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TOWARD UNDERSTANDING WATER CONFLICTS IN MENA REGION: A COMPARATIVE ANALYSIS USING WATER POVERTY INDEX

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Abstract

Under the premise that water scarcity is inherently multidimensional, and not limited to unique physical dimensions, integrated composite indices such as the Water Poverty Index have been developed, going beyond traditional hydrological measures. In this paper we discuss the evolution of these indices, and propose to evaluate the method of their calculation through the use of Principle Component Analysis (PCA). On this basis, this paper assesses levels of water poverty for countries in the MENA region. In particular, we compare oil-rich and water-poor countries (Gulf States) with those, which are relatively water-rich yet, money poor (East African states). We use this approach too to examine and understand some of the regional water-related conflicts including those between Jordan, Lebanon, Palestine and Israel, Egypt, Soudan and Ethiopia and Iraq, Syria and Turkey.

JEL Classifications: C43, Q25, P28, R23

Keywords: Water scarcity; Physical indicators; Water Poverty Index; Principal Component Analysis; Water conflicts; MENA region.

ملخص

في إطار فرضية أن ندرة المياه هي بطبيعتها متعددة الأبعاد، ولا تقتصر على الأبعاد المادية الفريدة من نوعها، تم تطوير مؤشرات مركبه متكاملة مثل قحط المياه، للذهاب أبعد من التدابير الهيدرولوجية التقليدية. في هذه الورقة نناقش تطور هذه المؤشرات، واقتراح لتقييم طريقة الحساب من خلال استخدام مبدأ تحليل المركبات (PCA). على هذا الأساس، تقيم هذه الورقة مستويات الفقر المائي لبعض الدول في منطقة الشرق الأوسط. على وجه الخصوص، قمنا بمقارنة (دول شرق افريقيا) الفقيرة الغنية بالنفط ودول فقيرة المياه (دول الخليج) مع تلك الغنية نسبيا بالمياه، بعد، المال. نستخدم هذا النهج أيضا لدراسة وفهم بعض الصراعات المتعلقة بالمياه الإقليمية بما في ذلك تلك التى تظهر بين الأردن ولبنان وفلسطين وإسرائيل ومصر وسودان وإثيوبيا والعراق وسوريا وتركيا.

1. Introduction

Hydrological modeling and the measurement of physical water shortage have for many years been considered the most important tools to examine water stress, and for many years few efforts were made to recognize the socio-political and ecological-economic drivers of water scarcity. In more recent years, water scarcity has been progressively recognized as an inherently multidimensional phenomenon (Salameh 2000; Sullivan 2001; Sullivan et al. 2003) highlighting the need to move to a wider perspective where the multiple dimensions of water scarcity are taken into account.

The Middle East and North Africa (MENA) region is known as one of the most water scarce regions of the world. In the last few years, several countries in this region have experienced a crisis of both water and sanitation, and this situation is expected to deteriorate in the future. In his many works on the challenges of water management in the Middle East, Allan (2001) has long emphasized the importance of *political economy* to the water management problem. Today, we consider this in the context of *adaptive capacity,* and we examine how a selection of MENA countries is confronted by the multidimensional problems of water scarcity. In addition to dramatic effects on groundwater and river systems, the water shortage in several countries of the MENA region is a major burden to society, causing waterborne diseases, hygiene problems and a constraint to human development. As suggested by Allan over a decade ago, this water crisis has recently become of greater political concern, due to rapidly rising population, industrialisation and pollution. The heavy cost of water, and high level of consumption of food and energy are building pressure on both natural and human systems across the region.

In the first part, the paper looks critically at the usefulness and shortcomings of biophysical water indicators as tools for water resource management in the 21st century. We discuss the possible improvements provided by a multidimensional approach linking diverse socio-economic factors characterising poverty, with physical water availability measures. To provide a focus for this work, we examine the state of various aspects of water poverty and main water conflicts in the MENA region. In particular, we consider how the Water Poverty Index (Sullivan 2000, 2002), can be improved to provide more accurate insights into conditions in these highly water stressed countries. Through the use of Principal Component Analysis, we hope to strengthen the structure of the index, and provide insights into those specific conditions in the MENA region which give rise to water poverty.

The second part of the study, investigates water conflicts in the MENA region through the three main basins (Nile, Jordan and Tigre and Euphrates Basins). The basins chosen as case studies represent the various environmental, water availability, socio-economic and institutional features that characterized the region. Moreover, the study looks at the working and principals rules and mechanisms for reducing or overcome disputes over water allocation and use.

2. A Review of Water Indices

It will not be long before half of the world's population will be living in conditions of physical water scarcity, and issue of increasing concern in all sectors. As demonstrated by a variety of measures (Alcamo et al. 2003; Oki and Kanae 2006;Vörösmarty et al.2010), the world's water resources are highly stressed, and given expected future human populations, this resource will need to be better managed in the future.

2.1 Indices accounting for human water requirements

Physical (hydrological) measures of freshwater scarcity are generally expressed in terms of annual per capita units, largely applied at a national scale. One of the earliest attempts to quantify this was that carried out at by Shiklomanov and Markova (1987). This work provided the basis for what has now become the most widely used indicator of water stress, the Falkenmark index (Falkenmark et al.1989), and was the first to use the logic of water availability per person to highlight the potential for conflict over water availability. Initially focused on sub-Saharan Africa, this approach considered water shortage as a function of the capability to sustain food self-sufficiency, expressed as the total water availability per capita per year, with water availability defined as the annual runoff available for human use[1]. From this work, a benchmark indicator of 1000 m^3 per capita per year has become widely accepted as a threshold of human water scarcity, usually expressed at the national scale. More recently, Falkenmark et al. (2007) have added 500 m^3/capita/year to these threshold values, to distinguish between different levels of water shortage. As a result, on this basis, absolute water scarcity is defined as being less than 500 m^3 per capita per year, ranging to no water scarcity, where over 1,700 m^3 per capita per year is available.

Other researchers have approached this water measurement challenge from the perspective of prioritising the satisfaction of all human water needs. Gleick (1996) has been seminal in this approach, highlighting the need to consider drinking, bathing, sanitation and modest cooking. This approach has been widely taken up by many national and international organizations to support water policy, in spite of the anthropocentric perspective it represents.

In response to this human focus, many authors, including Seckler (2000), Sullivan (2002), Smakhtin et al. (2004), and Rijsberman (2006) have emphasised the need for the inclusion of a measurement of environmental water requirements, as a way to ensure the maintenance of ecological integrity. In his widely cited work, Smatkin estimated that environmental water requirements could be calculated as a percentage of Mean Annual Runoff. In recent years, variations on this approach have gradually evolved into detailed hydro-ecological measurements, which are now incorporated into water policy in a number of countries including South Africa, Australia and many other developed and developing countries.

In the MENA region, Asheesh (2007) has applied a multidimensional approach to illustrate water resource conditions in Palestine and Israel. In this work he incorporates population growth, water availability, domestic and industrial water use, and ecological water needs. All of these dimensions had been included in the early manifestations of the now well-known *Water Poverty Index* (WPI) originally developed by Sullivan (2000, 2001) and elaborated by Sullivan et al. (2002, 2003), Sullivan and Meigh (2003,2006), and Cohen and Sullivan (2010).

2.2 Measuring vulnerability of water resources

The Criticality Ratio (CR) is defined as the percentage of total annual withdrawals to available freshwater resources. To understand the difference between this CR ratio and others indices, the terms need to be clearly defined. The lack of consistency and clarity in what these various water measurement terms mean creates a significant difficulty for water managers. For example, in the CR, water use in this indicator includes only annual withdrawals of water from surface or groundwater sources, instead of a true measure of consumptive use. This is mainly due to poor data on the quantity and quality of return flows, and the location of the water users within a watershed or country (Alcamo et al. 1997,5), Although this method takes no account of evapotranspiration, the ratio is useful as higher values can indicate expected changes in downstream water quality, and a greater likelihood of absolute water scarcity (Yang, 2008). Alcamo et al., (2000) further refined their earlier work to define levels of water stress now commonly used in water resources analysis, where a ratio of less than 10% indicates no stress, while a CR of over 40% indicates high levels of water stress.

[1] This in itself is an extremely difficult value to measure and has been approached in a number of different ways by different research groups.

While these efforts have contributed to improvements in the way water resources are considered in relation to human needs, they are still far from perfect. Lack of inclusion of groundwater for example in some approaches has been seen as a major weakness, especially in those many parts of the world where groundwater provides most of the world's potable water. A further criticism of many rapid assessment approaches is that they fail to address the temporal scale, and so work to develop more dynamic approaches to water resources assessment has gained attention (Yang et al. 2003).

Neglect of both spatiotemporal differences and infrastructure is a serious weakness in much conventional water assessment, and more emphasis is needed on water use efficiency (Feitelson and Chenoweth 2002) and socio-economic aspects (Malkina-Pykh 2002). As Dow et al. (2005) suggest having a standard threshold is unreliable for comparisons between industrialized and developing countries and also within countries. Another serious criticism of these various approaches are that they neglect the recycling capability of reusing water particularly in the case of industrialized countries where water can be used many times (Yang 2008). Vörösmarty et al., (2000) attempted to calculate a Water Reuse Index, defined as the fraction of aggregate upstream water use relative to discharge. While this was a step forward, significant further work was required for this to be eventually developed into the holistic basin-scale assessment technique described in the highly cited paper by Vörösmarty et al. (2010). This most recent approach takes advantage of vast improvements in computing capacity, and more reliable global datasets. The index-based modeling technique presented in that work can also facilitate presentation of much finer resolution data so that sub-national assessments can be carried out.

In the last 15 years, the concept of *virtual water* has become of interest to many researchers. This concept refers to the quantity of water embodied within a product (food, machinery etc.), While this is very useful when determining the way water is actually used by humans, and moved around the world through trade, it is has as yet mainly been applied to agricultural products. Debate remains about the extent to which *virtual water* actually contributes to water resources, or is just a manifestation of water in different uses. While this has been popularized in recent years (Chapagain and Hoekstra 2008) the concept of *virtual water* has long been put forward explicitly as a possible solution for water allocation decisions in the MENA region by Allan (2001).

Another very important hydrological concept in resource assessments is that of soil moisture content. This is a crucial factor for water use efficiency in agriculture. This concept, along with evapotranspiration is now at the core of what is being referred to as *green water* (Molden 2007). To date there has been little inclusion of this concept into assessment frameworks, once again mainly due to lack of both reliable data, and operational capacity

One of the biggest and most common concerns of all these physically based indicators is the fact that they make no real attempt to address the three domains of sustainability (economic, social and environment). Given the political commitment to sustainable development, as manifested by policies for Integrated Water Resources Management (IWRM), this is a serious gap in water resources assessment methodology. Greater recognition of the urgency of this challenge has brought about the evolution of a new generation of multidimensional indices including the now well-recognized *Water Poverty Index* (WPI).

2.3 Multidimensional approaches to water scarcity measurement

Water scarcity is now recognized as an inherently multidimensional phenomenon. To address the multidimensionality, Molle and Mollinga (2003) focused on different uses of water and the influence of its shortage on the society. Water scarcity was identified as physical, economic, managerial, institutional and political phenomenon (Swatuk 2002). Demonstrating the complexity of water scarcity highlights how important it is to move beyond the simple first-generation water scarcity indices like the Falkenmark index, to more comprehensive ones such as the Water Poverty Index (Sullivan 2001,2002; Sullivan et al. 2002, 2003), where multiple dimensions are both instrumentally and intrinsically important.

Such approaches try to link the biophysical and social worlds to produce a more meaningful and real assessment of what it means to be water poor. By explicitly taking account of the way water is used by humans, and recognizing that water must be allocated to maintain ecological integrity, the method recognizes the fact that levels of water stress are the result of much more than just a simple lack of water. This holistic, integrated approach enables a richer, deeper understanding of drivers of water poverty, beyond the simple statistic of per capita water availability. The term *water poverty* has been widely taken up and the concept has now become well established in the literature. Some authors, most notably Feitelson and Chenoweth (2002), were most concerned with water affordability, a crucial factor in water management decisions, but how this issue can best be dealt with is still to be resolved.

The overall objective of the Water Poverty Index (WPI) is to provide a mechanism by which water management decisions can be prioritized using a holistic standardized and transparent framework. Using Multi Criteria Analysis, the five major components (Resource, Access, Capacity, Use and Environment) are combined as a weighted average. Each component is represented by various sub-components, with the resulting scores ranging from zero (extreme water poverty) to one hundred (zero water poverty). In this structure, the component *Resources* can include surface and groundwater, as well as some measure of variability and water quality. The *Access* component may include access to water for domestic use, and access to irrigation. The *Use* component relates the use of water to the value of output it generates. The *Capacity* component focuses on individual and institutional capacity to manage water, and this is based on level of education, health status, and Gross Domestic Product (GDP). While ideally, issues such as value of investment in the water sector or number of water professionals would be highly relevant, such data is rarely available, so HDI components serve as a proxy. As a compromise, the *Environment* component is represented by sub-components such as biodiversity, soil erosion, or other form of environmental degradation. Since its first iteration, several other authors (Heidecke 2006; Komnenic et al. 2009, Garriga and Foguet 2010; Manandhar et al. 2011, and Jemmali and Matoussi 2013) have applied the approach in a wide range of countries across the world.

3. Water Scarcity in MENA Region

The Middle East and North Africa (MENA) region is variously defined[2], but in this study we are taking the widest definition which includes 30 countries (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). This is recognized to be the most water stressed area of the world, especially when considering the various types of scarcity as described by Molle and Mollinga (2003). The region is home to about 6.3% of the world's population, but has only 1.4% of the world's renewable fresh water. This situation of water stress is further exacerbated by the fact that over 80% of the renewable water resources in several MENA countries originate from outside their borders. By comparing the global average water availability per capita of about 8462m^3 per year with the 1383 m^3 per person per year in the MENA region, it is easy to see why more than half of the population of the region are facing extreme water stress.

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[2] In others studies the MENA region is defined differently and contains fewer countries. To get more robust results we opted for the larger set of states, which can be included.

In many countries of the MENA region, particularly in southern part, water use regularly exceeds the theoretical available renewable amount. This situation of water stress has given rise to many problems in the region, not least on human health, with high consequent costs. For example, many MENA countries have poor provision of sanitation, which has led to contamination of both surface and ground water, causing adverse effects on both ecosystems and public health. As in almost all countries of the world, the agricultural sector in the MENA region is by far the biggest water user, accounting for as much as 90% of water use in several countries. One of the reasons to include the efficiency of water use, as one of the components of the WPI is to try and highlight the variation in economic returns to water use, to enable decision makers to consider sectoral allocations of their scarce water resources.

Some countries of the wider MENA region, including Mauritania and Turkey do have significant water supplies, but overall, about 60% of the region faces conditions of water stress, with an average of less than 1000 m^3/person/year. Recently, concern over the impact of climate change has arisen, and it is anticipated that precipitation across the region may be reduced by as much as 20% in coming decades. Coupled with rapid demographic growth in many of the MENA countries, and rising levels of economic development, there is no doubt that the levels of water stress are going to rise across the region, especially in urban areas. Notably, these are mostly located in North Africa and the Arabian Gulf, with conditions in thirteen of these nations being even more severe, with available fresh water being less than 500 m^3/person/year. These anticipated future conditions do suggest that in the Arabian Gulf and North Africa, physical water scarcity will increase, while in the Horn of Africa (Ethiopia, Somalia, Eretria) economic water stress is likely to result due to lack of water infrastructure. In this latter region in particular, this situation is worsened by political constraints associated with institutional arrangements governing the waters of the Nile basin. Some aspects of this current level of water stress across the region are illustrated through application of the Falkenmark index (See Figure 1).

4. Application of Modified Water Poverty Index (mWPI)

The socio-economic and hydrological conditions differ greatly between low income yet water rich countries of the MENA region, (Ethiopia, Eritrea, Sudan) and high income yet water poor countries (Israel, Kuwait, United Arab Emirates). These multidimensional differences and their causes can be described and analysed by the Water Poverty Index (WPI). The Water Poverty Index is a composite index containing five components; each made up of a number of subcomponents and calculated across these as a weighted average (Sullivan 2002; Sullivan et al. 2003). In this paper, we use the same structure as in previous work, although some of the sub-components are different due to unavailability of data. Table 1 presents the indicators used to represent the five core components in this iteration of the WPI. We also consider the implications of using a multiplicative structure for data combination, and with the view to refining the overall WPI structure; we examine the relation between the variables using Principle Component Analysis.

All data collated for the process of this analysis is normalised on a scale of 0-100[3], reducing incommensurability of information. This is achieved using the formula in Eq.1:

$$x_i{}^* = \frac{x_i - x_{min}}{x_{max} - x_{min}} \times 100 \quad (1)$$

Where x_i^*, the current value of variable x for country (*i*), with x_{min} and x_{max} being the lowest and highest values of the considered variable in this group of 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. However some components do not follow

[3] Some data does not require this if already expressed as percentages.

this pattern and need to be adjusted accordingly. For example, a high under-five mortality rate is not a good thing, and so this needs to be inversed in this calculation.

As first outlined by Sullivan et al. (2002, 2003) and Jemmali and Sullivan (2014), it was considered useful to adopt two thresholds for domestic water use, to account for basic human needs (50 lts/day), and for excessive water use by households (150 lts/day), This means that countries which have daily domestic use below 50 lts/day (on that component) have higher levels of water poverty than those between 50 and 150 lts/day. For households where consumption is above 150 lts/day, this is considered wasteful, so their score is reduced to take account of this. Such an approach is illustrated in Eq.2:

$$USE_i = \begin{cases} \frac{x_i}{50} \times 100, x_i \leq 50 \\ 100 - \frac{x_i - 50}{x_{max} - 50} \times 100, 50 \leq x_i \leq 150 \\ 100 - \frac{x_i - 50}{x_{max} - 150} \times 100, 150 \leq x_i \end{cases} \quad (2)$$

Once all the indicator values are calculated and scaled accordingly, the weighted average is calculated. The implications of using additive or multiplicative aggregation have been much discussed (Garriga and Foguet 2010; Pérez-Foguet and Giné Garriga 2011), but in the interests of simplicity, we believe that the additive approach is most appropriate. Nevertheless, it is important to recognise that there may be some correlation between the various subcomponents, and as indicated by Hajkowicz (2006), and Nardo et al. (2005). Correlation between these subcomponents should be evaluated before calculating the final component values. To this end, a multivariate statistical technique, the Principal component analysis[4](PCA), is performed at the subcomponent level to explore whether chosen indicators are statistically well balanced.

Before applying PCA at index and sub-index level, we should both examine the overall significance of the correlation matrix using Bartlett's test of sphericity and analyze the factorability of indicators collectively and individually, by applying the Kaiser-Meyer-Olkin (MSA) Measure of Sampling Adequacy (Hair et al. 2006). Results of these tests of each sub-component are shown in Table 2, and based on these statistics; we conclude that PCA can be performed on the *Capacity* and *Access* components.

The main objective of this step is to reduce the number of correlated variables into a set of fewer and uncorrelated factors without losing too much information. Using the *variance explained criterion* to keep enough factors to account for 80% of the total variation (Nardo et al. 2005), only those components with scores above 80% are discarded. In this case, the first components in both *Capacity* and *Access* are extracted (respectively accounting for 81.81% and 91.58% of the total inertia). From this Principal Component Analysis, factor loading scores are used to determine the weights of various variables associated with each variable.

Table 3 compares two different weighting schemes applied to the WPI sub-components, referred to here as the Classic WPI and the modified WPI. In this first approach, the weights are simply determined by the number of sub-components in each core component set, whereas in the second approach, the weights have been determined using the Principle Component Analysis.

[4] 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 (Dunteman 1989; Morrison 1967). 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.

As can be seen from this table, these two approaches have resulted in the same weighting scheme. It is interesting to note that while the first approach is simply the implicit weights; the second approach was based on a well-established robust statistical method. At this point, it is important to reiterate that since the first establishment of the WPI by Sullivan (2001, 2002), it has always been argued that while these statistical assessments of weightings are useful, in practical application of the tool, weights should be established by the stakeholders in the relevant location, as the choice of weights indicate the importance of something, and in this case, this is a political rather than scientific issue.

A further examination of the WPI methodology involves considering the usefulness of each of the five core components. These core components were first established in a weeklong workshop held in Tanzania, involving a large international group of scientists and practitioners. Each was chosen due to the relevance and importance it has in supporting sustainable and equitable water allocations. In this work we examine these components to see if there is any statistical justification to either include or exclude them. The original weighted set of core components is shown in Eq.3:

$$WPI = \beta_R \times RES + \beta_A \times ACC + \beta_C \times CAP + \beta_U \times USA + \beta_E \times ENV \quad (3)$$

Where RES, ACC, CAP, USE et ENV denote respectively indexes of *Resources*, *Access*, *Capacity*, *Use* and *Environment* and β_R, β_A, β_C, β_U et β_E the weights associated with the five sub-components in the structure of the WPI. As we have done above in the case of the sub-components, we will now examine these core components using PCA, to see what weightings result. Again, before applying the PCA to the data set, we must analyze the degree of association among possible pairs of the five core components, and we use Kendall's correlation coefficient (*tau-B*) to do this (Cho et al. 2010). The results of this analysis are shown in Table 4.

There are three main outcomes from this analysis, Firstly, *Access* and *Capacity* exhibit the highest significant positive correlation (0.89) confirming that rich countries provide better access to water resources for their population and vice versa. Secondly, when examining how *Resources* interact with *Capacity* and *Access*, the significant negative correlations (-0.5485, -0.4151) of the two pairs respectively (*Resources*, *Capacity*) and (Resources, Access) demonstrate that globally, water rich countries are generally low and middle income countries, where often large proportions of population lack access to safe water and sanitation services. Thirdly, *Environment* and *Access* (0.0044) exhibit the lowest bivariate correlation suggesting that there may be little relation between access and environmental impact. On this, it is important to note that this could be the result of the use here of ineffective proxies of environmental quality, rather than a real result.

After analyzing the correlations between components, we use the Bartlett's sphericity test to assess the overall significance of the correlation matrix listed above. The test indicates the presence of significant nonzero correlations at 1% significance level ($\chi^2 = 58.929$; p-value = 0.000). In addition, we have used the recommended Kaiser-Meyer-Olkin Measure of Sampling Adequacy (MSA) (Kaiser 1974), to test for factorability of the indices, both collectively and individually. By comparing the observed correlation coefficients to the partial correlations, the KMO measure determines if the dataset has enough variance to make factor analysis relevant (Kaiser 1974). Here, the overall MSA value is 0.5, which falls in the lower end of the useful range (i.e., between 0.5 and 0.7),

By examining the individual MSA values, we can see which variables might be bringing the overall MSA value down. From this we can see that MSA value for both the *Use* and *Environment* components are low, (0.28, 0.33), both being less than the threshold value (0.5). To pursue the implications of this, we further investigate this by removing these two components from further analysis. After discarding the *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 significant correlations at the 0.01 level (χ^2 = 53.251; p-value = 0.000), and the overall KMO value is slightly higher than the value before discarding these two components, reaching 0.564, once again in the acceptable range. Similarly, 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 5 shows the characteristic roots and vectors of the PCA results.

When just three components are considered, 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 the global variance. When the *variance explained criteria* is applied to keep enough factors to account for 80% of total variation, we retain these two first components. In such a case, to get the final weighting scheme, the extracted components should be weighted with the proportion of variance measured by dividing the square root of the eigenvalue of each principal component by the sum of the square root of the eigenvalues 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 then be found using the formula shown in Eq.4 (Rovira and Rovira 2008 and Jemmali and Sullivan 2014).

$$w_i = \sum_{k=1,2} PCk_i \times \frac{\sqrt{\lambda_k}}{\sum_{j=1,2}\sqrt{\lambda_j}} \quad (4)$$

Where PCk_i is the factor loading of the index *i*, which can be *Resources, Capacity* or *Access*, on principal component *k* also called component loading (see Table 8).

At this point the aggregation of the WPI components can be carried out using the weights defined above, in order to re-assess water poverty level for each country of the MENA region. Numerically, the modified Water Poverty Index can be formulated as follows (Eq.5):

$$mWPI = \prod_{i=R,C,A} X_i^{w_i} \quad (5)$$

Where *m*WPI is the value of the restructured water poverty index, *Xi* 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. In this example we take note of the suggestions of Manandhar et al. (2011), Pérez-Foguet and Garriga (2011) and Jemmali and Sullivan (2014) who propose that the most appropriate aggregation function to calculate the WPI is the weighted multiplicative function, as it does not allow commensurability among the different components involved in the index formula.

5. Empirical Results

The result of the *m*WPI application on the MENA countries is shown in Figure 2. On the basis of this analysis, the countries with the lowest *m*WPI score are the *water poorest*, with the *water rich* countries having higher scores in the *m*WPI ranking (see Appendix for detailed scores). This *m*WPI map can also be compared to those individual maps for *Resources*, *Capacity* and *Access* (Figures 3, 4 and 5). These maps suggest that countries in the Horn of Africa are the most water poor (Ethiopia, Eritrea, Djibouti and Somalia) with Afghanistan and Mauritania displaying properties of a lack of water infrastructure, which can be interpreted as lack of institutional capacity.

For these most water poor countries, these results suggest that chronic food insecurity in these poorest countries may result from the lack of access and capacity; despite their relative water abundance compared to other MENA countries. On the other hand, this analysis shows high and middle income countries such as Israel, Libya, Kuwait, United Arab Emirates and other Gulf states are shown in the RWPI map as "water rich" although they are technically facing serious water shortages when faced by a lack of water resources. Thanks to their other resources such as natural gas and oil, Gulf States have adapted in the short and medium term by using high-cost techniques such as desalination to satisfy the demands of their rapidly rising populations, and the increasing demand on water resources from economic development in industry and agriculture[5].

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 urgently required to avoid dramatic effects of future water scarcity in this region. For example, more efficient use should be made of wastewater through the development of modern sewerage treatment and water recycling at least for agricultural use. It is clear that under the present system, although the water situation of the Gulf States is perhaps better than their neighbours at present, this cannot continue in the long run, where physical water scarcity will be an increasing problem and depletion of oil and gas resources will make desalination less attractive. On the other hand, those states, which may be more water poor, now (in spite of good water resources) will have a better prospect in the future if *access* and *capacity* can be further improved. In the case of Turkey, however, we see that their good water resources and medium income country status show promise for better water development in the future, as long as the political economy of the region can remain secure.

6. Discussion

This paper has demonstrated that it is essential to distinguish between indicators that focus only on physical water scarcity such as the *Falkenmark Index,* and those such as the *Water Poverty Index* (WPI), which addresses more systemic socioeconomic and ecological dimensions of water management. 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.

The challenges facing countries with different natural capital endowments can be striking. The analytical framework provided by the WPI facilitates examination of the various drivers of these differing water scarcity conditions. For example, the key difference between water scarcity in East African and in the Gulf states remains availability of water resources and *institutional capacity*. The Gulf region lacks sufficient water resources, while countries like Sudan, Somalia, Eritrea, and Ethiopia have relatively stable water abundance, which is shown by the WPI in the higher *Resources* score. As illustrated by the WPI *Capacity* component, these latter countries do however lack *institutional capacity* to manage and exploit these resources.

With population growth rates across the region being among the highest in the world, water poverty has spread to many MENA countries. As economic growth has progressed, industrialisation and urbanisation have also caused rapid growth in water demand per capita. At the same time, renewable fresh water resources are an increasing constraint, with much water infrastructure is coming to the end of its life, and the impacts of climate change possibly reducing future levels of rainfall. If we want to ensure that these increasing water scarcity challenges are appropriately addressed, the way water resources are assessed is extremely important. In addition to new approaches and strategies for water management, countries and regions will have to make concerted efforts to work together to address these increasing water stress problems. Legal and institutional arrangements must be put in place to facilitate cooperative approaches, while education and awareness rising will help to reduce domestic water consumption. For commercial operations, economic instruments can be used

[5] Approximately 70% of water desalination projects in the world are located in the Gulf region.

to modify water use, encouraging more efficient use to improve water productivity. To offset the high costs of water desalination, renewable energy sources including solar and wind should be developed.

From the information generated by the application of the WPI in the MENA region, we can see that for example, in the Gulf States, the site-specific nature of water stress there indicates that water recycling should be a priority, at least for agricultural use. To offset the high costs of water desalination, renewable energy sources including solar and wind should be developed. Sewage networks, still to be developed in many areas, must be constructed, ideally following a nutrient-recovery design rather than waste export. In contrast, for the countries of the upper Nile, their challenge lies in improving their human and institutional capacity, so that their ample water resources can be capitalised upon for national benefit, without jeopardising existing downstream legal arrangements.

7. Water Conflicts

In the literature there are two types of water conflicts. The first one refers to the most common of social and territorial disputes between different beneficiaries of such a vital resource as water is not required only for consumptive use (drinking, sanitation, washing, agriculture etc.) but it is also required for fishing, drainage, navigation, industry and ecology. Then, it is so easy to comprehend that for such resource, various groups of users on account of their strategic locations of changeable degrees of benefits will have opposed benefits, which may conflict particularly where there are limited water resources for growing population. The water poverty approach applied in this study takes account in the first step all these uses separately with special focus on efficiency of each one. Thus a potential water conflict between different users is ignored in the structure of the WPI; the index developed is criticized for such ignorance.

The second kind of water conflicts is transboundary water conflicts, which are different from the first type of conflicts explained above. They occur usually between upstream and downstream users (countries) sharing the same sources of water. The upstream denotes the geographical area where people are more profited than inconvenienced, while downstream will mean accurately the opposite sense. Unsurprisingly, then, the contradictory benefits will remain as the social tension kept alive for centuries and has kept water the center of disputes and conflicts throughout history. Such tension is seen manifest frequently in brutal conflicts, armed interventions or plain riot.

The transboundary water conflicts append a very different dimension to the water dilemma taking into account the geo-political concept of sovereign state. The dimension is imposed on practical human benefits in the form of an ideology and renders the conflict more complicated away from any resolution. A little bit of explanation of such conflicts is sufficient to confirm this point of view.

According to UNESCO, the existing intergovernmental conflicts take place chiefly in the Middle East and North African region where most countries share common water sources (conflicts stemming from the Euphrates and Tigris Rivers among Turkey, Syria, and Iraq; and the Jordan River conflict among Israel, Lebanon, Jordan and Occupied Palestine), as well as in Africa (Nile River-related conflicts among Egypt, Ethiopia, and Sudan). Some hydrologists and economists assume that due to rapid rise of human consumption of water resources, water conflicts will become increasingly complex and common very soon. Recently, Rwandan Genocide and war in Sudanese Darfur have been related strongly to water conflicts.

In 1997 the United Nations Convention on the Law of the Non-Navigable Uses of International Watercourses identifies a watercourse in its Article 2(b) as, "*a system of surface waters and groundwater constituting by virtue of their physical relationship a unitary whole* *and normally flowing into a common terminus*." This definition comprises rivers and their tributaries, lakes, aquifers, glaciers, reservoirs and canals and groundwater as part of subsurface water.

Actually, there are four central theories of international water law. The first is the absolute territorial sovereignty[6] theory where an upstream State can liberally exploit the water resources within its boundaries without the need of taking into account other States. The implication is that the State has absolute authority over the natural resources within its borders, including water resources. Nevertheless, this principle has received very little international support around the world.

Secondly, the principle of prior appropriation, which gives preference to the State, that first made use of the water source. This is illustrated in the treaty agreements on the Nile basin that allow Egypt and Sudan the use of approximately 90% of its water. While this principle of prior appropriation has had little international support in the formulation of recent international water agreements or in the negotiation of such agreements, it has traditionally remained the basis for many international water agreements until now.

Thirdly, the principle of absolute territorial integrity implies, alternatively, that a downstream State should not have its watercourse, interrupted by an upstream State in spite of priority. This third principle places an unnecessary burden on the upstream State without placing a similar burden on the downstream State. Another example of this agreement in MENA region is the situation of the upper riparian states on the Nile River to the lower riparian States.

The fourth principle is simply a middle point between restricted territorial sovereignty and restricted territorial integrity called "*in an equitable and reasonable manner*". This principle authorizes States to use the water resources within their boundaries in ways that will not prejudice the need and use of the same watercourse by other riparian States. Equitability means equality of right to a part of the uses and benefits. Contrary to the first principle, this principle has received wide international support but the major challenge has been the practical ways of implementing this principle of "*equitable and reasonable use*" to resolve some complicated disputes. It has been so difficult to implement as it assumes a watercourse is a single integrated system, which should be administered as a whole. This particular assumption is mainly problematic in the MENA region since the lack of political and social cooperation that exists between some of the riparian States in the region. Besides, power differences not depicted in the WPI structure and socio-economic disparities as illustrated by Capacity compound maps (Figure 4) make the application of this principle too difficult in this region.

After applying the multivariate analysis, the *external water resources* indicator has been assigned a significant weight (0.33), as indicated in table 3, but less than the weight accorded to *internal water resources* indicator. This is due principally to arbitrariness and incertitude of common resources. As noted above, these resources are subject frequently of conflicts and tensions. Then assessment of water availability for each country, which shares common resources with their neighbors or others states depend heavily on conflicts trends and how these conflicts are resolved.

In MENA region, most countries that rely on the same water resources are so differently ranked according to Access, Capacity and Use indices (see table of ranking in Annexes). Particularly, when looking at the Access map (Figure 3), we find that some countries particularly in the Middle East, despite limited internal water resources, sufficiently provide their populations with access to safe water and sanitation (such as Israel) while other

[6] The Principle is a development from the Harmon Doctrine, which was applied in 1895 to address a conflict between the United States of America and Mexico over the pollution of the Rio Grande River.

neighboring countries are unable to provide acceptable quality water at affordable prices to their populations (such as Jordan and Palestine). To understand such disparate situations that characterize specially the MENA region, we must look firstly to the Capacity map (Figure 4), which reflects the capability of people, in each country, to manage their own water resources. Without surprise, this map shows that some water scarce countries such as Israel and Egypt (as shown in the Falkenmark map, Figure 1) which rely primarily on external resources to provide enough clean water for their growing population are better ranked according to this sub-index and to the WPI than their neighbors. Thus, we can conclude that thanks to military superiority not taken into account in WPI calculation and socio-economic power these countries have exercised a strict control over water and dominate water policy in the considered region. A little bit of explanation of water conflicts in the three basin of the MENA region (Jordan, Nile and Tigris-Euphrates Rivers) shows that the location of country (upstream or downstream) added to military and economic power are the main factors that influence the transboundary water distribution in the region.

More deeply, the Riparian States of the Jordan River (Palestine, Jordan, Lebanon, Syria, and Israel), which have so different values of water poverty index, have depended on different international water law principles to put forward their claims based on their position on the river course. Lebanon, as an upper riparian, prefers the use of absolute territorial sovereignty principle while Jordan, a lower riparian State, favors the absolute integrity principle. Syria as both an upper riparian on the Jordan and Yarmuk and a lower riparian to its central source of water, the Euphrates and Orontes has oscillated between the two principles. Israel, the highest water poverty index (better situation), relies on to the absolute territorial sovereignty principle with regards to the Jordan River whereas the Palestinians considered as the most water poor in the region, revert to equitable utilization of both the Jordan and its common aquifers.

The history of Nile river Basin, is characterized by a different water poverty situation, as shown in maps (Figures 2 to 5), from the lowest WPI value (Horn African) to the better situation in the basin (Egypt), is also illustrative of the type of problems that could arise in the common utilization of a river by riparian States. Among the ten States within the Nile River Basin three, Sudan, Ethiopia and Egypt, are considered above to be in the MENA region. There have been growing tensions on the unfair water allocation regime under ancient agreements. Ethiopia, the most water poor and the main upstream state where 90% of the Nile water originates, was excluded from the agreement and has been the most unevenly harmed. Nevertheless, Sudan also complains of its own less share, which amounts to about 12% of the total Nile water. In this regard, spectacular projects in the region such as the building of the Aswan Dam improved the prestige of Egypt's rulers. Egyptian president Anwar El-Sadat seriously threatened Ethiopia if it's government decided to divert water for irrigation.

The Tigris-Euphrates River system is the only existent source of water between Turkey (better ranked than their neighbors in the WPI scale (see Annexes), Syria and Iraq and consequently has been a source of rising tension between those countries. The rivers are responsible for just about, 30% of Turkey's requirements. For this reason Turkey has constructed three dams on the Euphrates and has just commissioned a $32 billion dam on the Tigris while Syria has built one dam on the Euphrates and is planning to build another to satisfy 85% of its population needs. Iraq, the last riparian State of the two rivers has built dams both on the Tigris and the Euphrates to satisfy one hundred percent of population's needs. Historically, the potential of conflict between these riparian states was witnessed in the 1990s when Turkey effectively cut off the flow of the Euphrates from Iraq and Syria to fill the Ataturk Dam Reservoir.

In sum, for the MENA countries, similar to other regions in the world, there still is the need for formal political agreements on water problems such as treaties. These treaties may develop into legal theories, which can change into institutional applications of law that result in explicit and hopefully efficient policy. Currently there are no durable legal institutions dealing with water issues and conflicts in the region. This institutional gap has remained in the persistence of ingoing disputes in the region including the Iraqi stance with Syria and Turkey over the Euphrates, Syria and Lebanon on the Orontes and Egypt, Sudan and Ethiopia on the Nile.

8. Conclusion

This paper has served to provide an insight into the benefits of the use of a multidimensional assessment framework such as that provided by the Water Poverty Index. Providing a rapid appraisal methodology, this technique can be used by international organisations for country comparisons, or by individual countries to assess progress across their own diverse water landscapes. We have demonstrated how this approach provides a snapshot, serving as a baseline, with trends observed both within and between countries, or regions, when the technique is repeated over time. Some analysis has been made here of the impacts of simplifying the WPI approach by reducing the number of components used in its calculation. Using Principle Component Analysis to examine the structure of the WPI framework is a worthwhile exercise, but for a more robust examination, a more comprehensive and reliable dataset is needed, since the variables used in this study have not been able to effectively represent the five WPI components.

While the modified technique for the calculation of the WPI presented here does generate results with greater emphasis on water resource constraints, it loses the benefit of taking account of both ecological integrity and economic efficiency, since in the modified approach, the *Environment* and *Use* components are not included. To narrow the focus of the approach so that these two latter issues are excluded is to move away from the original intention and design of the WPI framework. At its inception, the WPI was designed to address water management challenges in such a way as to help decision-makers allocate water resources in such a way as to maximise the benefits from water use, while minimising the ecological impact of human actions.

On the basis of the work presented here, we can conclude that while efforts to refine and simplify the WPI approach are worthwhile, such refinement should not be detrimental to the important holistic assessment made through the use of the conventional WPI framework. We have also shown how the concept of water poverty, when applied to the countries of the MENA region, demonstrates wide variability. This can be illustrated through the use of a multidimensional tool such as the Water Poverty Index, enabling the various drivers of water poverty in different places to be demonstrated, and presented as a basis for remedial action. To this end, we suggest that by improving access to water data, and institutional cooperation in its generation, water managers would be in a better position to use the comprehensive WPI framework to make rapid, yet well-informed decisions about where expenditure on both *hard* and *soft* water infrastructure would be most beneficial.

From this work, we conclude too that if the MENA states could come together, , synchronize, implement adequate water laws and agree to recognize the international legal principles of equitable and reasonable utilization as best they understand it in the spirit of cooperation and peace the difficulties of climate change, water poverty and global food crisis might become manageable. The 2007 Cairo and the 2008 Marrakech International Conferences in the MENA Region were considerable steps in this direction. Using the results of this multidimensional analysis of water poverty, we hope that greater cooperation between riparian states will result, becoming a productive pathway for building confidence and cooperation.

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Figure 1: Water Crowding Index (Falkenmark Water Stress Index)

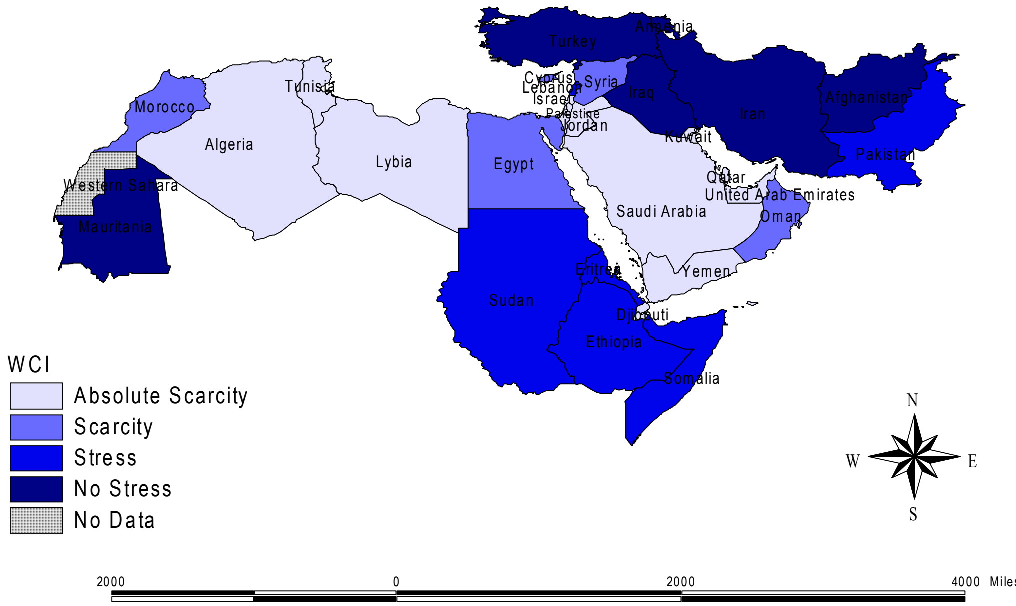

Figure 2: Modified Water Poverty Index

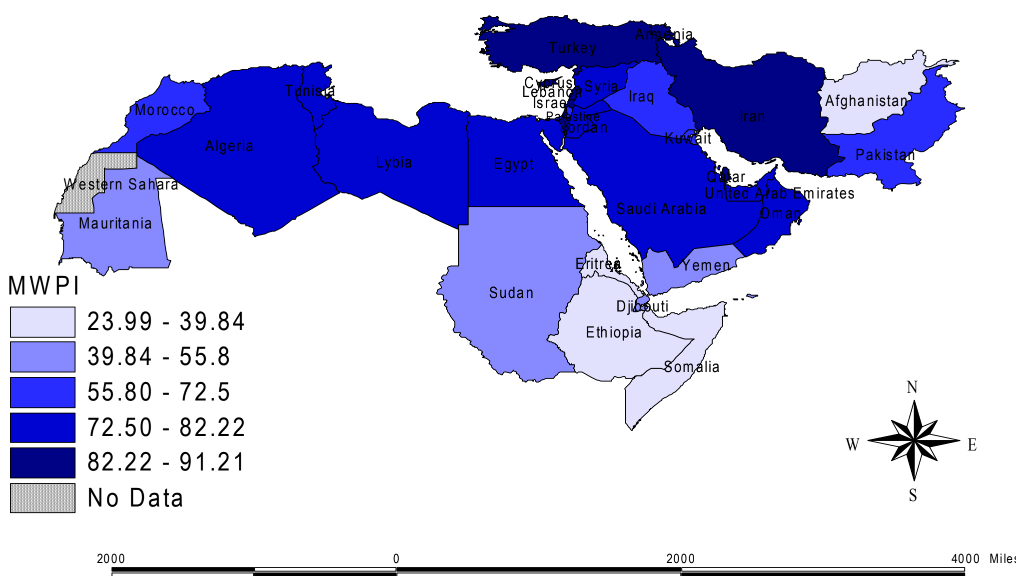

Figure 3: Resources Index

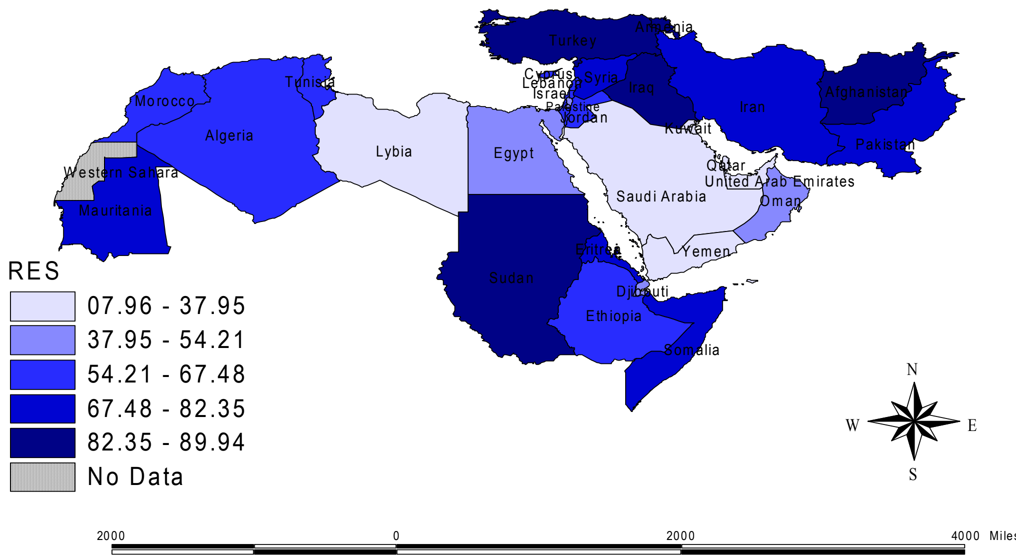

Figure 4: Capacity Index

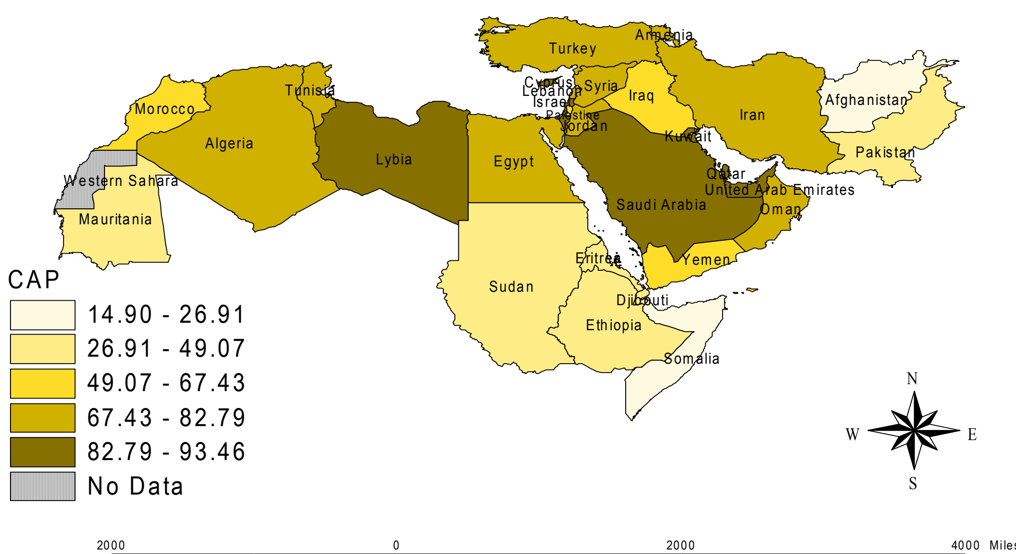

Figure 5: Access Index

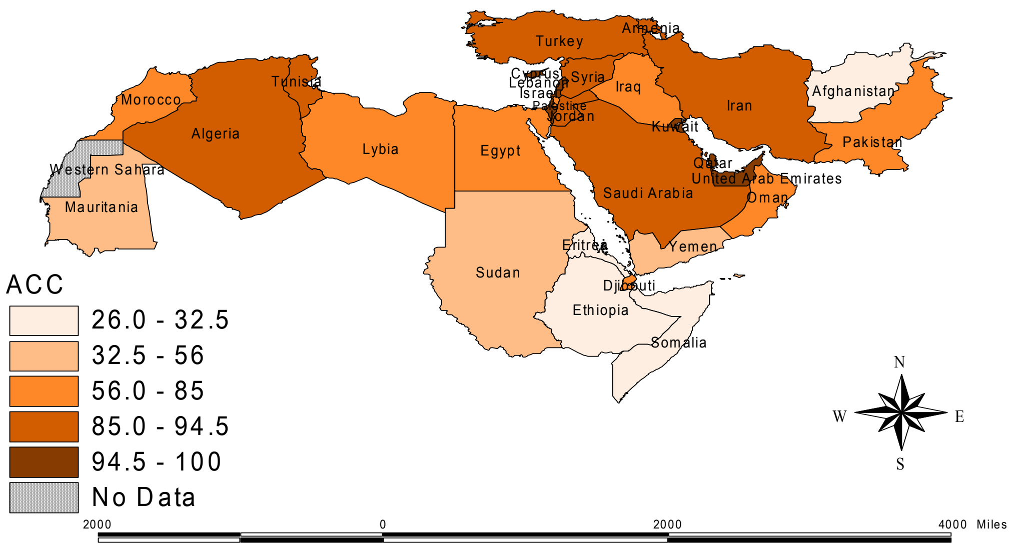

Table 1: Structure of the Water Poverty Index

Components	Sub-components (indicators)
Resources (RES)[1]	Per capita internal renewable water resources Per capita external renewable water resources
Access (ACC)[2]	Percentage of population with access to water Percentage of population with access to sanitation services Percentage of population with access to irrigation
Capacity (CAP)[3]	GDP per capita (adjusted by PPP) Under-five mortality rate Education enrolment rate Gini Coefficient
Use (USE)[4]	Domestic water use in liters per day Agricultural water use Industrial water use
Environment (ENV)[5]	Water Quality Index Water Stress Index

Notes:

1. Log scale applied due to large numbers in some cases.
2. Data on irrigation not available.
3. GDP per capita adjusted for purchasing power parity, but inadequate data on the Gini coefficient for many countries in the region led to this being excluded.
4. The use component used the ratio of water use by domestic, industrial and agricultural sectors against the value of GDP generated by each sector.
5. Environmental integrity was based on water quality and water stress indices calculated from the environmental sustainability database.

Table 2: Testing the Underlying Data

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
- p-value	0.447	0.000	0.000	0.082

Table 3: Weights of Indicators at Sub-index Level

	Weights	
Subcomponents	**Classic WPI**	**Modified WPI**
RES1: Internal water resources	0.66	0.66
RES2: External water resources	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

Table 4: Kendall's Correlations among the five WPI Core 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

Notes: * Correlation is significant at the 0.05 level

Table 5: 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

Appendix

The *modified* Water Poverty Index and its Sub-Index scores

Rank Country	RWPI	Resources	Capacity	Access	Use	Environment
1. Israel	91,21	59,25	93,46	100	61,55	42,37
2. Cyprus	88,65	56,51	88,34	100	70,23	67,18
3. Lebanon	86,91	67,48	80,53	99	66,74	69,97
4. Turkey	86,06	83,68	79,69	92,5	69,65	69,32
5. Iran	86	81,72	78,13	94,5	69,34	61,68
6. Armenia	85,43	87,17	75,34	94,5	0	27,98
7. Qatar	84,76	34,6	91,91	100	38,7	45,25
8. Bahrain	82,22	34,16	93,21	93	1,73	31,2
9. Tunisia	81,55	65,04	78,34	89,5	92,32	41,2
10. UAE	81,48	29,32	89,26	98,5	43,93	58,27
11. Syria	81,2	80,25	71,65	90,5	76,64	42,53
12. Jordan	81,09	60	77,12	91,5	87,98	14,57
13. Saudi Arabia	80,12	37,94	85,68	92	69,02	49,06
14. Algeria	79,37	58,41	75,68	89,5	90,6	59,15
15. Libya	78,89	37,95	90,56	85	58,46	36
16. Oman	78,87	51,74	82,79	84,5	87,93	51,4
17. Egypt	74,94	54,21	74,45	82	75,21	67,64
18. Palestine	72,5	51,48	67,22	84,5	87,69	24,75
19. Morocco	70,5	56,65	67,43	77,5	90,85	44,67
20. Kuwait	70,11	7,956	90,2	100	33,55	31,2
21. Iraq	69	89,94	56,25	76,5	33,42	46,35
22. Pakistan	62,99	76,16	49,07	74	98,9	52,22
23. Djibouti	55,8	48,79	38,23	79,5	98,94	49,8
24. Yemen	53,68	37,69	56,95	56	77,32	33,32
25. Sudan	52,45	87,41	44,74	52,5	96,51	66,7
26. Mauritania	47,63	73,52	48,34	42	85,85	51,33
27. Eritrea	39,84	79,77	40,92	32,5	35,53	62,79
28. Ethiopia	35,32	60,9	41,97	26,5	26,42	52,77
29. Afghanistan	30,65	87,65	26,91	26	99,64	46,5
30. Somalia	23,99	82,35	14,9	26	9,414	23,5