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Water Poverty in Africa: A Review and Synthesis of Issues, Potentials, and Policy Implications

Hatem Jemmali[1]

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Abstract This study details an application of an improved Water Poverty Index (iWPI) to investigate and assess state of water resources in 53 African countries for the period 2000–2012 with a special focus on an international comparison of water poverty among northern and sub-Saharan countries. A multi-faceted approach that combines physical estimates of water availability with socio-economic drivers of poverty and environmental factors, has been used to do such comparison. It is with this in mind that the iWPI was developed based on the theoretical foundations and recent development of the water poverty approach. This would permit an inclusive comprehension of the crosscutting nature of water issues and their impacts on human wellbeing and environment. The results highlight an obvious dissimilarity of water poverty situation between more developed, but water-poor countries located principally in North Africa with that of lower-income and water-rich countries in sub-Saharan region. This can be used to inform policy makers, governments, donors and other stakeholders to assist in prioritization of appropriate policies to be taken towards better service delivery and sustainable water management across space and time.

Keywords Water poverty · Improved Water Poverty Index · Multivariate analysis · North Africa · Sub-Saharan Africa

JEL Classification C43 · Q25 · P28

✉ Hatem Jemmali
hatemjemmali79@gmail.com

[1] Laboratory for Research on Quantitative Development Economics (LAREQUAD), Faculty of Economic Sciences and Management of Tunis, University of Tunis El-Manar, Tunis, Tunisia

1 Introduction

Water as a vital resource is ever more becoming among the most critically stressed resources and is playing a major role in poverty alleviation all over the world particularly in the African continent (Watkins 2006). Access to safe water and basic sanitation facilities is most heavily limited in sub-Saharan Africa[1] where a large part of populations are living in unsanitary conditions even though access to these services is the basic rights of the human being. Notwithstanding Northern Africa[2] and sub-Saharan Africa belong to the same continent, they have made different levels of progress towards the Millennium Development Goal on water. While North Africa has more than 90% coverage (drinking water and sanitation), Sub-Saharan Africa experiences a contrasting case with less than 40% of the total population without access to an improved source of drinking water and sanitation facilities (UN 2012). In Ethiopia, for instance, women with children of the villages are forced to travel long distances on foot to get a minimum level of drinking water. The main cause of such a situation lies in the mismanagement of available water resources, and not the shortage of these resources (Jemmali and Sullivan 2014).

Water issues are intrinsically local, interdependent and almost entirely reliant on the interaction between humans and their socio-technical environments (Alexander et al. 2003). Without appropriate strategies, ad hoc planning and proper assessment there is a risk that water resources management will be unregulated, formless or haphazard and likely to lead to unsuitable decisions and a range of negative socio-economic and environmental impacts (Mason and Leberman 2000). Hence, it is important to put continuous efforts in analyzing and assessing the current status of water resources as a basis for developing efficient water resources management policies taking into account their impacts on the resource itself, society, economy and environment.

In a world that is perpetually changing, considerable population growth linked to socioeconomic development and environmental mutations has been further challenges in water resources management (Kojiri 2008). As a result, any water resources management policies that focus only on physical aspect of water scarcity and ignoring others socio-economic and environmental aspects may lead to negative effects on human well-being and environment. In this regard, a composite index called Water Poverty Index (WPI) has been developed to be a viable way to express the different aspects of water scarcity in a simple and comprehensible form. The index is intended to take into account the whole range of issues related to water scarcity and its relationship to human and ecological needs (Sullivan 2001; Mlote et al. 2002; Lawrence et al. 2003). The WPI has been widely used as a holistic tool to assess the availability of water resources and access to them throughout the world and at different scales: international (Lawrence et al. 2003; Jemmali 2013; Jemmali and Sullivan 2014), national (Sullivan et al. 2006; Heidecke 2006; Sullivan and Meigh 2007; Jemmali and Matoussi 2013), district/basin (Sullivan et al. 2006; Manandhar et al. 2012), sub-basin (Komnenic et al. 2009; van Ty et al. 2010) and community (Sullivan and Meigh 2003; Sullivan 2005; Sullivan et al. 2006).

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[1] The sub-Saharan African countries considered in the current study are: Equatorial Guinea, Gabon, Central African Rep, Angola, Madagascar, Rwanda, Sierra Leone, Comoros, Guinea, Cameroon, Mauritius, Liberia, Cape Verde, Congo, Lesotho, Guinea-Bissau, Malawi, Côte d'Ivoire, Democratic Rep Congo, Ethiopia, Burkina Faso, Burundi, Zambia, Uni Rep Tanzania, Gambia, Ghana, Botswana, Uganda, Swaziland, Senegal, Namibia, Togo, Mozambique, Zimbabwe, Nigeria, Mali, Benin, South Africa, Kenya, Mauritania, Eritrea, Chad, Sudan and South Sudan, Somalia, Niger, Djibouti, Sao Tome and Principe, Seychelles.

[2] North African countries considered in the current study are: Algeria, Egypt, Libya, Morocco, Sudan, Tunisia.

In spite of consensus on the usefulness and accuracy of the WPI, it was widely criticized (Komnenic et al. 2009; Feitelson and Chenoweth 2002; Jiménez et al. 2009; Jemmali and Matoussi 2013; Jemmali and Sullivan 2014). All criticisms revolve around three conceptual weaknesses of the index, including redundancy among variables, the balanced weighting scheme, and the aggregation method. Recent studies (e.g., Pérez-Foguet and Garriga 2011; Jemmali and Matoussi 2013; Jemmali and Sullivan 2014) have attempted to address some of these drawbacks by applying objective weights to all the WPI components using a multivariate analysis.

A number of studies have assessed water poverty situation using the WPI approach at international scale and identified a set of indicators useful for some regions (Lawrence et al. 2003; Jemmali and Sullivan 2014). This reflects that water poverty and indices to represent its different aspects are location-specific and should be carefully selected (Manandhar et al. 2011). The main objective of the current study is to come up with a set of WPI indicators appropriate in the African context, depending on the local situation and data availability; and develop an improved WPI that handles the limitations of previous indices. The obtained iWPI results are then used for water poverty mapping intended to act as a framework for a policy tool that can be useful for monitoring the current and future state of water resources in the continent.

The remainder of the paper is structured as follows: the following section gives an overview of the water issues in Africa; Sect. 3 describes the theoretical and conceptual framework of the WPI; Sect. 4 provides a brief overview of the principal components methodology used to calculate the iWPI and its components scores; Sect. 5 presents the empirical analysis and the main obtained results while the last sections (Sects. 6, 7) are devoted, respectively, to policy recommendations and conclusions.

2 Overall Water Situation in Africa

It's well known that for a long time, the majority of Africa's populations face endemic poverty, food insecurity, lack of water access and pervasive underdevelopment, with almost all countries in the sub-Saharan region lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably. These countries still face great challenges in attempting to attain the United Nations water-related Millennium Development Goals (MDGs) (UN 2012).

To assess the overall availability of water resources supplies, we look firstly at one of the well-known indicators of water scarcity, the Falkenmark indicator called also "water stress index" and "water crowding index". This index, defined as the proportion of the total annual runoff available for each person and usually calculated on a national scale, is founded on linking the water availability (supply) to the human population requirements (demand). The logic underpinning this index is straightforward: if we could assess how much water is required for attaining a basic person's need, then the water availability per capita can be a relevant measure of water scarcity.

Using this index, water resources availability of each African country is computed based on the most recent statistics from the FAO's AQUASTAT (2014) database. Following Falkenmark et al. (1989, 2007), the water conditions in a country could be classified in an ascending order from the worst situation to the best one as: absolute scarcity, scarcity, stress and no stress (see Table 1). Hydrologists commonly consider 1700 cubic meters per person as the minimum national threshold for meeting agricultural, industrial and

Table 1 Water barrier differentiation proposed by Falkenmark

Water availability (m^3 per capita per year)	Category
>1700	No stress
1000–1700	Stress (Moderate water shortage)
500–1000	Scarcity (High chronic water shortage)
<500	Absolute water scarcity

environmental water requirements. Availability below this threshold represents a state of "water stress". If the amount of renewable water is below the 1000 m^3 threshold, a country is said to be experiencing "water scarcity"; while availability below 500 m^3 characterizes a state of "absolute scarcity".

Despite the high water availability in some African countries, the freshwater situation in whole the continent is critical. According to the Falkenmark map (Fig. 1) which presents the distribution of average annual water availability per capita among countries in the continent, it is clear that North African region is the most water-scarce with an average availability below 500 m^3. Three countries of this region (i.e. Tunisia, Algeria and Libya) are already experiencing absolute water scarcity. Contrariwise, the freshwater situation in

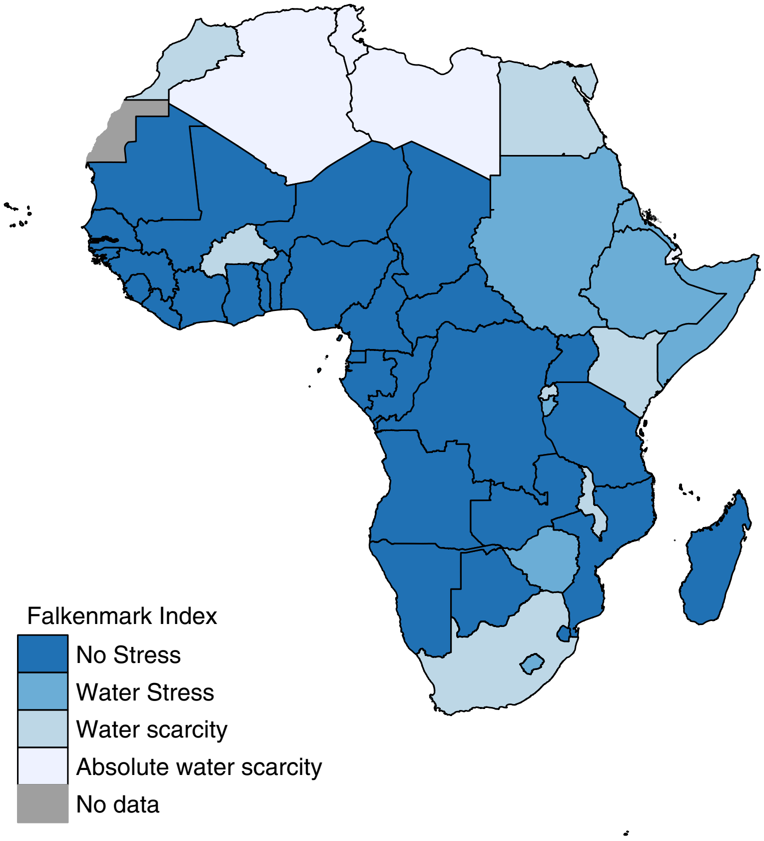

Fig. 1 Falkenmark index

the sub-Saharan region is better; for the most part, the water availability exceeds the 1700 m^3 threshold in this region.

As mentioned above, the Falkenmark index approach is broadly used because it is straightforward, simple to use, intuitive and easy to understand and the data required is readily available at international scale. Nevertheless, such a simplistic method of calculation has its own drawbacks: Firstly, it overshadows the spatial variation of water availability within countries or regions, only assessing water scarcity at a country level and failing to measure water stress at smaller scales. Secondly, it fails too to account for accessibility to current water resources, for example, a large part of freshwater resources included in the calculation of the index may be stored deep underground or may be considerably polluted. Thirdly, it ignores the man-made sources of freshwater such as desalination plants which may increase the amount of water availability beyond what naturally exists. Finally, the Falkenmark index is unable to take account for different uses of available water resources. For this reason, we should use others indicators of water scarcity to overcome a part or all these shortcomings.

When analyzing the trends of access to safe water and sanitation services in Africa as an alternative measure of water scarcity, it is gleaned from the recent statistics that Northern and sub-Saharan regions are progressing towards the Millennium Development Goal on water at different paces. While the majority of the Northern African's populations have a regular access to improved water, most of people in sub-Saharan Africa still suffer from lower access to these basic services. Some of these differences in access can be attributed to various physical and economic factors. Firstly, owing to Africa's severe climates, the sub-Saharan region has an abundant supply of rainfall, but seasonal and irregularly distributed causing regular floods and droughts. Moreover, due to chronic economic development and poverty problems, coupled with high population growth and rural–urban migration the sub-Saharan Africa becomes the world's poorest and the least developed region. Accordingly, these chronic issues hamper populations in this region from regular access to safe water and sanitation services.

Water scarcity has several definitions, it is not only a physical issue; it can also be human-made phenomenon. It is hence necessary to break it down into two general concepts: economic scarcity and physical scarcity. The first kind of scarcity occurs when finding a consistent source of clean water is time consuming and expensive. Otherwise, physical scarcity refers simply to lack of sufficient resources within a given region. Specifically, the Northern Africa, as well as the Southern part (Fig. 1), are the scarcest region in the continent due to rising global temperatures accompanying climate change which has intensified the hydrological cycle that leads progressively to repetitive dryer seasons. This considerably influences the availability, quality and quantity of current water resources that become more and more scarce. The consequences of such physical scarcity in this "water-poor" region include severe environmental degradation, declining groundwater, and unequal water distribution. Contrariwise, the majority of sub-Saharan region suffers from economic scarcity because of the population's shortage of the sufficient financial means to regularly exploit the existing water sources. Both political instability and ethnic conflicts have contributed as well to this deteriorated situation characterized by sever unequal distribution of water resources within the region. Out of the two forms of water scarcity, economic scarcity in this region can be overcome by the construction of several dams and basic infrastructures collecting rainwater from roofs, but this requires economic resources that several countries in this region lack.

3 Theoretical and Conceptual Framework of the WPI

Water scarcity, widely defined as the shortage of access to sufficient quantities of water for various human and environmental uses, is ever more being recognized in many countries particularly in Africa as a severe and rising concern. This concept of “water scarcity” is commonly used by many stakeholders in water sector, such as media, government, non-governmental organizations (NGOs), international organizations (UN and OECD), as well as hydrologists and academic researchers, to highlight regions where water resources are under severe pressure. Nevertheless, despite its large use, there is a divergence in characterizing and assessing water scarcity. Indeed, some areas can be qualified as water scarce in some reports and characterized differently in others. This may create confusion and divergence in answers to the question of which areas are under the most severe water scarcity.

In an attempt to bring the various approaches and methods of assessing both physical and economic water scarcity,[3] multidimensional approaches were developed based theoretically on the Amartya Sen’s capability approach. The core characteristic of such approaches is its focus not only on the measures of water availability and access but also on the measures of people’s capacity to access water. According to these approaches, people can be “water poor” in the sense of not having sufficient water for their basic requirements as it is not available (Lawrence et al. 2003). They may have to walk a long way to get enough water for different uses or even if they have access to water nearby, supplies may be restricted for different reasons. People can be also qualified as “water poor” as they are “economically poor”; though water is available, they cannot afford to pay for it.

The use of a numerical index as a management tool and a measure of water poverty has a long and chequered history. The most recent tentative of development of such indices gave rise to the appearance of composite indices which integrate aspects from different disciplines and nature. The WPI initially developed by Sullivan (2001, 2002) is one of these composite and interdisciplinary indices devoted to multidimensional assessment of water poverty at local and international scales. The underlying conceptual framework of the index encompasses physical water availability, access to water and sanitation, people’s capacity to get and sustain access to available water resources, use of these resources for different purposes and environmental factors that affect water quality and ecological integrity (Lawrence et al. 2003). Based on this theoretical and conceptual grounding, five components of the WPI were developed and defined: physical availability of water assessed by the *Resources* component that encompasses both surface and groundwater drawn upon by communities or countries; *Access* component, not limited only on access to simply safe water for drinking and cooking, but also takes into account access to water for irrigating crops and non-agricultural use; Capacity component intended to assess the economic ability of people in the sense of income to purchase safe water, education and health which interact with income and indicate a capacity to lobby for and manage a water supply; *Use* component that encompasses domestic, agricultural and non-agricultural uses of available resources; and finally, *Environment* component that comprises the ecological factors which are likely to impact on regulation and may affect people’s capacity. It is notable that this conceptual framework was developed as a consensus of opinion from a wide range of physical and social scientists, water

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[3] See previous section for more details about the differentiation between the two concepts.

practitioners, researchers and other stakeholders (more than 100 experts) in order to ensure that all the relevant issues were involved in the developed index (Sullivan et al. 2003). Numerically, the WPI was defined as the weighted arithmetic mean function of the five aforementioned components.

4 Data and Methodology

The methodology used in the current study to review and synthesize the different water issues in the African continent is based mainly on the WPI framework developed firstly by Sullivan (2002) and Lawrence et al. (2003). The index, as mentioned above, consists of five components. Initially, the final WPI score was calculated using the following formula:

$$WPI = \beta_R \times RES + \beta_A \times ACC + \beta_C \times CAP + \beta_U \times USE + \beta_E \times ENV \tag{1}$$

where RES, ACC, CAP, USE, and ENV denote respectively Resources, Access, Capacity, Use and Environment components and ($\beta_R, \beta_A, \beta_C, \beta_U,$ and β_E) are the weights assigned to these components such that $\beta_R = \beta_A = \beta_C = \beta_U = \beta_E = 0.2$. All these water poverty sub-indexes are expressed as percentage and range between 0 (worst situation) and 100 (best situation). Sullivan (2002, 2005), Lawrence et al. (2003) and Heidecke (2006) were so criticized for two conceptual weaknesses: the inadequate technique to combine available data and the poor statistical properties of the resulting composite. While using the same conceptual framework of the Sullivan's (2002) and the Lawrence's et al. (2003) WPI, the main purpose of the present paper is to propose a suitable methodology to assess water poverty that overcomes the aforementioned weaknesses. A detailed explanation of the proposed improvements of the ancient WPI is given hereunder.

Table 2 summarizes the WPI components, indicators and variables used in this study to calculate the final index scores. Five components and a battery of eighteen variables are employed to calculate the WPI. Their conceptual description, method of calculation and standardization are detailed below. It is noteworthy that a range of data-sets used in this exercise are from different sources; a large part of data on freshwater resources is from the FAO's AQUASTAT (2014) database for Africa, while the remaining part of data is drawn from the World Bank Indicators report (2013). The data on the 53 Africa countries covers the period from 2000 to 2012.

The Resource component captures the water availability of each country in the continent taking into account the arbitrariness of external water resources. As mentioned in Table 2, a higher value of this component reflects an abundant availability of water resources, while a lower value indicates a scarcity of water. It combines three separate indices: the first one (R11) is related to water quantity, the second (R12) to external water resources, and the third (R13) to precipitation patterns.

It is well known that shrinking in water resource availability will arise conflicts over the resource use while higher water availability levels (less stress) indicates the greater resilience of the society over direct access to water resources (Sullivan 2001). Hence, the per capita annual water resource availability (R11) could be used as an indicator of the population pressure on available water resources (Sullivan 2001). After using the *log* transformation to reduce the distortion caused by high values, it is standardized using the min–max approach which normalizes some indicators to have an identical range [0, 100] for all countries (see Eq. 2) (Nardo et al. 2005).

Table 2 iWPI structure: indicators and variables. *Source*: adopted and modified from (Sullivan 2001; Lawrence et al. 2003; Heidecke 2006; Pérez-Foguet and Garriga 2011; van Ty et al. 2010; Jemmali and Matoussi 2013; Jemmali 2013)

Component	Indicator	Variable	Target
Resource	Availability (R1)	Per capita annual water resources (R11)	High R11-Less water poverty
		Dependency ratio (R12)	Less R12-Less water poverty
		National rainfall index (R13)	High R13-Less water poverty
Access	Water supply (A1)	Percent of population with access to water supply in rural areas (A11)	High A11-Less water poverty
		Percent of population with access to water supply in urban areas (A12)	High A12-Less water poverty
	Sanitation (A2)	Percent of population with access to improved sanitation (A21)	High A21-Less water poverty
	Irrigation (A3)	Percentage of area equipped for irrigation (A31)	High A31-Less water poverty
Use	Domestic (U1)	Per capita per day domestic water use (U11)	High U11-Less water poverty
	Agriculture (U2)	share of water use by agriculture adjusted by the sector's share of GDP (U21)	High U21-Less water poverty
	Industry (U3)	share of water use by industry adjusted by the sector's share of GDP (U31)	High U31-Less water poverty
Capacity	Economic capacity (C1)	GDP per capita (current US$) (C11)	High C11-Less water poverty
	Social capacity (C2)	Under-five mortality rates (C21)	Less C21-Less water poverty
		Percent of the total population undernourished (C22)	Less C22-Less water poverty
		Literacy rate (C23)	High C23-Less water poverty
		Life expectancy of male (C24)	High C24-Less water poverty
		Life expectancy of female (C25)	High C25-Less water poverty
		Employment rate (C26)	High C26-Less water poverty
Environment	Environment (E1)	Water effects on ecosystem (E11)	High E11-Less water poverty

$$x_i^* = \frac{x_i - x_{min}}{x_{max} - x_{min}} \times 100 \tag{2}$$

where x_i is the value of variable x of the ith country, x_{min} and x_{max} being respectively the lowest and highest values of the considered variable. In order to compare how different countries in the continent depend on external water resources, the dependency ratio[4] is computed following the same method described in FAO/BRGM (1996). The dependency

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[4] The ratio does not consider the possible allocation of water to downstream countries.

ratio of a country is an indicator expressing the part of the water resources originating outside the country. Unlike the R11, this indicator (R12) is normalized differently using the Eq. (3):

$$x_i^* = \frac{x_{max} - x_i}{x_{max} - x_{min}} \times 100 \tag{3}$$

A country with a R12 equal to 0% receives all its water from outside without producing any water internally. The third indicator (R13) of water availability is the national rainfall index (NRI), defined by the Food and Agriculture Organization of the United Nations (FAO) as the national average of the total annual precipitation weighted by its long-term average. In order to get the indicator value ranging between 0 and 100, the min–max normalization formula, defined in Eq. (2) is used.

Adequate access to safe water sources and sanitation facilitates is necessary for better hygiene and sanitation conditions (Curtis et al. 2000). It reveals basically the ease of access to water for different human needs, such as drinking, cooking, agricultural and non agricultural requires which is crucial (but not sufficient) to eradicate extreme poverty in Africa (Sullivan and Meigh 2003). In order to take into consideration the differentiation in infrastructure between rural and urban areas, two variables are selected to assess access to safe water; one for access to water in rural zones and another for access to water in urban ones. The two percentages added to sanitation variable are *log* transformed and normalized using the formula showed in Eq. (2).

The Capacity component exhibits the effectiveness of citizens' capability to purchase and/or manage required water. Due to strong liaisons between society's ability and water management, the importance of integrated water resources management is more and more being recognized (Appelgren and Klohn 1999). Hence, it's easy to distinguish between two different kinds of capacity: economic capacity that permits access to safe water sources and technology to cope with water related issues while the social capacity push people increasingly to be aware of water, sanitation, health and environment issues (Sullivan and Meigh 2003; Pandey et al. 2011). Using the same methods of transformation and normalization cited above (Eq. 2), the only indicator of economic capacity, the GDP indicator, can be easily computed. Similarly, the rest of social capacity indicators are calculated using the *log* transformation and min–max method for normalization. Only the first two variables (undernourished population percentage and under-5 mortality rate) are normalized according to the formula described in Eq. (3).

The *Use* component correlates the ways in which water resources are used for various purposes (domestic, agricultural and industrial uses) and its contribution to the wider economy as water use is a key factor influencing the human activity and its consumption tends to rise with economic development (Sullivan 2001). As shown in Table 1, the index is evaluated by three indicators; the first indicator, the domestic water use per capita (U1), reflects the current state of resource use in daily household activities (such as cooking, hygiene, laundry…). Following Lawrence et al. (2003), the U1 component takes 50 L per person per day (lpcd) as the reasonable target for underdeveloped and developing countries (see Gleick (1996) for more details about the adoption of this standard) and 150 lpcd as the max [water ceiling that fulfills all water requirements (Lawrence et al. 2003)]. A three-way index is computed such that the value of the U1 for countries at 50 lpcd is equal to 100 (optimal use) and countries both below the minimum (under use) and above the maximum (excessive use) have lower value on the index the higher they are below 50 lpcd or above 150 lpcd (see Eq. 4).

$$USE_i = \begin{cases} \frac{x_i}{50} \times 100, & x_i \leq 50 \\ 100 - \frac{x_i - 50}{x_{max} - 50} \times 100, & 50 \leq x_i \leq 150 \\ 100 - \frac{x_i - 50}{x_{max} - 150} \times 100, & 150 \leq x_i \end{cases} \quad (4)$$

In order to assess the water use efficiency in agriculture and industry sectors taking into account its share in the economy, two indices (U2 and U3) are involved in the calculation of the overall score of the *Use* index. These two indicators are computed by dividing respectively the share of agricultural and industrial sector in GDP by the percentage of water withdrawals used for agricultural and industrial uses (Lawrence et al. 2003). The two indicators are similarly standardized using the same normalization formula mentioned in Eq. (2).

Finally, the Environment component attempts to evaluate the degree of environmental integrity by assessing the level of water quality and stress. Due to lack of some data, the only indicator used is the water effects on ecosystem indicator calculated by the Yale University's Centre for Environmental Law and Policy[5].

4.1 Aggregation and Weighting

After the calculation of the eighteen indicators, an appropriate weighting scheme is used to aggregate objectively all indicators in one composite index. The Balanced approach based on equal-weighting scheme used initially by Lawrence et al. (2003) and Heidecke (2006) has been criticized on different grounds. Even the first users of the index among others, have addressed some drawbacks of the existing WPI and have recommended further investigation to develop more appropriate and objective weighting scheme.

Before aggregation of different components, all variables shown in Table 2 need to be analyzed before computing the ten indicators. The final selection of these variables necessitates a balance between redundancy and comprehensiveness to avoid the issue of double-counting that may bias the obtained results (Hajkowicz 2006). In this regard, multivariate statistical method is used, similarly to previous studies, to investigate whether selected variables are statistically well-balanced or not. All variables are quantitative, then a Principal Component Analysis (PCA) is applied to estimate the scores of each component index, with the purpose of reducing the total number of variables in a set of fewer uncorrelated components (Pérez-Foguet and Garriga 2011). For each sub index, all variables transformed and normalized are entered into a correlation matrix and a *Varimax* orthogonal rotation with "variance explained criterion" is performed to keep enough factors accounting for at least 80% of the total variation. Table 3 shows that 12 principal components are generated, thus six variables are rejected from the iWPI calculation. Moreover, the proportions of the variance in the dataset that principal components accounted for are mentioned in details in Table 3. Each component index is then calculated as the average of considered raw variables that load most heavily on each principal extracted component.

The last step is the aggregation of obtained components. Assuming the non compensability between different variables, failure in one of the five components can't be compensated by success in another. Thus, poor performance in some attributes is penalized more heavily. To this end, the weighted multiplicative function is used as the most

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[5] This indicator is part of the environmental sustainability index which provides a composite profile of national environmental stewardship based on a compilation of indicators derived from several datasets.

Table 3 Principal components and discarded variables at sub-index level

Component	Remained variables	Explained variance (%)
Resource	2 out of 3 (R11, R12)	90.07
Access	3 out of 4 (A11, A21,A31)	90.46
Use	3 out of 3 (U11,U21, U31)	100
Capacity	3 out of 7 (C22, C23, C25)	86.97
Environment	1 out of 1 (E11)	100

In brackets, variables kept in the calculation of the five components index

suitable aggregation function for estimation of the final WPI (Pérez-Foguet and Garriga 2011; Jemmali and Matoussi 2013; Jemmali and Sullivan 2014). The weighting scheme is assigned through PCA technique, which determines objectively the set of weights explaining the largest variation in the original principal component (Slottje 1991). Weights are determined using factor loading scores and principal component extracted according to “variance explained criterion” and weighted with the part of standard deviation (square of eigenvalue) in the original set of variables explained by the first principal components of that particular component. The greater the proportion, the higher the weight. Solely, the first three principal components are extracted to determine the appropriate weighting scheme as the cumulative of variance explained by these three components reach the 80% threshold. Numerically, weight (w_i) of each index i can be formulated as follows (Nardo et al. 2005; Rovira and Rovira 2008):

$$w_i = \sum_{k=1,2,3} PCk_i \times \frac{\sqrt{\lambda_k}}{\sum_{j=1,2} \sqrt{\lambda_j}} \tag{5}$$

where PCk_i is the factor loading of the ith index, which can be Resources, Access, Capacity, Use and Environment, on kth principal component also called component loading.

Since the values of weights deducted from the characteristic vector associated, do not sum to unity, the iWPI will not lie between 0 and 100 without rescaling. Table 4 summarizes the simple and improved weighting schemes that will be used, respectively, in the calculation of the classical WPI (cWPI) and the iWPI. The comparison between the two weighting methods, applied at the sub-index level (components) and referred to here as the cWPI (the weights are simply determined by the number of components) and the iWPI (the weights have been determined using PCA), shown in Table 4, reveals that the two approaches yield nearly to the same equal weighting scheme. Notwithstanding this similarity in weighting schemes, it is clear that while the first approach (cWPI) is simply the implicit weights; the second approach, developed in the current study, is based on a well-established robust statistical method. In terms of index results interpretation, it is of primary importance to provide an appropriate and compelling justification for the specific weighting scheme adopted.

At this level, since the five components can not compensate each other’s performance, a multiplicative function is used for the aggregation. The iWPI is then assumed as a weighted geometric average of the five components as follows:

$$iWPI = \prod_{i=R,A,C,U,E} X_i^{\mathrm{w_i}} \tag{6}$$

where iWPI is the value of the improved Water Poverty Index for a particular country, X_i refers to the ith component (Resource, Access, Capacity, Use and Environment) and w_{i} is the weight attributed to that component. It is noteworthy, as shown in Table 4, that Use is

Table 4 Weighting scheme

Component	IWPI's weighting scheme	cWPI's weighting scheme
Resources	0.314	0.2
Access	0.202	0.2
Capacity	0.319	0.2
Use	0.019	0.2
Environment	0.145	0.2

Table 5 Pearson's correlations among the five iWPI sub-indexes

	RES	CAP	ACC	USE	ENV
RES	1				
ACC	0.2350	1			
CAP	0.3885[a]	0.4107[a]	1		
USE	0.0097	−0.3742[a]	−0.2733	1	
ENV	0.5338[a]	−0.1503	−0.0174	0.3976[a]	1

[a] Correlation is significant at the 0.05 level

the lower weighted component, while Resources, Capacity and Access components are considered having the great importance (0.3), i.e. any change in the value of the former indices will induce an important variation in the value of the final index.

Using the weighting scheme shown above and the iWPI formula (see Eq. 6), the calculated index ranges between 0 and 100. The highest value of the iWPI calculated, 100, is taken to be the most excellent situation (or the lowest possible level of water poverty), whereas 0 is the worst (or the more severe situation of water poverty). Finally, it has been stated previously that weak relationship among components is a required property, as correlated variables may cause redundancy which could reduce the utility of the obtained results. In this regard, to verify the robustness of the obtained iWPI scores and to provide some insights into the degree of correlation among the ten possible pairs of the five components, the values of Pearson's product moment correlation coefficient (r) are calculated (Table 5). Two main points are apparent from the Table 5 and Fig. 8: Firstly, all components are weakly inter-correlated (the high significant score is 0.53) which proves that these components are not redundant within them, being all lower than 0.7 (see Table 5). Secondly, the figure shows that only the Resources component is strongly correlated with iWPI. This may imply that being water poor depends largely on water resource availability and haven't sufficient water resources, constitute a major handicap even for more developed countries in the African continent.

5 Empirical Analysis and Discussions

As mentioned above, water poverty is a multidimensional and highly heterogeneous phenomenon. Its spatial distribution broadly differs between and within various geographic and administrative locations. Water poverty mapping allows an obvious depiction of such heterogeneity, and affords a widespread data framework that combines socio-economic, physical and ecological information (Henninger and Snel 2002; Sullivan 2002). The resulting iWPI is presented in details in the Table 7 (Appendix). The table reveals the values of the five components (RES, ACC, USA and ENV) the iWPI final scores, and

Table 6 HDI, iWMPI, cWPI, and iWPI component scores (a) North Africa, (b) sub-Saharan Africa

	Mean	SD	Min	Max
(a)				
HDI	0.689	0.07	0.591	0.769
iWMPI	43.58	9.75	28.71	52.12
cWPI	45.66	4.79	39.73	50.59
Resources	41.01	19.18	12.27	64.04
Access	82.48	11.32	69.13	99.57
Capacity	58.03	7.73	49.50	64.69
Use	31.54	9.84	15.97	39.08
Environment	15.22	9.41	8.92	30.73
(b)				
HDI	0.464	0.112	0.304	0.806
iWMPI	51.88	11.67	30.88	87.99
cWPI	52.42	9.83	35.04	80.09
Resources	47.89	21.97	19.63	95.81
Access	62.71	13.66	30.40	91.87
Capacity	58.24	11.58	38.61	95.72
Use	45.49	11.64	0.06	96.11
Environment	47.76	21.10	11.95	100

cWPI. The fifty countries[6] are in descending order of the iWPI scores ranging from the less poor country (Equatorial Guinea) to the most poor one (Egypt). In order to do a comparison between the iWPI's and the cWPI's results, a column that contains the cWPI scores is added to the Table 7. The cWPI is calculated using equal weights for all the components arguing that no convincing reason to favor one over another was found.

The results shown in this Table reveal, as expected, an obvious dissimilarity in terms of Resources, Access, Use, Capacity and Environment between the Northern Africa and the sub-Saharan Africa. The levels of water poverty assessed by the two indices iWPI and cWPI are as well so different between the two regions. It is noteworthy from the table that the ranking by the iWPI is not quite different from that based on the cWPI. This is due mainly to the similarities between the two indices in weighting the different components (see Table 4). To focus more on the disparity between the two regions, some basic statistics of different indices computed for each region are shown in Table 6. A comparison of the descriptive statistics among the iWPIs of the two regions reveals that the iWPI values in the northernmost part of the continent are found to be lower in average (mean = 43.58; SD = 9.75) than the average of the index values in the sub-Saharan region (mean = 51.88; SD = 11.67) (see Table 6). Same figure is observed when using the cWPI as an assessment of the water poverty. For the sake of clarity, we provide hereafter a detailed explanation of the such disparity using the water poverty mapping (WPM) to explore and document the levels of water poverty in the two regions (Cullis 2005).

Figure 2 points up the spatial distribution of water poverty at the international scale, based on the iWPI scores. It is gleaned from this map that water poverty in Africa follows a heterogeneous spatial pattern, ranging from 28.71 (Egypt) to 87.99 (Equatorial Guinea).

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[6] Due to missing data in the calculating of some indicators, the iWPI could not be computed for the three countries: Djibouti, Sao Tome and Principe, and Seychelles.

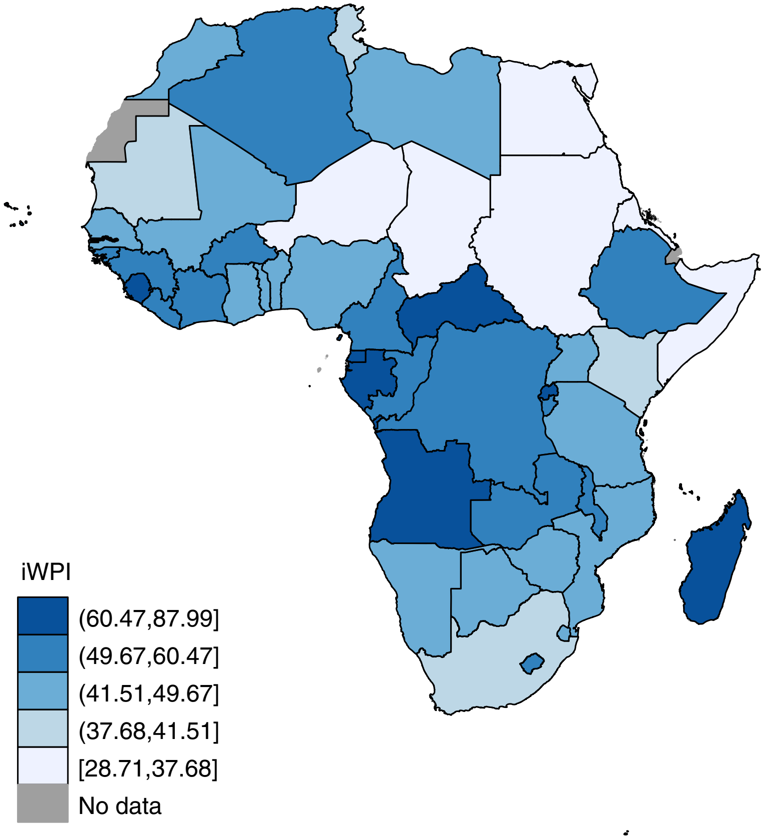

Fig. 2 Improved Water Poverty Index

Looking at the bottom of the ranking (iWPI < 38), shown in Table 7 and the iWPI map (Fig. 2), we find one North African country and five sub-Saharan countries where low iWPI scores reveals the highest levels of water poverty in the continent. These latter countries are hence qualified as "water poor" countries. On the contrary, at the top of the ranking (iWPI > 60.00) we find the most "water rich" countries which are mainly located in the sub-Saharan Africa, in the Central and the Western parts. To decipher the main causes and aspects of such dissimilarity in water poverty, a closer analysis of the spatial distribution of different components is highly recommended.

When we dig deeper into water poverty differences, it can be gleaned that the lower-ranked countries, the most water-poor nations in the continent, are lower scored at least in one of the five components rankings because the used multiplicative (geometric) function in the index construction does not permit compensability among the different variables. Countries, found to be the least water-poor, are not penalized by any component index, and at least two of them score higher than 70. A closer analysis of the the Resources map (Fig. 3) illustrates that higher values of this component occur; similar to what might be expected, in the sub-Saharan Africa, where water resources are much more abundant with low dependency on external flows. Despite this relatively "water wealth", some countries in this region, being unable to provide regular access to improved water to their populations (Fig. 4), face serious socio-economic problems (Fig. 5).

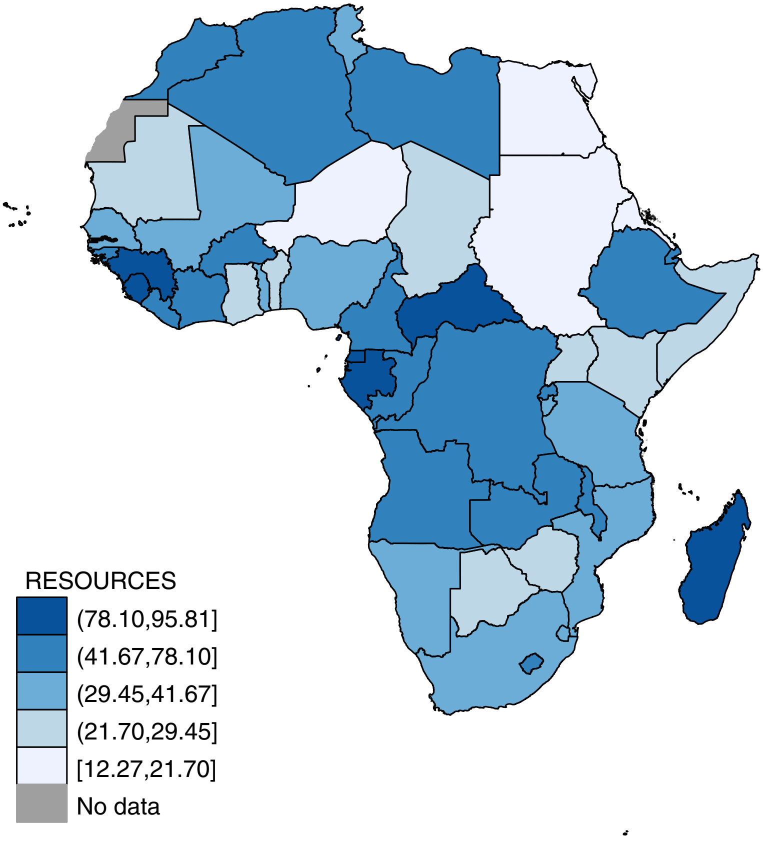

Fig. 3 Resources Index

When focused on the Capacity map (Fig. 5), one might concludes that in sub-Saharan region, where average HDI is equal to 0.46 (Table 6), the institutional capacity to manage water facilities is far from being satisfactory. This is due mainly to the absence of industrial development and appropriate poverty alleviation strategies in most of the sub-Saharan countries particularly the underdeveloped ones such as Niger, Chad, Ethiopia and Somalia. Even though water resources in this region are largely available, some countries are not able to presume their management commitment because qualified staff and required funds aren't enough available to construct appropriate water related infrastructures such as dams and reservoirs or to improve the existing water network system.

With an average HDI over the sub-Saharan countries of just 50% (Table 6), North African countries appear to be well ranked compared to the latter countries according to the Capacity and Access Indices (Table 7). In this respect, it can be easily observed from the Access map (Fig. 4) that nearly all North African countries are able to provide adequate access to safe water, sanitation services and irrigation system to their populations, while access to these basic services in some sub-Saharan countries (such as Mali, Niger and Chad) is the lowest in the continent.

It is noteworthy when looking simultaneously at the Falkenmark and Resources maps (Figs. 1, 2), that the majority of North African countries (except for Egypt) are found to be abundant with water resources according to the Resources map (Fig. 2), but they are shown

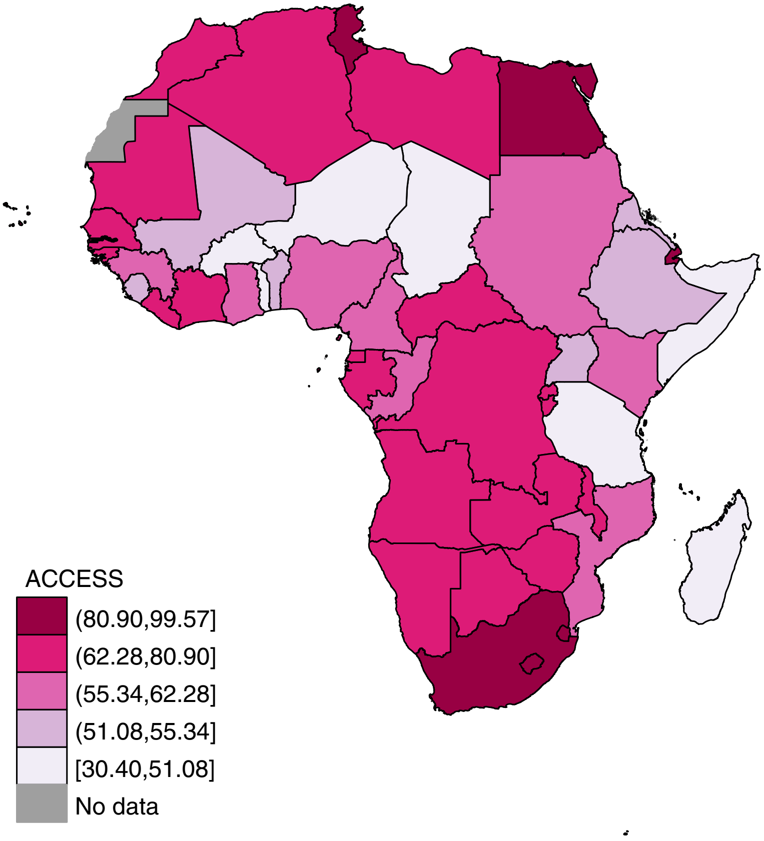

Fig. 4 Access Index

in the Falkenmark map (Fig. 1) to be under severe water stress conditions. The dependency ratio (R12), introduced into the Resources index, is the main cause of this contradiction. For example, Tunisia, Libya and Algeria, considered according to the Falkenmark map as severe water-scarce countries, are shown differently in the Resources map as not under water stress conditions. In this regard, we should mention that the Falkenmark index is criticized for not taking into account the arbitrariness of external water inflows that are less secure than those generated internally within a country.

Even though the current conditions in the North African region score quite well compared to the sub-Saharan region; average of Resources, Access and Capacity indices are respectively 41.01, 82.48 and 58.03 (see Table 6), there are pressures, which may prevent the efficient use of water, particularly in the agriculture sector. According to the *Use* map (Fig. 6), it's clear that the entire Northern region belongs to the lower class. This finding implies that different water users in this region have to use current water resources more efficiently to preserve this vital resource for them and future generations. At last, it is gleaned from the Environment map (Fig. 7) that the environmental impact of water use appears to be fairly severe in Central Africa and more severe in Northern and Southern parts. To overcome this situation, water quality surveillance needs to be improved in these regions, both in terms of efficiency and periodicity. It is also noted that only one indicator has been used to define this environment component, hence not only a deeper analysis

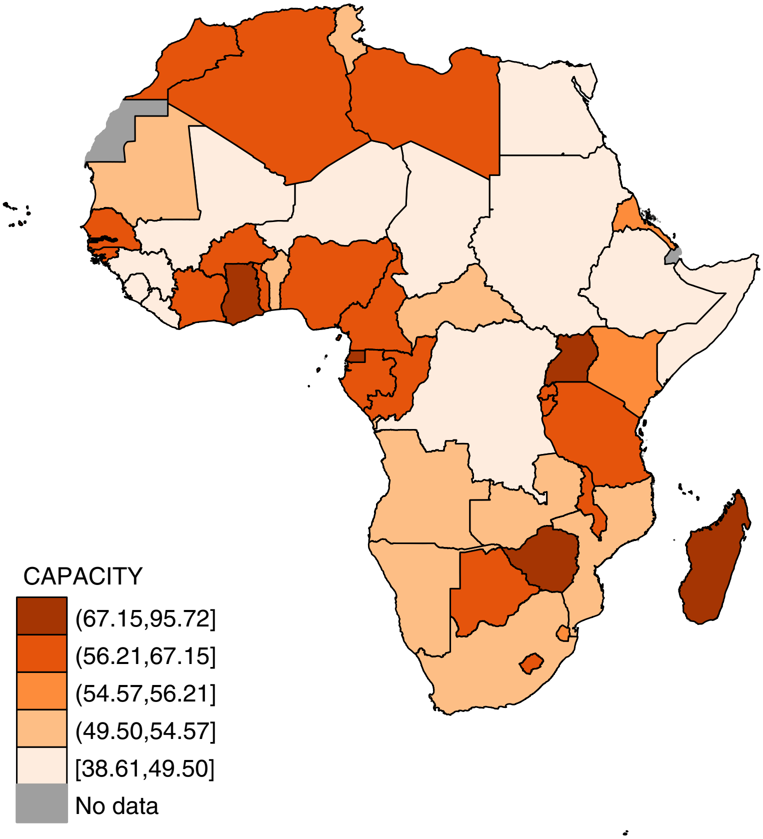

Fig. 5 Capacity Index

might be required, but also ameliorates access to supplementary data sources to draw a more accurate picture of the situation is so needed in the future.

6 Policy Implications

The main objective of the current exercise is to document how water poverty mapping based on an improved version of the WPI can assist the water management in the African continent. It should assist with as many as possible of the subsequent aspects: the collection and investigation of all relevant data concerning the availability of water resources, its different uses, current supply status, current water allocation details and the state and processes of water deprivation, and dissemination of information and recommendations arising from the exercise thereof to all concerned (governments, water service providers, organizations…). The water poverty mapping developed in this study is intended to serve as managing tool for the review and synthesis of various water related issues in the African continent giving direction to managerial policy and appropriate allocation of resources. It can also become an important political tool, allowing both experts and the lay public the possibility of judging the effectiveness of government policy, which in turn, guides

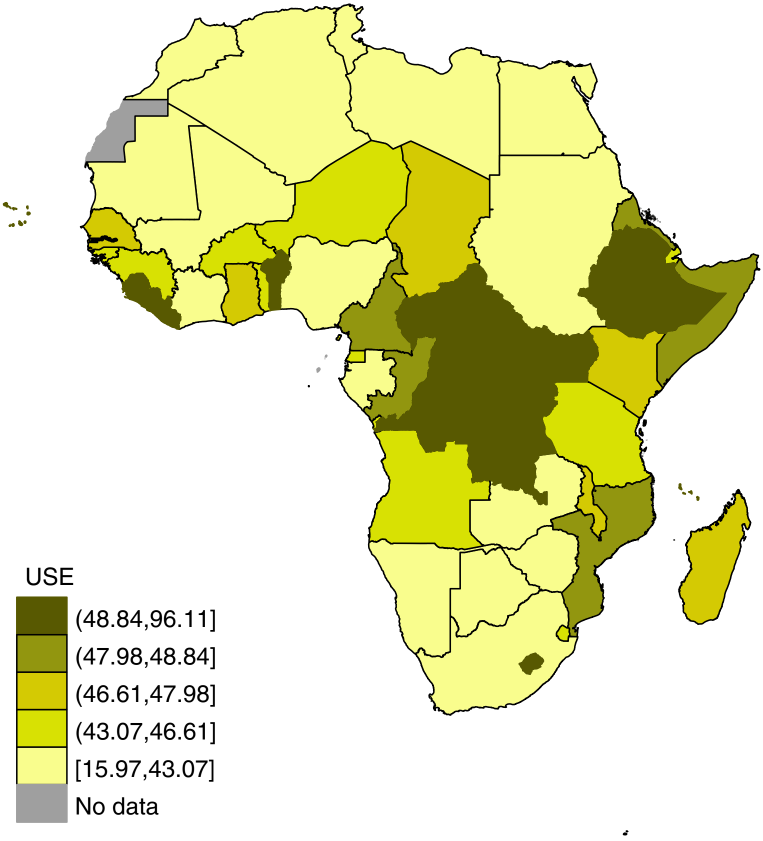

Fig. 6 Use index

infrastructure development and water management strategy. It affords a powerful tool for maintaining monitoring, assessment and comparative analysis as well as targeting and prioritization. Indeed, the water poverty mapping helps to recognize countries or regions that need urgent actions toward alleviation of the severity of water scarcity issues and to understand the origins of water conflicts in some basins in the continent.

When used index values as performance indicators, this approach reveals its accuracy to discriminate among countries in the continent, and permits comparison analysis to be done by recognizing the issues and success of each region. Identifying differences among various water poverty indicators might be of primary importance given that policies and sector strategies depend mainly on the aspects of water scarcity being addressed (physical, socio-economic and ecological aspects). For this reason, iWPI and its components are investigated jointly to provide an accurate and relevant assessment of the complexity of water issues in the African continent.

As policy recommendations, we suggest from this study that more awareness of resource providers, international and national organizations, donors, governments, researchers and civil society, should be raised on the water research thematic among African countries. In fact, the revealing negative effects of inappropriate management of existing water resources particularly in sub-Saharan region are heavy on the society since

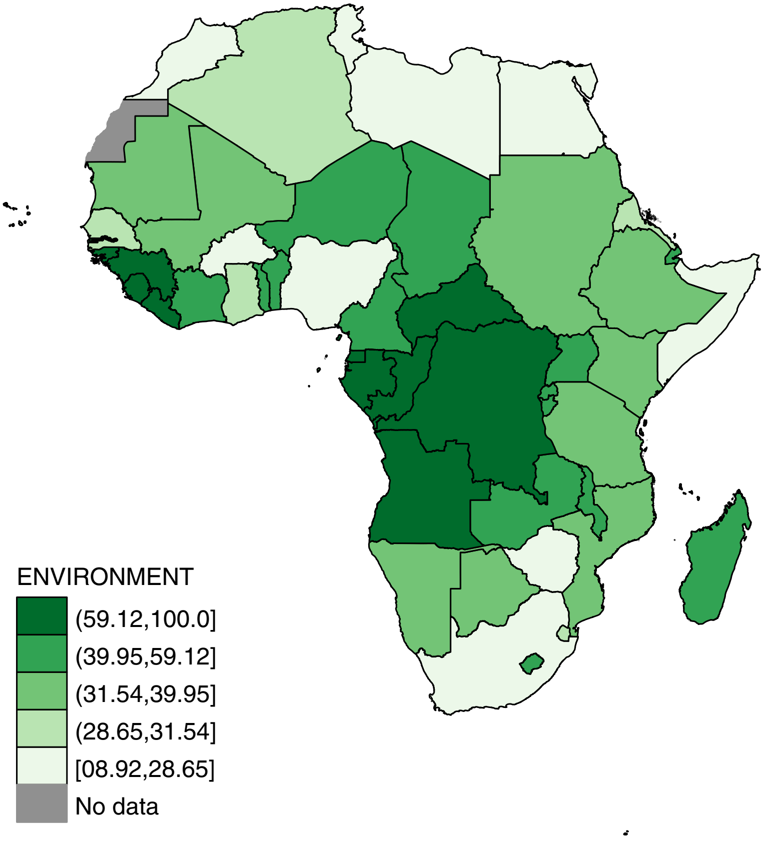

Fig. 7 Environment Index

water poverty hinders development and hampers economic growth. To avoid such issues and provide enough water for different users, policy-makers need an obvious framework on which their decisions can be founded. To this end, a multidisciplinary approach is adopted in this study to merge the physical, environmental and social dimensions which are affecting the sustainable development of water resources. This approach provided a holistic tool, the iWPI, intended to explore and better comprehend water and poverty nexus in the African continent. The iWPI proposed focus on enhancing water management performance across the African Continent, particularly the most "water poor" countries.

The analysis and findings presented in the current study have also been focused on demonstrating the considerable potential of water management as part of a country's poverty alleviation strategy. Indeed, lack of access to safe water sources and sanitation facilities either due to water scarcity (Northern region) or poor management and distribution of existing resources (sub-Saharan region), perpetuates undoubtedly poverty in these regions. Any improvement in access to such vital resource will surely free up. time and enable households head to provide their children with a healthy start in life.

Besides, the paper emphasizes the importance of water related infrastructures such as dams and reservoirs that permits better water management particularly in case of inundations and droughts. Some countries, specifically the poorer ones, in Horn of Africa and majority of the sub-Saharan region, exposed frequently to such natural disasters, haven't the required economic resources and funds to implement such investments. That's why international and national organizations should collaborate together to provide more opportunities to finance these important investments. At the same time, all stakeholders (policy-makers, practitioners, civil society…) should participate in enhancing development programs and anti-poverty processes in these countries.

7 Conclusion

As has been argued previously, inadequate management of water services, and the related socioeconomic and environmental impacts, not assessed by the physical scarcity indicators, significantly influence sustainable development of water resources in a specific region. Sufficiently reflecting all these factors and conditions in simple and accurate indicators is so important for resource managers, donors, governments, academics, practitioners and civil society in project planning. The idea of combining the five components (Resources, Access, Capacity, Use and Environment) related to natural, socioeconomic and ecological dimensions of water scarcity using a multivariate technique (PCA) to compute the final iWPI scores is an appropriate step toward accurately providing a comprehensive overview of the water sector in the continent.

This study analyzed the applicability and usefulness of the WPI as an accurate, transparent and monitoring tool for water resources development and related outcomes in the African continent. The results have been scattered throughout water poverty maps, and indicate that in Africa, water poverty follows a heterogeneous spatial pattern. When iWPI's components are studied separately, the index identifies those countries in water management that necessitate urgent policy consciousness, and by doing so, guides decision-makers in the direction of more efficient practices.

The demographic explosion of populations in several nations within Africa combined with climate change and growing industrialization in some countries is causing intense strain within and between nations. In the past, countries have attempted to resolve water conflicts through negotiation, but there is predicted to be an escalation in aggression over water accessibility. To comprehend origins of water tensions in this continent, a deeper study of water situation using WPI approach could be used. Time and open dialogue to further enhance the accuracy and applicability of this instrument, including standardized data sets, time series data and standard boundaries, and more stakeholder inputs will improve surely its use as a comprehensive, policy-support tool throughout the world.

Appendix

See Table 7 and Fig. 8.

Table 7 iWPI Ranking and components index values

Rank	Country	iWPI	RES	ACC	CAP	USE	ENV	cWPI
1.	Equatorial Guinea	87.99	88.53	77.17	95.72	43.95	95.07	80.09
2.	Gabon	78.15	95.81	72.52	63.23	32.46	100	72.80
3.	Cen.African Rep	69.19	78.45	74.24	53.44	96.11	80.75	76.60
4.	Angola	65.86	78.10	76.41	54.33	45.80	59.40	62.81
5.	Madagascar	64.45	83.02	51.08	69.85	46.62	45.11	59.14
6.	Rwanda	63.86	63.68	74.8	66.77	50.23	48.30	60.76
7.	Sierra Leone	63.25	86.55	55.34	44.86	49.09	85.04	64.18
8.	Comoros	62.29	67.74	48.09	63.31	49.96	73.95	60.61
9.	Guinea	60.47	85.28	58.88	41.92	43.90	69.65	59.93
10.	Cameroon	59.88	66.23	62.28	64.19	48.01	40.34	56.21
11.	Mauritius	59.52	69.74	91.87	73.22	00.06	36.90	54.36
12.	Liberia	59.16	62.78	68.75	40.31	52.44	99.65	64.79
13.	Cape Verde	58.54	61.35	87.85	76.33	49.67	17.19	58.48
14.	Congo	58.33	53.04	56.60	63.80	48.30	62.91	56.93
15.	Lesotho	57.36	66.88	57.12	58.56	49.14	40.38	54.42
16.	Guinea-Bissau	57.36	42.23	66.10	65.57	46.37	69.97	58.05
17.	Malawi	56.53	44.75	69.23	61.92	47.98	59.12	56.60
18.	Côte d'Ivoire	56.04	55.72	62.59	61.07	41.27	42.01	52.53
19.	Dem Rep Congo	53.55	47.10	65.48	45.65	55.59	75.49	57.86
20.	Ethiopia	52.64	67.11	54.25	47.47	50.05	37.74	51.32
21.	Burkina Faso	52.31	62.58	50.04	60.30	45.07	28.22	49.24
22.	Algeria	52.12	43.22	79.61	62.25	37.15	30.73	50.59
23.	Burundi	51.91	34.60	76.18	61.20	49.16	51.36	54.50
24.	Zambia	50.15	43.67	66.52	52.79	42.70	41.72	49.48
25.	Uni Rep Tanzania	49.67	41.67	47.69	67.15	46.61	39.95	48.61
26.	Morocco	49.59	64.04	77.97	63.97	37.93	09.03	50.59
27.	Gambia	49.40	29.45	80.90	59.54	43.81	51.37	53.01
28.	Libya	48.72	50.00	69.13	64.69	15.97	17.66	43.49
29.	Ghana	47.50	28.57	61.29	80.78	47.61	31.15	49.88
30.	Botswana	46.92	28.75	74.20	63.65	37.20	37.76	48.31
31.	Uganda	46.52	28.35	54.92	69.49	49.95	44.19	49.38
32.	Swaziland	46.46	32.80	81.33	54.97	43.85	31.54	48.90
33.	Senegal	45.90	33.65	69.37	58.32	47.83	29.75	47.78
34.	Namibia	45.26	32.56	64.91	54.30	39.33	38.19	45.86
35.	Togo	45.20	36.80	40.67	59.19	46.48	44.96	45.62
36.	Mozambique	45.00	35.79	57.34	54.57	48.57	34.19	46.09
37.	Zimbabwe	44.72	27.71	66.95	72.35	36.52	25.65	45.84
38.	Nigeria	44.00	34.25	56.43	60.12	43.07	27.07	44.19
39.	Mali	43.34	36.56	54.09	49.14	36.24	35.77	42.36
40.	Benin	41.85	26.79	53.79	50.41	50.12	50.24	46.27
41.	South Africa	41.51	36.99	89.77	52.00	24.45	11.95	43.03
42.	Kenya	41.20	24.53	57.48	56.21	47.40	39.44	45.01
43.	Mauritania	39.50	22.50	66.37	50.55	41.72	37.41	43.71

Table 7 continued

Rank	Country	iWPI	RES	ACC	CAP	USE	ENV	cWPI
44.	Tunisia	38.75	35.52	86.13	49.72	39.08	08.92	43.87
45.	Eritrea	37.68	21.70	54.53	56.04	48.84	30.00	42.22
46.	Chad	36.04	27.76	42.07	39.04	47.80	41.30	39.59
47.	Sudan	35.86	19.63	58.48	48.66	42.32	33.42	40.50
48.	Somalia	31.30	22.90	35.51	39.84	48.32	28.65	35.04
49.	Niger	30.88	20.36	30.40	38.61	45.20	45.10	35.93
50.	Egypt	28.71	12.27	99.57	49.50	27.57	09.75	39.73
51.	Djibouti		57.33	87.01		44.57	45.30	
52.	Sao Tome and Principe		81.74	82.97	76.89		34.38	
53.	Seychelles		100.00	97.18	98.05	18.58		

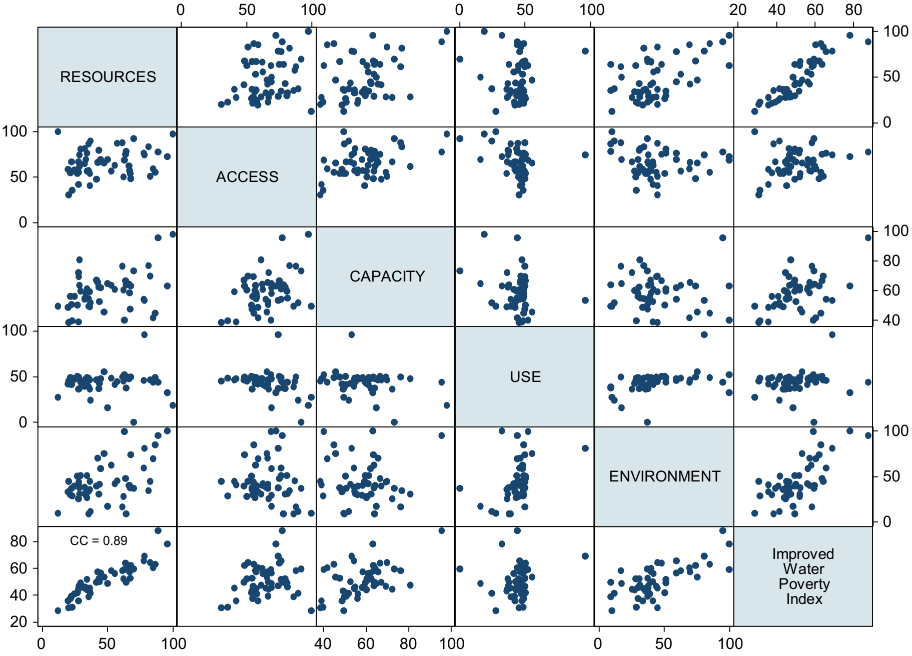

Fig. 8 Scatter graphs of iWPI components and their correlation coefficients

References

Alexander, K. S., Moglia, M., & Miller, C. (2003). Water needs assessment: learning to deal with scale, subjectivity and high stakes. *Journal of Hydrology, 388*(3), 251–257.

Appelgren, B., & Klohn, W. (1999). Management of water scarcity: A focus on social capacities and options. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 24*(4), 361–373.

Cullis, J. (2005). *Water poverty mapping: Development and introduction using a case study at the local municipal scale for the Eastern Cape*. Water Research Commission.

Curtis, V., Cairncross, S., & Yonli, R. (2000). Review: Domestic hygiene and diarrhoea–pinpointing the problem. *Tropical Medicine and International Health, 5*(1), 22–32.

Falkenmark, M., Finlayson, M., Gordon, L. J., Bennett, E. M., Chiuta, T. M., Coates, D., et al. (2007). Agriculture, water, and ecosystems: avoiding the costs of going too far. In D. Molden (Ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Colombo: Earthscan, London and International Water Management Institute.

Falkenmark, M., Lundqvist, J., & Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches. *Natural Resources Forum, 13,* 258–267.

FAO/BRGM. (1996). *Les ressources en eau*. Rome.

FAO-AQUASTAT. (2014). *FAO's global information system on water and agriculture, FAO*. Retrieved February 19, 2014, from http://www.fao.org/nr/aquastat.

Feitelson, E., & Chenoweth, J. (2002). Water poverty: Towards a meaningful indicator. *Water Policy, 4*(3), 263–281.

Gleick, P. (1996). Basic water requirements for human activities: Meeting basic needs. *Water International, 21,* 83–92.

Hajkowicz, S. (2006). Multi-attributed environmental index construction. *Ecological Economics, 57*(1), 122–139.

Heidecke, C. (2006). *Development and evaluation of a regional water poverty index for Benin* (Vol. 145). Washington: International Food Policy Research Institute (IFPRI).

Henninger, N., & Snel, M. (2002). *Where are the poor? Experiences with the development and use of poverty maps*. Washington: World Resources Institute.

Jemmali, H. (2013). Mesures de la pauvreté en eau: analyse comparative et développement de l'indice de pauvreté en eau. *VertigO-la revue électronique en sciences de l'environnement*, *13*(2). doi:10.4000/vertigo.13982

Jemmali, H., & Matoussi, M. S. (2013). A multidimensional analysis of water poverty at local scale: Application of improved water poverty index for Tunisia. *Water Policy, 15*(1), 98.

Jemmali, H., & Sullivan, C. A. (2014). Multidimensional analysis of water poverty in MENA Region: An empirical comparison with physical indicators. *Social Indicators Research, 115*(1), 253–277.

Jiménez, A., Molinero, J., & Pérez-Foguet, A. (2009). Monitoring water poverty: A vision from development practitioners. *Water Ethics*, pp. 151–177.

Kojiri, T. (2008). Importance and necessity of integrated river basin management. *Physics and Chemistry of the Earth, Parts A/B/C, 33*(5), 278–283.

Komnenic, V., Ahlers, R., & Zaag, P. V. D. (2009). Assessing the usefulness of the water poverty index by applying it to a special case: Can one be water poor with high levels of access? *Physics and Chemistry of the Earth, Parts A/B/C, 34*(4), 219–224.

Lawrence, P., Meigh, J., & Sullivan, C. (2003). *The Water Poverty Index: An International Comparison* (No. KERP 2002/19). Centre for Economic Research, Keele University.

Manandhar, S., Pandey, V. P., & Kazama, F. (2012). Application of water poverty index (WPI) in Nepalese context: A case study of Kali Gandaki River Basin (KGRB). *Water Resources Management, 26*(1), 89–107.

Mason, P., & Leberman, S. (2000). Local planning for recreation and tourism: A case study of mountain biking from New Zealand's Manawatu region. *Journal Sustainable Tourism, 8*(2), 97–115.

Mlote, S. D., Sullivan, C., & Meigh, J. (2002, October). Water poverty index: a tool for integrated water management. In *Water demand management for sustainable development, Proceedings of 3rd symposium, Dar es Salaam,* pp. 30–31.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2005). *Handbook on constructing composite indicators: Methodology and user guide*. Paris: OECD Publishing.

Pandey, V. P., Babel, M. S., Shrestha, S., & Kazama, F. (2011). A framework to assess adaptive capacity of the water resources system in Nepalese river basins. *Ecological Indicators, 11*(2), 480–488.

Pérez-Foguet, A., & Garriga, R. G. (2011). Analyzing water poverty in basins. *Water Resources Management, 25*(14), 3595–3612.

Rovira, J. S., & Rovira, P. S. (2008). Assessment of aggregated indicators of sustainability using PCA: The case of apple trade in Spain, *Conference on life cycle assessment in the agriculture food Zurich,* pp. 133–143.

Slottje, D. J. (1991). Measuring the quality of life across countries. *The Review of Economics and Statistics, 73*(4), 684–693.

Sullivan, C. (2001). The potential for calculating a meaningful Water Poverty Index. *Water International, 26*(4), 471–480.

Sullivan, C. (2002). Calculating a water poverty index. *World Development, 30*(7), 1195–1210.

Sullivan, C. A. (2005). *Method to develop and describe community level water poverty index scores*. Wallingford: CEH.

Sullivan, C., & Meigh, J. (2003). Considering the water poverty index in the context of poverty alleviation. *Water Policy, 5*(5), 513–528.

Sullivan, C. A., & Meigh, J. (2007). Integration of the biophysical and social sciences using an indicator approach: addressing water problems at different scales. *Water Resources Management, 21*(1), 111–128.

Sullivan, C. A., Meigh, J. R., Giacomello, A. M., Fediw, T., Lawrence, P., Samad, M., et al. (2003). The water poverty index: Development and application at the community scale. *Natural Resources Forum, 27,* 1–11.

Sullivan, C., Meigh, J., & Lawrence, P. (2006). Application of the Water Poverty Index at Different Scales: A Cautionary Tale: In memory of Jeremy Meigh who gave his life's work to the improvement of people's lives. *Water international, 31*(3), 412–426.

United Nations (UN). (2012). *The Millennium development goals report 2012*, New York.

van Ty, T., Sunada, K., Ichikawa, Y., & Oishi, S. (2010). Evaluation of the state of water resources using modified water poverty index: A case study in the Srepok river basin, Vietnam-Cambodia. *International Journal of River Basin Management, 8*(3–4), 305–317.

Watkins, K. (2006). Human Development Report 2006-Beyond scarcity: Power, poverty and the global water crisis. *UNDP Human Development Reports (2006)*. http://hdr.undp.org/en/reports/global/hdr2006/ISBN0-230-50058-7.

World Bank. (2013). *Africa development indicators 2012/13*. Washington, DC: World Bank.