

Multidimensional Analysis of Water Poverty in MENA Region: An Empirical Comparison with Physical Indicators

Hatem Jemmali · Caroline A. Sullivan

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Abstract It is not easy to determine whether water is really scarce in the physical sense or whether it is available, but people cannot get access to it, or use it better. This paper reviews selected physical water scarcity indicators, and criticisms made against them on several grounds. Under the premise that the water scarcity issue is inherently multidimensional, a composite Water Poverty Index has been developed, to complement the traditional physical water indicators. In this paper we propose some technical refinements based on principal component analysis, in order to improve the method of calculation of the index. Using the proposed methodology, the present paper assesses the applicability of the index for the MENA region, by comparing the situation of oil-rich and water-poor countries (Gulf States) with that of lower-income yet water-rich countries (Horn of Africa states).

Keywords Water scarcity · Physical indicators · Water Poverty Index · Principal component analysis · MENA region

1 Introduction

During the last two decades, much effort has gone into the development of water scarcity indicators. The first assessments focused particularly on the vulnerability of communities

H. Jemmali (✉)
Faculty of Economics Sciences and Management of Sousse, University of Sousse, Sousse, Tunisia
e-mail: jemmalihatem@yahoo.fr

H. Jemmali
Taieb M'hiri Avenue, Public POST PO Box No. 177, 2080 Ariana, Tunisia

C. A. Sullivan
School of Environment, Science and Engineering, Southern Cross University, Lismore, NSW,
Australia
e-mail: caroline.sullivan@scu.edu.au
URL: http://works.bepress.com/caroline_sullivan

C. A. Sullivan
PO Box 157, Lismore, NSW 2480, Australia

or countries to physical water shortage, and fail to emphasize the impacts of socio-economic and political factors. More recently, water scarcity has been progressively recognized as an inherently multidimensional phenomenon. Ohlsson (1998), Salameh (2000), Sullivan (2002) and Lawrence et al. (2002) point to the need to move away from the unique physical sense of water scarcity to a wider space where multiple dimensions are both instrumentally and intrinsically important. They strive to reconcile the socio-economic variables above with physical ones to produce a more meaningful and real assessment of water poverty. Indeed, this index is the culmination of a multidimensional approach that includes both the physical water availability and the diverse socio-economic factors linked to poverty that affect water resource management.

This paper looks critically at the usefulness and shortcomings of water physical indicators before reviewing the possible improvements of the Water Poverty Index, the multidimensional water scarcity index first proposed by Sullivan (2002). It then analyzes the water situation of the MENA region in order to define and quantify a state of *water poverty* in this region and establish a comparison between countries to inform policy makers to the necessary actions to be taken.

The Middle East and North Africa (MENA) region is one of the most water scarce regions of the world. In the last few years some countries in this region have experienced a crisis of water and sanitation and there is anticipation that the water situation will deteriorate from bad to worse. In addition to dramatic effects on groundwater and river systems, the water shortage in these countries is a major burden to society, causing waterborne diseases, hygiene problems and a constraint to human development. This situation became worse because of the rapidly rising population growth, the heavy cost of water, the high consumption of food and pollution created by the extensive industrialization. In a context where household surveys were not as widespread as nowadays and particular variables e.g. income and access to safe water were difficult to measure, water scarcity studies were restricted to few specific surveys and physical dimensions. As household surveys started to expand in this region, and were progressively made available to the public, multidimensional studies using a composite index structure, became feasible and useful, as well as uni-dimensional ones. Since then both the two approaches have co-existed. Consistent with a multidimensional understanding of water poverty, the approach, adopted in this paper, applies to a wide territorial perspective. It focuses particularly in a comparative context, on the adaptive capacity of MENA countries to confront problems of water scarcity. To this end, we use a set of relevant socio-economic, demographic and physical indicators combined into one composite index, the Water Poverty Index.

In summary, this paper looks critically at the potential of physical water indicators to define and quantify a state of water shortage, and it proposes specific refinements to the composite Water Poverty Index first developed by Sullivan (2000), this approach concerns the use of the principal component analysis to strengthen the structure of the index. The following sections introduce initially the physical indicators used to monitor water scarcity (Sect. 1) and secondly the multidimensional indices (Sect. 2). An overview of the study case, the MENA region, is given in the third section (Sect. 3). Finally, we describe the methodology used and analyze the results of the application in the two last Sects. 4 and 5; throughout we will emphasize the importance of this index to highlight the multidimensional aspect of water poverty.

Table 1 Water stress differentiation proposed by Falkenmark et al. (1989)

Water availability (m ³ per capita per year)	Category
>1,700	No stress
1,000–1,700	Stress (moderate water shortage)
500–1,000	Scarcity (high chronic water shortage)
<500	Absolute water scarcity

2 Physical Indicators: A Critical Review

Due to economic development and the rapidly growing population and water use per capita, roughly one-third of the total world's population presently lives under physical water scarcity (Alcamo et al. 2003; Oki and Kanae 2006; Vörösmarty et al. 2000). In recent years several indicators have been developed to assess quantitatively this water resources shortage. In this section we provide an overview of the primary used water scarcity indices and their assessment methodologies divided into two main categories: Indices based on human and environment water requirements and water resources vulnerability Indices (Brown and Matlock 2011).

2.1 Indices Based on Human and Environment Water Requirements

Water scarcity usually results from the combined effects of available water resources and human and environment requirements. Thus, physical (hydrological) measures of freshwater scarcity are generally expressed in terms of annual per capita and largely applied on a national scale. The logic behind the development of this set of indices is merely that if we know the human and environment water requirements, then the water that is available to each person can be used as an indicator of scarcity (Rijsberman 2006). The Falkenmark water stress index, also known as the water crowding index (WCI¹), was the first to use this simply logic (Falkenmark et al. 1989). Initially focused on sub-Saharan Africa, Falkenmark et al. (1989) considered water shortage as a function of the capability to sustain food self-sufficiency. The indicator, usually used on a national scale, is defined thus as the total water availability per capita per year.²

According to the conventional use of this index, the levels of water availability 1,700 m³/capita/year³, 1,000 m³/capita/year and 500 m³/capita/year are used respectively by Falkenmark et al. (1989) as the thresholds between water stressed, scarce and absolute scarce situations as illustrated in the Table 1 above.

The Falkenmark index provides results that are intuitive and easy to understand if the data used is entirely available and accurate. However, the index is rightly criticized for obscuring important scarcity information at smaller scales by using national annual averages. It appears to under-assess the water availability in small areas and fail to measure water stress at these scales. In addition, the thresholds used to classify countries omit major variations in water demand due to culture, lifestyle, climate, etc. (Rijsberman 2006).

¹ It is nearly the most widely used indicator of water stress in the press.

² The water availability is defined as the annual runoff available for human use.

³ The 1,700 m³ threshold is calculated based on estimates of basic water requirements in the domestic, agricultural, industrial, energy and ecological sectors. Gleick (1996) and Rijsberman (2006) evaluated basic human water needs as 50 L per capita per day (excluding food production).

In this respect, Gleick (1996) developed a different water scarcity index as an assessment of the ability to satisfy all basic water requirements for human needs such as drinking, bathing, sanitation and modest cooking. Gleick (1996) suggest that international organizations and water providers have to adopt the total recommended basic water requirement as a new threshold for satisfying these basic needs, regardless of climate change, technology, and culture. He developed the *benchmark indicator* of 1,000 m³ per capita per year as a standard that separate between the two water conditions: no water stress and water stress; this threshold has been adopted by Falkenmark et al. (1989) and accepted after by the World Bank.

Furthermore, others thresholds have been developed by considering other factors and requirements such as food production (Yang et al. 2003). The approach to calculate thresholds developed by Yang et al. (2003) is dynamic unlike the Falkenmark and Gleick ones. However this approach neglects the use of non-renewable groundwater because the lack of systematic data; hence the threshold values calculated are fairly conservative.

Based on these criticisms, Smakhtin et al. (2004) has developed a Water Stress Indicator (WSI) that take into account environmental water requirements considered as an important parameter of available water resources. The following equation (Eq. 1) illustrates how to calculate this index:

$$WSI = \frac{\text{withdrawals}}{MAR - EWR} \quad (1)$$

where *MAR* is the mean annual runoff used as a proxy for total water availability, and *EWR* is the estimated environmental water requirements expressed as a percentage of long-term mean annual river runoff that ought to be allowed for ecological needs. The Table 2 below illustrates the various cases of water scarcity that depend on the WSI values.

Likewise, Asheesh (2007) take into account the environment water requirements in his Water Scarcity Index (WSI) that incorporates, in addition, population growth rate, water availability, domestic, industrial and ecological water uses.

2.2 Water Resources Vulnerability Indices

Thus far, the last water scarcity indices have assessed freshwater resource status based on fixed human water needs and water availability without considering renewable water supply and annual water demand (Rijsberman 2006). Shiklomanov and Markova (1987) from the State Hydrological Institute in St. Petersburg used population and economic factors as driving variables to estimate current and predicted water resources use for many regions around the world. Various water uses (industrial, agricultural, and domestic uses) are recognized in this assessment, as well as water lost from reservoir evaporation. Raskin et al. (1997) has modified the Shiklomanov approach by substituting water withdrawals in place of water demand as this last compound varies largely between societies, cultures, and

Table 2 Categorization of environmental water scarcity

WSI (range)	Degrees of environmental water scarcity of river basins
WSI > 1	No stress
0.6 < WSI < 1	Stress (moderate water shortage)
0.3 < WSI < 0.6	Scarcity (high chronic water shortage)
WSI < 0.3	Absolute water scarcity

Source: Smakhtin et al. (2004)

regions and can lead to inaccurate assessments (Rijsberman 2006). Then, a Water Resources Vulnerability Index, often called the criticality ratio (CR), was defined as the percentage of total annual withdrawals to available freshwater resources (Alcamo et al. 2000).

To understand the difference between this CR and others indices, it is necessary to define the terms used in the definition above. Water use in this indicator includes only water withdrawals water from surface water or groundwater over a year. This is due to the unknown quality of return flow and the location of the water users within a watershed or country is unknown (Alcamo et al. 1997, p. 5.). On the other hand, water availability is defined by Alcamo et al. (1997) and Raskin et al. (1997) as the amount of surface runoff and groundwater recharge; the total of precipitation evaporated or transpired by plants, is not included in the Alcamo indicator. If the ratio is between 20 and 40 %, Raskin et al. (1997) considered a country as water scarce, and severely water scarce if it exceeds 40 %. Other thresholds have been used by Alcamo et al. (2000) to define the following levels of water stress commonly used in water resources analysis:

- 0–10 %: no stress
- 10–20 %: low stress
- 20–40 %: mid stress
- 40–80 %: high stress
- 80–100 %: very high stress

In comparison to other water scarcity indicators the main advantages that make these two simple indicators (Falkenmark and CR indices) intuitive and relevant is availability of data, comprehensibility, clarity, and measurability. This is why they are widely used for scientific purposes, and for communication to the wider public, in spite of their clear shortcomings. The neglect of both spatiotemporal differences and infrastructure in these measures is a weakness, reducing the accuracy of measurements of the availability of water at smaller scales. In addition Rijsberman (2006) considers that the indicators do not pay enough attention to both socio-economic aspects (Malkina-Pykh 2002) and water use efficiency (Feitelson and Chenoweth 2002).

The CR also has some more specific shortcomings. First of all the neglect of the recycling capability of reusing water⁴ in assessing the amount of water use, particularly in the case of industrialized countries where water can be used many times (Vörösmarty et al. 2000). A second point of criticism is the disregard of *virtual* (Allan 1998) and *green water*⁵ (Savenije and Van der Zaag 2000). Thirdly, the setting of a standard threshold of 40 % is not recommended in comparison of water stress situation particularly between industrialized and developing countries and also within countries (Dow et al. 2005).

One of the major concerns of all physical indicators defined above, is the disregard of all three domains of sustainability (economic, social and environmental domains) excepted some indices that take into account the environmental requirements such as the WSI cited above. These domains are included in a new generation of multidimensional indices such as the Social Water Stress Index and the Water Poverty Index described in the following section.

⁴ Vörösmarty et al. (2000) developed a new index called the water reuse index which's defined as the fraction of aggregate upstream water use relative to discharge.

⁵ The green water (generally the soil moisture and water as evapotranspiration in plants) is the main source responsible for most of the food production in many regions of the world, and as a result is substantial for human well-being.

3 Multidimensional Approach

In many areas of the world, the physical water scarcity (or water resources scarcity) assessed by the indicators above, is not the sole scarcity that human populations face. Many of them can also face another kind of water scarcity induced by political and/or socioeconomic factors called social water scarcity (or second order water scarcity) as noted firstly by Ohlsson and Turton (1999). These authors, who were the first to pay attention to the society's *adaptive capacity*, argue that the deprivation of water, or its scarcity, may be associated with many circumstances and have many different facets. Ohlsson (1998) suggested that the Human Development Index (HDI⁶) could be considered as a workable proxy for social adaptive capacity, and combined with the Falkenmark index, could be used to generate what he terms a Social Water Scarcity/Stress Index (SWSI) (Eq. 2).

$$SWSI = \frac{WCI}{\frac{HDI}{2}} \quad (2)$$

where WCI is the Water Crowding Index (Falkenmark Index). By dividing this quantitative stress index by the HDI, Ohlsson (1998) integrated the capacity to adapt to water stress through economic, technological or other means. He argued that this adaptive capability depends on the distribution of wealth, education system, and political participation. The resulting values of this index are then sorted reflecting four stages of water availability (Ohlsson 2000):

- <5: relative sufficiency
- 5–10: stress
- 10–20: scarcity
- >20: beyond the barrier

After a Department for International Development (DFID) funded scoping study, the concept of the Water Poverty Index (WPI) first appeared in the literature as new concept for water resource management. This was first presented by Sullivan in an number of workshops in London, Canada and the Netherlands, and in the second World Water Forum in the Hague in 2000 and the World Summit on Sustainable Development in Johannesburg in 2002 (Sullivan et al. 2002). Salameh (2000) demonstrated the relevance of such measures to food security, He defines water poverty as a lack of availability of water for household uses and for the food production per capita per year under the prevailing climate conditions (Salameh 2000, p. 146). Focusing on water resources availability the Salameh Index was recognized as a useful indicator of water stress depending on food self-sufficiency and water for domestic use, but it was criticized for its neglect of environmental water requirements and virtual water. Feitelson and Chenoweth (2002) also used the term water poverty as *a situation where a nation or region cannot afford the cost of sustainable clean water to all people at all times*. This is introduced to demonstrate the cost of providing water and sanitation facilities compared to a country's Gross National Product (GNP).

After a DFID funded study to develop and test the Water Poverty Index, Sullivan et al. (2002) produced a detailed report on four possible approaches to calculation of the

⁶ The Human Development Index assesses the average accomplishments in a country in three main dimensions of human development such as longevity, knowledge and a decent standard of living. A composite index, the HDI hence comprises three indicators: life expectancy, educational attainment (adult literacy and combined primary, secondary and tertiary enrolment) and real GDP per capita.

composite Index (WPI). These four approaches were a time analysis approach, a water poverty gap approach, a matrix approach and a composite index approach. This latter was identified as the most preferred option in workshops with water managers and decision makers in South Africa, Sri Lanka and Tanzania, where the initial testing was done. The report concluded that the Water Poverty Index (WPI) would be most useful as an aggregate index capturing human welfare in relation to water resource availability, taking account of water use efficiency and environmental needs. The outputs of this study were widely disseminated through an international press release by the World Water Council in 2003, at the World Water Forum in Kyoto.

Explicitly, the WPI includes five different components (Resources, Access, Use, Capacity, and Environment) (Sullivan et al. 2002); each component is made up of various sub-components identified to capture a wide range of water problems. Building on the structure used in the Human Development Index (HDI), the WPI is defined as a composite index ranging from 0 to 100, where a low score indicates high levels of water poverty. As part of the original WPI report, the WPI was applied to international data to generate national WPI scores (Sullivan et al. 2002). In this work, the component *Resources* includes the amount of groundwater and surface water resources in order to assess the total water availability, taking account of variability. The *Access* component includes access to drinking water and water for domestic use and hygiene, as well as access to irrigation, recognizing that water availability for growing food is essential for domestic consumption, especially in subsistence households. The *Use* component combines domestic water use and consumption of water in different productive sectors, such as industry and agriculture. The *Capacity* component focuses on water institutional capacity by combining a set of human development indicators of a country, like gross domestic product (GDP), health, education and water investment. The last component *Environment* so complex to evaluate, including sub-components such as biodiversity, soil erosion, water quality, and environmental degradation, aimed to capture the degree of maintenance of ecological integrity. At that time, no measures of environmental water needs were available, so these were used as proxies.

To assess the multidimensional aspect of water scarcity, Molle and Mollinga (2003) focused on different uses of water and the influence of its shortage on the society. They distinguished four categories of water use such as the domestic use like drinking, cooking, hygienic purposes and laundry; the food production uses which corresponds to human need for additional water to grow the food consumed; economic production which means the industrial use of water and ecological needs considered humans part of the environment. On the other hand, they enumerated five types of scarcity. First of all, they considered the situation of arid and desert areas where the water sources are naturally scarce in the physical sense, and then defined economic scarcity as the financial incapacity to satisfy one of the above water needs or uses. In the same context, the managerial scarcity may occur when improper management of available water resources occurs (aquifer depletion, inappropriate irrigation schemes, leakage of water distribution networks, etc.). In addition there's an institutional scarcity when the society fails to cope with rising supply/demand imbalances and to conserve the environment. This kind of scarcity can be partly attributed to the incapacity to anticipate such imbalances and the adequate technological and institutional innovations which must be done. Finally, Molle and Mollinga (2003) argued that a political scarcity occurs in cases where people can't access to available sources of water because the political situation. These various kinds of scarcity may be temporally variable or permanent. According to the above classifications, Molle and Mollinga (2003) defined a matrix of 25 quite different situations. For example, the second type of scarcity combining

with the economic uses of water illustrate the cases of some African countries where the domestic water is available but the majority of persons cannot access to it. Other countries from southern Africa like Zimbabwe and South Africa provide a good example of political scarcity.

In brief, it is apparent from the various studies assessing water stress that the first-generation water scarcity indices like the Falkenmark index can be complemented by the incorporation of other aspects of the water management issues, as in the Water Poverty Index. The attraction of a dimensionless, holistic and easy-to-understand index such as the WPI is simply too important to be replaced by a simple, one-dimensionless and restrictive indicator. The WPI was firstly developed for local application, participation of water managers, hydrologist, economist and other stakeholders to improve the effectiveness and equity of water allocations (Sullivan et al. 2002, 2003) As part of that study, to demonstrate the global applicability of the method, the approach was applied to international data and reported for 147 countries worldwide (Lawrence et al. 2002) Subsequently, other researchers have applied the WPI in a variety of sub national applications at a smaller scale (Garriga and Foguet 2010; Heidecke 2006; Komnencic et al. 2009; Manandhar et al. 2012).

4 Background on the MENA Region

From all regions of the world, it is widely recognized that the MENA region is under serious water threat. In this study, we use the wider MENA region, including 30 countries⁷ (Afghanistan, Algeria, Armenia, Bahrain, Cyprus, Egypt, Eritrea, Ethiopia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Mauritania, Oman, Palestine, Pakistan, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, the United Arab Emirates, and Yemen.). Julia Bucknall, a Lead Natural Resources Specialist at the World Bank, said *the MENA region will be seeing a lot more people trying to manage with a lot less water.*

Largely considered the most water-scarce region of the world, this region is currently home to about 6.3 % of the world's population, yet has only 1.4 % of the world's renewable fresh water (see Fig. 1). Furthermore, over 80 % of the renewable water resources of several of these countries originate outside their borders, increasing their vulnerability. The global average water availability per capita is about 8,462 m³ per year; whereas it is limited only to 1,383 m³ per person per year in the MENA region (see Fig. 2). More than half of the population in the region is facing water stress.

In many countries of the MENA region, particularly in southern part, water use regularly exceeds the theoretical available renewable amount. That's why more than 80 % of the groundwater resources in these countries are continuously depleted, with the water level in some aquifers declining by at least 60 meters in the last 30 years. On the other side, water is an important economic factor for the whole region, reaching more than 3.5 % of GDP. Moreover the financial cost of environmental degradation of water is an important burden on many MENA countries, reaching above 0.5 % of GDP in some nations. For example the lack of sanitation in some areas has led to contamination of surface waters and aquifers, which leads to adverse effects on the ecosystem and public health. For example, in Iran, diseases and deaths resulting from this pollution, and the subsequent collection and treatment of waste water, were an enormous cost to the nation; in 2002, this amounted to almost one quarter of GDP.

⁷ In others studies, the MENA region is defined differently and contains less of countries. In this analysis, we aimed to include as many countries in the region as possible.

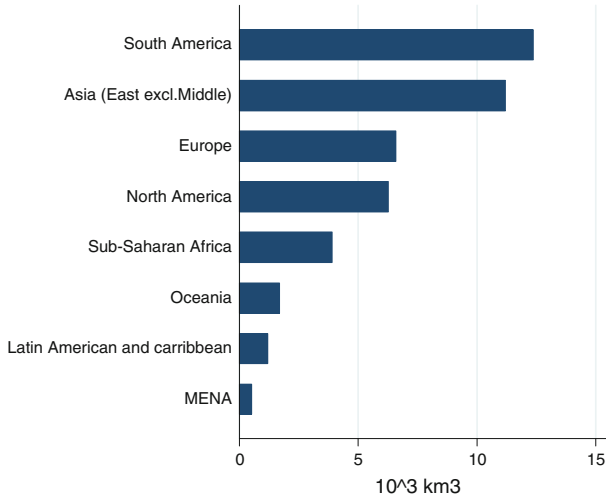


Fig. 1 Internal water resources.

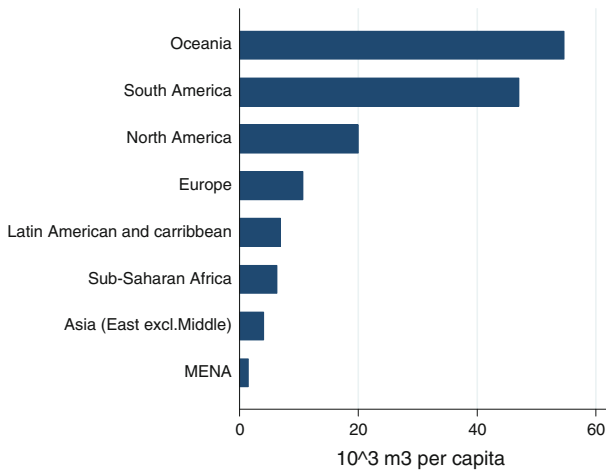


Fig. 2 Current water resources

The agricultural sector is by far the most intense water user, accounting for more than 90 % of the water use in several countries in the MENA region. Furthermore, climate change will have dramatic impacts by reducing precipitation by around 20 % in some regions in coming decades, although much uncertainty exists in such predictions. The demographic growth of many MENA countries is still rapid and increasing, simultaneously causing increases in the demand for water resources. By 2030, the population is estimated to rise by 90 % and almost all growth will take place in urban areas. Due to the converging effects of climate change, limited water resources and rapidly increasing demographic growth, the physical scarcity of water is likely to become a greater problem. This is particularly true in the Arabian Gulf and North Africa, while populations in the Horn of

Africa (Ethiopia, Somalia, and Eritria) face economic water shortage, where countries lack the necessary infrastructure to take water from rivers and aquifers. In order to examine in depth the first kind of water scarcity in the considered region, we first apply the Falkenmark index (WCI) (Fig. 3) and the criticality ratio (CR) (Fig. 4), and compare these to the Social Water Scarcity Index (SWSI) (Fig. 5).

The Fig. 3 shows more than three-quarters of the MENA countries are said to experience water stress, as the annual water supplies drop below $1,700 \text{ m}^3/\text{person}/\text{year}$. The region's water supply is from just six countries: Mauritania, Turkey, Iraq, Armenia, Afghanistan and Iran. About 60 % of the region is located in North Africa and the Arabian Gulf, and these face water scarcity conditions with an average of less than $1,000 \text{ m}^3/\text{person}/\text{year}$. In thirteen of these nations, available fresh water is less than $500 \text{ m}^3/\text{person}/\text{year}$, namely Tunisia, Djibouti, Algeria, Israel, Palestine, Jordan, Bahrain, Libya, Yemen, Saudi Arabia, Qatar, UAE and Kuwait.

As is noted above, Water stress, is defined differently by Alcamo et al. (1997), as an imbalance between water use and water resources. The criticality ratio in the Fig. 4 which involves that type of water stress depends essentially on the variability of resources, and assesses the proportion of water withdrawal with respect to total renewable resources in the MENA region. The analysis shows that the water stress situation is heterogeneous over the region; the countries with the highest CR (high water stress) are located mainly in the Arabian Gulf, considered above as an absolute water scarcity region (see Fig. 3) while most of the Horn of Africa states (Eritrea, Djibouti and Ethiopia) have the lowest value of CR, indicating no stress conditions. In those countries which have abundant and untapped stores of water to support population growth, water supply exceeds demand. However, coverage levels for water and sanitation are among the lowest in the world, indicating that human wellbeing is not supported from the abundance of available water resources.

In contrast to this result, when we use the SWSI to take into account the socio-economic dimension of water scarcity in the case of the MENA region, some countries like Libya, Saudi Arabia, Qatar, United Arab Emirates and Kuwait are no longer classified as water-stressed (see Fig. 5), thanks to their higher level of social adaptive capacity represented by a higher HDI, putting them into the relatively sufficient group (first class in Fig. 5). Compared to this, the Eastern African countries such as Somalia, Ethiopia, Eritrea as well

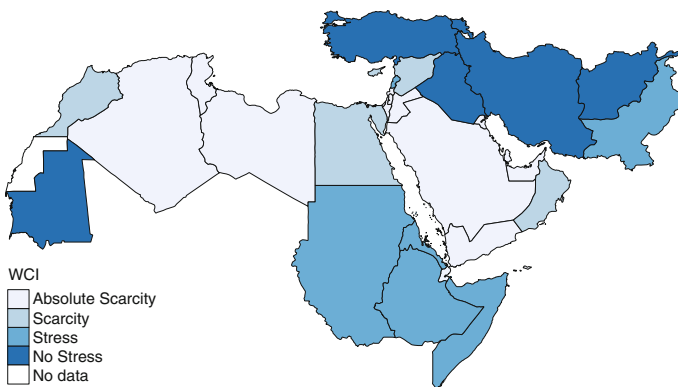


Fig. 3 Falkenmark Index 2007

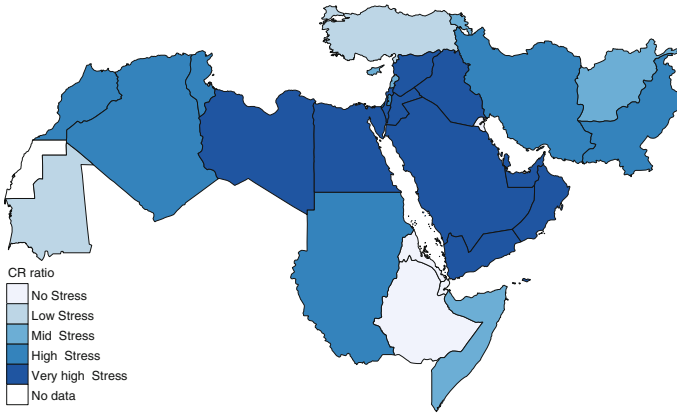


Fig. 4 Criticality ratio 2007

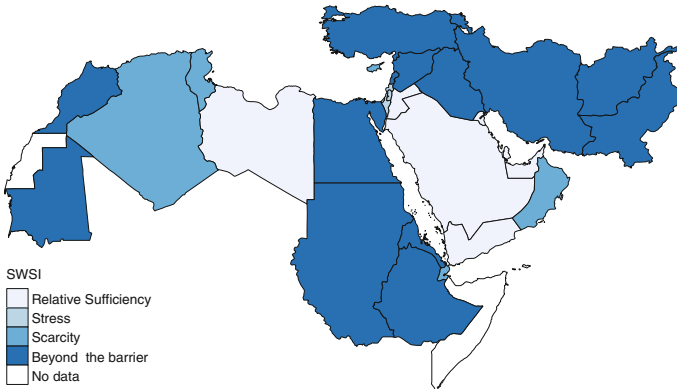


Fig. 5 Social Water Scarcity Index

as Egypt and Sudan and other underdeveloped states like Afghanistan and Iraq, are moving from *relative sufficiency* to *absolute water stress*. This is due to the low adaptive capacity measured by the HDI. The SWSI likewise seems to be able to highlight the anomaly of Israel, a developed country which maintains a high level of modern society, despite being characterized as *beyond the barrier* according to the first generation of physical water scarcity indices. The Fig. 5 shows that Israel is merely water-stress (second class), thanks to its high level of social adaptive capacity (HDI). A similar change of category has occurred in the cases of North African states such as Tunisia and Algeria. It is also the case that in some of these areas, extra water resources are obtained from large transboundary aquifers which are not fully quantified.

5 Application of the Water Poverty Index

With the purpose of testing the usefulness of Water Poverty Index (WPI) at an international scale, the approach was applied to the MENA region, where the socio-economic and hydrologic conditions differ greatly between low income, water rich countries (Ethiopia, Eritrea, Sudan) and high income, water poor countries (Israel, Kuwait, United Arab Emirates).

As noted in the previous section, The Water Poverty Index is defined as a composite index made up of five key components: Resources, Access, Capacity, Use and Environment (Sullivan 2002; Sullivan et al. 2002, 2003). Each component is a weighted average of sub-indices that are calculated by normalization of initial variables corresponding to each sub component. Sullivan et al. (2002) and many others authors (Heidecke 2006; Komnencic et al. 2009 and Manandhar et al. 2012) have used the arithmetic mean to calculate the final value of each component and *min-max* normalization to calculate the sub-components. Sullivan et al. (2002) suggest a list of indicators used to calculate each component and the Water Poverty Index. In this paper, we consider an improved methodology to calculate a refined WPI using the same list of indicators above, although some were omitted due to insufficiency of data. The following Table 3 captures the salient characteristics of each of the five sub-components forming the WPI.

Within this structure, some of the variables used for the calculation of the WPI are expressed in a log scale to reduce distortion induced by high values. This applies to Resources, GDP, etc.; all are expressed on a per capita basis. The *Access* component is represented by the percentage of population with access to safe water and percentage of population with access to sanitation services. The *Capacity* component includes: GDP per capita adjusted by PPP; under-five mortality rates and education enrolment rates. Domestic

Table 3 Structure of the Water Poverty Index

Components	Sub-components (variables)
Resources (R)	Internal freshwater flows
	External inflows
	Population
Access (A)	Percentage of population with access to safe water
	Percentage of population with access to sanitation services
	Percentage of population with access to irrigation
Capacity (C)	GDP per capita (adjusted by PPP)
	Under-five mortality rates
	Education enrolment rates
	Gini coefficient
Usage (U)	Domestic water use in liters per day
	Agricultural water use
	Industrial water use
Environment (E)	Water Quality Index
	Water stress index

Source: Adapted from Sullivan et al. (2003)

daily water use and proportion of water used respectively by industry and agriculture is adjusted by the sector’s share of GDP, and these were aggregated to calculate the *Use* component. Water quality and water stress indexes from the Environmental Sustainability Index⁸ (ESI) are included in the *Environment* component. Owing to incomplete and insufficient data, the irrigation index of the Access component, Gini coefficient, the fourth sub-component of Capacity index, industrial and agricultural indices are omitted.

Applying the same *min–max* normalization method introduced initially by Sullivan et al. (2002), the ten variables cited above are transformed into indicators ranging from 0 to 100. This process is not applied when data is already expressed as an index value (water quality index, water stress index) or as a percentage (water connection and sanitation rates, under-five mortality and education enrolment rates). The sub-indices are obtained using following formula:

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

where x_i^* , x_{min} and x_{max} are respectively the current value of variable x for country (i) after scaling, the lowest and highest values of the considered variable between MENA countries.

The majority of indices are defined in such a way that the higher the value of the index, the better the country’s water situation and vice versa. While higher values of a *negative* component such as under-five mortality rates indicate the presence of increased water problems. Hence, a modification in the formula used in Eq. 3 is required in the case of such variables. For instance, without adjustments, countries with high child mortality rates would score relatively highly, *ceteris paribus*, on WPI than others with lower index value, which is incorrect. To avoid this problem of classification, the specific scores for those variables are deducted from 100 to get the reciprocal value. Then the following variant of the formula above is used Eq. 4:

$$x_i^* = \frac{x_{max} - x_i}{x_{max} - x_{min}} \times 100 \tag{4}$$

when dealing with domestic water use, to avoid misrepresentation, two thresholds 50 and 150 L per person per day are used in the index formula, following the process outlined by Lawrence et al., (2002). These thresholds take account of both extreme shortages, and overuse. This is illustrated in Eq. 5:

$$USE_i = \begin{cases} \frac{x_i}{50} \times 100, & x_i \leq 50 \\ 100 - \frac{x_i - 50}{x_{max} - 50} \times 100, & 50 < x_i \leq 150 \\ 100 - \frac{x_i - 150}{x_{max} - 150} \times 100, & 150 < x_i \end{cases} \tag{5}$$

when all sub-components are calculated for the Resources, Access, Capacity, Use, and Environment components, these are then combined as a weighted additive index. There is little difference overall if a multiplicative index were to be used, so keeping a simple

⁸ The Environmental Sustainability Index (ESI) is a composite index that was published from 1999 to 2005; it tracked 21 elements of environmental sustainability including natural resource endowments, past and present pollution levels, environmental management efforts, contributions to protection of the global commons, and a society’s capacity to improve its environmental performance over time.

Table 4 Factorability tests

Statistic	RES	CAP	ACC	ENV
Determinant of the correlation matrix	0.979	0.178	0.308	0.896
Overall KMO index	0.500	0.741	0.500	0.500
Bartlett test of sphericity				
Chi square	0.578	46.861	32.343	3.026
DF	1	3	1	1
<i>p</i> value	0.447	0.000	0.000	0.082

Note: Unfortunately in this example, the Use component contains only one indicator; therefore, multivariate analysis is not required for that component

additive approach is preferred. This can be represented in Eq. 6. (Garriga and Foguet 2010; Foguet and Garriga 2011):

$$I = \sum_{j=1}^n w_j x_j^* \quad (6)$$

where I is one of the five WPI components, w_j is the weight accorded to each normalized sub-component x_j^* .

Some indicators however are highly correlated with each other, and so run the risk of double counting, biasing the outcome when using the formula above (Hajkowicz 2006). Hence, the correlation between these subcomponents and their nature needs to be evaluated before calculating the final components values (Nardo et al. 2005), which necessitates an arbitration between redundancy and comprehensiveness. The data set used should remain sufficient to exhaustively depict the water situation of each country. To achieve this end, a multivariate statistical technique, the principal component analysis⁹ (PCA), is performed at subcomponent level to explore whether chosen indicators are statistically well-balanced.

Before applying PCA at index and sub-index level, we should examine both the overall significance of the correlation matrix using Bartlett's test of sphericity to analyze the factorability of indicators, both collectively and individually, by applying the Kaiser–Meyer–Olkin measure of sampling adequacy (MSA) as outlined by Hair et al. (2006). Results of these tests of each sub-component are presented in Table 4. Based on these statistics, we concluded that the PCA is only really needed for the Capacity and Access components.

In situations where all global and individual MSA scores are above 0.5, no variable is likely to impair the factor solution, and thus should not be rejected as a consequence. The main objective of this step in the procedure presented here is to reduce the number of correlated variables into a set of fewer uncorrelated factors. On the issue of the number of components that should be kept in the analysis without losing too much information, we have chosen the *variance explained criterion* to keep enough factors to account for 80 % of

⁹ The Principal components analysis (PCA) is a data reduction technique used to extract a smaller set of uncorrelated variables, called principal components, from a large set of correlated variables. Each principal component is a weighted linear combination of the original variables with mathematically determined characteristic vectors of the correlation matrix of the original data as weights; it can be argued that PCA can provide a good solution for the problem of arbitrary choice of weighting scheme.

Table 5 Weights of Indicators at Sub-index Level

	Subcomponents	Weights	
		Classic WPI	Refined WPI
Note: The classical application of the WPI as first outlined by Sullivan (2002) and Sullivan et al. (2002, 2003) used more variables, and weights were kept neutral at a value of one, leaving the possibility of different weights being applied after stakeholder consultation. This allows the computed WPI to be tailor made for each location, but of course if weights are different, results cannot be compared.	RES1: internal water resources	0.66	0.66
	RES2: external water resources 1	0.33	0.33
	ACC1: access to safe water	0.5	0.5
	ACC2: access to improved sanitation	0.5	0.5
	CAP1: economic capacity	0.33	0.33
	CAP2: under-five mortality rates	0.33	0.33
	CAP3: education enrollment rate	0.33	0.34
	USE1: domestic water consumption rate	1	1
	ENV1: water quality	0.5	0.5
	ENV2: water stress	0.5	0.5

the total variation (Nardo et al. 2005). Both in the cases of the *Capacity* and *Access* indices, only the first components, which represent respectively 81.81 and 91.58 % of the total variability, are extracted. Factor loading scores in these principal components are then used to determine the weights of various variables associated to each index. Our case here is to suggest that this is a more robust approach to simple arbitrary weighting selection. An alternative to this, as suggested by Sullivan et al. (2002) is that the weightings are inherently socio-political constructs (based on societal values to indicate the importance of an attribute), and thus they should be determined by stakeholders consultation rather than by science or mathematics.

The Table 5 above summarizes the different weighting schemes used to calculate the five components. As can be seen from this table, the two approaches, the classical WPI and the refined WPI result are almost in the same weighting scheme. We should note however that the refined approach is based on robust statistical methods, not arbitrary or subjective choice.

To decide if the set of defined components was appropriate to calculate the refined Water Poverty Index, we considered the following five-component WPI, as developed by Sullivan et al. (2002) and shown in Eq. 8:

$$WPI = \beta_R \times RES + \beta_A \times ACC + \beta_C \times CAP + \beta_U \times USA + \beta_E \times ENV \quad (8)$$

where *RES*, *ACC*, *CAP*, *USE* and *ENV* denote respectively indexes of Resources, Access,

Table 6 Kendall’s correlations among the five WPI components

	RES	CAP	ACC	USE	ENV
RES	1				
CAP	-0.5485*	1			
ACC	-0.4151*	0.8894*	1		
USE	0.1146	-0.1024	0.0207	1	
ENV	0.2396	0.0157	0.0044	0.2705	1

* Correlation is significant at the 0.05 level

Capacity, Use and Environment and β_R , β_A , β_C , β_U and β_E the weights associated with the five sub-components in the construction of the WPI.

One of our purposes in this paper is to determine the usefulness of this PCA approach to calculating the weights. Before applying the PCA to data set, we must analyse the degree of association among the ten possible pairs of the five components (Cho et al. 2010). The values of Kendall's correlation coefficient (tau-B) are reported in the Table 6 above.

This table shows apparently three main things.. Firstly, Access and Capacity exhibit the highest significant positive correlation (0.89) which means that rich countries provide better access to water resources for their population and vice versa. Secondly, the significant negative correlations (-0.5485 , -0.4151) of respectively the two pairs (Resources, Capacity) and (Resources, Access) prove that water rich countries globally are often low and middle income countries, where a large proportion of the population lacks access to safe water and sanitation services. The Environment and Access exhibit the lowest bivariate correlations (0.0044) which means that there is not a significant relation between these two components.

After analyzing the correlations between components, we use the Bartlett's Sphericity test to assess the overall significance of the correlation matrix described above. This test indicates the presence of significant nonzero correlations at 1 % significance level ($\chi^2 = 58.929$; p value = 0.000). In addition, it's recommended to test for factorability of the indices collectively and individually, using the Kaiser–Meyer–Olkin Measure of Sampling Adequacy (Kaiser 1974). By comparing the observed correlation coefficients to the partial correlation ones, the KMO measure determines if the data set has enough variance to make factor analysis relevant (Kaiser 1974). The overall MSA value is 0.5, which falls in the somewhat useful range (i.e., between 0.5 and 0.7), although it might be necessary to examine the individual MSA values to see what variables might be bringing the overall MSA value down. Both the Use and Environment MSA value (0.28, 0.33) are less than the threshold (0.5). For this reason, we opted for rejecting these two components from further analysis. After discarding Environment and Use components, we repeat the same process above for the three remaining components (i.e., Resources, Access and Capacity). Bartlett's test for sphericity indicates also at the 0.01 level ($\chi^2 = 53.251$; p value = 0.000) significant correlations. Their KMO value is slightly higher than the value before discarding the two components; it's reached 0.564 which also lies in the acceptable range. However, the individual KMO values turn out to be 0.55 for Access, 0.54 for Capacity and 0.68 for Resources, all of which lie in the somewhat useful range.

Table 7 Results of the PCA

	Principal component		
	Comp 1	Comp 2	Comp 3
Eigenvalues	2.26	0.64	0.1
Proportion of variance explained	75.31	21.46	3.23
Cumulative proportion of variance explained	75.31	96.77	100
Eigenvectors			
RES	-0.477	0.8669	0.1446
CAP	0.6361	0.227	0.7375
ACC	0.6065	0.4437	-0.6597

The main characteristic roots and vectors of the correlation matrix are shown in The first principal component explains the largest percentage of the variation in the three components (75.31 %), with the two first dimensions in the component space accounting for approximately 97 % of global variance (see Table 7). When applied the *explained variance criteria* to keep enough factors to account for 80 % of total variation, we decided to retain these two first components.

To get the final weighting scheme, the extracted principal component should be weighted with the proportion of variance measuring by dividing the square root of eigenvalue of each principal component, by the sum of the square root of eigenvalue of the two components retained; the greater the proportion, the higher the weight of the component. The weight (w_i) of each index i can be found (Rovira and Rovira 2008), using the following formula in Eq. 9

$$w_i = \sum_{k=1,2} PCk_i \times \frac{\sqrt{\lambda_k}}{\sum_{j=1,2} \sqrt{\lambda_j}} \quad (9)$$

where PCk_i is the factor loading of the index i , which can be Resources, Capacity or Access, on k th principal component also called component loading (see Table 7). The last step in this process is the aggregation of WPI components with their weights defined above, in order to assess water poverty for each country of the MENA region.

According to Manandhar et al. (2012); Foguet and Garriga (2011) the most appropriate aggregation function to calculate the WPI at this level, is the weighted multiplicative function. They suggest that this does not allow compensability among the different components involved in the index formula.

Using this refined Water Poverty Index approach, the numerical scores can be calculated as shown in Eq. 10:

$$rWPI = \prod_{i=R,C,A} X_i^{w_i} \quad (10)$$

where $rWPI$ is the value of the refined water poverty index, X_i refers to value of component i which can be Resources (R), Capacity (C) and Access (A), and w_i is the weight associated to each component.

5.1 Refining the Sub-components of the WPI

In the original project to develop the WPI, after deliberation over 1 week, a team of 21 international scientists and practitioners identified five major components as being core to water management. These became the five core components of the WPI, Resource, Access, Capacity, Use and the Environment. Since water management is such a complex issue fraught with uncertainty, there are clear interactions between these five components, which can weaken the usefulness of the structure. Principal component analysis could be used to more clearly define the five core components of the WPI, by narrowing down the number of individual variables, dismissing each individually if they are shown to be redundant.

When this approach was applied on the five core components, results indicated that two of the WPI components (Environment and Use) should be dropped, as their KMO coefficients are below the threshold 0.5. Unfortunately, the removal of these two components removes the holistic quality of the original WPI structure, which tries to describe the problem as a whole, rather than just in parts. To be effective, any water management decision must take both demand and supply of water into account. The Use and the

Table 8 Weights of WPI components

Components	Weights	
	Classical WPI (cWPI)	Refined WPI (rWPI)
Resources	0.2	0.12
Access	0.2	0.48
Use	0.2	0
Capacity	0.2	0.4
Environment	0.2	0
Total	1	1

Environment components in the WPI provide those extra dimensions that make the tool unique, more effective in identifying root causes which need attention.

Considering Use, this represents the efficiency with which we use water. It is vital that humans must consider this in great detail. At present, data on water use is almost non-existent in many countries, and is very inaccurate, globally. Part of the rationale for the WPI in the first place was to promote a more streamlined, effective approach to data collection and storage, so that water accounting could be widely implemented. Only by real accounting for water can we consider how to pay for its services as a factor of production. This is an essential step if we are to achieve sustainable development. The Use component draws attention to our behavior, and thus is valuable, in spite of having a low KMO score, which may be due to poor data.

For Environment, this component tries to represent the maintenance of ecological integrity; this means making sure we protect the basis of our life support system (water). This is a much more important criterion to be considered, rather than the KMO score, which may be inaccurate. In fact, in the case of the environment component, there is no suitable data available to capture *ecological integrity*, which is what that component is meant to represent. The data used instead, represents biodiversity or national park areas etc., and these are used as proxies for a healthy environment. These proxies are simply not reliable enough as a measure to represent this complex concept. This is one possible reason why the PCA approach produces a low KMO score, suggesting the component itself is not of use. This is a spurious correlation and should be discarded.

6 Sensitivity Analysis

Since the quality of WPI significantly depends mainly on the PCA constraints, sensitivity analyses can help gauge the robustness of the composite index, and improve its transparency and usefulness. We thus analyze the sensitivity of the results for different weighting scheme: PCA determined weights and equal ones. A comparison between these two methods of weighting is shown in the Table 8.

7 Main Empirical Results

The result of the rWPI and cWPI application on the MENA countries is shown respectively in the following maps (Figs. 6, 7).

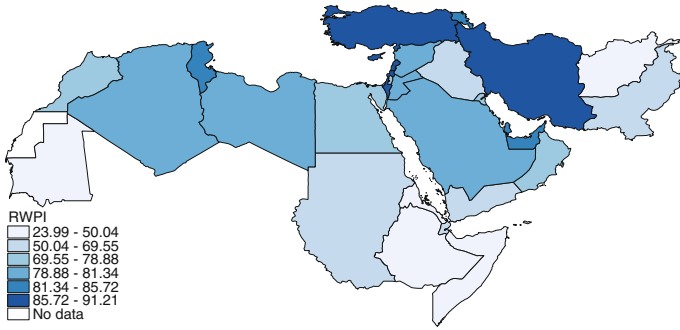


Fig. 6 Refined Water Poverty Index

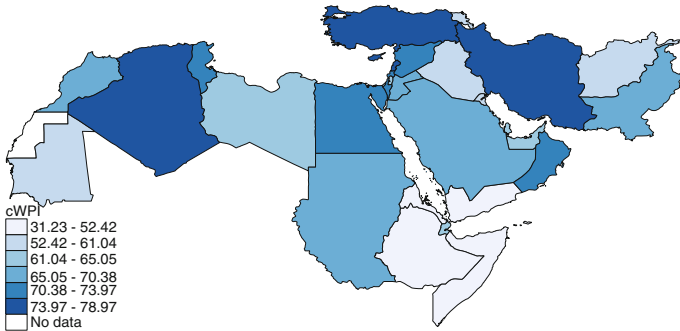


Fig. 7 Classical Water Poverty Index

Figures 6 and 7 indicate how the modification of the classic WPI structure by reducing it to just 3 core components (to create the rWPI) results in less differentiation between countries. This reduces the usefulness of the tool. Rankings of countries using the cWPI and rWPI approaches are provided in Table 9 in Appendix, with the lowest scores indicating the greatest degree of water poverty. These two map (Figs. 6, 7), added to the *Resources*, *Capacity* and *Access* maps below (Figs. 8, 9, 10), suggest that water poor countries are located mainly in the Horn of Africa (Ethiopia, Eritrea, Djibouti and Somalia) and Afghanistan and Mauritania. Although, these countries have enough water resources to satisfy populations' requirements, they are suffering from economic water scarcity through the lack of water infrastructure. In some studies, this is called *weak institutional capacity* (Figs. 9, 10).

The results are chronic food insecurity in these poorest countries (Fig. 9) despite their water abundance compared to others MENA countries (Figs. 3, 8).

Interestingly, as shown in Figs. 6 and 7 high and middle income countries such as Israel, Libya, Kuwait, Emirates Arabs United and other Gulf states located in very arid zones (Fig. 8), are shown as *water rich* by both the rWPI and the cWPI maps. Thanks to their non renewable resources such as natural gas and oil reserves, Gulf States have adapted, at most in the medium term, to the increasing demand on water resources. They have been able to

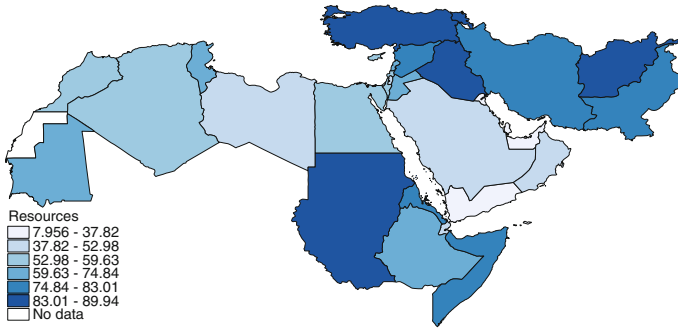


Fig. 8 Resources Index

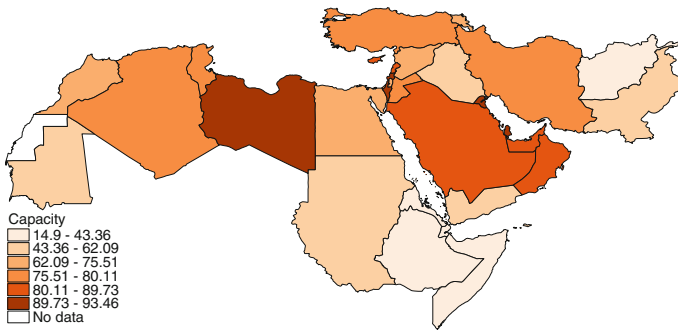


Fig. 9 Capacity Index

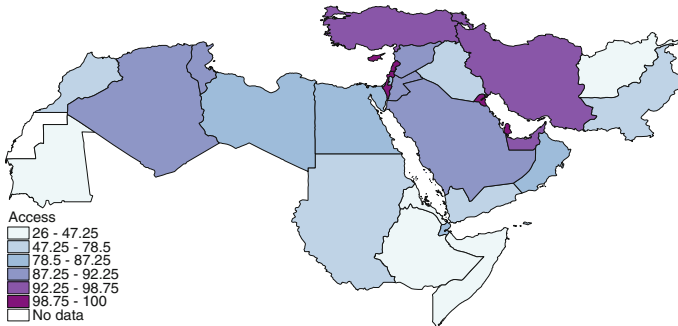


Fig. 10 Access Index

use their natural capital (oil etc.) to develop very high-cost techniques such as desalination to satisfy the demands¹⁰ from rising populations, industrial development and agriculture.

According to many experts, water consumption per head in these states is among the highest in the world, and that a better management system and a more sustainable strategy are required urgently to avoid dramatic levels of water scarcity in this region. For example, sewage networks should be constructed and water recycling should be a priority for at least agricultural use.

¹⁰ Approximately 70% of water desalination projects in the world are located in the Gulf region.

According to the two WPI approaches, the water situation of Gulf States is better than that of the countries in the Horn of Africa. This suggests that the lack of institutional capacity in poor countries reduces their ability to harness their water resource abundance. Nevertheless countries with economies based on finite natural resources (oil, gas) can not necessarily overcome physical water scarcity in the long term, unlike other water scarce, yet developed countries such as Israel and Armenia. The situation of Turkey is different to the other countries, as shown respectively in the *Resources* and *Capacity* maps (Figs. 8, 9). It is a middle income country yet water rich at the same time.

To understand the difference between the rWPI and cWPI maps (Figs. 6, 7) we should examine maps of the two components Use and Environment which are included in the classical WPI and dropped in the refined one (Figs. 11, 12). The Use map has been developed (Fig. 11) to show at a glance the level of the efficiency with which water is used. This map illustrates that populations in naturally water rich regions such as the Horn of Africa cannot use these water resources efficiently, while population in water-poor countries use their limited resources more efficiently. In the WPI, the maintenance of ecological integrity is represented by the *Environment* component. Figure 12 shows the spatial distribution of this last component, illustrating those countries (particularly Gulf States) which have more access to water resources may not be concerned about the ecological dimension of water scarcity. Those countries are in the bottom of the environment ranking (see Table 9 in “Appendix”).

8 Summary and Conclusions

In conclusion, it can be seen that it is paramount to distinguish between indicators that focus only on physical water scarcity such as the Falkenmark Index and those which address more systemic dimensions, where management, socioeconomic and ecological aspects are crucial factors to consider, as in the Water Poverty Index (WPI). The WPI is defined as multidimensional measure which binds household capacity with physical water availability and indicates the degree to which water shortage affects human populations. Contrasting the water scarcity levels of rich and poor oil countries yields interesting results. Clear disparities exist between countries on how these problems are treated.

Key differences in water scarcity between East African and Gulf states are the level of water availability and institutional capacity. While the Gulf region lacks sufficient water, countries like Sudan, Somalia, Eritrea, and Ethiopia maintain relatively stable water abundance, but lack institutional capacity to manage and exploit these resources. This is the result not only of their level of economic development, but also due to legally imposed restrictions that have existed since 1928, on how they can use the water flowing from their rivers, along the Nile and into Egypt. This is a good example of why we need to distinguish between the two principal concepts of physical and economic water scarcity, to understand the multidimensional concept of water poverty. With population growth, economic development, little infrastructure and limited water resources, water poverty has spread to many MENA countries. Greater efforts will be needed to meet these water scarcity challenges and overcome resulting food insecurity, or social and political instability. New approaches and strategies will be required to use and manage water resources more effectively, and concerted efforts will also be necessary to slow the growth in human consumption for water and improve its productivity. For example, in Gulf States, where physical water scarcity is high, sewage networks must be constructed and water recycling should be a priority for at least agricultural use. Renewable energy sources like solar and

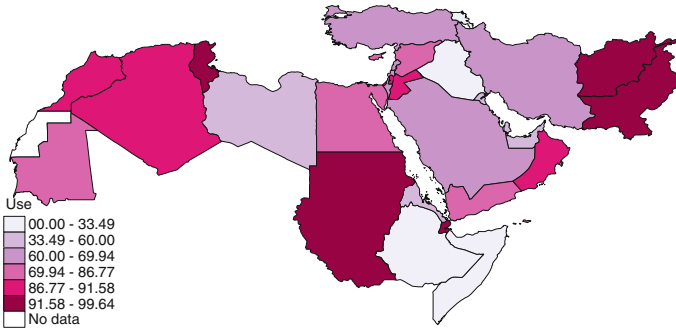


Fig. 11 Use Index

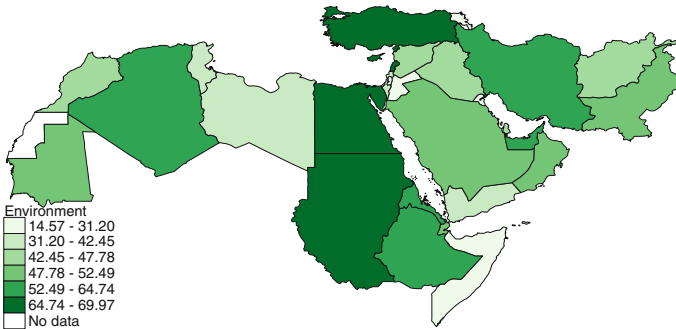


Fig. 12 Environment Index

wind should be promoted to reduce the high cost of water desalination, and high level of emissions from water treatment processes. Since water stress can only get worse in the face of population grown and limited resources, actions must be put in place now to prevent future problems.

This paper has shown how the Water Poverty Index is a useful tool in the analysis of water stress. It directly links water resources to the various uses that are important for humans, including the maintenance of ecological integrity. While statistical techniques such as those described here can have an important role in refining such approaches, it is essential to remember that the basic data from which the WPI scores are calculated. To continue to improve the use of this tool in the future, it will be important not only to refine the mathematical structure but also to build more integrated and comprehensive data bases on which it can be based.

Appendix

See Table 9.

Table 9 The Refined Water Poverty Index and Sub-Indices

rWPI	cWPI	Resources	Access	Use	Capacity	Environment
Israel	Turkey	Iraq	Israel	Afghanistan	Israel	Lebanon
Cyprus	Iran	Afghanistan	Cyprus	Djibouti	Bahrain	Turkey
Lebanon	Lebanon	Sudan	Qatar	Pakistan	Qatar	Egypt
Turkey	Cyprus	Armenia	Kuwait	Soudan	Libya	Cyprus
Iran	Algeria	Turkey	Lebanon	Tunisia	Kuwait	Sudan
Armenia	Tunisia	Somalia	UAE	Morocco	UAE	Eretria
Qatar	Syria	Iran	Armenia	Algeria	Cyprus	Iran
Bahrain	Oman	Syria	Iran	Jordan	Saudi Arabia	Algeria
Tunisia	Israel	Eretria	Bahrain	Oman	Oman	UAE
UAE	Egypt	Pakistan	Turkey	Palestine	Lebanon	Ethiopia
Syria	Pakistan	Mauritania	Saudi Arabia	Mauritania	Turkey	Pakistan
Jordan	Sudan	Lebanon	Jordan	Yemen	Tunisia	Oman
Saudi Arabia	Morocco	Tunisia	Syria	Syria	Iran	Mauritania
Algeria	Saudi Arabia	Ethiopia	Algeria	Egypt	Jordan	Djibouti
Libya	Jordan	Jordan	Algeria	Cyprus	Algeria	Saudi Arabia
Oman	UAE	Israel	Libya	Turkey	Armenia	Afghanistan
Egypt	Palestine	Algeria	Palestine	Iran	Egypt	Iraq
Palestine	Djibouti	Morocco	Oman	Saudi Arabia	Syria	Qatar
Morocco	Qatar	Cyprus	Egypt	Lebanon	Morocco	Morocco
Kuwait	Libya	Egypt	Djibouti	Israel	Palestine	Syria
Iraq	Iraq	Oman	Morocco	Libya	Yemen	Israel
Pakistan	Mauritania	Palestine	Iraq	UAE	Iraq	Tunisia
Djibouti	Afghanistan	Djibouti	Pakistan	Qatar	Pakistan	Libya
Yemen	Armenia	Libya	Yemen	Eretria	Mauritania	Yemen
Sudan	Kuwait	Saudi Arabia	Sudan	Kuwait	Sudan	Bahrain
Mauritania	Yemen	Yemen	Mauritania	Iraq	Ethiopia	Kuwait
Eritrea	Bahrain	Qatar	Eritrea	Ethiopia	Eritrea	Armenia
Ethiopia	Eritrea	Bahrain	Ethiopia	Somalia	Djibouti	Palestine
Afghanistan	Ethiopia	UAE	Somalia	Armenia	Afghanistan	Somalia
Somalia	Somalia	Kuwait	Afghanistan		Somalia	

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