regulatory simplification and address integration of water supply management between water utilities and informal water vendors. Hence this study strongly recommends the formalization of tanker vendors. Since our concern is to encourage the growth of a market for reclaimed water, the required degree of private initiative is summarized in Table 10-16.

The findings have shown that there are fixed routes for water supply tankers for known target consumers and known water demand. To build on the existing informal arrangement, a pilot operation with a separate set of tankers can supply treated water from STPs to assess the following:

- Route optimization which will aid in allocating the number of tankers to meet the immediate needs;
- Return on Investment estimation for the non-potable water demand that is to be met by these tankers and the STPs to come up with moderate pricing for users and incentives for suppliers;
- An online mechanism may be set up wherein users requesting water for specific purposes is logged by the BWSSB. If this process is done for a few months, it would provide data to forecast trends in demand and consumption of various types of non-potable water demand. This can serve as an interim measure until dual piping (see following) is set up in new localities.

Responses from tanker vendors reveal their interest in the business to supply reclaimed water is revenue generation. Hence the tanker dependent communities are paying more and many individual dwellings are using free water from their own borewells. The study recommends to devise proper pricing to have all users pay for the water they use to overcome inequity in the way water is supplied and associated costs.

5.3. Way Forward

The most common interventions thought of to enable water reuse are dual piping with a separate distribution network and storage for reclaimed water. The study identified challenges to these interventions (Table 10-17).

These are predominant challenges which will be faced by any developed urban periphery to consider any one of the above interventions. Hence, reclaimed water supply through tanker vendor seems to avoid most of the operational and economic challenges water utilities have to face. For the behavior challenges, steps for the path forward suggested are:

1. The focus should be on increased sample size of the independent residential units for better understanding and perceptions of users as the current study sample size of 350 covers a heterogeneous group of users. Due to the complexity and variability of factors affecting attitudes and knowledge, this small sample size may not fully identify weak associations or differences.
2. Understanding how to educate communities to see reclaimed water use as a long-term investment benefit rather than the short-term high cost is vital. Extensive studies of this kind will help divide the groups to target the kind of outreach required. For example, in this study we know that the tanker dependent community members are early adapters. They expressed their readiness and willingness to use reclaimed water as they see the benefit of reduced cost. Currently, expenditure on tanker supply incurred is high as there are no other alternatives to procure water and assured quality is not based on scientific tests or analysis.
3. Once public outreach effectively brings in support from the majority of communities, designing appropriate policies followed by legislation, technical and financial measures will be relatively easier to implement for respective target groups.

> *“Formalizing the tanker supply system will substantially expand and improve water and sanitation provision in peri-urban areas, especially in ways that will benefit low-income and vulnerable groups.”*

Key drivers for the acceptance of reclaimed water include positive perceptions about the treatment process and reclaimed water, and the extent to which other people might influence a person’s decisions about the quality of water that STPs produce. So, personal communication channels (i.e. family, friends, and colleagues) must share messages of the benefits of using recycled water instead of focusing primarily only on the issues and challenges of operating an STP.
The marketing strategies used by the water board and even private land developers should be devised in an attractive manner.

Further study should be carried out on demand assessment from different supply sources after the 2019 notification was released by BWSSB. It is a welcome move to supply reclaimed water through tankers. Understanding if the public have accepted it, and assessing the quality and return on investment to date, would aid in scaling up this initiative to peri-urban areas and simultaneously inform regulation of the private tanker vendors.

Competing water demands have been a matter of concern with the growing requirements within and across sectors. Peri-urban areas can facilitate pilot testing opportunities which can give a better understanding for urban planners and policy formulators to translate practices to city wide planning. Formalizing the tanker supply system will substantially expand and improve water and sanitation provision in peri-urban areas, especially in ways that will benefit low-income and vulnerable groups.

Table 10-17 Challenges for Reclaimed water usage for non-consumptive uses (Source: Author’s compilation)

No	Interventions or mechanisms	Operational challenges	Behavioral challenges	Economic challenges
1	Distribution network from STP to households.	Laying pipeline networks, pumping stations	Public will question why this alternative provision is needed, instead of fresh water supply pipelines	Additional infrastructure cost for construction and maintenance
2	House service – dual piping connections	Construction and rework on existing buildings	Public acceptance is very difficult. For example, rain water harvesting structures with very little alteration of structure have received opposition	Cost to the consumers for construction and maintenance
3	Storage	Quality will deteriorate if, kept for too long. People cannot provide separate tanks	Spatial constraints will not allow the public to accept the idea at the first instance	Additional cost for maintenance and disposal

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Appendix

Questionnaire for private water supply tanker vendors

No	Water Tankers		Skip Logic – Question no to be asked
	Name of the supplier: Agency Name:		
	Contact no:		
1	Since when you have started this business?		
2	What is the motivation behind you starting this business?		
3	How many and Which localities do you cater to?		
4	What is the radius of operation? Kms. Within Bellandur ward?		
5	How many trucks do you have?		
6	What is the range of capacities these trucks have?		
7	What is the price range according to the capacity? Have you employed people and what are their roles? How many personnel do you need to supply water? Driver, the one who places the pipe into the tank? Total investment in business? Specific costs – Capital costs and O and M costs		
8	Can you please tell how many tankers operate in this ward? And their contact numbers		
9	What is the demand in each locality? Can you please list or help in telling which houses in specific areas or establishments take more water from you? Per day or per week basis? When is the demand high? Is there any pattern?		
10	What is the source of water for you?		

11	During scarcity, what are the options you resort to get water? Public stand posts Lake Purchase from individual houses Purchase from neighbouring areas Purchase from apartment complex How much do you pay and are there variations in costs of payment across these above mentioned sources and time – peak and normal? Are there situations when you do not get water from any of these sources? At such times, do you refuse to supply water? Will this affect your business and reliability? How is the competition in tanker business? Do you think more number of people are getting into this business and how does it affect you?		
12	What are the problems you encounter in your business? What do you think is useful to make things easier for people and you since you are the lifeline to people who get water from you? Do you feel this business is sustainable in the long run?		
13	What will you do if the source which your drawing water from cannot be reliable in terms of quantity and quality?		
14	Do you check quality of water? If yes, what is the process adopted?		
15	Have people complained to you about quality? Or do they question you about the source of supply? Have you received any complaints about water quality? If yes, please explain the type of complaints? How do you handle them?		
16	Have you had problems with supply? i.e., has there been a situation where water was not available when you had to supply?		
17	What is the Seasonal demand and tanker operating during summer and other season Specify, no. of tankers supplied in a week during summer and off season? Frequency and quantity?		
18	Price variation across seasons, I understand that when you pay more, you have to charge more, please give details		
19	Do you have any association of Tankers? If yes, how does it function, formal or informal functioning methods and how do you help each other? Are areas of supply defined informally or formally? Can you supply water in someone else's area? Is there any objection of supplying water to areas other than your area?		
20	If BWSSB sells its treated water for you, are you willing to buy and supply it to consumers?		
21	Is there anything else you would like to share – The problems or issues with Water supply		

Notes

1. There are increased number of paying guest accommodations that have mushroomed in the city to cater to the flow of migrant population from all over the country. These paying guest accommodations largely do not have kitchens and aid working professionals. We have chosen this category since it alters the water demand calculation requirement within the ward premises.
2. Rangoli is a very popular folk art that has several religious connotations across the expanse of India. This age-old tradition is about drawing geometric patterns or abstract in courtyards. The designs depend on the theme of the occasion.

11

Toward SDG 6: Exploring the Potential for Wastewater Reuse in Nairobi, Kenya

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Abstract

Targets 6.1 and 6.2 of SDG 6 focus on delivering and ensuring drinking water and sanitation for all people. There is considerable possibility for achieving these targets in particular through improved use and management of water currently available to people both as blue water (rainfall and accessible groundwater) and reclaimed wastewater. Put differently, there is great potential for a city such as Nairobi to make better use of the water that it already has. Wastewater reuse is proving to be an economically and environmentally sound demand and supply management strategy, especially with climate change uncertainties in mind.
To establish the current use and possible uptake of wastewater reuse in Kenya, 27 in-depth interviews were conducted with the main stakeholders of water recycling within Nairobi and its environs. They included government officials, technical experts of recycling systems and formal and informal wastewater users. While not definitive, our results indicate that grey and wastewater recycling can reduce both freshwater demands and the amount of untreated wastewater being discharged into the environment. Public authorities and implementers need to engage with other stakeholders to provide regulation and standardization of the industry. Improving the level of knowledge of these systems among members of the public would also build trust and increase the uptake of these systems.

Keywords

Greywater, wastewater, reuse, SDG 6, Nairobi, governance

01
Introduction

The conventional methods of water supply and wastewater management systems utilize centralized large infrastructure to capture, store and transport massive amounts of water over long distances. These methods have been shown to be unsustainable for economic, societal and environmental reasons and have failed to guarantee water security[1]. They are expensive to construct, have negative environmental impacts, and leave basic human water needs still unmet (Gleick, 2000).

It is estimated that in the coming years, 60% of the world's population will be urban dwellers (Stavenhagen *et al.*, 2018). This population growth brings about unprecedented challenges, with provision of water and sanitation being a pressing issue that is painfully felt when lacking. Municipal water systems are facing immense pressure to meet the needs of the rapidly growing population and in some places, pressures to meet increasing industrial demands and/or rising luxury expectations of the relatively advantaged, fueling the need for sustainable water use. While this reality presents several challenges, it also offers an opportunity to move away from past inadequate water management systems to more innovative ways that incorporate integrated urban water management solutions like demand management strategies which involve the use of treated wastewater to meet demands (WWAP, 2017).

"There is significant potential for the uptake of grey/wastewater reuse across Nairobi. However, there are considerable – but not impassable – barriers to overcome."

In Kenya, ever since the construction of the Ruiru Dam in the 1930s, water managers in Nairobi have consistently focused on large-scale development of surface water to meet increasing demand (Blomkvist & Nilsson, 2017). Water is sourced from distant river basins in greater proportions and at a greater pace to meet the demands of the fast-growing metropolis (Nilsson , 2011). A strategy based on supply extension is both physically and economically unsustainable, calling for the need to diversify water sources (Ledant, 2013). Alternative water sources include rainwater, brackish water, municipal wastewater and greywater. Of these, grey and wastewater present potentially viable options for Nairobi based on reliability, availability and raw water quality as illustrated by Kariuki *et al.* (2011).

This chapter explores the question, what is the potential for greywater and wastewater reuse to contribute to water security in Nairobi? We present our findings in relation to: (i) the drivers for and benefits from recycling greywater and wastewater; (ii) the barriers to the uptake of wastewater reuse; and (iii) the role of greywater and wastewater reuse in planning for urban water security.

Nairobi is Kenya's capital city whose metropolitan region has a current population of approximately 4 million people. Inadequate infrastructure and services can be seen in the region's water and sanitation sector where a large portion of the population relies on informal vendors for household water and disposes liquid and solid wastes into ditches, streams and open dumpsites (World Bank, 2011). According to the 2009 census, the main sources for water for Nairobi residents were: piped water 76%, water vendor 16.5%, and spring/well/borehole 7.2%; sewerage service connection was at 48% (KNBS, 2009). Somewhat masked by these statistics are the significant socio-economic differences that exist within the city. Kibera, for example, is a well-known slum within Nairobi's boundaries with an estimated population between 300,000 to close to 1 million people. The slum is situated on a mere 2.5 square kilometers of land approximately 5 kilometers from the city center. Kibera informal settlements suffer from a host of challenges that include inadequate healthcare, security, energy, housing and access to water and sanitation (Mutisya & Yarime, 2011).

Wastewater systems range from a variety of simple low-cost devices which divert greywater to direct reuse in, for example, toilet flushing and lawn irrigation to complex treatment systems that incorporate sedimentation tanks, bioreactors, filters, pumps, and disinfection. Some wastewater systems are home-built piping and storage systems, but there are also a variety of commercial wastewater systems available which filter water to remove hair, debris, pollutants and bacteria from wastewater (Allen *et al.*, 2010). For the purposes of this study, formal systems are loosely defined as commercial systems that treat and store the water before reuse. Informal systems include the bucket method (use of a bucket to collect used water for reuse) and home-built direct reuse systems that do not go through a treatment process before reuse. Grey/wastewater systems are defined as systems that can treat both greywater and blackwater.

As discussed briefly in Section 2, the study chose two economically different areas for analysis: Kibera, where the challenges are greatest as is the need for potable water and improved sanitation; and different sections of middle-to-high income Nairobi, as reflected in the commercial reach of private companies selling and installing greywater/wastewater reuse systems. The study did not aim to be definitive; rather, it sought to explore the potential for the roll-out of systems of greywater/wastewater reuse to be meaningful contributors to achieving SDG 6. Our research suggests that there is significant potential for the uptake of grey/wastewater reuse across Nairobi. However, there are considerable – but not impassable – barriers to overcome. Somewhat ironically, grey/wastewater reuse at household scale is very common across Kibera through the bucket system but the capacity for either taking up or scaling up formal systems is limited. Across more affluent sections of Nairobi, where the capacity for both taking up and scaling up formal systems is considerable, the willingness to do so is hampered by a variety of social, political and economic factors.

The balance of the paper proceeds as follows: in Section 2 we describe our methodology. Section 3 presents our results in terms of six drivers for reuse (lack of sewerage connectivity; practical benefits; legislation; financial incentives; modern technology; and environmental altruism) and five barriers to uptake and/or expansion (cost; lack of government support; public perceptions regarding health; lack of knowledge; absence of standardized systems).Section 4 presents a discussion where we explore, among other things, the economic, technical and social feasibility of grey/ wastewater reuse and its potential to contribute to urban water security. Lastly, Section 5 presents our conclusions and makes several recommendations for further studies.

02
Methodology

2.1. Data Collection

Data collection consisted of both primary and secondary methods. Primary data collection involved fieldwork which included in-person and phone interviews with various stakeholders of grey and wastewater recycling within the city as well as observations. Secondary data included review of government documentation, reports and other relevant literature.

Building on the foundational literature, primary data was collected using semi-structured interviews and an interview guide was used to ensure that all themes were covered. Interviews were conducted in person whenever possible. Participants were grouped into four different categories and a set number of similar, open-ended questions were asked of participants in the same category (see Appendix for the questions). This approach ensured regularity within the different categories while also allowing for unexpected themes and considerations to be explored if they came up.

In total, 27 interviews were conducted, and they consisted of 6 government officials from different departments, 6 technical experts who are in grey and wastewater recycling business, 5 clients who use the formal systems and 11 residents of Katwekera village in Kibera who use the informal system. Of the 27 interviews, 22 were conducted in person by the researcher and audio recorded, 2 were carried out by an assistant and the responses written down, one respondent declined to be recorded while another interview was conducted telephonically.

2.2. Data Analysis

Qualitative analysis was used to understand the participants' perspectives within their different social contexts. It was loosely based on the six step thematic analysis as outlined by Braun & Clarke (2006). Firstly, the data was transcribed, and ideas noted. Next, initial codes were generated from these ideas, followed by a search for themes. The themes were then reviewed and defined and finally, a report was written. Thematic analysis is a method used to identify, analyze and report patterns within data and to interpret various aspects of the research topic (Boyatzis, 1998; Braun & Clarke, 2006). It is a useful method for examining the different perspectives of the research participants, exploring the similarities and differences and generating unanticipated insights from the data (Nowell *et al.*, 2017). This method was suitable for this study given the different participant categories and thus, different perspectives on the same issue.

Interview questions were not necessarily pre-coded but followed a similar pattern which helped in developing initial codes throughout the interviews, facilitating coding and analysis. Additionally, the qualitative data analysis software NVIVO was used so that, upon identification of the major themes, the user could separate the information within them to suit different subcategories. Some of the considerations made in the creation of subcategories for this study included highlighting specific words or ideas that reoccurred during the interviews, classifying a range of answers, and identifying conflicting responses within a theme. In essence, while coding is done by the researcher, the program facilitates the organization of large chunks of data and eases the process of finding connections and understanding patterns within the data.

To maintain confidentiality, participants were coded according to their representative group followed by a numerical digit. Government officials were coded as GO, technical experts as TE, formal users as User and Kibera residents (informal users) as KR. Participants were referred to based on their codes, e.g. "according to GO2", "User 1 mentioned", or "TE1 said…"

"In Nairobi, one of the major drivers for wastewater recycling is the lack of connection to the sewer line for many households in the city."

03 Results

3.1. Drivers for Grey/Wastewater Reuse

3.1.1. Lack of Adequate Sewerage Infrastructure

In Nairobi, one of the major drivers for wastewater recycling is the lack of connection to the sewer line for many households in the city. The law requires that wastewater should only be discharged after it has met certain standards for houses, industries and other establishments that are not connected to the main sewer lines, forcing house owners to invest in various sanitation solutions such as septic tanks, biodigesters and recycling systems. "On most occasions, people who consider wastewater in this country or East African countries do it because they don't have access to the sewer line, prompting widespread use of septic tanks. But over the years, the septic tanks have caused problems with neighbours, filling up and overflowing and people started looking into other options like recycling water" (TE1).

Issues with lack of connection to a sewer line also brought to light the reason why most users mix their grey and black water. "It's difficult to sell the concept to someone with a sewer line unless someone actually wants to recycle the water. That's why most people don't differentiate their wastewater and want you to treat all of it" (TE1). With these wastewater recycling systems, one can take care of both their grey and black water, which would otherwise require a different sanitation solution to deal with each.

3.1.2. Practical Benefits

An overwhelming majority of participants agreed that reusing grey and wastewater reduces the reliance on freshwater. In turn, this reduces water bills and provides more water for non-potable uses. Estimates on cost savings were given by three technical experts. According to TE4 and TE6, reusing water cut their clients' costs by 60% and 70% respectively. According to TE5, one of his clients started reusing wastewater to water his lawn and was able to reduce his monthly water bill by Kshs 10,000 [approximately US $94].

In Kibera, 5 out of 6 of the participants interviewed state that reusing greywater helps them reduce the use of, and the cost of obtaining, freshwater. In terms of cost saving for formal users of grey/wastewater systems, recycling water also reduces the costs that would otherwise have been incurred through sewerage services or paying for septage hauler trucks to empty septic tanks (User2, User 3, User 4, User 5).

Besides user benefits, wastewater recycling has positive ecological impacts as it reduces the amount of untreated wastewater discharged into the environment. The rivers in Nairobi are fed by effluent discharge and treatment before disposal reduces the pollutant loads in the rivers, as TE5 explains: "Most people actually discharge into rivers. If we had a way of capturing this water and treating it to at least a certain standard, even if it is half the standard and releasing it back to the environment, you can imagine how clean Nairobi river and all of the rivers in Nairobi would be".

3.1.3. Legislation

Water quality regulations (2006) of the Environmental Management and Coordination (Water Quality) Regulations, 2006 (Cap. 387) stipulate that wastewater should not be discharged into the environment or public sewers (for businesses with additional pollutants) without some level of treatment. This opened up the market for wastewater solutions, making them a necessity: "The reality is the local legislation drove our business to come about. You would have customers with waste challenges, and you'd solve their problem but generally people don't like to spend money on wastewater, unless someone from NEMA [National Environmental Management Authority] is harassing them" (TE2).

The Water Resources Management Authority [WARMA] also encourages reusing wastewater: "We promote zero discharge. We provide the permit for abstractors and eventually they must commit how they are planning on managing the waste that comes from their water use. We compel them to invest in waste management, and if they can recycle and have zero discharge, that's better" (GO5).

3.1.4. Financial Incentives

Grey/wastewater recycling systems are expensive and as such, can only be afforded by specific clientele, leaving a big portion of the population unable to obtain these systems. One of the participants explained how their company increased their market reach to middle-income areas within Nairobi: "When we started, we used to do Karen, Kileleshwa, Lavington -- the suburb areas -- but nowadays we've been able to penetrate Machakos, Kitengela and Syokimau [middle-income areas]. We've come up with special pocket-friendly packages for those people. Instead of asking for the whole contract amount, you do an arrangement with a client where they pay what they can, maybe monthly, quarterly, etc." (TE6).

3.1.5. Appreciation for Modern Technology

There is an appreciation for new technology that some people have, which can be linked to education and exposure. Our evidence suggests that willingness and capacity to invest in these systems varies directly with level of education. Formally educated individuals are interested in how these systems work and appreciate the technology. "We've encountered different clients; there are those who buy because of the technology, the doctors and engineers, but we also have those who buy purely for the need" (TE6). According to TE5, a majority of his clients are not really concerned about their water costs, which requires him to use a different strategy to convince clients to invest in the systems. "At the entry point, we hardly use water-saving as a selling point. We use modern technology as a key selling point" (TE5).

3.1.6. Environmental Altruism

This 'green' sentiment is associated with those who are concerned about the state of the environment and was mentioned by some participants: "The cost of water is not really the reason why people are using the systems. There is the issue of using modern systems, reliability of cost and environmental awareness. People want to be able to reuse at least some of the water in their gardens" (TE5).

3.2. Barriers to Grey/Wastewater Reuse

3.2.1. Cost/Financial Barriers

The cost of acquiring and maintaining the systems was established to be one of the barriers hindering uptake. Most, or sometimes all parts of the system are imported, which increases the cost of obtaining them. Having a greywater system also requires having separate plumbing lines within the house and increases the costs of having these systems which makes many people opt for having all-inclusive wastewater recycling systems. "Wastewater recycling is not widely practiced because it's an expensive affair" (TE4).

These systems require regular maintenance for optimal functioning and have monetary costs. There are also energy requirements as they run on electricity which can be costly, depending on the size of the system and the house occupancy. That also means that one needs to be connected to a reliable power supply, with power cuts affecting regular functioning (TE1). In addition, one needs to factor in the cost of chemicals like chlorine, which is needed for disinfection before using the water. As shown in Table 11-1, the average first year cost of a grey/wastewater household system, according to study participants, is approximately Kshs. 615,000, or US $5,080 – an amount far beyond the affordability of most Kenyans.[2]

Table 11-1 Average Grey/Wastewater Household System Cost in The First Year (Author's Compilation based on Data Provided by Technical Experts and Formal System Users)

System	300,000
Civil works	250,000
Electricity per annum	25,000
Chlorine per annum	20,000
Service contract per annum	20,000
Year 1 total	**Kshs.615,000** [Approx. US $5,080]

3.2.2. Lack of Government Support

Participants attested to a lack of government support, especially for technical experts who are in the industry. When asked what the government is currently doing to aid in wastewater recycling in Kenya, three technical experts answered 'nothing' (TE2, TE6, TE5). "Instead of making business easier by e.g. doing subsidies for people who choose to put in wastewater treatment system to conserve water and what not, they charge you additionally. There's absolutely nothing to promote business" (TE2).

The lack of support can also be seen in the lack of proper guidance regarding wastewater reuse. TE5 explained this, comparing it to Japan where the government has regulations regarding what system must be used when not connected to the sewer system. "I'd say a lot of people want to do the right thing, but the government has only given a guideline to the standards you should meet. They haven't told the people what they should be using, and how to do it. Like in Japan, they identified a system; like the Jokaso[3] system is a product across the country, anybody can actually start producing their own Jokaso as long as it meets and passes the required standards" (TE5).

> *"The lack of support can also be seen in the lack of proper guidance regarding wastewater reuse."*

One government official pointed out a lack of collaboration between people who practice wastewater recycling and the government: "Unless they come to us for technical advice, we really don't interact with people who are recycling" (GO4).

3.2.3. Public Perception and Health Risks

The perception on wastewater recycling can be demonstrated in two ways: through a dismissive attitude towards water and the 'yuck factor' associated with recycled water. The amount of water required for household activities is far less than that required for industries, including agriculture, and as such there is a reluctance to recycle water for conservation purposes.

Reusing recycled water is still viewed negatively in Kenya, and fuels health concerns over the safety of the water. While most system users voiced no concerns over the quality of the recycled water, some participants attested to the negative perceptions surrounding wastewater recycling among the public. Formal users of the recycling systems found the quality of the water to be adequate for non-potable uses which include lawn watering, car washing and pavement/driveway cleaning.

3.2.4. Lack of Knowledge and Awareness

Our findings suggest that knowledge on recycling systems is limited in Kenya. The high costs of systems make them accessible to only a specific segment of the population, with limited knowledge of them among those who cannot afford them. Most of the participants interviewed in Kibera did not know about these 'complex' systems or how they worked. Technical experts also acknowledged the lack of awareness among the public and even those close to people who recycle water. "You'll find in a place like Karen where we've done a lot of projects, your neighbor will reuse this water, but you don't even have any information about it and you didn't have any idea that this can be done" (TE6).

3.2.5. Lack of Standardized Systems

Currently, suppliers of recycling systems source whole units as a complete package or import parts from different countries and assemble systems locally. Participants mentioned that local manufacturing would reduce the costs of the systems and would also help in standardization of the industry.

The different systems have different maintenance requirements as explained by technical experts. For some, maintenance is done every four months, some twice a year, and others once a year with periodic checks in between, especially during the holiday seasons when it may be challenging to avoid overloading the systems. While these differences may be ideal for the client, they would present a challenge for government regulation of this fledgling industry, especially if the systems are not vetted for consistency in quality and efficiency. However, the imported systems are said to be well developed due to their prevalence in the countries from which they have been sourced, which include USA, Germany and Japan.

04
Discussion

4.1. Recycling as Sanitation Solution

Findings show that one of the major drivers for the adoption of grey and wastewater recycling and subsequent reuse at the residential level is the lack of connection to the sewer system for many households. Both technical experts and formal users discussed this, with technical experts emphasizing the difficulties of selling the treatment systems to those connected to the sewer line. All the formal users used the systems as their main wastewater discharge system, which established the need to mix both grey and black water and to minimize pollution from either wastewater sources.

In line with the literature, our study suggests that as a form of decentralized wastewater management, recycling systems offer significant benefits to the user, are less resource intensive and more ecologically sustainable. The results of this investigation indicate that there are opportunities for the adoption of decentralized wastewater schemes in Nairobi, whether for individual houses or for clusters of homes. For example, one of the technical experts discussed the possibility of having one recycling system for a cluster of 100 homes as a sanitation solution in middle income areas, providing the benefit of reusing water to all of those in the cluster while distributing the costs of the system among the users.

4.2. Water Reuse Benefits

As established in the interviews here as well as in the literature (e.g. Friedler, 2008; Morel & Diener, 2006), grey/wastewater reuse has several economic and environmental benefits. At a household level, it reduces water bills while providing water for non-potable use. On a larger scale, the reduction in domestic water consumption can reduce freshwater demand and lower the rate of groundwater extraction. Results from this study suggest that wastewater reuse has the capability to reduce demands over time. However, these findings are limited in their geographic scope and sample size and would benefit from further research. Nevertheless, they are indicative of grey/wastewater's potential and are in line with findings from peer reviewed and grey literature (e.g. Al Baz *et al.*, 2008).

Use of reclaimed water for non-potable needs can free up capacity in the existing water supply system, allowing it to serve more people. The findings of this study suggest that, with several parts of Nairobi experiencing water rationing several times a week, freshwater saved through water reuse could be supplied in greater quantity to more people and at lower cost. A direct environmental benefit of recycling is the reduction in pollutant discharge in streams and rivers. With only 48% of residents connected to the sewer line, a large portion of the population disposes liquid and solid waste in ditches, streams and open dumpsites, posing public health risks.

Studies have shown that the viability of water reuse increases, and more benefits are realized, when the practice is implemented on a large scale rather than at the individual level. A study conducted by Friedler (2008) in Israel established that for a country experiencing water shortages, the benefits of reusing greywater were much more significant when the practice was rolled out nationally or regionally as opposed to by individual consumers. The same would apply for Nairobi, where the economic benefits of reusing grey/wastewater can currently only be realized by the individual users. The lack of ability to apply them at a larger scale is one possible explanation for the apparent reluctance of government officials to prioritize issues related to residential water reuse.

4.3. Need for Better Governance

The current water quality discharge regulations fueled the current growth of the wastewater recycling sector in Kenya. Technical experts attested to the regulations being a positive influence on business as EIA approvals required effluent discharge plans. These regulations fueled the need for homeowners to look into different sanitation solutions, enabling technical experts to tap into the market. However, there are no quality guidelines for domestic reuse of the treated effluent. Participants adhered to the treatment standards for effluent discharge and for irrigation purposes for their non-potable uses. In a study of Kenya's water reuse policy, Wakhungu (2019) established that the current water reuse guidelines are inadequate, and there is a need to formulate reuse guidelines for domestic and industrial sectors, in line with the findings for this study on residential water reuse.

Establishment of guidelines and a focal institution for wastewater recycling would help in standardization of the industry, which is currently lacking. This would also help in guaranteeing consistent quality and efficiency of the systems being sold to the end user, and the resultant treated effluent. On a broader scale, this would also ease the management of both grey and wastewater reuse practices which currently vary according to income levels.

4.4. Ways to Overcome Barriers

Participants suggested ways to lessen the burden of cost on the system purchaser that included tax rebates and subsidies. An effective strategy would also be the establishment of financial agreements between lending institutions and government to provide credit facilities for system purchasers. This would help new homeowners to be able to secure housing loans that cover the installation of the systems during construction, which would overall make it cheaper. Those who would want to retrofit their houses but lack the financial capacity would also benefit from this strategy.

A more complete understanding of grey/wastewater reuse systems would help all stakeholders to make better informed decisions and create a knowledgeable platform upon which the industry can develop. Technical experts mentioned education and exposure levels as aspects that affect the acceptance of recycled water which should be factored in education efforts. It is possible that some negative perceptions are fueled by unsafe reuse practices and should be countered by investing in and demonstrating acceptable reuse standards.

4.5. Grey/Wastewater Reuse Feasibility

4.5.1. Economic Feasibility

Price is an important variable that can significantly affect the uptake of reuse practices. There are price considerations for the grey/wastewater systems themselves as well as for potable water. Some participants attested to water being relatively low-priced in Kenya, but based on a study conducted by Ledant (2013), this perspective may differ depending on one's income level. Those with lower income levels have been found to pay higher costs for water compared to those in higher and middle-income areas, yet the latter is the segment of the population that is better able to afford grey/wastewater reuse systems. Technical experts indicate that saving on water costs was not a leading driver for business based on return on investment considerations. Users, on the other hand, attest that savings on water costs is one of the benefits they have received from having the systems, although not a motivation to install them. However, sufficient demand for the systems would reduce their costs through economies of scale as well as through increased marketplace competition, allowing them to become more widely adopted.

> *“Educational efforts tailored towards different population segments could help change the attitudes and could improve the appreciation of both freshwater and reclaimed water, for both the social good and economic good involved.”*

4.5.2. Social Feasibility

Technical experts give a low score to knowledge of water reuse among the public but are quick to acknowledge that there has been a significant increase in the number of people adopting the practice and seeking out their services. Educational levels were found to influence the awareness of water reuse, with more educated people appreciating the technology and the benefits of having a water reuse system. Income levels determine who would be able to afford the systems, with purchase and maintenance costs being a big factor.

The public's attitude towards water affects conservation efforts. Viewing water as a social good but not as an economic good limits the number of people willing to use water conservatively, especially at the residential level, where domestic water consumption is far less compared to industrial and agricultural use. Also, the 'yuck factor' associated with recycling water makes people shy away from adopting the practice. This is evident in Kibera where some participants are opposed to paying for a decentralized, neighborhood-scale system and wonder how the water would be 'clean'. Nevertheless, residents in high-density suburbs such as Kibera are de facto recyclers of grey/wastewater. Despite limited formal education and knowledge of complex systems of water recycling, it is clear that efficient usage of a scarce resource such as water for the household (including small scale urban agriculture) is common practice, not only in our study area, but across other parts of Africa (Ndunda, 2014; Mukheli *et al.*, 2002). Thus, educational efforts tailored towards different population segments could help change the attitudes and could improve the appreciation of both freshwater and reclaimed water, for both the social good and economic good involved.

4.5.3. Technical Feasibility

Wastewater recycling systems require both availability of land and secure tenancy for construction, presenting quite a hurdle for those who have neither. While the systems are automated for day-to-day operations, they are known to be maintenance intensive. They need to be monitored on a regular basis to ensure that the pumps are working, and chlorine levels are enough to treat pathogens. Technical services must be performed at various regular intervals throughout the year depending on the type of system. Participants report that the water quality is good for their non-potable uses (lawn watering, car washing, cleaning driveways) but that systems need appropriate maintenance for that water quality to be sustained. As discussed above, it was also both economically viable and practical to install systems that can treat all domestic wastewater and thus, systems that do so are the most prevalent in Nairobi. For Kibera participants in the study, the bucket method is sufficient with no treatment prior to water reuse.

4.6. Water Reuse and Urban Planning for Water Security

The third objective of this study was to find out the role of greywater and wastewater reuse in planning for urban water security. The analysis shows that reclaimed water can play a major role in urban water security as it is both a water conservation strategy and a sanitation solution.
In discussions with participants, it emerged that government officials leaned towards conventional 'end-of-pipe' solutions with little consideration for other measures in planning for future water supply. The focus of the government is on increasing distribution and minimizing losses of potable water. However, with distribution losses estimated to be 38% as of 2018 (WASREB, 2018), an increase in production would also result in more water loss. Complementary systems of water supply need to be thoroughly considered for Nairobi; grey and wastewater reuse present climate-independent water supply strategies that become increasingly important with increases in water use.

05

Conclusion and Recommendation for Future Research

The barriers that hinder wider adoption of the practice should be possible to overcome. The growing number of urban wastewater recycling systems globally indicate that water reuse is a viable strategy for sustainability efforts. Water reuse practices have already been found to be a water conservation measure and sanitation solution for some in Nairobi. Financial incentives for homeowners may be a good means to overcome the barriers identified. Additionally, educational efforts focused on the technical systems and safe reuse practices, tailored to different audiences, are also important strategies for increased uptake. Furthermore, there is a need for the government to formulate proper water reuse regulations that address water quality needs for all sectors (including domestic non-potable uses) in order to carry out implementation plans that match policy statements.

> *"There is a need for the government to formulate proper water reuse regulations that address water quality needs for all sectors in order to carry out implementation plans that match policy statements."*

Findings from this study suggest a reduction in potable water demand through water reuse over time but was unable to quantify the exact amount that would be saved. A study on a larger sample size across a greater geographical region conducted over a longer period of time would be able to give approximate amounts of water that is saved and quantify the percentages of reduced demands. A study on consumer behavior and attitudes towards reclaimed water would also be beneficial for greater sustainability.

Economic feasibility is an important consideration for more widespread adoption of any innovative strategy.
Future water reuse research in Nairobi would benefit from an in-depth, cost-benefit analysis on the use of treatment systems at the residential level. Cost estimates based on capital infrastructure are different from the true economic costs and benefits of the systems. Additionally, the economic value of environmental costs and benefits are also not included in this analysis and have therefore not been quantified.

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Appendix

1. Interview guide for industry/technical experts

Basic Information and expertise

Please state the current organization you're employed in and your position

What are the duties of your current position?

What is your personal or professional experience with wastewater reuse?

How did you first become involved with water reuse systems for residential use?

How has your experience been ever since?

Growth of the region and climate change uncertainty

What do you think should be the focus of the city in accommodating the water needs of increasing population?

Is a supply strategy the most reliable way of providing water services? Do you think demand management should be a focus for water provision?

Climate change is an uncertainty in planning for future water supply, how has it been incorporated in the plans for water supply? Can the construction of big dams be the sole answer to water provision? Is it feasible?

Wastewater reuse viability

Does wastewater reuse provide a viable means of supplementing or reducing reliance on municipal water supply? Why? Why not?

What are the benefits and drawbacks of wastewater reuse?

What type of permits (if any) or precautions should be considered before one installs a wastewater system?

Do you think other technologies are a more viable means of water conservation? Why?

Wastewater systems feasibility

What is the financial feasibility of installing a system in an existing house in comparison to a new house that's being constructed?

Are there more installations for existing homes or for new homes?

What is the ease of operating a wastewater reuse system? What is needed and who can do it?

What are the maintenance requirements (financial, regulatory and capability) for a wastewater system?

Barriers

Wastewater recycling is not widely practiced in Kenya, why do you think this is the case? How could these barriers be overcome?

What are the concerns of reusing water? How can they be addressed?

Drivers

What incentives would enable an uptake of wastewater systems installations?

What legislative and institutional frameworks are you aware of that are in place to support the adoption of wastewater reuse?

What is the government doing to promote wastewater reuse in households? Does it provide subsidies for the systems?

In your opinion, what do you think the government should do to improve wastewater reuse in households?

Other: How would you gauge the knowledge of wastewater among the residents of Nairobi?

2. Interview guide for government officials

Basic Information

Please state the current organization you're employed in and your position

What are the duties and responsibilities of your department?

What is your personal or professional experience with wastewater reuse?

Growth of the region and climate change uncertainty

What do you think should be the focus of the city in accommodating the water needs of increasing population?

Is a supply strategy the most reliable way of providing water services? Do you think demand management should be a focus for water provision?

Climate change is an uncertainty in planning for future water supply, how has it been incorporated in the plans? Can the construction of big dams be the sole answer to water provision? Is it feasible?

What's the focus of your department in promoting water conservation and ensuring water security now and in the future? According to you, is this sufficient? If no, what do you think should be done?

Wastewater feasibility

What is your department doing with regards to wastewater management in Nairobi?

Does wastewater reuse present a viable means of supplementing or reducing reliance on municipal water supply? Why? Why not?

What type of permits (if any) or precautions should be considered before one installs a wastewater system?

Do you think other technologies are a more viable means of water conservation? Why?

Barriers

Wastewater recycling is not widely practiced in Kenya, why do you think this is the case? How could these barriers be overcome?

What are the concerns of reusing wastewater? How can they be addressed?

Drivers

What are the incentives for greywater reuse and wastewater reuse broadly defined?

What legislative and institutional frameworks are in place to support the adoption of wastewater reuse?

In your opinion, what do you think the government should do to improve wastewater reuse in households?

Other: How would you gauge the knowledge of wastewater among the residents of Nairobi?

3. Interview guide for formal system users

Basic Information

Area of residence

Are you a house owner or a renter?

Domestic water access

What is the source of your domestic water?

How often do you receive municipal water?

Could you describe how you use water? How much water do you use for each activity?

Is the water you use sufficient in quality and quantity for your needs?

What motivated you to install a wastewater reuse system?

What kind of activities do you use your recycled water for?

How often do you use the water?

Is the water quality satisfactory?

What variables affect the reuse of recycled water? Is there a time that you use it more?

On average, how much did it cost to have the system installed? What changes did you make to your house, e.g. piping, before installing the system?

Did you need a license or permit to install the recycling system? If yes, what was the ease of obtaining them?

What benefits would you say you obtain from reusing wastewater?

What are your concerns about reusing wastewater? How do you address them?

Are you aware of any legislations regarding the reuse of wastewater?

Does the government provide subsidies for wastewater systems? If not, do you think it should?

In your opinion, what do you think the government should do to improve wastewater reuse in households?

4. Interview guide for Informal greywater users

Basic Information

Area of residence

Are you a house owner or a renter?

Domestic water access

Where do you source your domestic water from?

How often do you obtain water?

How much water on average, do you obtain in a day? How much does it cost?

Could you describe how you use water? How much water do you use for each activity?

Is the water you obtain enough for all your needs? If no, what challenges do you experience in obtaining sufficient water?

Do you practice water conservation in your home? If yes, how do you minimize water use in your home?

Do you reuse any of your water? E.g. from laundry, bathroom or kitchen? If no, why not?

Could you describe how you reuse water?

What variables affect the reuse of water? Is there a time that you use it more?

How long have you been carrying out this practice? What motivated you to start?

Why do you reuse wastewater?

Do you treat the water before reusing it?

What benefits would you say you obtain from reusing greywater?

What problems if any, have you encountered from reusing water?

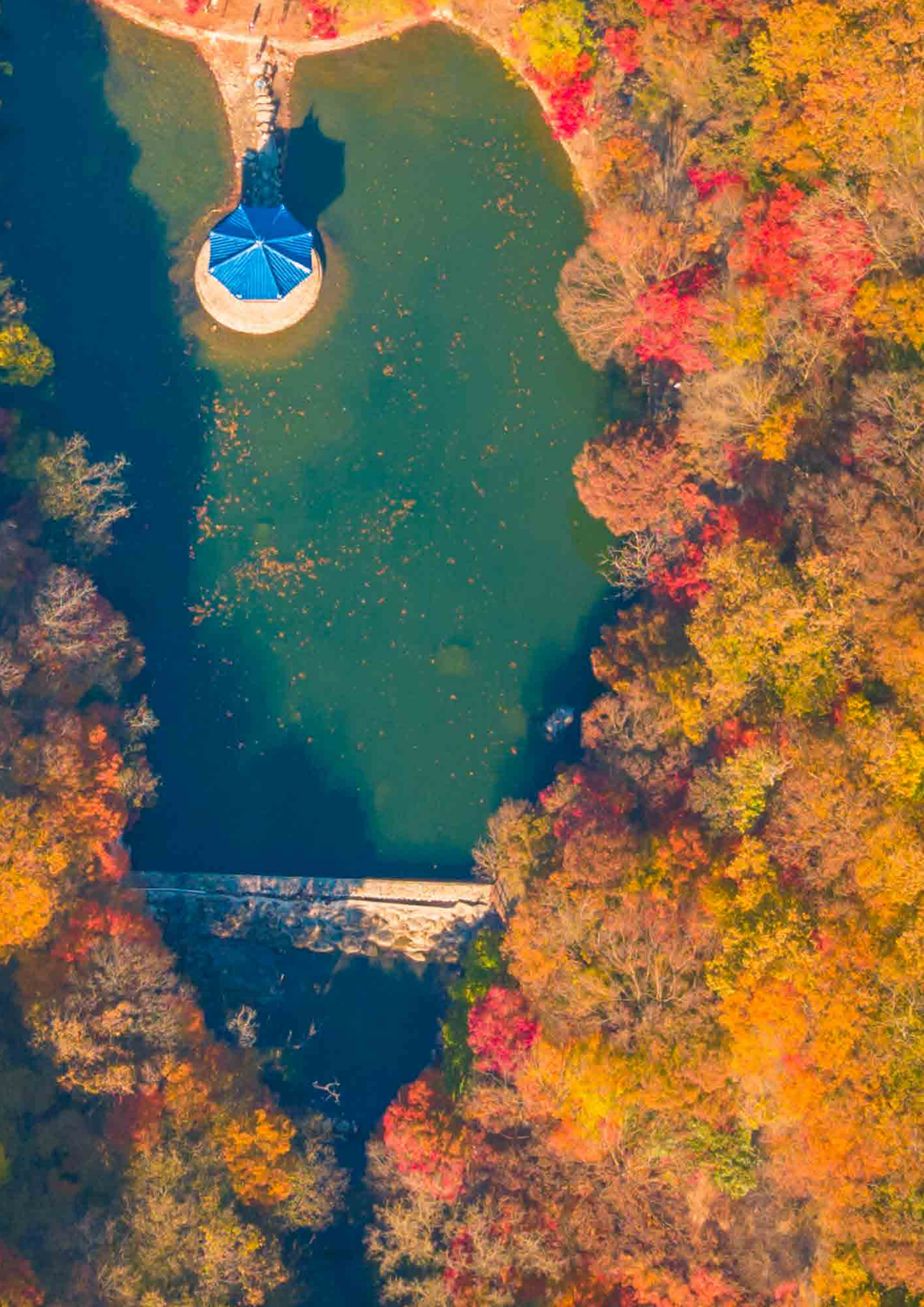
What method do you use?

Would you pay to have an improved grey/wastewater system?

In your opinion, what do you think the government should do to improve grey/wastewater reuse in households?

Notes

1. The United Nations defines water security as 'The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability'
2. As reported on 9 April 2018 in the Kenyan newspaper, The Standard, an Ipsos Public Affairs survey reported that '[n]early half of Kenya households earn less than Kshs. 10,000 per month' while '1 percent earn between Kshs. 55,000 to Kshs. 75,000 and another one percent earning [sic] between Kshs. 75,000 and Kshs. 100,000 per month.'
See: https://www.standardmedia.co.ke/business/article/2001276202/what-majority-of-kenyan-households-earn-in-a-month.
3. Jokaso is a Japanese word that translates to 'purification tank onsite wastewater treatment system' (Gaulke, 2006)



V
Technology for Water Reuse

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12

The Capability of Forward Osmosis Based Hybrid Processes in Adaptation to Water Scarcity and Climate Change

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Abstract

This study aims to present the latest research trend of forward osmosis (FO) based hybrid processes, as well as other advanced technologies, to solve the emerging water security-related issues and improve current policy on safe water production and management. Advanced technologies could play a vital role in achieving the sustainable development goals, which were developed by UN-Water in 2015. In the light of this, membrane-based technologies, including FO membranes, have emerged as an effective solution for water shortage and security. Although FO demonstrates high potential for improving capability of water markets, there are still several disadvantages to getting closer to commercially viable. Hybrid processes are therefore proposed to resolve all existing barriers. With lower energy consumption and higher water quality production compared to conventional processes, the use of low-energy hybrid FO system can be adapted to address water security, climate change, and environmental aspects in the future. Following that, current policy on water production and management should be improved as well.
This paper will review comprehensively i) Sustainable growth through improved water security, ii) Solutions to water problems for sustainable development through case studies and experimental research, iii) The use of advanced water treatment technology in adaptation to water scarcity and its linkages to current water policy focusing on the main goal of UNESCO i-WSSM.

Keywords

Advanced water treatment technology, case study, water security, water reuse optimization, policy

01

Introduction

Over the next two decades, demand for water is projected to grow dramatically, with an increase of 1% per year in all sectors. Advanced technologies could play a vital role in achieving the sustainable development goals, which were developed by United Nations (UN)-Water in 2015 (UN-Water, 2015a). Water production technologies, such as desalination as well as wastewater reuse are dominant factors in meeting the challenges of adaptation to achieve water security and sustainable climate for the future.

Advanced membrane based technologies, including forward osmosis (FO) membranes, have emerged as an effective solution to deal with water shortage and security. Although FO demonstrates high potential for improving the capability of the water market, there are still several disadvantages to getting the technology closer to commercialization. Hybrid processes are therefore proposed to resolve all existing barriers. With lower energy consumption and higher water quality production compared to conventional processes, the use of low-energy hybrid FO systems can adapt to water security, climate change, and environmental aspects in the future.

In order to bring the innovation closer to commercially viable, the support of policy may play a vital role to facilitate application of advanced technologies. However, there is a gap between technologies and current policy, which should be taken into consideration to enhance the role of policies in improvement of water security for sustainable growth.

The major purpose of this study is to have a look briefly at the latest trend in application of advanced FO membrane based hybrid processes in water production and treatment to solve the emerging water security-related issues. Apart from that, successful case studies around the world are discussed with respect to their contribution to adaptation for water scarcity. Furthermore, we will point out existing challenges in terms of engineering and policies as well as the current efforts that are underway to address those. Future prospects for research will be also recommended to provide an effective approach to the main goal of UNESCO i-WSSM, including adequate amount of water, acceptable quality of water, and sustainable access.

02

Water Security and Sustainable Development

2.1. Water Security

According to UN Water (2013), water security is defined as "the capacity of population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN-Water, 2013a). Currently, water resources around the world are under high pressure and are being reduced at extremely rapid rates.

Water for agriculture is projected to account for over 70% of global water withdrawals by 2050, while the figures for industry and domestic uses are approximately 20% and 10% respectively (UN-Water, 2013b). Moreover, food production is predicted to increase by 50% by 2050. Considering water consumption associated with agriculture and food production, there will be extreme consequences for water demand. In addition, an 85% increase in water consumption for the energy production industry is expected in the next two decades (USAID, 2017; Kulkarni, 2011). Water demand for other industries such as minerals and the manufacture of goods and fuel production will also increase rapidly in the near future. It is therefore important to do an action plan to address water that is "too little, too much, too dirty, too erratic" (USAID, 2017).

Figure 12-1 *Water-Food-Energy Nexus (Source: adapted from UN-Water, 2013)*

2.2. Improvement of Water Security for Sustainable Development

Sustainable development is defined as the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (UNEP, 2005; UN, 1987; UN, 2015).

According to UN Water (2013), "investment in water security is a long-term pay-off for human development and economic growth, with immediate visible short-term gains", which means that water security improvement plays a vital role in guarantee of sustainable development (UN-Water, 2013a). Enhancing water security comprises water services and capacity building, as well as providing good governance, the maintenance of water-related services, and natural infrastructure as well will alleviate the needs for significant funds funnelled thorough channels such as development aid, consequently, promote the policy on sustainable development. In particular, water security was proposed as a heart of the project on SDGs funded by UN water, 2015. The relationship between water security and water's cross-cutting valuable to food, energy, and other priority development areas was figured to achieve not only economic but also social development as well as environmental sustainability (Figure 12-1).

Water, in relationship with food and energy, plays an important factor in improvement of sustainable development goals. In this way, water is a fundamental component of both energy and food as it is needed to generate energy as well as for the growth of food. Thereby, guarantee of water security means guarantee partly of food security and energy security as well, which finally attain global security by sustainable development.
In which, advanced solutions in production of fresh water and treatment of wastewater play a pivotal role in enhancement of water security for sustainable development.

03

Advanced Solutions for Water-Related Issues

As discussed, global climate change is already starting to affect water supply and demand, water-related diseases as well as destruction and depletion of aquatic habitat.
It is therefore essential to carry out various activities including good management practices and technical solutions to improve water security for sustainable development (WHO & UNICEF, 2006).

3.1. Management Solutions

Water management means a series of activities involving careful planning, development, distribution and resource management. Water management helps water demands to be met by encouraging water conservation and sustainability initiatives, raising awareness of water conservation and equitable distribution of water.

> *"Guarantee of water security means guarantee partly of food security and energy security as well, which finally attain global security by sustainable development."*

Addressing water scarcity requires a cross-sectorial and multidisciplinary approach to water resource management to improve equitable economic and social benefits without sacrificing the conservation of vital ecosystems. This integration needs to take account of development, supply, use, and demand (FAO, 2003). Integrated water resources management (IWRM) provides a broad framework for governments to align water use patterns with the needs and demands of different users, including the environment (Gleick *et al.*, 2001; UN-Water, 2019). Integrated water resource programs aim is to analyse all water resources and infrastructure issues and to decide holistically how to address the needs of drinking water, wastewater and storm water (Town of Medway MA, 2019). Where drought recently impacted agriculture in a region causing water scarcity, rainwater and drained water were recirculated in constructed wetlands to limit saltwater intrusion, to provide irrigation water for crops during the dry period (Town of Medway MA, 2019; US-EPA, 2019).

3.2. Technological Solutions

3.2.1. Conventional Technologies for Water Treatment and Reuse

Water reuse or recycling refers to the use of treated wastewater, grey water including agriculture, industrial processes, groundwater recharge, recreational use and non-potable urban wastewater (i.e., fire protection and toilet flushing). Treatment of wastewater to make it usable is one of the most essential strategies to reduce water scarcity and protect water resources from depletion. Current technologies are classified as intensive i.e., need large quantity energy and extensive technologies, i.e., require a large amount of land (Table 12-1). In which intensive technologies include physical-chemical system, membrane technologies, disinfection technologies, and radionuclide removal, while extensive technologies include waste stabilization ponds, constructed wetlands, infiltration percolation systems, and organic removal processes. Intensive technologies such as membrane filtration usually require high energy consumption, whilst extensive processes, for instance constructed wetlands require large area for plants using for wastewater treatment.

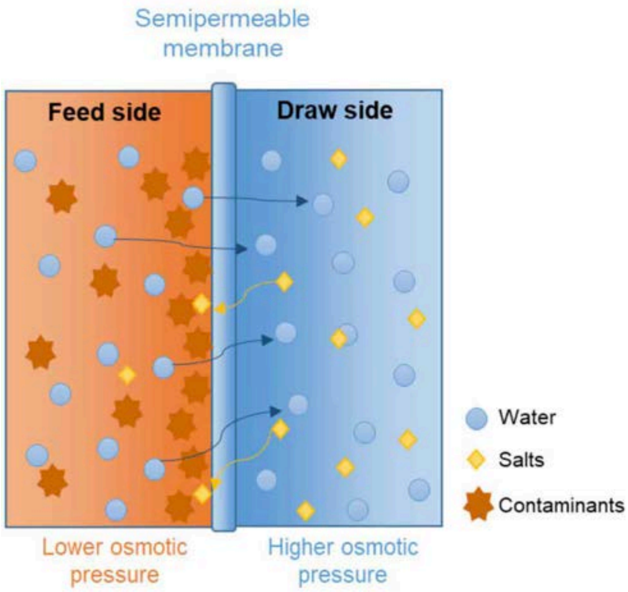

Figure 12-2 *Forward osmosis process (Source: adapted from Viet et al., 2019)*

3.2.2. Forward Osmosis (FO) Processes

In the FO process, water, driven under osmotic pressure, is transported from a lower osmotic pressure solution (i.e., feed side, low salt concentration) to a higher osmotic pressure solution (i.e., draw side, high salt concentration) through a semipermeable membrane (Figure 12-2). In order to regenerate draw solution (DS) for continuous operation, further processes such as reverse osmosis, or membrane distillation, etc. are necessary (Viet *et al.*, 2019).

Although FO technology has had significant development in the last decade, it is still in the phase of pilots and a few demonstration sites. The major benefit of the FO process is its lower energy consumption owing to the use of osmotic pressure, which results in lower membrane fouling than pressure-driven processes, finally leading a lower cost requirement. In addition, organic matters, nutrients, as well as micropollutants are retained well by FO membrane, producing high quality permeate water. However, current FO membrane generations have demonstrated low stable water flux and high reverse salt flux. These drawbacks may decline overall efficiency as well as increase operating cost.

Therefore, combination of FO technology with other processes is required to obtain better removal efficiency and reduce operating cost as well. Advanced treatment strategies may bring the technology closer to commercially viable.

Table 12-1 *Conventional technologies for water treatment and reuse (Source: adapted from National Research Council, 2012)*

Intensive technologies	Extensive technologies
• **Physical chemical system** coagulation, flocculation, sand filters, clarification sedimentation, dissolved air flotation • **Membrane technologies** ultrafiltration, nano-filtration, microfiltration, reverse osmosis, membrane bioreactor, electro-dialysis • **Disinfection technologies** ultraviolent radiation, chlorination, ozonation, photocatalysis • **Radionuclide removal** Softening, Sand filtration, precipitation by barium sulphate, and Electrodialysis	• **Waste stabilization ponds** Maturation ponds, stabilization reservoirs… • **Constructed wetlands** vertical flow horizontal flow… • **Infiltration percolation system** • **Organic** synthetic and naturally occurring compound removal • **Aeration** air stripping, tower aeration, diffused and tray aeration, multistage bubble aeration

04

Application of Advanced Water Treatment Technology to Adapt to Water Scarcity

4.1. Background

Treatment of wastewater using advanced available processes to make water usable is one of the most important ways to reduce water scarcity, save human health and protect water resources from depletion. In India and Pakistan, for instance, water recovery from wastewater is available for irrigation in the dry season. Well-treated wastewater can replenish water supplies, consequently, reduce the demand gap. Practices of using treated wastewater for irrigation are growing in Europe and it is particularly well established in Spain, Italy, Cyprus and Greece as well (Harishankar, 2014; IWA, 2015). Applications of treated wastewater around the world are in a wide variety, including, agricultural, industrial, residential and in some areas for direct drinking.

Reuse systems of wastewater include a multi barrier treatment framework consisting of advanced unit processes and incorporating resilience, redundancy, and robustness to ensure success (National Research Council, 2012). Water reuse requires physical and chemical treatment to achieve the quality of the water needed for the proposed use. Conventional treatment systems rely on processes of physio-chemistry and biology. From the point of view of wastewater reclamation, i.e., high quality purposes, complete removal of contaminants from wastewater is important. Advanced wastewater treatment (WWT) processes are used to treat used water from different sources to a quality that meets its intended purpose (Al-Rekabi *et al.*, 2007).

Advanced treatment processes produce high quality water as mentioned in the table of technological solutions for wastewater in section 3.2, which can address current issues of water quality (National Research Council, 2012). Membrane technology is a promising and advanced technology in water industries for WWT and desalination of sea water owing to its higher removal efficiency and smaller footprint compared to conventional technologies such as micro/ultra/nano-filtration and reverse osmosis (MF, UF, NF, RO). Transmembrane pressure difference generated by pumping is utilized and water molecules move through the membrane while impurities are rejected (Al-Rekabi *et al.*, 2007) but they are not effective in removing emerging micro-pollutants such as pharmaceuticals, personal care products (PPCPs), steroid hormones, or pesticides. The energy demand of these conventional membrane processes is very high compared to forward osmosis (FO), a type of membrane that uses the osmotic pressure gradient between two different solutions to produce water flow through a membrane (Zhao *et al.*, 2012).

4.2. The FO Hybrid System Based Solutions for Water Production

Due to the increasing global water scarcity; rising energy demand, energy costs; and negative impacts on the environment, osmotic processes such as forward osmosis (FO) have gained renewed interest. FO technology can play a major role in solving water shortages by alternative sources of water such as saltwater and wastewater recycling. This innovation would have a significant impact on a drought-affected country such as South Africa, where saltwater is plentiful in the form of coastal seawater and inland brackish groundwater (Achilli *et al.*, 2009).

FO only allows water molecules to pass through it by diffusion. It uses an osmotic pressure gradient as a driving force to drive the permeation of water across the membrane, leaving contaminants behind as they are filtered by the membrane (Linares *et al.*, 2014). Applications of FO can be classified as in Figure 12-3. Using of FO for water desalination includes direct and indirect desalination, while application

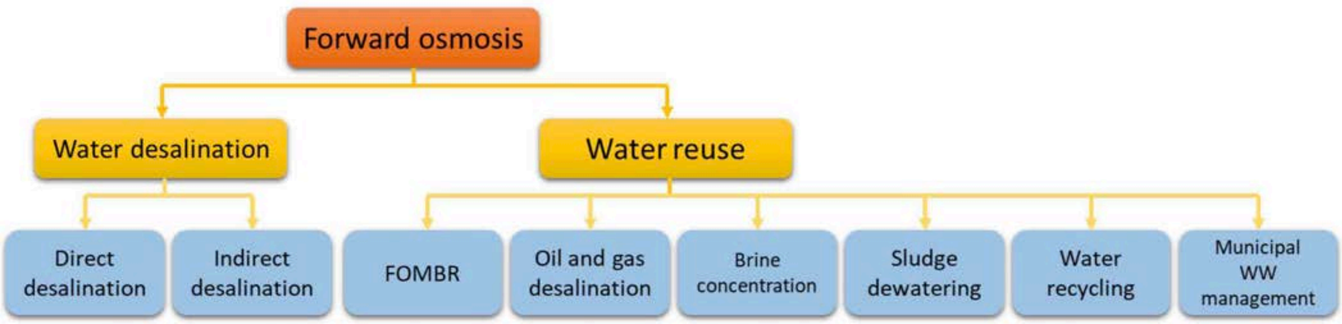

Figure 12-3 Applications of forward osmosis

“The use of FO hybrid systems could be more feasible for efficient reconcentration of DS and a better alternative than the performance of the FO process alone for WWT.”

of FO on water reuse comprises FO-membrane bioreactor (FOMBR), oil and gas desalination, brine concentration, dewatering of activated sludge as well as municipal wastewater treatment.

Hybrid processes are a combination of at least two processes which influence each other.
In most cases, the FO method is combined with other separation processes. For example, (1) to separate the DS from product or as an advanced pre-treatment technology, (2) to enhance the performance of conventional a process by using FO as pretreatment, (3) to improve the permeate water quality, and (4) to reduce energy consumption by using low cost energy sources such as osmotic pressure, waste heat energy for DS regeneration. Applications of FO hybrid systems show that they outperform conventional processes. For example, integration of a FO system with anaerobic treatment, i.e., treatment process without oxygen to remove nutrient from wastewater and to generate biogas has been described as a promising avenue for research and development in future (Chekli *et al.*, 2016). Use of FO as a pretreatment process can enhance the performance of conventional desalination processes (Nicoll, 2013). In FO-electrodialysis (ED) hybrid systems for desalination of seawater, FO is used as a pretreatment to reduce the multivalent ions concentrations in the feed water; removal of these ions results in reduced scaling effects on heat exchangers and enables thermal processes to work at higher temperatures and improve water recovery rates (Award *et al.*, 2019).

It is important to consider the environmental and economic aspects of FO hybrid systems while evaluating their performance (Award *et al.*, 2019). FO has commonly been known to be cost and energy efficient process because the energy consumption for regeneration of DS is always neglected in lab scale demonstration. In the case of DS regeneration, using membrane distillation is possible to utilize waste heat, for instance, from liquefied natural gas (LNG) recovery process or nuclear power plant or use solar thermal energy to reduce the carbon footprint.
Use of a FO-nanofiltration (NF) plant for wastewater reuse in agriculture has indicated that the total energy consumption is almost 40% higher than that of another conventional hybrid treatment processes by Ultrafiltration-Reverse osmosis (UF-RO) (Goh *et al.*, 2019). More research in hybrid systems is therefore required to optimize overall performance.

4.3. The Role of FO Hybrid Based Processes to Combat Water Scarcity

Regarding increasing water shortages and resource depletion, current water management strategies focus on hybrid water reuse and desalination technologies as alternative sources of water. Due to the high cost for membranes and system operations, seawater desalination and wastewater treatment using FO need to be hybrid with other WWT processes.
The use of FO hybrid systems could be more feasible for efficient reconcentration of DS and a better alternative than the performance of the FO process alone for WWT (Chekli *et al.*, 2016). In last couple of years, several hybrid processes have been developed in many applications including desalination of seawater and brackish water, fertigation, protein concentration, and dewatering of RO concentrate (Figure 12-4).

Figure 12-4 Applications and advantages of FO hybrid systems (Source: adapted from Chekli et al., 2016)

05
Case Studies

5.1. FO Hybrid System Around the World

Recently, a large number of FO hybrid systems have been introduced, however, due to it being a very new technology, a small number of full-scale systems were set up around the world. There are several successful full-scale and pilot-scale examples of hybrid FO systems in operation to date. In this section, we are going to show several successful case studies as well as its contribution to reduction of water scarcity.

5.1.1. Hybrid FO-RO System for Water Production

Desalination produces daily water needs for over 300 million people around the world (IWA, 2016). Meanwhile, the conventional membrane for desalination, in particular RO, is now over 50 years old and has demonstrated several drawbacks recently such as high cost of membrane, high energy consumption, and serious membrane fouling as well. Hybrid system of FO-RO demonstrates many benefits compared to RO system alone.

In 2012, as a part of adapting to new technology, a world's first commercial hybrid FO/RO plant was constructed in Oman by Modern Water, an UK-based company, with a contract of $759,800 (Figure 12-5). This plant supplies over 200 m^3 of potable water per day for public residents with 30% loweᵒr in energy consumption compared to a conventional RO plant (Voltas Water Management Division, 2018). Owing to the dry conditions as well as water scarcity for supplying a growing population, water demand for potable or process water in Oman is set to rise to 1.3 million m^3/d by 2020 (Global Water Intelligence, 2016). Therefore, the FO/RO hybrid system accounted for approximately 6% of total water supply in Oman. The integration of RO and FO membrane in this system resulted in a lot of benefits compared to a conventional RO process, including (1) inherently low fouling characteristics in both particulate and biological fouling; (2) significant reduced product boron levels without post-treatment when compared to conventional RO; and (3) higher availability than a conventional RO plant due to low fouling, simple cleaning and ease of operation (Voltas Water Management Division, 2018).

Figure 12-5 *The world's first commercial FO plant in Oman (Source: Nicoll, 2017)*

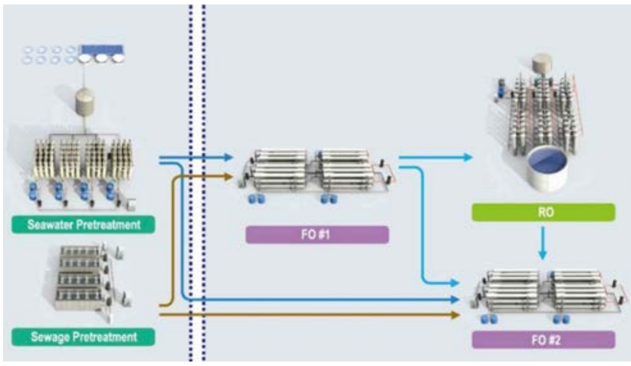

Figure 12-6 *FO-RO hybrid system in Korea (Source: Sohn, 2017)*

The plant includes (1) pretreatment process using low energy membrane; (2) Two modules of FO membrane were combined with RO system to simultaneously produce freshwater and treat wastewater.

In addition to Oman, a FO-RO hybrid desalination project (FOHC) was built in Korea from 2014 to 2019 with the budget of 28 million USD funded by Korea's Ministry of Land, Infrastructure, and Transport. This project aims to develop a FO-RO hybrid demonstration plant with capacity of 1,000 m^3/d for simultaneous production of fresh water and treatment of sewage (Figure 12-6). To date, a pilot plant was successfully operated with energy consumption of only 2.5 kWh/m^3 compared to 3.5 kWh/m^3 for the average energy consumption of the world's leading desalination plants, reducing of production cost up to 25% (Sohn, 2017).
In terms of water cost, the hybrid FO-RO demonstrated much lower cost compared to conventional RO; if FO recovery reaches 120%, water cost will be reduced approximately 7% (Figure 12-7).

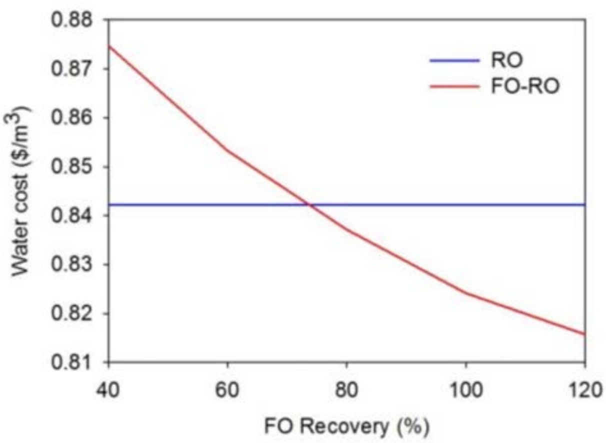

Figure 12-7 *Water cost according to the particular system (Source: Sohn, 2017)*

The capacity of desalination plants around the around the world is predicted to reach 120 million m^3/d by 2020. The success of these case studies has recently facilitated the application of advanced technologies for simultaneous reduction of energy consumption and increase of water production.

5.1.2. Fertilizer Drawn Forward Osmosis (FDFO) in Australia

As one of the most potential processes to commercialize at full-scale, FDFO-NF hybrid systems have so far been mostly studied through lab-scale or pilot-scale applications. For instance, a pilot-scale of FDFO-NF was operated in the State of New South Wales, Australia in 2015 (Figure 12-8). In this system, saline water (i.e., feed solution) collected from a groundwater treatment plant, which removes mineral compounds from groundwater, was utilized to supply water for dilution of fertilizers (i.e., draw solution) used for agriculture. Diluted fertilizer, after FDFO process, was then processed by the NF membrane and finally, used directly for irrigation of turf grass farm and tomato plants in Australia (Phuntsho *et al.*, 2016).

The pilot system was made up of the FO process containing two spiral wound cellulose triacetate (CTA) FO membrane modules connected in parallel with a total membrane area of 20.2 m^2. The pure water permeability was observed to be 1.02 ℓ/(m^2·h·bar) and salt rejection of 93% (Phuntsho *et al.*, 2016). The FDFO-NF hybrid system consumed 21% less energy than the UF-RO hybrid system in irrigation water production. Moreover, the cost of producing water was estimated at AUD \$0.46/m^3, while the figures for MF-RO and UF-RO were AUD 0.49/m^3 and 0.54/m^3, respectively (Phuntsho *et al.*, 2016). The agriculture sector may consume up to 70% of total fresh-water by 2050, the use of a low energy consumption FDFO-NF hybrid system is therefore an effective strategy to adapt to water scarcity, especially for the agriculture sector. In addition, the nutrients recovered through the treatment of a wastewater stream can supply nutrients for fertigation.

Figure 12-8 Pilot-scale of FDFO-NF hybrid system in Australia (Source: Phuntsho et al., 2016)

5.2. What are Challenges in The Application of Advanced Technology?

Even though hybrid systems show high potential as a superior species of membrane separation technology in a wide range of industrial applications, there are several obstacles, which should have attention paid to bring this hybrid process closer to commercially viable.

5.2.1. Challenges Associated with The Most Common Treatment Options

5.2.1.1. Challenges in Hybrid Technologies for Water Production and Reuse

When water is the final product of the process, a hybrid membrane acts as a water production technology. In this process, water production by the recovery of DS may cost high energy. Thus, the actual energy consumption of a hybrid system may exceed the economic benefits if it is not optimized. Moreover, the low water flux of FO membranes is an obstacle from the perspective of water scarcity in the future as water demand becomes higher and higher.

The implementation of a FO module into an existing system requires costly additional area for relevant water streams due to the change. It means that higher costs for new systems are required for production of potable water around the world. Consequently, less developed countries do not have access to sufficient clean water.

In terms of water reuse, we can utilize specific sources of DS, such as fertilizer or chemical wastewater streams with high conductivity, which then can be used directly for further purposes without any additional process for regeneration. Therefore, the problems related to energy consumption are not barriers of this process. Meanwhile, the capability of advanced hybrid systems in rejection of micro-pollutants in wastewater is still inefficient so far. Moreover, due to a lack of proof of principles and pilot plant data, convincing end users in the water treatment industry of the economic benefits of hybrid system is very hard. Therefore, research data for further analysis is necessary to enable novel hybrid system to approach closer to commercialization.

5.2.1.2. Challenges in Linkages Between Technologies and Current Policy

As mentioned in section 3, science and technology must play a vital role in devising the solutions that will be necessary to overcome the problems caused by water scarcity to guarantee sustainable development. However, there are some challenges in linkages between technologies and current policy, which should be addressed in the future to enhance water production and reuse to adaptation to water security.

- **Lack of Criteria for Making Decision on Technology Use**

Globally, even though technologies are more and more advanced, water policy, in particular decisions on technology use, is based on mostly non-technical criteria, such as global and local knowledge or adapting alternatives from abroad to local conditions, cost, or even political reasons. This lack of technical criteria, as well as related concerns in economic, social, and cultural aspects, lead to difficulties in deployment of advanced technologies to populations, especially in developing countries. Therefore, there is a requirement for policy making in a technical area given the economic, social, and cultural needs along with geographical and physical variability. In which developing countries should have many chances to gain benefits from choosing the best technologies by using sustainable criteria (UN-Water, 2015b).

- **Lack of Policy to Eliminate Barriers for Water Technology Application**

Barriers - such as weak water market demand, uncertain return on investment or lack of technical skills and capacity, inhibit the adoption of water technologies. Meanwhile, policies may be applied to evaluate its potential to support or prevent these barriers to facilitate new technologies (UN-Water, 2015b). However, lack of clear governance on elimination of barriers leads to the difficulty of decision makers in providing effective support for implementation of water related solutions. In Nigeria, for example, the representative said that his country faced serious problems in providing adequate irrigation, as water competed with other needs for domestic resources. However, poor water policies on grants for water resources caused a barrier for technological transferring as well as international assistance (UN, 2014).

- **Lack of Policy on Protection of Intellectual Property Rights (IPR)**

Innovation of advanced technologies depends on new patented knowledge rather than public knowledge. Therefore, inappropriate protection of intellectual property rights may work against the application of new water technologies, especially in some countries where the intellectual property laws are weak or ineffective. Moreover, lack of efficient IPR in developing countries may reduce technology flows from developed countries to developing ones. When the IPRs protection policy of developing countries is effective, the entry of foreign technologies is easier. This result implies that this policy is likely to increase the expansion of water servicing (Mrad, 2017).

- **Lack of Supporting Funding for Water Technologies**

Policy incentives in the form of tax breaks or tariff protection give significant benefits for the development and diffusion of water technologies. Wealth provides critical resources to mitigating water risks; as countries become wealthier, reducing water risks becomes more affordable.
However, in several countries, where these policies are weak or ineffective, the implementation of successful innovation is much lower. The policies in state must therefore favour such technologies and encourage the actors to adapt them by various incentive mechanisms. Currently, investment in water technologies for supply or sanitation has not kept pace with the needs. The UN-water global analysis and assessment of sanitation and drinking water (GLAAS) report documents a huge financing gap between plans and budgets for water supply and sanitation, with 80% of countries indicating insufficient financing for the sector. In Japan, for instance, the investment for water supply system needs coincides with a projected decline in available financing, such that they will exceed the potential available funds for investment by 2025. It is therefore critical to introduce efficient policy to find other sources for water-related projects (OECD, 2016).

5.2.2. Current Efforts are Under Way to Address Existing Challenges

In order to deal with drawbacks of the hybrid system as mentioned in section 4, technical solutions have been discovered and applied. For instance, utilization of waste streams based DS such as brine RO effluent (i.e, very high salt concentration solution), concentrated industrial wastewater, or inorganic fertilizers may reduce the total energy consumption of hybrid systems as well as, saves the cost for waste treatment. Besides, utilization of waste heat and renewable energy such as solar energy for re-concentration processes of DS is being studied to reduce the total operation cost, i.e., the energy consumption of hybrid processes.

Transferring from lab-scale to pilot-scale and full-scale is the most important task, which researchers, as well as businesses and end-users, have to undertake to ensure that the technological advancement can be used for commercial purposes. Likewise, prior studies provide with the date set for the application of advanced membrane hybrid system in full-scale for the upcoming projects in near future.

In terms of policy making, knowledge sharing between technicians and policy makers as well as among different countries around the world is leading us to better decision-making on water technology utilization. Knowledge Sharing Program (KSP), for instance, including 76 partner countries and 9 International Organization, is currently aiming to share knowledge for expansion of economic and political cooperation. This includes not only the dissemination of techniques but also to the enabling conditions that may favour their transfer and adaptation and of the capacities to make them viable (UN-Water, 2015b). Moreover, international cooperation is also currently expanding as mentioned in the water development goal (Target 6.a) to support developing countries in water and sanitation, wastewater treatment and reuse technologies.

06
Future Perspectives

Advanced FO hybrid systems have demonstrated lots of benefits compared to standalone process. However, to bring the innovation closer to commercialization, there are some situations, in both aspects of engineering and policy, that should be paid attention in the future.

6.1. In the Engineering Aspect

Low energy consuming advanced hybrid systems should be innovated to reduce operating cost as well as to increase these systems' efficiency. A combination of FO process with processes using solar power or waste heat from thermal plant to save energy for recovery of DS could be a high potential technology for sustainable development.
Further optimization of FO hybrid systems, in particular on membrane permeability or packing density to simultaneously enhance water flux and reduce membrane fouling as well as increase the rejection of micro-pollutants, will likely enable these systems to reach full-scale faster than current processes (UN-Water, 2015b). Finding a sustainable DS, which can enhance water flux effectively as well as being environmentally friendly for the recovery process, is an interesting issue for academic research in the future.

6.2. In the Policy Aspect

The problem is how technical innovation can be effectively applied in real cases so as to improve the adaptation of technologies to water scarcity around the world.
As mentioned above, there is some lack of policies on criteria for making decisions on water technologies, on inhibition of barriers for application of technologies and on protection of property rights. Water investment, which supports the use, transfer, and adaptation of new technologies to water scarcity, is also not enough yet. Bridging the gap between technologies and water policies is not just a question of technologies but also about how the policies are improved to make a more efficient application of advanced systems. Therefore, international and local cooperation is critically necessary to provide "sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses" as the human right to water adopted by United Nations (UN-Water, 2003).

07
Conclusion

With current scenario of water scarcity and climate change, advanced technologies and effective linkage between technologies and policies play a pivotal role in the facilitation of innovation in order to tackle related-water issues.
Advanced FO hybrid systems have demonstrated its benefits in adaptation to water scarcity through a lot of research data as well as successful case studies around the world.
However, there are obstacles which should be addressed to bring it closer to commercially viable, in which policy making is the dominant factor. Attention on the lack of global and local policies on technological application as well as the linkage between innovations and policies also should be high on the agenda of all governments in the future to improve water security for sustainable development.

"Attention on the lack of global and local policies on technological application as well as the linkage between innovations and policies also should be high on the agenda of all governments in the future to improve water security for sustainable development."

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Subject Index

Providing clean and secure water resources is key to achieving SDG 6, "Ensure availability and sustainable management of water and sanitation for all". Water is essential for human activities and is critical to many sectors of the economy, therefore its sustainable use is fundamental in a circular economy model.

In accordance with the United Nations' World Water Development Report 2019, global water demand is expected to increase by 20-30% by 2050 and this increased demand will exacerbate water security issues generally. Rapid urbanization and population growth are creating even more challenges to supplying safe water. Climate Change is also resulting in more frequent occurrences of floods and severe droughts, which in turn also affect the availability of secure water supply and sanitation. In this context, it is now more important than ever to look for non-conventional water resources to ensure sufficient water resources for all basic human needs.

According to UN-Water, 80% of wastewater flows back into the ecosystem without being reused or treated, and 1.8 billion people are exposed to contaminated drinking water sources as a result. Wastewater is a potential resource that can fill this supply gap in industry and agriculture. Reused water is not just an alternative source of water, it is an opportunity to provide benefits for many human activities.

This second GWSI series examines the critical role of water reuse in the circular economy, demonstrating that wastewater and other marginal water sources should be seen as resources that are too valuable to simply ignore or discard. The case studies within this report explore how water reuse can be a major tool and part of a strategy to achieve the SDGs. Water reuse also presents an opportunity to develop sustainable water resources that protect our communities and ecosystems.

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