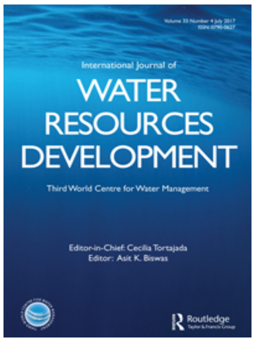


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# Mapping water poverty in Africa using the improved Multidimensional Index of Water Poverty

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**ABSTRACT**

This article details the application of the improved Multidimensional Index of Water Poverty, which associates human economic welfare with physical water availability to point out the degree to which water scarcity impacts African populations. The index and its components vary widely across the African continent, suggesting the need for location-specific policy interventions. These findings highlight more specifically a significant disparity in water poverty between more developed but water-scarce countries, located mainly in northern and southern Africa, and water-rich but lower-income countries in sub-Saharan Africa.

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## Introduction

According to figures in the latest WHO/UNICEF Joint Monitoring Report (2014), improvement in access to clean water and sanitation services in recent decades remains alarmingly slow, more specifically in Africa. Of the world's population, 89% have access to 'improved' water sources, but only 64% of sub-Saharan Africa's population. Nearly 64% of the total population have access to improved sanitation services, but only 30% in sub-Saharan Africa. According to this report, lack of access to improved water and basic sanitation are among the leading causes of the rising under-five mortality rate in Africa. In rural areas, women and girls particularly bear the burden of walking long distances to gather water from unprotected sources such as streams, ponds, and wells.

Water issues are intrinsically local, mutually dependent and totally linked to the interaction between humans and their socio-economic environments (Alexander, Moglia, & Miller, 2003). Without appropriate strategies and ad hoc planning based on accurate and multidimensional assessment of water resources, water management policies may be unregulated, formless and haphazard and likely to lead to unsuitable decisions and a range of negative socio-economic and environmental impacts (Mason & Leberman, 2000; United Nations Development Program [UNDP], 2010).

It is noteworthy in the literature that water is strongly linked to poverty through different aspects. Rijsberman (2003) distinguished five main aspects: water for adequate sanitation and health; water for production and employment generation; water for environmental

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health; water for gender equality; and water rights and entitlements of the poor. Moreover, inadequate water supply is considered simultaneously a cause and a result of poverty (Cook, Fisher, Andersson, Rubiano, & Giordano, 2009). Indeed, lack of access to safe water may hamper any effort to alleviate poverty and specifically has an adverse effect on persons who lack social security due to incapacity to supply labour in a productive way (Barker, van Koppen, & Shah, 2000; Hansen & Bhatia, 2004; Wang, Xu, Huang, & Rozelle, 2005). Other important aspects such as capacity to manage, efficiency in use, and environmental integrity should also be considered when studying the links between water scarcity and poverty. Turton (1999) claimed that a society characterized by low social adaptive capacity will be unable to face the problem of water scarcity; he called this situation 'water poverty'. In this regard, a composite index called the Water Poverty Index (WPI) was developed, initially by Sullivan (2002), and refined by numerous researchers at the Centre for Ecology and Hydrology in Wallingford, UK, to be a viable way to express the multiple dimensions of water issues in a simple and comprehensible form.

The WPI is defined as a holistic tool designed to capture the whole range of water issues related to water scarcity and human and ecological needs (Lawrence, Meigh, & Sullivan, 2003; Mlote, Sullivan, & Meigh, 2002; Sullivan, 2001). The index has been broadly used throughout the world at different scales: international (Jemmali, 2013; Jemmali & Sullivan, 2014; Lawrence et al., 2003); national (Heidecke, 2006; Jemmali & Matoussi, 2013; Sullivan & Meigh, 2007; Sullivan, Meigh, & Lawrence, 2006); district/basin (Manandhar, Pandey, & Kazama, 2012; Sullivan et al., 2006); sub-basin (Komnenic, Ahlers, & Zaag, 2009; Van Ty, Sunada, Ichikawa, & Oishi, 2010); and community (Sullivan, 2005; Sullivan & Meigh, 2003; Sullivan et al., 2006). In spite of agreement on its usefulness and reliability, the WPI has been widely criticized (Feitelson & Chenoweth, 2002; Jemmali & Matoussi, 2013; Jemmali & Sullivan, 2014; Jiménez, Molinero, & Pérez-Foguet, 2009; Komnenic et al., 2009). All this criticism revolves around three conceptual weaknesses: redundancy among variables; use of a balanced weighting scheme; and use of a simple arithmetic aggregation function. To avoid such weaknesses, certain authors (e.g. Jemmali & Matoussi, 2013; Jemmali & Sullivan, 2014; Pérez-Foguet & Giné Garriga, 2011; Wilk & Jonsson, 2013) have suggested using a multivariate technique (principal component analysis).

The main objectives of the article are two. First, it offers a set of WPI indicators appropriate for the African context, depending on local peculiarities and data availability, as water poverty issues and the indicators used to assess them are location-specific and should be neatly selected in each exercise. It also provides data against which the causes of water poverty can be analyzed. Second, it examines, over space, the water poverty situation in Africa using this improved Multidimensional Index of Water Poverty, to depict the obvious dissimilarity of the water poverty situation in different countries. The main purpose of mapping such dissimilarity is to enable policy makers and national and international organizations concerned with water provision and management to monitor, via transparent analysis of opportunities and risks of intervention, both the resources available and the socio-economic factors affecting water management policies.

The rest of the article is organized as follows. The structure and the conceptual framework of the WPI are described in the following section. The third section gives an overview of the methodology and data used to estimate the improved Multidimensional Index of Water Poverty (iMIWP) and its components. The main findings of the application and a sensitivity analysis of the results are discussed in the fourth and fifth sections, respectively. The last section concludes and highlights the policy relevance of the exercise.

## Strengths and limitations of the existing WPI

The use of a numerical index as a management tool has a long and chequered history, going back at least to the first development of the WPI by Sullivan (2002). As all composite indices should do, the WPI integrates aspects from different disciplines and nature. It provides a sound theoretical and conceptual framework that explains the phenomenon of water poverty to be observed at different scales. This concept of water poverty has been broadly discussed (Feitelson & Chenoweth, 2002; Shah & van Koppen, 2006; Sullivan, 2002), while its definition is still subject of debate. The present article is based on the concept of water poverty suggested by Sullivan (2002) and by Lawrence et al. (2003), who claimed that people could be qualified as 'water poor' owing to two reasons: they have not enough water to meet their basic needs because of the shortage of clean water; or because they are 'income poor', and cannot afford to pay for water despite its availability.

Based on this conceptualization, and aimed at evaluating the degree to which lack of safe water may impact human populations, the concept of water poverty was concretized by Sullivan as a composite index, the WPI. The development of such an index aims mainly to enable decision makers to target cross-cutting issues in an integrated way, by identifying and tracking the physical, socio-economic and ecological drivers that link water scarcity to poverty (Sullivan, 2002). It could be used as a scalable evaluation tool in evaluating poverty regarding water resource availability. Its conceptual framework involves numerous aspects which reveal the main preoccupations associated with provision of clean water and improved sanitation in developing and underdeveloped countries. The WPI as suggested by Sullivan and Lawrence et al. was based on five different components – resources, access, use, capacity and environment – to capture the complexity of the water situation in a country. Each of these components consists of a number of elements, each carrying weight in the computing of the final index. The *resources* component combines both surface and groundwater, taking into account the availability and the variability of global water resources. *Access* comprises access to water for domestic use, including the distance and time needed to reach a safe water source; it also includes water for food production and industrial uses. *Use* focuses on the water allocation among different sectors: domestic consumption as well as different productive sectors, such as industry and agriculture. *Capacity* is a collection of indicators focusing on the effectiveness of people's ability and socio-economic and institutional capacity for sustaining access to safe water. This component is interpreted in the sense of income allocated to allow purchase of safe water and access to education and healthcare, which are related to income and indicate a capacity to lobby for and manage available water resources. The most common indicators used to calculate this component are gross domestic product (GDP), education, health, and investment in the water sector. *Environment* is the most complicated component to calculate, containing variables, such as biodiversity, environmental degradation, soil erosion and water quality, which impact the water supply directly or indirectly. This component aims to assess the degree of maintenance of ecological integrity required to ensure ecologically sustainable development.

The use of these five components, corresponding to the broad themes that need to be incorporated in the WPI structure, is a useful but methodologically flawed approach. In fact, the components themselves are not commonly amenable to assessment; each one comprises several subcomponents, or variables, that can be directly measured or assessed in different ways. For the computation of the current WPI, the selection of variables is often driven by the availability and accuracy of data. As stated by Sullivan and Meigh (2003), one of the objectives of the WPI is the use of existing data where possible, rather than looking on data requirements regardless of availability. There is, hence, built-in flexibility in the selection of variables, though at the cost of comparability in some cases. Such ad hoc selection of indicators is still subject to criticism. Furthermore, the WPI is criticized for using weighting and aggregation methods that may negatively influence the coherence and interpretability of the final values (Nardo et al., 2005). The first aggregation method used was the weighted arithmetic mean of different components. Numerically, the WPI was defined as:

$$WPI = \beta_R \times RES + \beta_A \times ACC + \beta_C \times CAP + \beta_U \times USE + \beta_E \times ENV \quad (1)$$

where *RES*, *ACC*, *CAP*, *USE* and *ENV* are the resources, access, capacity, use and environment indices, respectively. The value of each component, expressed as a percentage, ranges from 0 (the worst situation) to 100 (the best situation), and the same weight is assigned to all five indices ($\beta_R = \beta_A = \beta_C = \beta_U = \beta_E = 0.2$). Such an undefined weighting scheme is subject to individual judgments (Feitelson & Chenoweth, 2002), though an equal average weighting is not effectively justified either. Similarly, Molle and Mollinga (2003) claimed that the original WPI suffers from a number of deficiencies, such as conflating disparate and correlated pieces of information with arbitrary weights. In this respect, Heidecke (2006) noted the importance of a more transparent display of the determined weighting scheme to avoid misinterpretation. Other weighting schemes, suggested by Pérez-Foguet and Giné Garriga (2011) and by Jemmali and Sullivan (2014), aimed to determine more appropriate and objective weights for the different components.

It is also argued that the additive aggregation function may imply full compensability among the different components and then a possibility of counterbalancing poor performance in some indicators by amply high values of other indicators (Nardo et al., 2005). In much the same way as with the weighting scheme, other, less widespread aggregating methods, including multiplicative, geometric and nonlinear aggregation functions, are used to overcome the drawbacks of the additive form (Jemmali & Matoussi, 2013; Jemmali & Sullivan, 2014; Pérez-Foguet & Giné Garriga, 2011). Overall, the significance, soundness and usefulness of the index as a meaningful policy tool tends to be spoilt by a number of drawbacks, involving quality of data, arbitrariness of weights, high correlation between the index and its components, and loss of information in the aggregation process.

## Methodology and data

The methodology used in this study to deeply analyze the water situation in the African continent is based mainly on the mentioned WPI framework, developed initially by Sullivan (2001, 2002) and Lawrence et al. (2003). The first WPI, intended to fully and simultaneously assess the physical availability of water resources, extent of access to water, water uses for different purposes, environmental factors impacting ecology and water systems, and a range of capacities for sustaining access to clean water, is the starting point of this exercise. It consists of five components, as mentioned above, and the final index (WPI) is calculated as a simple average of these components. The present study uses the same structure as the original WPI, with some empirical improvements as proposed by Pérez-Foguet and Giné Garriga (2011), Jemmali and Matoussi (2013), and Jemmali and Sullivan (2014). The weighting scheme used to compute the final index is determined objectively by using a data-dependent statistical tool, principal component analysis.

### *iMIWP components, their indicators and their standardization*

In the first step, and with regard to data compilation, a number of data-sets are used from different sources (e.g. FAO-AQUASTAT, 2016; World Bank, 2013, 2015). Twenty-two variables are proposed and sorted into five components (see Table 1 for more details). For the normalization of variables, a score between 0 and 100 is assigned to each parameter depending on its meaning, where a value of 0 is assigned to the poorest level and 100 to the optimum one. Continuous variables, such as water availability per capita and long-term average rainfall, are standardized as follows:

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

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

where $x_i$ is the current value of variable $x$ for country $i$, and $x_{min}$ and $x_{max}$ are the lowest and highest values, respectively, of the considered variable in the continent. Equation (3) is used to normalize *negative* variables such as the two variability indicators (inter-annual and seasonal variability); the lowest levels of these variables present the best situation. The remaining variables are sorted into four predetermined scale scores (0, 33%, 66% and 100%). Table 1 presents the levels and scores of all used variables. A more detailed description of the included indicators is given below.

The resource component captures mainly the total physical availability and variability of water resources. The first indicator (R1), annual per capita water availability, measures water quantity sufficiency, as defined previously by Falkenmark, Lundqvist, and Widstrand (1989). R2, the dependency ratio, is introduced to capture the arbitrariness of external water inflows, which are characterized by less security than those generated internally within a country (Jemmali & Sullivan, 2014). To take into account the aridity, the long-term average precipitation (R3) is involved in the structure of the component. Inter-annual and seasonal variability are assessed by the indicators R4 and R5, respectively.

The access component considers whether people benefit from adequate access to safe water sources, sanitation facilities and irrigation services (A2, A5 and A7). As rural areas are the most vulnerable, access to water and sanitation (A1 and A4) in these regions are included in the calculation of the access index. Furthermore, two indicators assessing the progress made in terms of access to safe water and sanitation facilities (A3 and A6) are added to the analysis. The capacity component attempts to capture those socio-economic factors that could affect citizens' ability and the ability of water entities to oversee the operation and management of the water supply. For this purpose, the Human Development Index, which is calculated as a geometric mean of normalized indices for each of three dimensions (health, education and economic), is introduced in the structure of the capacity index to assess achievement in the three key dimensions of human development (a long and healthy life, being knowledgeable, and having a decent standard of living). Economic capacity is assessed by two indicators: World Bank (2015) classification of economy (C2), and average economic

**Table 1.** Variables, Levels and Scores (adopted and modified from Lawrence et al. (2003) and Jemmali and Sullivan (2014).

| WPI component | Indicator | Levels and scores | | | |
|---|---|---|---|---|---|
| | | Fair (100%) | Acceptable (66%) | Poor (33%) | Risky (0) |
| Resources [1] | R1: Water availability | Annual water availability ($m^3$ per capita per year) | | | |
| | R2: Dependency ratio | <25% | 25–50% | 50–75% | >75% |
| | R3: Long-term rainfall | Long-term average precipitation (mm/y) | | | |
| | R4: Inter-annual variability | Inter-annual variability | | | |
| | R5: Seasonal variability | Seasonal variability | | | |
| Access [2] | A1: Access to safe water | Total population with access to safe drinking water (%) | | | |
| | A2: Access to safe water in rural areas | Rural population with access to safe drinking water (%) | | | |
| | A3: Progress towards MDG target (safe water) | Target met | Good progress | Moderate progress | Limited or no progress |
| | A4: Access to sanitation | Total population with access to improved sanitation (%) | | | |
| | A5: Access to sanitation in rural areas | Rural population with access to improved sanitation (%) | | | |
| | A6: Progress towards MDG target (safe water) | Target met | Good progress | Moderate progress | Limited or no progress |
| | A7: Access to irrigation | Percentage of agricultural water-managed area equipped for irrigation (%) [1] | | | |
| Capacity | C1: Human development level [3] | Human Development Index | | | |
| | C2: World Bank classification of economy [4] | >USD 12,736 (high income) | USD 4,125–12,736 (upper-middle income) | USD 1,045 – 4,125 (lower-middle income) | USD 1,045 > GNI (low income) |
| | C3: Economic growth [5] | Average annual growth (%) in GDP per capita (2000–2010) | | | |
| | C4: Water investments [5] | ODA gross disbursements for water supply and sanitation sector (USD millions) | | | |
| Use [1] | U1: Domestic water consumption rate (per capita) | Ample (>40 lpd) | Basic (20–40 lpd) | Limited (10–20 lpd) | Scarce (<10 lpd) Excessive (>100 lpd) |
| | U2: Water use efficiency in agriculture | Share of water use by agriculture, adjusted by the sector's share of GDP | | | |
| | U3: Water use efficiency in industry | Share of water use by industry, adjusted by the sector's share of GDP | | | |
| | E1: Water quality | Water quality index [6] | | | |
| Environment | E2: Fertilizer consumption | Fertilizer consumption (kg per ha of arable land) [5] | | | |
| | E3: Forest area | Forest area (% of land area) [5] | | | |

Notes: MDG = UN Millennium Development Goals.; GNI = Gross national income; lpd = litres per day; ODA = official development assistance

Data Sources:

[1]Food and Agriculture Organization of the United Nations (FAO's) AQUASTAT data (2016): most of the data come from government representatives and/or publications from within each country and data not generated by a country is displayed with a suitable qualifier.

[2]WHO/UNICEF Joint Monitoring Programme (JMP) (WHO/UNICEF Joint Monitoring Report, 2015): Progress on sanitation and drinking water, 2015 update and MDG assessment.

[3]United Nations Development Program (2014), Human Development Report, Sustaining Human Progress, United Nations Development Program, New York.

[4]World Bank Group (Ed.). World development indicators 2015. World Bank Publications.

[5]World Bank Group (Ed.). (2012/13). African Development Indicators 2013. World Bank Publications.

[6]Estimations of Srebotnjak, Carr, de Sherbinin, and Rickwood (2012).

growth (C3). The level of investment in the water sector is assessed by the fourth indicator (C4). For more details on the sources of the data, see Table 1.

The use component reflects the ways safe water resources are used in different sectors (domestic, agricultural and industrial uses). As illustrated in Table 1, three indicators are considered, one for each use (agricultural, municipal and industrial). Domestic water use (U1), which reflects the current state of resource use in daily household activities, is standardized using four thresholds: 10, 20, 40 and 100 litres per day (see Table 1 for more details). U2 and U3 (agricultural and industrial indicators) are computed by dividing the shares of the agricultural and industrial sectors, respectively, in GDP by the percentage of water withdrawal used for agriculture and industry. Equation (1) is used thereafter for the standardization of the two parameters. The fifth component, environment, is used to assess the degree of environmental integrity by measuring water quality (E1), fertilizer consumption rate (E2) and forest area percentage (E3).

### *Aggregation and weighting*

In the second step, after computing the different indicators, an appropriate weighting scheme is used to objectively aggregate all indicators into five composite indices. Before the aggregation of these obtained indices, the correlation between them is analyzed, as redundancy or correlation between variables may cause double-counting (Pérez-Foguet & Giné Garriga, 2011) and bias the outcome (Hajkowicz, 2006). For this purpose, a multivariate statistical technique is used to analyze whether the chosen variables are statistically well balanced.

All the variables are quantitative; for this reason principal component analysis (PCA) is implemented for each component, after checking the factorability of data using the known exploratory tests (the determinant of the correlation matrix, Bartlett's test of sphericity, and the Kaiser-Meyer-Olkin measures of sample adequacy). The main purpose of the PCA is the reduction of the complex set of 22 indicators into a set of fewer uncorrelated components using varimax orthogonal rotation. To determine how many factors should be retained in the analysis without losing too much information, the 'variance explained' criterion is used to keep enough factors to account for at least 80% of the total variation (Nardo et al., 2005). At this level, since sub-indices can compensate each other's performance, additive aggregation is used to compute the five component indices (Pérez-Foguet & Giné Garriga, 2011). All sub-indices ($V_j$) are considered to have the same importance; thus no specific weighting is introduced. Each component ($X_i$) is calculated as a simple average of the $n$ retained variables:

$$X_i = \frac{1}{n} \sum_{j=1}^{n} V_j \tag{4}$$

The last step is the aggregation of the five components, assuming non-compensability between them – failure in one of these components cannot be compensated by success in another; poor performance in one of them will be penalized more heavily. Thereafter the weighted multiplicative function is used, as it is considered the most suitable aggregation function for estimation of the final index that takes into account the non-compensability among the different components (Jemmali & Matoussi, 2013; Jemmali & Sullivan, 2014; Pérez-Foguet & Giné Garriga, 2011). The appropriate weighting scheme is found using PCA, after checking the factorability of data with the aforementioned tests. This technique allows objectively determining the set of weights explaining the largest variation in the original components (Slottje, 1991). Then the final index can be formulated numerically:

$$\text{iMIWP} = \prod_{i=R,A,C,U,E} X_i^{w_i} \tag{5}$$

where iMIWP is the final value of the index, $X_i$ is the $i$th component, and $w_i$ is the weight assigned to that component. Weights are determined using the squared rotated factor loading scores obtained after applying varimax orthogonal rotation and the variance explained criterion, which allow keeping enough factors to account for at least 80% of the total variation (Nardo et al., 2005). The selected intermediate components, which explain the largest part of variance, are aggregated by assigning each a weight that depends on the proportion of the explained variance in the data; the greater the proportion, the higher the weight.

### *Water poverty mapping*

As explained above, water poverty is a multidimensional and highly heterogeneous phenomenon, and its spatial distribution differs widely between and within various geographic and administrative entities. Mapping water poverty permits an obvious depiction of this spatial heterogeneity, and provides a common data framework within which to merge socio-economic, physical and ecological information (Henninger & Snel, 2002; Sullivan, 2002). This may guarantee the most efficient way to use internal and common water resources, taking into account the development objectives and priorities of each country (Jemmali & Sullivan, 2014). Besides, it has been found that water poverty maps may assist in the analysis of water-related issues, and afford a practical way for policy makers and different international organizations, such as the World Bank, the African Development Bank and the FAO, to enhance transparency of decision making and policies. It also provides an accurate and transparent tool for maintaining monitoring, assessment and comparative analysis, as well as targeting and prioritization. More specifically, water poverty mapping, based on the index values that follow a heterogeneous spatial pattern, may help in recognizing countries or regions that need urgent actions through the spatial identification of the neediest.

When index values are used as performance indicators, this approach reveals its accuracy in discriminating among countries in the continent, and permits comparison analysis to be done by recognizing their strengths and weaknesses in the water sector. However, 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 (physical, socio-economic or ecological) being addressed. Accordingly, the iMIWP's components might be also assessed separately as thematic indicators rather than a composite and multidimensional index. Analyzing and mapping the values of the five components separately may draw attention to those water-sector requirements that necessitate urgent policy intervention and specific strategies.

## Empirical analysis and discussion

The methodology presented in the previous section is applied to the data-set containing the 22 variables related to the five components (resources, access, capacity, use and environment) and pertaining to 54 African countries. The main objective of the current application is to determine the optimal and appropriate weighting scheme ($\beta_R$, $\beta_A$, $\beta_C$, $\beta_U$, $\beta_E$). The proportions of variance in the data-set that the principal components accounted for are

**Table 2.** Different weighting schemes of indicators and explained variances.

| Indicator | Equal weighting | PCA weighting | Variance explained (%) |
|---|---|---|---|
| R1: Water availability | 0.2 | 0.333 | |
| R2: Dependency ratio | 0.2 | 0.333 | |
| R3: Long-term rainfall | 0.2 | 0 | 83.56 |
| R4: Interannual variability | 0.2 | 0 | |
| R5: Seasonal variability | 0.2 | 0.333 | |
| A1: Access to safe water | 0.143 | 0.333 | |
| A2: Access to safe water in rural areas | 0.143 | 0 | |
| A3: Progress towards MDG target (safe water) | 0.143 | 0.333 | 87.74 |
| A4: Access to sanitation | 0.143 | 0.333 | |
| A5: Access to sanitation in rural areas | 0.143 | 0 | |
| A6: Progress towards MDG target (safe water) | 0.143 | 0 | |
| A7: Access to irrigation | 0.143 | 0 | |
| C1: Human Development Index | 0.250 | 0.333 | |
| C2: World Bank classification of economy | 0.250 | 0 | |
| C3: Economic growth | 0.250 | 0.333 | 87.07 |
| C4: Water investments | 0.250 | 0.333 | |
| U1: Domestic water consumption rate (per capita) | 0.333 | 0.333 | |
| U2: Water use efficiency in agriculture | 0.333 | 0.333 | 100 |
| U3: Water use efficiency in industry | 0.333 | 0.333 | |
| E1: Water quality | 0.333 | 0.333 | |
| E2: Fertilizer consumption | 0.333 | 0.333 | 100 |
| E3: Forest area | 0.333 | 0.333 | |

Source: Author's calculations, based on the data described in Table 1.

given in detail in Table 2; 8.33% of the total information was discarded. Each component index is calculated as the average of the variables considered that load most heavily on each extracted component, as mentioned above.

It has been stated in the literature that weak relationships among components is a required property, as correlated variables may cause redundancy; this was one of the main weakness of the original WPI. To verify the robustness of the iMIWP, Kendall's $\tau_b$ correlations are estimated to provide some insight into the degree of correlation among the 15 possible pairs of the five components and the final index (Table 3). Two major points are apparent from this table. First, the five components are weakly correlated with each other; the highest significant score is 0.26 (which is much lower than 0.7). Second, the table shows that only the use component is strongly and significantly correlated with iMIWP (0.59). This implies that being water-poor depends largely on the level of water use efficiency.

Before applying PCA to the five computed components, it is necessary to evaluate the overall significance of the correlation matrix using Bartlett's sphericity test (see e.g. Field (2000) for more details). It is also recommended to test the factorability of the five components collectively and individually using the Kaiser-Meyer-Olkin measure of sampling adequacy (MSA; see Hair, Black, Babin, Anderson, & Tatham, 2006). Bartlett's test, which points out the existence of nonzero correlations, is significant at the 1% level ($\chi^2 = 21.928$; $p < .01$), indicating significant correlation. Moreover, the overall MSA measure, which takes into account the correlations between components and their patterns, is 0.611, exceeding the minimum requirement of 0.50. The individual MSA values are 0.52 for resources, 0.62 for access, 0.65 for capacity, 0.64 for use, and 0.51 for environment, all of which lie in the acceptable range (> 0.5). Accordingly, the five components satisfy the criteria for appropriateness of PCA.

**Table 3.** Correlation matrix: sub-indices and iMIWP (Kendall's $\tau_b$ correlations).

| | Resources | Access | Capacity | Use | Environment | iMIWP |
|---|---|---|---|---|---|---|
| Resources | 1.00 | | | | | |
| Access | −0.01 | 1.00 | | | | |
| Capacity | 0.06 | 0.17 | 1.00 | | | |
| Use | −0.06 | −0.26* | −0.15 | 1.00 | | |
| Environment | 0.11 | −0.12 | 0.03 | 0.08 | 1.00 | |
| iMIWP | 0.16 | −0.12 | 0.06 | 0.59* | 0.27* | 1.00 |

*$p < .01$.; Source: Author's calculations, based on data described in Table 1.

**Table 4.** Weighting schemes of component indices.

| Components | Classic weight | PCA weight |
|---|---|---|
| Resources | 0.20 | 0.19 |
| Access | 0.20 | 0.13 |
| Capacity | 0.20 | 0.14 |
| Use | 0.20 | 0.27 |
| Environment | 0.20 | 0.27 |
| Total | 1.00 | 1.00 |

Source: Author's calculations, based on data described in Table 1.

After conducting PCA of the five indices and pursuing the same methodology as above to find the adequate weighting scheme, we find the results displayed in Table 4. Rescaling is applied to correct the weight assigned to each component in order to get a final index between 0 and 100. Furthermore, Table 4 compares the two weighting schemes: the classical one used to calculate the original WPI, and the new weighting system found in the current application. In the new scheme, the access and capacity components receive the lowest weights, less than 0.2; the resources component keeps its weight of 0.2; and the use and environment indices are both weighted at 0.27.

To better investigate the spatial variation of water poverty in the continent, Figure 1 shows the level of water poverty for different countries. It is gleaned from this iMIWP map and Table A1 that water poverty in Africa follows a heterogeneous spatial pattern, ranging from a low of 11.16 (Seychelles) to a high of 55.79 (Djibouti). The countries belonging to the first class (iMIWP 11.16–24.94), namely the four North African countries (Egypt, Algeria, Tunisia and Libya) and three states from the southern part of the continent (Botswana, Namibia and South Africa), are found to be the most water-poor. On the other side, countries belonging to the upper class (iMIWP 46.73–55.79), mainly from the central and the western parts, are found to be the most water-rich. To unravel the main factors and causes that explain and drive such dissimilarity, we need to turn to investigating the different aspects of water poverty.

When we dig deeper, it can be found that the countries (Libya, Gabon, Tunisia, Cape Verde, Mauritius, South Africa, Algeria, Namibia, Egypt, Botswana and Seychelles) that belong to the bottom of the ranking (iMIWP less than 24) have the lowest use index (less than 2.9; see Table A1). Some of these countries are high on other indices (e.g. Mauritius has access at 98.09, and Gabon has resources at 89.86). It is noteworthy, in this respect, that the multiplicative (geometric) function used for the aggregation of different components does not permit compensability among them. The aforementioned countries are then penalized in iMIWP due to their highly inefficient use of available water resources. At the top of the ranking (iMIWP over 48.00), countries mainly from the sub-Saharan region (Djibouti, Morocco, Mali,

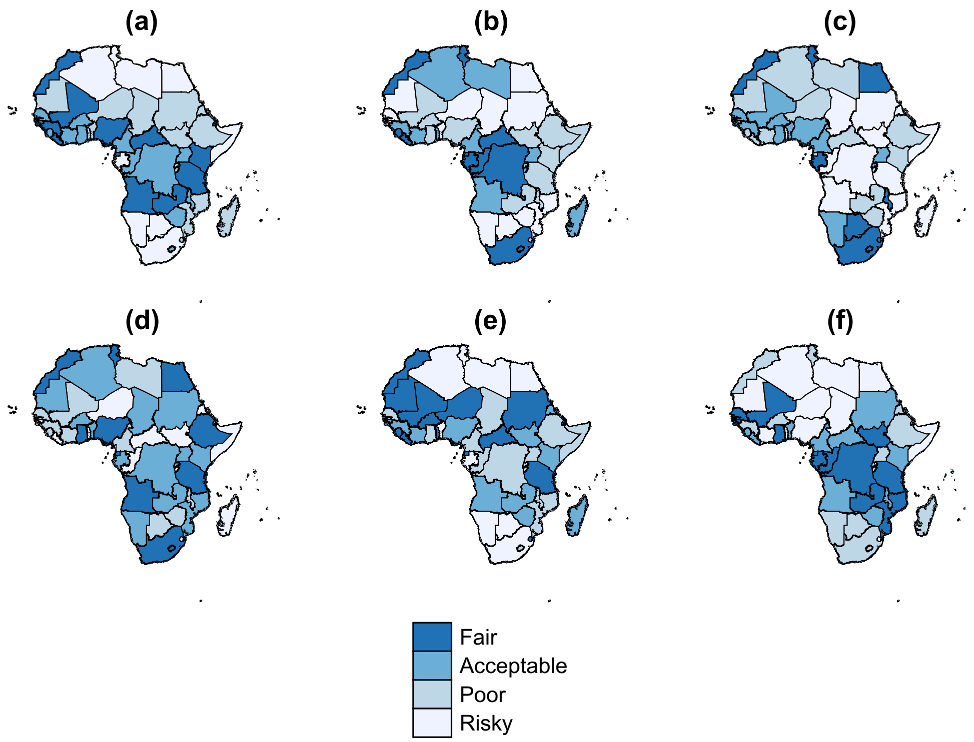


**Figure 1.** Values of iMIWP and its five components for countries in Africa. (a) iMIWP, (b) Resources Index, (c) Access Index, (d) Capacity Index, (e) Use Index, (f) Environment Index. Source: Author's calculations, based on the data described in Table 1.

Equatorial Guinea, Zambia, Kenya and Central African Republic) are less water-poor, as they are well ranked according to the five component indices.

A deeper scrutiny of water resources availability issues, as shown in the resources map, illustrates that higher values of the index occur, as might be expected, in Central Africa, where water resources are much more abundant, with low dependency on external flows. Despite this relative water wealth, some countries in this region face serious problems in the management of their resources and are considered in a risky situation, as shown in the composite iMIWP map. The use map illustrates that these countries are not able to presume their management commitment, probably because of the lack of qualified staff and necessary funds to construct appropriate water-related infrastructure, such as dams and reservoirs, that make use of the available resources more efficient. Gabon is one of these countries: it belongs to the set of water-poor countries due to its low use index, despite high scores in the rest of the indices.

The situation of the North African countries, except Morocco, is somewhat different. The resource map shows that these countries are in a better situation than others despite low availability of water resources. This could be explained by the fact that these countries are less dependent on the water resources of their neighbours. Besides, the access and capacity maps reveal, as expected, that the majority of these countries are in a better situation. This means that they have the ability to manage water outage or shortage situations without delays in providing safe, potable water and sanitation services to their populations. But, looking at the use and environment maps, it appears clear that these two components are mainly responsible for the medium-to-low iMIWP ranking of the aforementioned countries.

## Sensitivity analysis

As seen above, construction of the iMIWP involved three stages where subjective judgment was made: the selection of variables used to calculate the different sub-indices; the choice of weighting method; and the selection of aggregation function. Given that the quality of the WPI results depends considerably on the soundness of earlier assumptions, sensitivity analyses can help check the robustness of the iMIWP results and enhance their transparency. For this purpose, the sensitivity of the results for some countries, the highest, medium, and lowest-scoring ones, was analyzed. The results are illustrated in Table 5. It is clear from the first two columns of this table that when comparing the values of iMIWP (geometric function) and iMIWP-ar (arithmetic function) water poverty levels appear to rise if the arithmetic aggregation model is applied. This difference might be particularly inflated if only the lowest positions are considered. Indeed, the arithmetic form raises the average WPI score 22.06%, from 37.00 to 45.17. This is also depicted in Figure 2, in which the variation of the iMIWP-ar values for the additive function with respect to the changes of the iMIWP values for the geometric function is plotted. Though both indices remain fairly well correlated ($R^2 = 36.13$), Figure 2 shows that all values are located above the geometric = additive line ($y = x$), particularly for small values. Another remark regarding the geometric aggregation, discussed above, is that all lagging countries in the iMIWP ranking have low scores in at least one index (i.e. use), as this method does not allow compensation of low values in any variable. Though meaningless in terms of water poverty, this finding maintains the fact that the multiplicative function helps recognize the hot spots in the data-set.

For a second sensitivity analysis, the rankings of the three indices (iMIWP, iMIWP-ar and cl-WPI – the classical Water Poverty Index) are compared. It is gleaned from Table 5 that at the top five, nothing changes significantly between the three indices, apart from Equatorial Guinea, which shows a slight tendency to slip to a lower position in the iMIWP-ar, and Morocco, which jumps from 2nd rank in iMIWP to 26th in the cl-WPI. In the middle of the list, as well as at the very bottom, ranks vary considerably, and greater differences occur depending on the methods of weighting and aggregating variables. It is also found that important gains in rank position, nearly 10 points, occur at the bottom of the list when the additive aggregation form is used. In sum, it must be emphasized that rankings are sensitive to the approach used and are not always robust. Thus, the method used for the selection of indicators and the choice of the aggregation function clearly determine the ranking.

## Conclusion and policy implications

The present article proposes a set of five components (resources, access, capacity, use and environment) and an improved Multidimensional Index of Water Poverty to assess the situation of water poverty in the African context, considering local issues and limited data availability. The applicability and usefulness of the developed indices at the international scale have been tested through a real case study in Africa. The iMIWP provides a robust

**Table 5.** Sensitivity analysis results for the selection of weights and aggregation function.

| Country | iMIWP | | iMIWP-ar | | cl-WPI | |
|---|---|---|---|---|---|---|
| | Score | Rank | Score | Rank | Score | Rank |
| Djibouti | 55.79 | 1 | 57.72 | 2 | 53.24 | 5 |
| Morocco | 55.49 | 2 | 57.99 | 1 | 61.00 | 1 |
| Mali | 54.53 | 3 | 55.38 | 3 | 53.16 | 7 |
| Equatorial Guinea | 50.78 | 4 | 54.05 | 5 | 55.30 | 3 |
| Zambia | 49.33 | 5 | 51.38 | 8 | 53.21 | 6 |
| Kenya | 49.12 | 6 | 50.49 | 14 | 52.00 | 14 |
| Central African Republic | 48.87 | 7 | 53.43 | 6 | 50.58 | 19 |
| Liberia | 47.77 | 8 | 50.85 | 11 | 49.62 | 22 |
| Tanzania | 47.51 | 9 | 52.99 | 7 | 52.95 | 9 |
| Angola | 47.48 | 10 | 50.77 | 12 | 49.51 | 23 |
| Guinea | 47.47 | 11 | 48.93 | 17 | 51.42 | 15 |
| Nigeria | 47.00 | 12 | 48.08 | 20 | 50.58 | 18 |
| Ghana | 46.73 | 13 | 51.09 | 10 | 55.25 | 4 |
| Sierra Leone | 46.59 | 14 | 48.36 | 19 | 48.61 | 26 |
| Burkina Faso | 45.60 | 15 | 46.51 | 24 | 47.78 | 29 |
| Senegal | 44.85 | 16 | 49.55 | 15 | 53.04 | 8 |
| Cameroon | 44.77 | 17 | 49.07 | 16 | 52.93 | 10 |
| Uganda | 44.23 | 18 | 47.72 | 21 | 47.63 | 30 |
| Côte d'Ivoire | 43.46 | 19 | 44.94 | 28 | 49.18 | 24 |
| Malawi | 43.24 | 20 | 47.11 | 23 | 51.39 | 16 |
| Congo DRC | 41.70 | 21 | 48.82 | 18 | 50.43 | 20 |
| Zimbabwe | 41.39 | 22 | 42.81 | 35 | 44.49 | 40 |
| Guinea-Bissau | 41.00 | 23 | 46.43 | 25 | 45.96 | 36 |
| Gambia | 40.95 | 24 | 45.05 | 27 | 45.97 | 35 |
| Congo | 40.60 | 25 | 46.38 | 26 | 50.34 | 21 |
| Sao Tome and Principe | 40.49 | 26 | 51.32 | 9 | 57.28 | 2 |
| Lesotho | 40.10 | 27 | 43.39 | 32 | 46.86 | 32 |
| Mozambique | 39.13 | 28 | 42.86 | 34 | 44.01 | 41 |
| Togo | 38.82 | 29 | 40.70 | 40 | 43.42 | 43 |
| Ethiopia | 38.76 | 30 | 43.97 | 31 | 47.93 | 28 |
| Mauritania | 38.54 | 31 | 39.20 | 45 | 42.29 | 46 |
| Swaziland | 38.12 | 32 | 41.11 | 38 | 43.62 | 42 |
| Madagascar | 37.92 | 33 | 41.72 | 37 | 44.49 | 39 |
| Sudan | 36.88 | 34 | 40.43 | 41 | 46.02 | 34 |
| Rwanda | 36.37 | 35 | 44.01 | 30 | 48.09 | 27 |
| Comoros | 35.44 | 36 | 39.38 | 44 | 44.86 | 38 |
| Benin | 33.97 | 37 | 40.77 | 39 | 45.11 | 37 |
| Niger | 33.84 | 38 | 34.72 | 51 | 37.00 | 50 |
| Burundi | 33.25 | 39 | 40.07 | 42 | 42.62 | 44 |
| South Sudan | 33.05 | 40 | 39.47 | 43 | 42.39 | 45 |
| Chad | 32.69 | 41 | 34.46 | 52 | 35.99 | 52 |
| Eritrea | 31.39 | 42 | 33.17 | 53 | 34.39 | 53 |
| Somalia | 24.94 | 43 | 31.28 | 54 | 32.42 | 54 |
| Libya | 22.21 | 44 | 36.20 | 50 | 38.52 | 48 |
| Gabon | 20.02 | 45 | 54.13 | 4 | 52.10 | 13 |
| Tunisia | 19.33 | 46 | 50.74 | 13 | 52.58 | 11 |
| Cape Verde | 19.22 | 47 | 42.88 | 33 | 51.05 | 17 |
| Mauritius | 18.06 | 48 | 42.09 | 36 | 46.68 | 33 |
| South Africa | 17.47 | 49 | 47.72 | 22 | 46.94 | 31 |
| Algeria | 17.02 | 50 | 36.46 | 49 | 39.56 | 47 |
| Namibia | 16.52 | 51 | 39.19 | 46 | 36.88 | 51 |
| Egypt | 15.65 | 52 | 38.49 | 48 | 48.79 | 25 |
| Botswana | 11.58 | 53 | 38.86 | 47 | 37.14 | 49 |
| Seychelles | 11.16 | 54 | 44.22 | 29 | 52.25 | 12 |
| Average | 37.00 | | 45.17 | | 47.35 | |

Note: iMIWP = improved Multidimensional Index of Water Poverty, geometric aggregation function. iMIWP-ar = improved Multidimensional Index of Water Poverty, arithmetic aggregation function. cl-WPI = classical Water Poverty Index.
Source: Author's calculations, based on data described in Table 1.

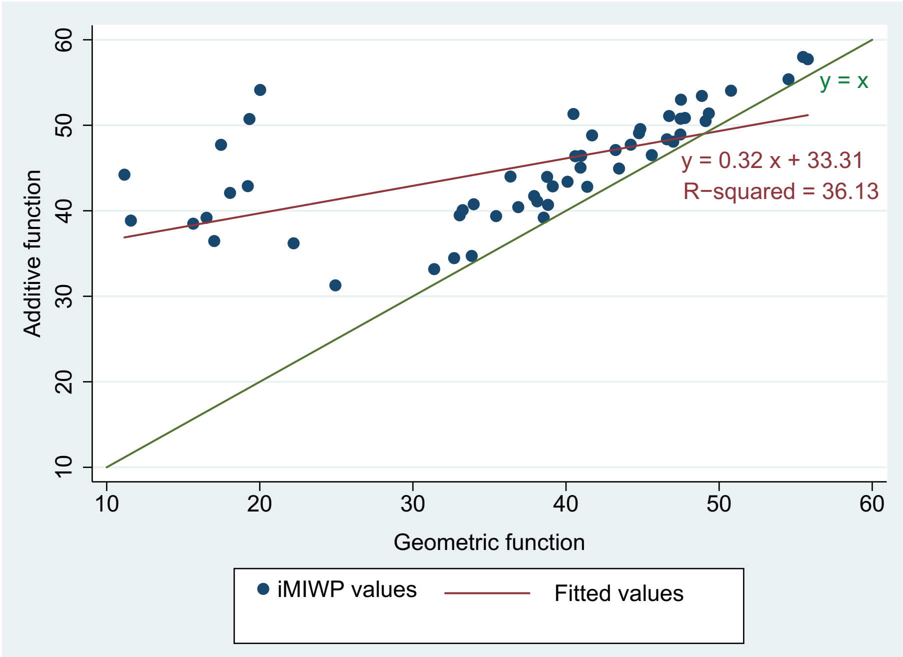


**Figure 2.** Geometric function versus additive function. Source: Author's calculations, based on estimated iMIWPs.

methodology for the assessment of water poverty in the continent that is not based on strict and subjective assumptions. All together, 50 indicators were chosen carefully and objectively from 22 variables to compute the final component indices and visualize the water poverty situation in a simple and comprehensive form. The results, scattered across a number of water-poverty maps, show that in Africa, water poverty follows a complex and heterogeneous spatial pattern, with developed and water-scarce countries located mainly in northern and southern Africa and water-rich but lower-income countries in the sub-Saharan region. Looking at the iMIWP's components separately, the findings allow us to identify those countries that require urgent policy attention in water management, and by doing so, guide decision makers in the direction of more efficient practices.

As a policy recommendation, this study suggests that for the case of North African countries, where surface water resources and groundwater are very limited, highly polluted and irregularly distributed, more attention needs to be given to improve the use of scarce water resources in agriculture and other sectors. Then, higher water efficiency and consumer conservation programmes to increase the sustainability of water supplies are required. Water use efficiency could be improved through supply-side practices, such as precise meter reading and leak detection and maintenance programmes, as well as through demand-side strategies, such as conservation-based water rates, school water awareness, and conservation programmes. On the other hand, in the sub-Saharan region, where the distribution of water resources is not well matched to the distribution of the population (i.e. the availability of water across the region varies widely from country to country across seasons and years) and access to piped water and sanitation facilities remains generally very low, more attention needs to be given to access to safe water and effective sanitation. If the situation remains unchanged, many nations in this region, which suffer from extreme rainfall variability and repetitive floods and droughts, are unlikely to achieve the MDG target of reducing by half the proportion of people without sustainable access to safe drinking water. In addition, several of these countries will not achieve the sanitation target, to reduce by half the proportion of the population without sustainable access to basic sanitation services. In this respect, establishing a water market may be an appropriate solution for distributing scarce water resources between nations. Such water markets are considered flexible mechanisms that theoretically should adjust for varying prices, and respond to variation in market conditions (e.g. low rainfall, drought, or greater demand). Compared to supply-side solutions such as increased storage capacity and transportation infrastructure (e.g. dam and aqueduct construction), as a response to water shortage and increasing demand, water markets between countries in the same region or in different regions may be more beneficial in the future. Due to the financial burden and higher capital costs of construction and maintenance of dams, which underdeveloped countries cannot bear, decreasing available sites for dam construction, and increasing awareness of environmental damage from dam construction, water markets remain the preferable solution in the short and long term for sub-Saharan Africa and for the whole continent.

In addition, providing people in such countries with access to safe drinking water and effective sanitation by building standpipes, pumps, toilets and sewage systems in and around villages, and access to education on the benefits of good hygiene practices and the effective use of water, are some of the most cost-effective ways of attaining real results in poverty alleviation and health. It helps underprivileged populations, particularly those who live in rural areas, as well as women and girls, beat poverty and famine. International organizations and all stakeholders should cooperate to help governments, citizens and the private sector in such countries better manage water resources. This will give more poor families, farmers and businesses access to the water and sanitation services they need. Besides, to understand the main origins of water conflicts in the continent, a deeper study of water situation using the WPI approach is needed. Time and open dialogue to further enhance the accuracy, transparency and applicability of this tool, including more standardized and accurate datasets and more stakeholder input, will surely improve its use as a comprehensive policy support tool throughout the world. In addition to this, as the international level of water poverty assessment may partially or completely mask the lower-level (local) water poverty situation, a required robust assessment of water poverty at various scales could provide a main tool for management interventions. According to the main findings of the application, the present study clearly illustrates a need for more location-specific policy interventions and planning at different levels to improve the water poverty situation in the continent.

## Disclosure statement

No potential conflict of interest was reported by the author.

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## Appendix

Table A1. iMIWP ranking and component index values.

| Country | Resources | Access | Capacity | Use | Environment | cl-WPI | iMIWP | iMIWP-ar |
|---|---|---|---|---|---|---|---|---|
| Angola | 67.40 | 24.76 | 57.76 | 33.63 | 65.69 | 49.51 | 47.48 | 50.77 |
| Burundi | 66.93 | 47.61 | 32.02 | 11.45 | 50.53 | 42.62 | 33.25 | 40.07 |
| Benin | 41.65 | 60.66 | 42.55 | 11.31 | 58.65 | 45.11 | 33.97 | 40.77 |
| Burkina Faso | 48.30 | 62.81 | 42.61 | 34.38 | 51.28 | 47.78 | 45.60 | 46.51 |
| Botswana | 40.86 | 85.51 | 37.86 | 0.20 | 53.14 | 37.14 | 11.58 | 38.86 |
| Central African Republic | 68.94 | 34.46 | 17.58 | 66.70 | 58.15 | 50.58 | 48.87 | 53.43 |
| Côte d'Ivoire | 68.25 | 41.31 | 35.65 | 33.58 | 46.89 | 49.18 | 43.46 | 44.94 |
| Cameroon | 66.01 | 69.01 | 37.76 | 22.51 | 59.88 | 52.93 | 44.77 | 49.07 |
| Congo DRC | 68.98 | 18.10 | 45.93 | 22.75 | 77.92 | 50.43 | 41.70 | 48.82 |
| Congo | 73.50 | 24.92 | 32.96 | 22.48 | 69.45 | 50.34 | 40.60 | 46.38 |
| Comoros | 56.77 | 39.15 | 17.42 | 22.44 | 56.12 | 44.86 | 35.44 | 39.38 |
| Cape Verde | 48.16 | 86.50 | 55.37 | 0.99 | 52.44 | 51.05 | 19.22 | 42.88 |
| Djibouti | 65.41 | 76.65 | 33.34 | 66.74 | 46.89 | 53.24 | 55.79 | 57.72 |
| Algeria | 65.79 | 54.77 | 53.77 | 1.03 | 32.96 | 39.56 | 17.02 | 36.46 |
| Egypt | 30.13 | 98.45 | 63.48 | 0.76 | 38.43 | 48.79 | 15.65 | 38.49 |
| Eritrea | 29.71 | 27.03 | 22.01 | 25.53 | 52.33 | 34.39 | 31.39 | 33.17 |
| Ethiopia | 57.80 | 53.60 | 57.66 | 15.40 | 50.72 | 47.93 | 38.76 | 43.97 |
| Gabon | 89.86 | 76.21 | 43.31 | 0.61 | 77.48 | 52.10 | 20.02 | 54.13 |
| Ghana | 51.93 | 64.16 | 57.70 | 22.36 | 69.11 | 55.25 | 46.73 | 51.09 |
| Guinea | 62.67 | 60.26 | 39.10 | 33.84 | 54.01 | 51.42 | 47.47 | 48.93 |
| Gambia | 27.33 | 80.93 | 24.59 | 33.52 | 61.84 | 45.97 | 40.95 | 45.05 |
| Guinea-Bissau | 44.89 | 61.75 | 13.00 | 33.78 | 70.37 | 45.96 | 41.00 | 46.43 |
| Equatorial Guinea | 80.89 | 32.56 | 53.81 | 34.14 | 66.24 | 55.30 | 50.78 | 54.05 |
| Kenya | 58.22 | 45.91 | 53.63 | 33.99 | 62.25 | 52.00 | 49.12 | 50.49 |
| Liberia | 79.82 | 47.14 | 29.20 | 34.64 | 60.38 | 49.62 | 47.77 | 50.85 |
| Libya | 66.67 | 43.57 | 38.68 | 2.80 | 43.33 | 38.52 | 22.21 | 36.20 |
| Lesotho | 72.97 | 44.05 | 45.28 | 22.23 | 42.62 | 46.86 | 40.10 | 43.39 |
| Morocco | 68.60 | 85.06 | 64.47 | 34.94 | 56.55 | 61.00 | 55.49 | 57.99 |
| Madagascar | 66.65 | 22.61 | 32.49 | 24.27 | 56.43 | 44.49 | 37.92 | 41.72 |
| Mali | 47.27 | 62.02 | 39.80 | 54.37 | 67.05 | 53.16 | 54.53 | 55.38 |
| Mozambique | 43.89 | 25.48 | 50.99 | 22.91 | 66.50 | 44.01 | 39.13 | 42.86 |
| Mauritania | 29.19 | 46.91 | 51.22 | 35.04 | 40.01 | 42.29 | 38.54 | 39.20 |
| Mauritius | 58.22 | 98.09 | 41.67 | 0.89 | 44.06 | 46.68 | 18.06 | 42.09 |
| Malawi | 51.66 | 74.40 | 38.01 | 22.61 | 59.58 | 51.39 | 43.24 | 47.11 |
| Namibia | 44.51 | 72.38 | 49.75 | 0.70 | 51.60 | 36.88 | 16.52 | 39.19 |
| Niger | 23.03 | 36.50 | 29.90 | 34.10 | 45.19 | 37.00 | 33.84 | 34.72 |
| Nigeria | 55.75 | 59.43 | 56.29 | 33.58 | 47.14 | 50.58 | 47.00 | 48.08 |
| Rwanda | 58.34 | 63.70 | 49.87 | 11.30 | 53.68 | 48.09 | 36.37 | 44.01 |
| Sudan | 21.21 | 17.78 | 50.79 | 41.51 | 58.61 | 46.02 | 36.88 | 40.43 |
| Senegal | 43.60 | 71.09 | 41.57 | 23.00 | 73.69 | 53.04 | 44.85 | 49.55 |
| Sierra Leone | 68.26 | 39.51 | 38.88 | 34.25 | 58.17 | 48.61 | 46.59 | 48.36 |
| Somalia | 52.46 | 6.14 | 16.86 | 18.73 | 49.49 | 32.42 | 24.94 | 31.28 |
| South Sudan | 49.23 | 13.22 | 12.36 | 33.57 | 66.36 | 42.39 | 33.05 | 39.47 |
| Sao Tome and Principe | 77.97 | 75.49 | 41.30 | 11.40 | 65.90 | 57.28 | 40.49 | 51.32 |
| Swaziland | 56.34 | 72.54 | 23.34 | 37.56 | 27.72 | 43.62 | 38.12 | 41.11 |
| Seychelles | 66.15 | 64.65 | 38.90 | 0.12 | 65.65 | 52.25 | 11.16 | 44.22 |
| Chad | 34.80 | 22.30 | 47.03 | 22.30 | 45.79 | 35.99 | 32.69 | 34.46 |
| Togo | 63.22 | 28.12 | 26.00 | 34.38 | 45.56 | 43.42 | 38.82 | 40.70 |
| Tunisia | 70.49 | 96.49 | 69.57 | 0.63 | 53.93 | 52.58 | 19.33 | 50.74 |
| Tanzania | 60.67 | 14.88 | 60.67 | 39.15 | 76.59 | 52.95 | 47.51 | 52.99 |
| Uganda | 65.09 | 60.96 | 51.49 | 22.45 | 52.23 | 47.63 | 44.23 | 47.72 |
| South Africa | 69.09 | 85.10 | 58.33 | 0.50 | 55.53 | 46.94 | 17.47 | 47.72 |
| Zambia | 54.04 | 40.97 | 52.71 | 33.77 | 71.69 | 53.21 | 49.33 | 51.38 |
| Zimbabwe | 42.66 | 33.06 | 34.27 | 33.87 | 61.37 | 44.49 | 41.39 | 42.81 |

Note: iMIWP = Multidimensional Index of Water Poverty, geometric aggregation function. iMIWP-ar = Multidimensional Index of Water Poverty, arithmetic aggregation function. cl-WPI = classical Water Poverty Index.

Source: Author's calculations, based on the data described in Table 1.