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Assessment of health impacts of quality water provisioning from groundwater sources: a micro-level study in India

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ABSTRACT

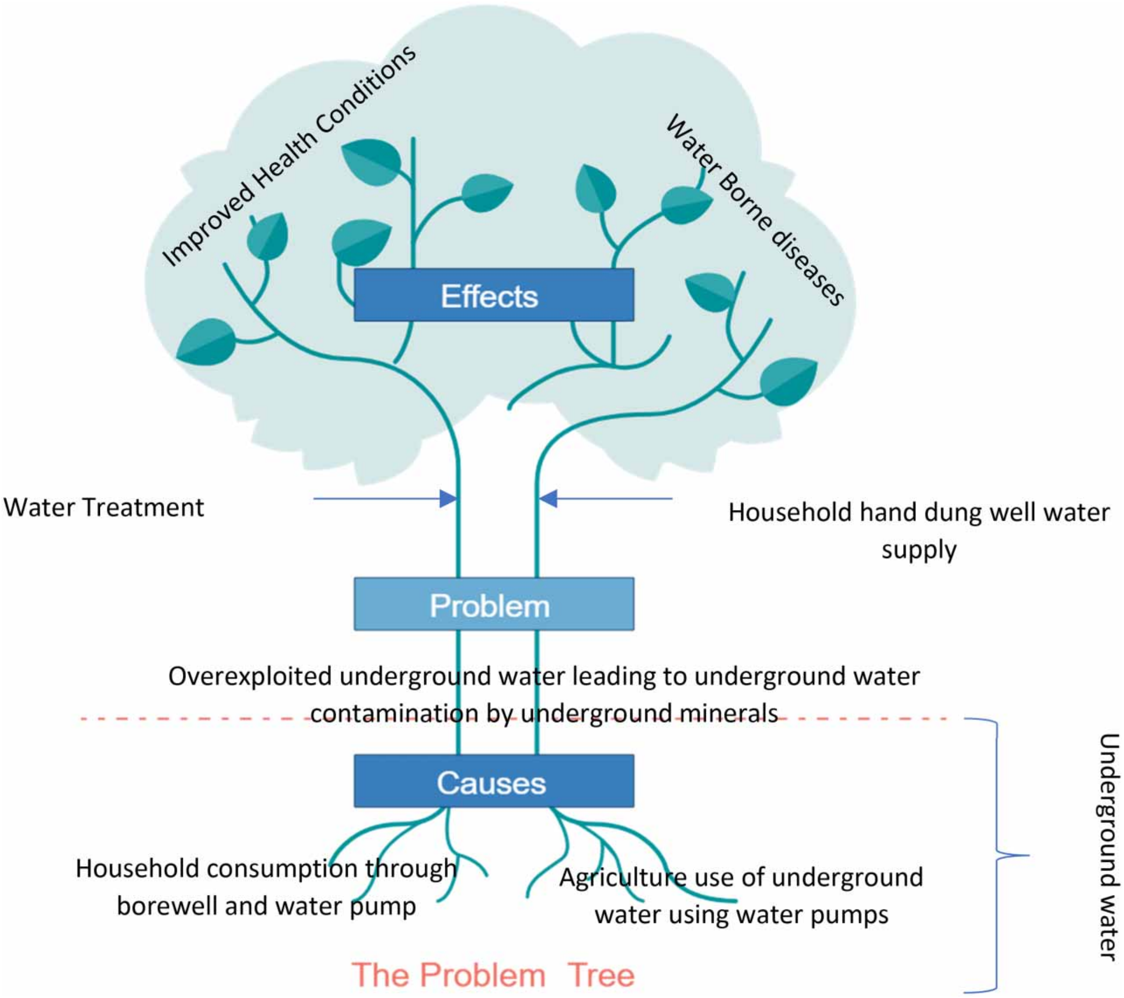
Many nations have implemented policies to improve drinking water quality, but challenges arise from overexploited or contaminated groundwater-based sources. This paper aims at examining the aspects of water scarcity, security, and sustainability within an Indian village context. We attempt to compare two rural water supply sources in Nagla Chandi village in Uttar Pradesh, India: (a) untreated groundwater sourced from bore wells and (b) treated water from a reverse osmosis (RO) plant. We observed that subterranean minerals are the primary pollutants of unprocessed water drawn from borewells, which form the main source of drinking water. Even though water from the RO plant meets all the quality parameters of potability, frequent breakdowns of the plant due to improper management force the villagers to drink untreated water from the dug wells fitted with hand pumps, affecting their health. We also found a high incidence of water-borne diseases. The case analysis suggests enhancing village water treatment projects by training local artisans in system repair and increasing Panchayat staff to include trained engineers for technical advice and maintenance. The paper proposes reducing water testing cost in rural areas to make it possible Q4 for local organizations to regularly assess water quality and implement corrective actions.

Key words: Rural India, Sustainable development, Water-borne illnesses, Water policy, Water quality, Water scarcity

HIGHLIGHTS

- This paper compares two rural water supply sources in Nagla Chandi village, Uttar Pradesh, India: untreated groundwater from bore wells and treated water from a reverse osmosis plant.
- Underground minerals were found to be the primary pollutants in untreated water from borewells.
- An enhanced model for community water system management is proposed.
- Lowering water testing costs for rural communities is recommended.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Access to safe water is a fundamental human right and a policy goal in many nations (Bain *et al.*, 2020). The UN Sustainable Development Goals (SDGs) 2030 agenda, *inter alia*, includes global goals for water, sanitation, and hygiene. For instance, SDG 6 aims to 'ensure availability and sustainable management of water and sanitation for all' to address water quality issues. Concerns with water quality are addressed by SDG indicator 6.1, safely managed drinking water (SMDW) services. SMDW services are improved sources of clean, contaminant-free drinking water that is accessible on-site (WHO, 2017; Marchese *et al.*, 2018).

1.1. Literature review

Reportedly, in 2020, 75% of the world's population got access to safe drinking water leaving about 25% without access (WHO & UNICEF, 2022). Furthermore, there is a stark division between urban and rural access to 'improved' and 'safe' water sources (UNICEF & WHO, 2019). According to the Joint Monitoring Program

(JMP), 2 billion people do not have access to SMDW worldwide, with sub-Saharan Africa as well as Central and South Asia having the highest in access rates (WHO & UNICEF, 2017). Development activities pollute both surface and underground water sources (Chandra Mohan *et al.*, 2014). While toxin percolations from the soil to ground water contaminate drinking water (Khan & Srivastava, 2012), polluted water tends to host cholera-causing *Vibrio* and schistosomiasis (Rahman *et al.*, 2018).

Water quality challenges are addressed in other SDGs as well, such as those dealing with poverty reduction (SDG1), health and wellbeing (SDG3), and sustainable consumption and production (SDG12), due to their links to important environmental, socioeconomic, and development issues. As a result, the emphasis on water quality in multiple SDGs reflects the growing need to improve global water quality (Ezbakhe, 2018).

Like many other countries, India is also facing the major concern of growing threat to groundwater quality posed by anthropogenic activities. Reportedly, in India, which occupies 2.2% of the world's land, 4% of its water resources, and 16% of the global population (Hrvatin *et al.*, 2020), groundwater overexploitation degrades water quality (Nigam & Srivastava, 2019). India faces the most serious water shortage issue in the 21st century. Groundwater quality deterioration in rural India poses significant challenges for safe drinking water because it is the primary source of rural water supply (Kumar *et al.*, 2022). Water quality is deteriorated by bacteria, fluoride, salinity, and arsenic, besides contamination due to nitrates, silica, uranium, lead, and other substances (Rajawat & Madheswaran, 2016; Saleem *et al.*, 2016). Water with high iron content can cause tooth discolouration, diarrhoea, and skin problems (Kumar *et al.*, 2017). Also the use of heavy metal contaminated ground water can cause toxic elements to accumulate in cereals and vegetables, posing human health risks (Jenifer & Jha, 2018; Zhang *et al.*, 2018).

The Government of India spends an amount of Rs. 6,700 crores (USD 805 million) each year for the treatment of people suffering from water and sanitation-related diseases. This amount is barely Rs. 52 crore (USD 6.25 million) lower than the country's Central Health Ministry's annual budget, but more than that allocated for education (Narain, 2002; Khurana *et al.*, 2008).

People in India mostly use public water sources for drinking, domestic, and other non-domestic uses, where these sources mainly include groundwater, public taps, water from nearby rivers, ponds, and harvested rainwater. The reliance on untreated sources is partly attributed to the irregularity and inconsistency of pipe water distribution systems (Yadhunath *et al.*, 2020).

In India and other developing countries, the emphasis is on ensuring universal access to clean water, as water pollution detection is often overlooked due to the limited capacity of local institutions to conduct such tests (Kanyagui & Viswanathan, 2022). Water supply is a national issue, whereas pollution is a local issue with ramifications for policy and actions (Abbaspour *et al.*, 2007). In recent years, pollution control boards in many Indian states have conducted various water quality tests in order to better understand the types of pollution that are harming public health and the economy. This was aimed at a better understanding of the relative impact of various types of pollution in the country (Central Pollution Control Board, 2020).

Kansal *et al.* (2017) emphasized the importance of protecting and conserving water resources, prioritizing water quality, and implementing integrated planning, demand management, and water pricing to address India's growing water challenges. It was observed that a clear, science-based water resource policy is required at the central and state levels along with an effective legislation for groundwater and surface water regulation at the state level. The need for restructuring and empowering of the existing water institutions at the local level was also highlighted to improve efficiency and sustainability. In this regard, Kumar *et al.* (2022) observed that government's long-term policies should focus on building scientific capabilities of local agencies, restructuring them to effectively perform water quality management and pollution control, and implementing projects that adequately respond to environmental concerns in rural areas.

Against this backdrop, this study explores the aspects of water quality and household water scarcity in a village (Nagla Chandi) in Mathura district in Uttar Pradesh, India. It evaluates the water quality status of two water supply systems, viz., a hand-dug well fitted with hand pumps and a cutting-edge water filtration system, known as the Jivamritam (meaning, 'elixir of life') filtration system. Besides a comparative assessment of the water quality and water delivery aspects of the Jivamritam water filtration system with the hand pump system, this study also examines the potential health impacts and draws relevant insights for public policy and actions, as concerns of water scarcity and security and sustainability pose critical challenges at the national and local levels.

2. DATA AND METHODOLOGY

The study adopts a mixed methods approach for assessing water quality parameters and its implications on health outcomes in the study village. Raju *et al.* (2012) and Ahmed *et al.* (2020) note that the contamination of water sources can be assessed using qualitative and quantitative methods of defined water quality parameters. A quantitative analysis of data on important water parameters was carried out based on the test results of various mineral contents carried out at an independent environmental and analytical laboratory.

Besides water quality assessment, we also conducted focus group discussions (FGDs) involving women of the Nagla Chandi village along with key informant interviews to discuss the water supply, sanitation, and health outcomes. The FGDs included eight participants carefully chosen for the breadth of their knowledge (Djamba & Neuman, 2002; Coghlan & Brydon-Miller, 2014; Jilcha, 2019) pertaining to water quality and sanitation problems in the village.

The study protocol was approved by our institutional review board, and the subjects were given an informed consent authorization form (Nagla Chandi Village) by the Institute of Medical Sciences Healthcare, Education & Research, Institutional Ethics Committee, Kochi, Kerala (Protocol No. – IEC-AIMS.2O22. ASSD.255 and 05/10/2022).

The rest of the paper is organized as follows. Section 2 discusses the results of the comparative water quality assessments of the two systems. In Section 3, we discuss the health impacts of the water sources. The section then reports the results of the FGDs and key informant interviews concerning water-related illnesses in the study village. Section 4 presents the conclusions and policy suggestions to improve the water delivery services in similar rural contexts.

2.1. Profile of the community

Nagla Chandi, also known as Nagla Purivia, is situated 16 km west of Mathura district in Uttar Pradesh in India. It is part of the Raal Panchayat of the Agra Division. The study area has semi-arid climate characterized by high temperature variation and low seasonal rainfall (monsoon season). The region's geology is primarily composed of a single rock formation and does not exhibit any notable structural problems (Ahmed *et al*., 2018). Figure 1 shows the location map of Nagla Chandi in Mathura district, Uttar Pradesh.

As the national population census 2011 data do not include Nagla Chandi village, we relied on the headcounts undertaken as part of an ongoing village project. Based on the headcount, the total population of the village in October 2022 was 350 (Kanyagui *et al.*, 2023).

The village's primary water sources include 43 covered hand-dug wells that are installed in homes equipped with pumps. The recently introduced Jivamritam water filtration system is the secondary source for household use, provided by the Amrita Live-in-Labs®'s project, an initiative by Amrita Vishwa Vidyapeetham in India. Amrita Live-in-Labs® is a multidisciplinary experiential learning program that aims to develop sustainable solutions for rural communities' challenges. It breaks classroom and lab barriers, allowing participants to study, observe, and interact with rural populations (Ajith *et al.*, 2022). There is also an old uncovered well in the middle of the village that is not utilized. Water from hand-dug wells is mostly utilized for domestic uses such as laundering, consumption, food preparation, bathing, animal bathing, and construction.

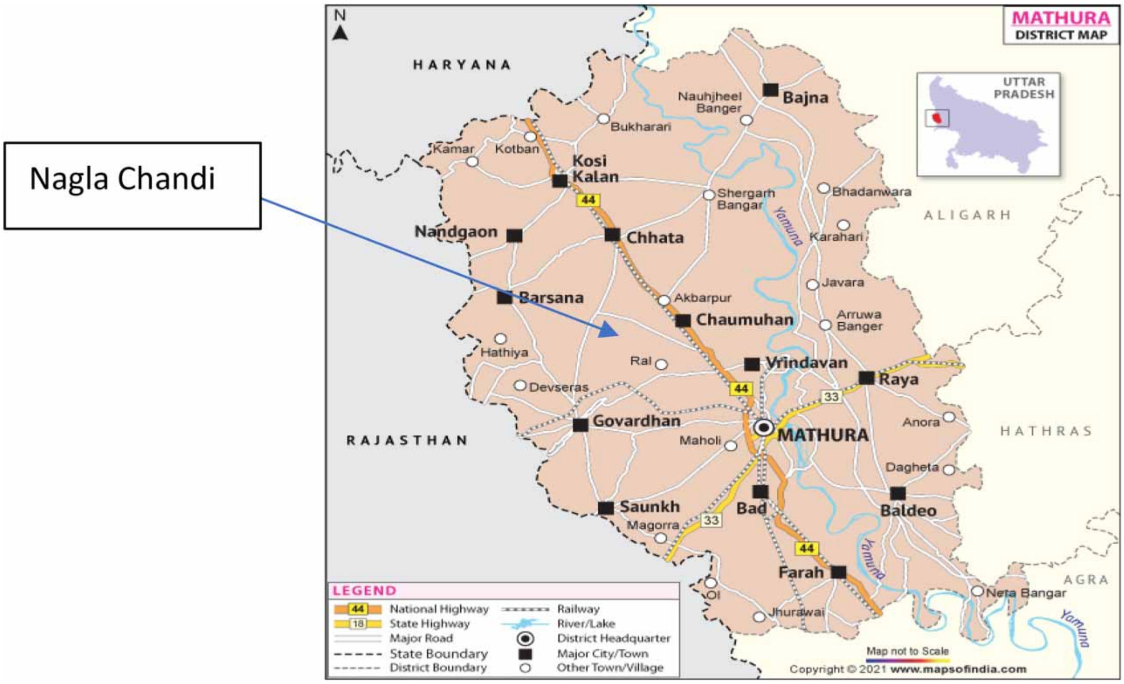


Fig. 1 | Map of Mathura District.

The choice of Nagla Chandi village for the study was based on several considerations, including the fact that it is the only village in the Ral block to have benefited from any Civil Society Organisation (CSO) interventions in the form of the installation of a drinking water system (Ajith *et al.*, 2022). Like many other villages within the block, almost every household has its own borewell. The scenario also provides an opportunity to examine the factors influencing household choices of alternative water sources in relation to water quality, as well as how this affects water system sustainability. Furthermore, it is expected that the lessons learned from the study will help in scaling up of similar intervention within the Ral block and in other rural areas in India, which face water quality problems. Furthermore, while underground water quality tests have been conducted in other villages in the Mathura district (Ahmed *et al.*, 2018), no such tests have been conducted in the study village to determine the suitability of underground water for drinking purposes.

3. RESULTS AND DISCUSSION

3.1. Water quality assessment in the village from a comparative perspective

Samples of two bottles (1 L) of water at 29 °C (sample code: 20220413/ S007) were collected from two water sources and sent to the Standard Environmental & Analytical Laboratories. The samples were assessed as fit for analysis. The water quality test was conducted during the period April 14–18, 2022. Figure 2 shows one of the typical borewells installed with handpump in the study village.

In what follows, we present a comparative analysis of the water quality test results in the case of the handpump water (referred to as raw water), followed by the test results of the water sample drawn from the Jivamritam water filter, which is a new intervention in the village.

Fig. 2 | Handpump installed in houses, Nagla Chandi.

The water quality parameters were compared with the required threshold values as per the Indian Standard (IS) 10500: 2012. Table 1 shows the parameters that are within the acceptable limits, and Table 2 shows parameters that are above the acceptable threshold for handpump water.

The results of handpump water quality tests show that test items listed in Table 1 are within the parameters and those listed in Table 2 exceed the limit. Hence, it is observed that the handpump water is unsafe for consumption. The health implications of the water quality from the handpumps will be examined in the Discussion section.

3.1.1. Jivamritam water filter system – reverse osmosis

Several NGOs in India work with the governments to meet rural water needs (Asad & Kay, 2014). Jivamritam is a community-based clean drinking water solution, a scaled-up Live-in-Labs® project launched in October 2017, supported by the CSO[1]. Phase 1 of the project aims to provide clean drinking water to 10 million people in 5,000 villages in India. When complete, the system is expected to serve 2,000 people a day.

3.1.1.1. Rationale and design of Jivamritam water filter system. The initiative aims to reduce water-borne diseases by providing a common water source to the water-deprived communities. The initiative focuses on community ownership and management of the water system, with funds generated from operating the system used for operation and maintenance (O&M) and addressing other water issues like scarcity (through conservation). Also, the initiative facilitates the formation of water committees responsible for the O&M of the system. The initiative also organizes sessions and awareness campaigns to educate communities about water-borne diseases. To reduce the increasing dependence on packaged drinking water, which is commercially available in 20-L cans at a high cost, the initiative aims to supply drinking water at a price at least 10 times lower than the commercial water supply (Amrita Vishwa Vidyapeetham, 2020).

[1] https://www.amritapuri.org/

Table 1 | Borewell water quality parameters (within acceptable threshold (IS 10500:2012)).

Parameters	Test method	Unit	Result	Requirement as per acceptable limit of IS 10500:2012
Colour	IS 3025 (Part 4):1983	Hazen	1	Max 5
Odour	IS 3025 (Part 4):2018	mg/L	Agreeable	Agreeable
pH	Is 3025 (Part 4):1983	mg/L	7.03	6.50–8.50
Total alkalinity as $CaCo_3$	IS 3025 Part 23:1986	mg/L	101	Max 200
Fluoride as F	APHA 23 Edition 4500-F-B D:2017	mg/L	0.63	Max 1.00
Arsenic as As	APHA 23 Edition 4500-F-B D:2017	mg/L	BDL (LOD-0.001	0.01
Manganese as Mn	IS 3025 Part 59:2006	mg/L	BDL (LOD-0.016)	0.1
Nitrate as NO_3	APHA 23 Edition 4500-F-B D:2017	mg/L	13.9	Max 45.0

Source: Field sample data from the water source (handpump).

Table 2 | Borewell water quality parameter (above acceptable threshold (IS 10500:2012)).

Parameters	Test method	Unit	Result	Acceptable threshold (IS 10500:2012)	Variance (above acceptable IS 10500:2012)
Turbidity	IS 3025 (Part 10):1984	NTU	5.4	Max 1	−4.4
Total hardness as $CaCO_3$	IS 3025 (Part 21):2009	mg/L	1,030	Max 200	−830
Total dissolved solids	Is 3025 (Part 16):1984	mg/L	3,748	Max 500	−3,248
Calcium as CA	IS 3025 (Part 40):1991	mg/L	104	Max 75	−29
Chloride as Ca	IS 3025 (Part 32):1988	mg/L	1,129	Max 250	−879
Magnesium as Mg	IS 3025 (Part 46):1994	mg/L	186	Max 30	−156
Iron as Fe	IS 3025 (Part 53):2003	mg/L	1.51	Max 1	0.51
Sulphate as SO_4	IS 3025 (Part 24):1986	mg/L	628	Max 200	−4,226

Source: Field sample data from the water source (handpump).

3.1.1.2. The design of the RO system. Reverse osmosis (RO) is a process that removes impurities in drinking water, including harmful ions, organisms, and pesticide residues (Kumar & Shah, 2006; Ahuchaogu *et al.*, 2018). The Jivamritam dual sand/activated carbon filter eliminates toxic substances like fluoride, fertilizer, pesticide residues, heavy metals, suspended particles, and turbidity. Following that are 5- and 1-μm filters. Each system includes an ultraviolet water purifier to remove infectious agents as well as two storage tanks to preserve filtered and unfiltered water separately and avoid contamination. The system's filtered water tanks are connected to taps for drinking water.

3.1.2. RO water test results (Jivamritam)

Water from the system was subjected to a quality test for comparative purposes as discussed already. Figure 3 illustrates the RO water system installed in the study village.

The water quality parameters were compared with the required threshold values as per the IS 10500: 2012. Table 3 shows the results of the test.

Fig. 3 | Water treatment plant at Nagla Chandi (Jivamritam).

The water test results in Table 3 show that the water is of sufficient quality to be used as drinking water by the community when compared to IS 10500:2012. The discussion that follows highlights the definition of the borewell water parameters that exceed the IS 10500:2012 threshold and the associated health implications.

3.2. Implications on health of water quality parameters exceeding limits

3.2.1. Implication on related SDGs

SDG indicator 1.4.1, which measures the percentage of people living in households with access to basic services, is directly impacted by the findings of the water test results. Even though access to potable water has significantly improved in rural India, the situation in Nagla Chandi falls short of the national progress. It is in such situations that the need for effective implementation of schemes such as Jivamritam holds immense potential for implementation to achieve the national targets associated with water and sanitation and related SDGs. Table 4 below provides details of the health implications of the water test result.

The outcomes of the water quality tests carried out as reported above have implications for SDG indicator 3.9.2, which pertains to death rate attributable to poor sanitation, unclean water, or lack of hygiene (Water, Sanitation and Hygiene (WASH)), expressed as the number of deaths per 100,000 persons in a specific population (Biswas *et al.*, 2022). India's death rate due to unsanitary conditions (WASH) was 36 per 100,000 population in 2019 (Global Burden of Disease (GBD) Collaborative Network 2019). The continued reliance on highly contaminated, untreated borewell water has negative effects on attaining the national goal of lowering the death rate owing to water-related diseases by 2030. Kumar *et al.* (2022) observed that adverse health impacts of poor-quality groundwater are widespread, and preventive and curative measures may not receive priority due to institutional inadequacies in monitoring and preventing groundwater pollution.

Table 3 | RO water result (all within acceptable threshold (IS 10500:2012)).

Parameters	Test method	Unit	Result	Requirement as per acceptable limit of IS 10500:2012
Colour	IS 3025 (Part 4):1983	Hazen	1	Max 5
Odour	IS 3025 (Part 4):2018	mg/L	Agreeable	Agreeable
pH	Is 3025 (Part 4):1983	mg/L	7.21	6.50–8.50
Total alkalinity as $CaCo_3$	IS 3025 Part 23:1986	mg/L	76.4	Max 200
Fluoride as F	APHA 23 Edition 4500-F-B D:2017	mg/L	0.10	Max 1.00
Arsenic as As	APHA 23 Edition 4500-F-B D:2017	mg/L	BDL(LOD-0.001	Max 0.01
Manganese as Mn	IS 3025 Part 59:2006	mg/L	BDL(LOD-0.016)	Max 0.1
Nitrate as NO_3	APHA 23 Edition 4500-F-B D:2017	mg/L	3.94	Max 45.0
Turbidity	IS 3025 (Part 10):1984	NTU	0.6	Max 1
Total hardness as $CaCO_3$	IS 3025 (Part 21):2009	mg/L	106	Max 200
Total dissolved solids	Is 3025 (Part 16):1984	mg/L	442	Max 500
Calcium as CA	IS 3025 (Part 40):1991	mg/L	12.0	Max 75
Chloride as Cl	IS 3025 (Part 32):1988	mg/L	128	Max 250
Magnesium as Mg	IS 3025 (Part 46):1994	mg/L	17.8	Max 30
Iron as Fe	IS 3025 (Part 53):2003	mg/L	0.30	Max 1
Sulphate as SO_4	IS 3025 (Part 24):1986	mg/L	62.1	Max 200

Source: Field sample data from the water source (Jivamritam).

3.3. Health issues in the village: Some evidence

We conducted an FGD with a village women's self-help group (SHG) to determine the primary ailments, if any, particularly, water-borne diseases in the community (Figure 4).

The group's biggest complaint about the hand-dug well, which served as their main source of drinking water supply, was that the water tasted salty. The group highlighted a number of common water-borne illnesses, such as skin disorders, hair loss, yellowing of teeth, and diarrhoea. These health issues can be attributed to the high iron content (Tiwari *et al.*, 2016) in the water as shown by the water test results.

The FGD with women SHG also revealed that although the village had a water treatment facility, its frequent breakdowns and remote position from the homes contributed to people preferring untreated water from hand-pumps within homes as their primary source of water. Water pumps are often regarded as one of the most significant interventions in India, wherein the national and state governments had made huge contributions (with varied impacts) in terms of water supply schemes with aid from multilateral agencies, such as the World Bank and Asian Development Bank.

The group noted that households do not prefer RO water as its use involves payment of user charges. They are forced to rely on the contaminated, free water from the hand-dug well because of their circumstance, which has exacerbated the occurrence of water-borne ailments.

3.4. Results of key informant interviews

As part of the study, we also carried out key informant interviews covering 22 household heads out of the total 49 households. The key household heads were randomly selected. Figure 5 provides the incidence of cases of major diseases reported in the village.

Table 4 | Summary of test results, implication of exceeding parameters on health and corrective measures.

Parameters	Description of parameter	Test result	Health and other related implications
Turbidity	Water clarity is measured by turbidity, which rises in direct proportion to suspended sediment concentrations and loading standards. Turbidity is also a dimension of the light scattering effects of Suspended Particulate Matter (SPM) in water. Pesticides and phosphorus are more readily absorbed by sediment particles when there is turbidity (Khatri & Tyagi, 2015; Meride & Ayenew, 2016).	Untreated water 5.4 NTU Treated water 0.6 NTU **Untreated water is far above the Max standard of 1.**	Some studies have found an association between turbidity and endemic diseases, and others have not (Mann *et al.*, 2007). For example, a study conducted in New York established an association between turbidity, diarrhoea, and gastrointestinal illness (Hsieh *et al.*, 2015).
Total hardness as $CaCO_3$	Hard water is defined as water with a high amount of calcium and magnesium ions (Sengupta, 2013).	Untreated water 1,030 mg/L Treated water 106 mg/L **Untreated water is above the maximum limit of 200 mg/L**.	Hard water has a negative impact on health because of its calcium and magnesium salts, which can contribute to hair loss by forming a film on the surface of the hair, making it difficult for moisture to penetrate (Sasikaran *et al.*, 2012).
Total dissolved solids	TDS refers to all inorganic and organic substances dispersed in water, including minerals, salts, metals, or anions (Hussain, 2019). Generally, solids must fit through a 2-μm sieve.	Untreated water 3,748 mg/L Treated water 442 mg/L **Untreated water is more than the maximum threshold limit of 500 mg/L.**	TDS levels in groundwater are generally not harmful to humans, but high concentrations may affect those with kidney and heart diseases. According to Sasikaran *et al.* (2012), water with high solids content can be laxative or constipating. Adult hypertension and saline drinking water are related, with females, older age groups, and people who consume saline water that has been highly concentrated being more vulnerable (Nahian *et al.*, 2018). Individuals may experience constipation problems if there are a lot of solids in their water (Meride & Ayenew, 2016).
Chloride as Cl	Chloride is mainly obtained by dissolving hydrochloric acid. The contamination of chlorides in water may occur due to nearby salty rocks, dissolution of salty industrial wastes, and agricultural or irrigation discharges (Omer, 2019; Devi *et al.*, 2020).	Untreated water 1,129 mg/L Treated water 128 mg/L **Untreated water is far more than the acceptable standard of 250 mg/L.**	Metal pipes, buildings, and plant growth are all affected by high chloride concentrations (Meride & Ayenew, 2016). High chloride levels in drinking water pose little risk to health, but frequent consumption can raise blood chloride levels, a condition known as hyperchloremia (WHO, 2017).
Sulphate as SO_4	Nearly all water bodies contain sulphate and it is derived from	Untreated water 628 g/L Treated water 62.1 g/L	Natural water may contain sulphate concentrations as high as 100 mg/L,

(*Continued.*)

Table 4 | Continued

Parameters	Description of parameter	Test result	Health and other related implications
	sulphuric acid salts (Meride & Ayenew, 2016).	**Untreated water far in excess to the acceptable maximum limit of 250 mg/L**.	but there are no significant negative effects on health (Meride & Ayenew, 2016). People who are not used to drinking water with high sulphate content may experience diarrhoea and dehydration as a result, according to 'The Minnesota department of health'. Compared to adults, babies are more sensitive to sulphate. High concentrations can also cause the water's flavour to change and can corrode plumbing, particularly copper piping.
Magnesium as Mg	The eighth most common element in the crust of the Earth is magnesium, yet it does not naturally occur alone. Minerals like magnesite and dolomite contain significant quantities of it (Galan *et al.*, 2002).	Untreated water 186 mg/L Treated water 17.8 mg/L **Untreated water is far above the 30 mg/L thresholds**.	According to studies, consuming excessive amounts of magnesium and sulphate might cause diarrhoea (Galan *et al.*, 2002). In addition, consuming magnesium and sulphate in water may cause laxative/constipation and a change in bowel habits (Sengupta, 2013).
Iron as Fe	Iron is the fourth most prevalent element, accounting for 5.6% of the crust. Along with geological sources, geogenic iron can also be found in industrial and domestic waste (Kumar *et al.*, 2017).	Untreated water 1.51 mg/L Treated water 0.30 g/L **Untreated water is far above the 1 mg/L threshold.**	Its excessive use results in heart disease, cirrhosis, diabetes, liver cancer, infertility, etc. (Kumar *et al.*, 2017). Adults are substantially more likely than children to experience non-cancerous health hazards from drinking water containing iron and manganese (Ghosh *et al.*, 2020). Oral health may be influenced by the quality of the drinking water consumed. Rebelo de Sousa *et al.* (2012) and Al-Shalan (2009) note that changes in dental enamel colour might result from the presence of iron in drinking water, which can lead to aesthetic issues.

Source: Authors' compilation.

Apart from reporting joint pains that are not directly related to quality of water, most of the other reported diseases are water related. Figure 5 shows that the most common water-related diseases in the village are the reddening of teeth followed by diarrhoea, which is linked to the high iron content of the handpump water. Based on the outcome of the test results, it is evident that the incidence of water-borne infections is likely to decrease over time if households exclusively utilize RO water instead of handpump water for drinking and cooking. This is because the RO water's test results for all parameters are within the safe (permissible) limits. In this regard, Kumar *et al.* (2022) noted that demineralization using an RO system can remove hazardous impurities from drinking water and is cost-effective in areas with high total dissolved solids (TDS), nitrate, and fluoride levels.

Fig. 4 | FGD with women SHG in Nagla Chandi.

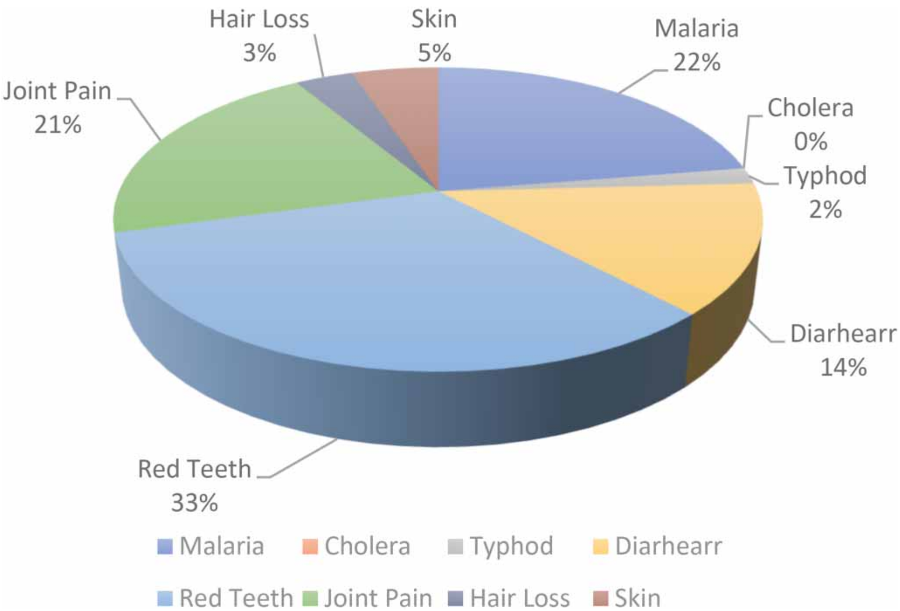


Fig. 5 | Reported major diseases (key Informants). *Source*: Key informant interviews covering 22 household heads.

3.5. Effect of treated water delivery scenario

Apart from the direct effect of drinking untreated water on health outcomes, the status of the quality water delivery system has both positive and negative social, economic, and environmental effects in the village, as shown in Figure 6.

3.6. Improving the Jivamritam model

Most rural water schemes face operational challenges due to lack of technical and managerial skills in local institutions, such as Panchayats. Furthermore, due to low income status and the lack of livelihood opportunities for rural communities, they are unable to pay for treated water at appropriate rates to ensure adequate revenue to fund the O&M of community-based water systems. There are also limited resources for educating communities about groundwater quality issues and treatment methods. Various models have been used in various countries to ensure the sustainability of community-based water systems to improve access to treated water. In what follows, we examine three such models to identify best practices, which can help draw parallels with respect to the Jivamritam model and suggest modifications or improvements needed if any.

3.6.1. Whave model

Whave, a Ugandan social enterprise in Uganda, is an advisory body advocating for improved rural water service delivery through public–private partnerships (Harvey, 2017, 2019, 2021). The enterprise works with local governments to develop regulatory structures and maintenance protocols. As a guaranteed service provider, Whave

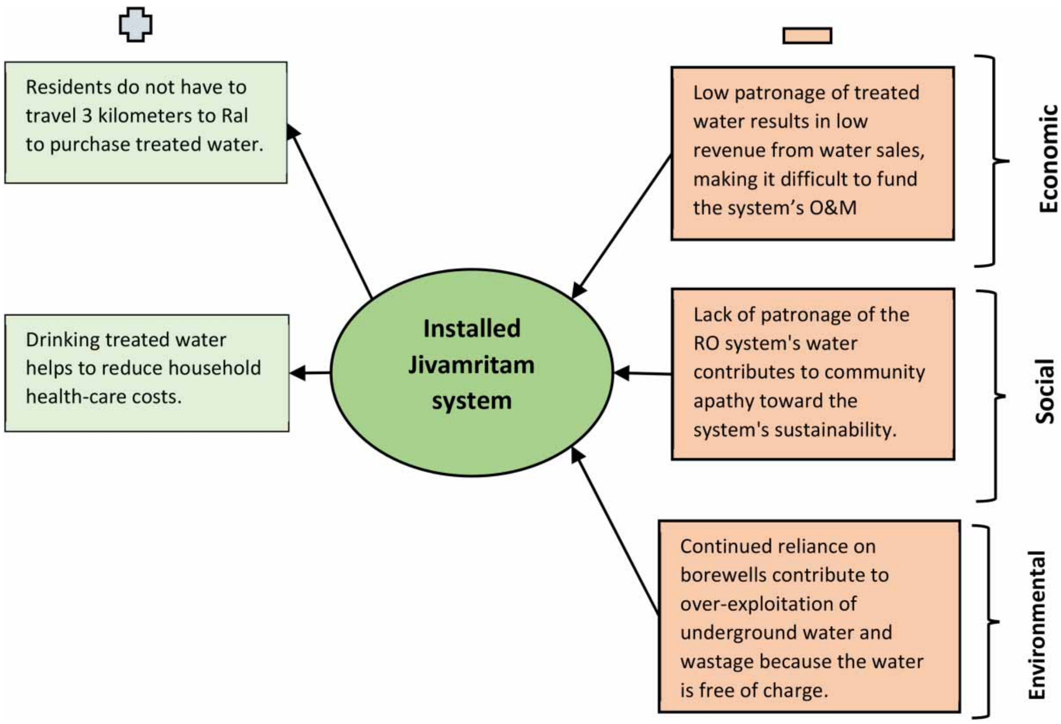


Fig. 6 | Positive and negative effects of treated water delivery scenario.

contracts local handpump mechanics for performance-based payments and ensures water supply functionality. The company works with local governments to develop payment options, including subscriptions (Nyaga, 2020).

3.6.2. Safe Water Network model

The Safe Water Network model (Safe Water Network 2021a, 2021b), used in Ghana and India, is a market-based approach to delivering safe water to communities. The approach involves identifying local water sources, testing for contaminants, and providing capital for treatment systems known as safe water stations. Local community members are trained on station operation and maintenance, and water is sold through ATMs and delivered to households or retailers. User fees cover operating and maintenance costs, while unit costs pay for higher water quality. Technical support is provided by local engineers, and the model focuses on supply chain strengthening. Key performance indicators include cost coverage, financial reserves, and household participation (Nyaga, 2020).

3.6.3. FundiFix model

The FundiFix model (REACH 2016) in Kenya aims to maintain rural water infrastructure through a guaranteed service approach. Local maintenance service providers (MSPs) are established in two counties, Kwale and Kitui, as independent social enterprises. These MSPs, equipped with tools, training, and office space, set up annual performance-based contracts with communities and schools. The local government is responsible for asset replacement and major repairs. Smart monitoring data from hand pump sensors is used to inform MSPs of system conditions and repair needs (Goodall & Katilu, 2016; Nyaga, 2020).

3.6.4. An enhanced Jivamritam model

In developing an enhanced Jivamritam model, we considered the models mentioned above for some key strengths that, when added to the current Jivamritam model, will increase the model's sustainability and ensure reliable access to treated water. The current model needs to be improved in two major areas: institutional elements and supply chain strengthening. The enhanced Jivamritam model is depicted in Figure 7.

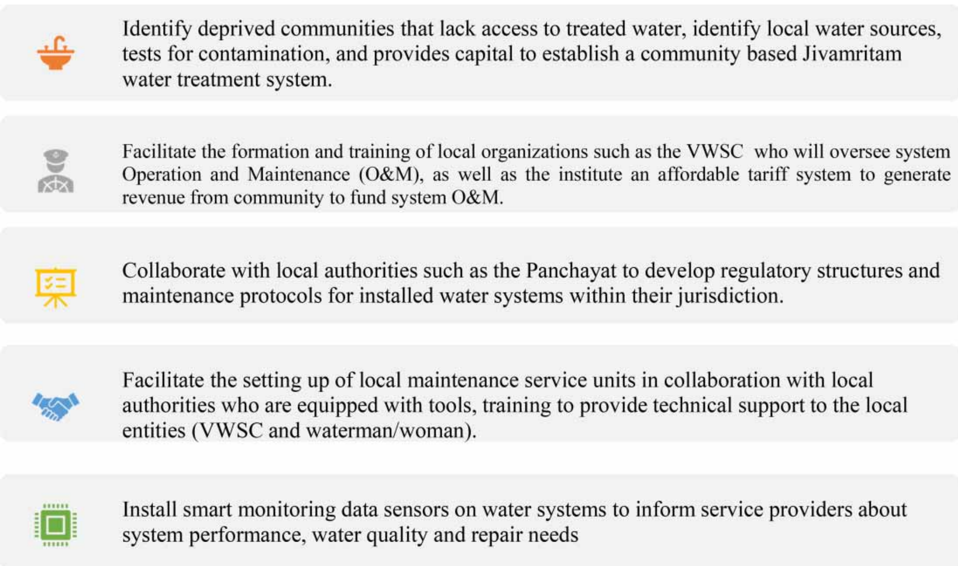


Fig. 7 | Enhanced Jivamritam model.

Table 5 | Conclusion and suggestions.

Key Issue	Details
Performance of water supply system	While the Government of India has clearly demonstrated its commitment to achieving SDG 6.1 through various policy initiatives such as the Jal Jeevan Mission, the population lacking access to treated water is still high in rural India, suggesting the need for improving the performance of rural drinking water supply systems.
Functionality of rural water systems	We used participatory rural appraisal to assess socioeconomic factors contributing to the situation in household water supply and use and sanitation situations in the study village. The outcome of the water quality test emphasizes the need for more efficient and functional water filtration systems, such as the Jivamritam, to provide reliable treated water to rural Indian communities.
Investment in rural water infrastructure	Investment in rural water infrastructure is critical for achieving government policy objectives and interventions in the water sector. Furthermore, water delivery stations need to be installed within a cluster of houses to reduce the distance travelled in the village to collect treated water. Long-term plans for connecting pipe systems from treatment plants to homes are also needed, as many residents continue to rely on treated water as their primary source of drinking water.
Technical skills development	It is critical that local artisans or caretakers are trained to repair and maintain water treatment systems that are installed in the villages. In addition, the local government bodies may incorporate trained engineers who will oversee the working of the water schemes and provide technical assistance as needed at the village level. Furthermore, because broken system parts can be difficult to replace, organizations that provide water treatment systems in collaboration with local institutions need to make arrangements with spare part dealers to stock their shop with the necessary parts so that they are available when needed.
Funding for rural water delivery	Village water systems require reliable sources of funds for operation and maintenance. To address the challenge of low-income village dwellers, it is important for the Village Water and Sanitation Committees (VWSCs) to facilitate community discussions on affordable water user charges. These charges can be paid at the point of purchase or levied on households, with periodical rendering of accounts to build trust. Full community patronage ensures adequate funds for operation, maintenance, and future expansion of village water treatment systems. The introduction of water ATM and the use of smartcards for water purchase can also be employed to improve access.
Subsidize water quality test for rural communities	To make it easier for VWSCs and local organizations to test the quality of drinking water and take necessary steps to correct it, the costs of examining the quality of water for potability should be assisted and rendered obtainable especially in rural communities. To maintain water supplies, quality, and ensure a balance between usage and sustainability, competent monitoring and management

(*Continued.*)

Table 5 | Continued

Key Issue	Details
	are required. Also, there is a need to expand the monitoring network by setting up water monitoring stations at the local level and conducting seasonal monitoring and assessments of all water sources. Where contamination is found, action plans for dealing with the sources need to be developed and operationalized. This should also include building well-equipped laboratories with well-trained workers. The resulting data should be made public. Creating, analysing, and exchanging data are all essential components of effective water management. A geographic information system can facilitate mapping, modelling, and decision-making.
Sensitization on the sustainability of public utility services	The study highlights the low patronage of treated water due to cost concerns. It is important that communities recognize that scarce resources, such as water, are priced to reflect their scarcity value. Sensitizing local communities on the importance of public utility provisioning is critical because it will help them overcome water security and quality water provisioning challenges. Local organizations such as CSOs and relevant government agencies are key stakeholders who can carry out this sensitization initiative. Educational institutions in communities can also sensitize students, and temples can be used as avenues to sensitize devotees about the importance of maintaining public utility services and their role in doing so. To increase acceptability and improve access, the community must collectively fix the price of water from water systems such as the Jivamritam at an affordable rate in order to achieve economies of scale.
Strategic water quality management plans and funding for monitoring water quality in rural areas	The creation of strategic plans for managing water quality is essential, and donor support as well as funding by the local governments should be focused on local water quality monitoring systems. This will enable the national and local governments to devote equal weight to the priorities of water supply and water quality. This study also describes the drinking water quality in the community and its effects on health outcomes in the village context. Nevertheless, more research is required to understand how local water quality influences food, nutrition, child development, health, and wellbeing of households in the villages in India.
Future research direction	Future research into how to incorporate self-service mechanisms using smartcards into community water system design is critical to improving access. Most community-based water systems require water venders to be physically present to sell water to community members or the purchase and installation of water ATM systems at a cost that is frequently out of reach for local communities. Furthermore, more research is required to develop low-cost methods of testing water quality at home. This will allow household and VWSCs to periodically test the quality of the water they drink and take remedial action when required.
Limitation	This study is limited in scope as it is specific to a particular village context. However, the proposed solutions are applicable to rural communities with similar context.

4. CONCLUSIONS AND POLICY SUGGESTIONS

The study highlights issues related to the performance and functionality of rural water systems and the need for investment in rural water infrastructure to improve access to treated water. It also emphasizes the need for community sensitization of the sustainability of public utilities and the need for strategic water quality management plans and funding for monitoring water quality in rural areas. A summary of the conclusions, policy suggestions, and future research directions is presented in Table 5.

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AUTHOR CONTRIBUTION

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by MKK, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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