Development of Arab Water Sustainability Index Using Principal Component Analysis

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Abstract

The growing interest in the use of indices is closely connected to the increasing complexity of policy problems and the amount of available data. In the water sector, beyond their face value, indices can provide various types of information: descriptive, communication, assessment, showing trends and predicting the future. Because the Arab world is the most water-scarce part of the world, most of the region's countries put additional priority on water storage, balancing competing claims for allocation, promoting more efficient water use and self-sufficiency. In order to address the water sustainability, and its relationship to human and ecological needs, this study aim to develop an index for the water sustainability in the Arab region.

The Arab Water Sustainability Index (AWSI) is a conceptual framework incorporating a variety of physical, socio-economic and environmental elements of the water status in the Arab region.

A multivariate model, based on the principal component analysis, is designed to provide information on the most meaningful parameters, which describe whole data set affording data reduction with minimum loss of original information. Four theme-based components have been proposed for the AWSI to reflect a useful and meaningful breakdown: water crowding, dependency, scarcity and environmental sustainability. The index is developed as a policy tool to measure a sustainability state relative to a base condition or period, which allows for comparison between regions and for comparison over time.

Keywords: Water Indicators; Sustainability; Composite Index; Principal Component Analysis; Arab Region.

Introduction

The Arab region is facing one of the severest water scarcities in the world. Despite its diversity of landscapes and climates, most of the region's countries cannot meet current water demand. The water in the Arab world has the worldwide lowest per capita availability. Therefore, many countries face a full-blown crisis. With two thirds of its annual renewable surface water coming from outside the region, the region has the world's highest dependency on international water bodies. Per capita water availability will fall by half by 2050, with serious consequences for the region's already stressed aquifers and natural hydrological systems (Hamdy and Lacirignola, 2005). As the region's economies and population structures change over the next few decades, demands for water supply and irrigation services will change accordingly, as will the need to address the risk of water quality deterioration.

Facing similar water problems, societies across the region grew with a need to adapt the variability and scarcity of water. A series of technical and policy changes to the water sector in most Arab countries is needed if the countries are to accelerate their progress in order to avoid the environmental, economic and social hardships that might otherwise occur (World Bank, 2007). Monitoring progress in the water sector requires an interdisciplinary approach that should involve both qualitative and quantitative assessment techniques. There is a great need for a monitoring tool, based on simple indicators that can be utilized to examine the water status among Arab countries and its relationship to human and ecological needs. The objective of this study is to develop such tool, designated: the Arab Water Sustainability Index (AWSI).

AWSI was designed as a tool for assessing the state of the water sustainability in Arab communities and evaluating progress by comparing the present state with the desired target. As a multivariate statistical model developed by the principal component analysis (PCA), the composite index approach was chosen because it can present complex information in a simple and holistic way for use as a policy tool. It is a conceptual framework incorporating a variety of physical, socio-economic and environmental elements of the water status in the Arab region.

Arab Water Crisis

However, the Arab region represents 10% of the world's area; it possesses only 0.5% of the world's renewable fresh water resources (Hamdy and Lacirignola, 2005). This is due to the fact that the arid and semi-arid weather dominates 82.2% of the whole region. Rainfall precipitation is estimated to be 2,228 BCM. The losses amount to 90.4% due to evaporation. The Arab region, which is home to 5 percent of the world's people, contains less than 1 percent of the world's annual renewable freshwater. The water demand in the region is growing fast and the population has more than doubled in the past 30 years to about 340 million, and could double again in the next 30 years. Thus, water demand for domestic and industrial sectors is not currently met with the available amounts in most of the Region. In some cases, readily available financial resources have enabled the Gulf Cooperation Council countries to mitigate water shortage by developing their seawater desalination industry. However, other countries, such as Jordan and Yemen, are still seeking foreign aids and scrapping for financial resources in order to solve their water shortages problems.

The agricultural sector is the largest user accounting for 85% of total use in the region compared to around 60% worldwide water use for agriculture. In the Arab peninsula, for example, the volume of water consumption for agriculture totaled more than 19 BCM in 1990 (ESCWA, 2003). Moreover, not only countries blessed with large river flows in the Region, such as Egypt, Iraq, and Syria allocate most of their water supply for the agricultural sector, but countries like Jordan and Yemen which suffer from severe shortage still over allocate water for agriculture. Agricultural sector contribution to the gross domestic products of various countries in the region is relatively small. Therefore, it could be argued that the amount of water allocated to this sector within current practices is economically unreasonable, especially when the substantial impact on the already scarce water resources in the region is taken into consideration. Moreover, the goal of self-sufficiency in food production and food security, which is the stated reason behind sticking to the flagrant imbalance in sectoral water allocation throughout the Arab region, is proving economically and physically unrealistic day by day (UNESCO, 2005).

The main issues of water concern are access to safe drinking water and sanitation services, as well as water quality management. Sixteen percent of the region's population is lacking safe water, and more than 80 million lacking safe sanitation. Water sustainability in Arab countries is compounded by pollution. The main sources of pollution are the intensive use of fertilizers and pesticides, dumping of municipal and industrial wastewater into rivers and lakes, solid waste deposits along river banks, and uncontrolled seepage from unsanitary landfills (UNESCO, 2005). They are degrading freshwater resources and imposing health risks, especially for children, the primary victims of waterborne diseases.

The composite index approach

The structure of the Arab Water Sustainability Index is developed by a mathematical aggregation of eight indicators based on 22 variables and condensed into manageable information sets, which are then further condensed into an index that can then be translated into policy-oriented measure. The aggregation was implemented across different measurement units to keep the result dimensionless. The variables as incorporated in equations presented in the next section give a clear picture of the water issue being assessed and monitored. Based on the aggregation of variables, indicators are used to simplify, quantify, communicate and create order within complex data. They provide information in such a way that both policy-makers and the public can understand and relate to it. They help monitor progress and trends in the use and management of water resources over time and space. Similarly, indicators can compare results in countries and examine potential links between changing conditions, human behavior and policy choices.

An index aims to provide compact and targeted information for management and policy development. Aggregating a number of indicators to one index involves the various steps of selection, scaling (transforming indicators into dimensionless measures), weighting (valuation), aggregation and presentation. These steps will be explained by the next two sections. Given the integrated nature of water systems, the components of a composite water index will not be completely independent. In this study, principal component analysis is used to investigate the number of distinct dimensions that exist within the AWSI indicator matrix and to show the influence of the indicators along these dimensions. It is furthermore used to determine a set of weights for the indicators based on their statistical importance. The weights are used to adjust for unequal variances of the indicators, and hence their unequal levels of certainty. The specification of the weights is thus an integral part of composite index development. Statistically determined weights have the advantage of neutral and data-reliant weighting.

Development of Indicators

One measure of dependence on water resources is the population served per million cubic meters per year from the combined conventional and non conventional sources. This can be called as the ‘‘water crowding’’ indicator, with levels on the order of 1,000 - 600 people per million cubic meters per year (that is, 1,000 - 1,700 cubic meters per year supply per person) showing water stress, and above 1,000 people (that is, less than 1000 cubic meters per year per person) indicating extreme water scarcity (Falkenmark, 1997). External water inflow amounts are reduced by 50%; this is an arbitrary factor, but it is an attempt to give reduced weight to external water inflows because these resources are less secure than those generated internally within a country. The resources measure is a basic indicator of water availability

In order to check the hypothesis of water sustainability, indicators of both water scarcity and virtual water import dependency are important measures of relieving the pressure on the nation’s own water resources (Chapagain and Hoekstra, 2003). The sum of volumes of water use in a country and net virtual water import can be considered as the ‘water footprint’ of a country. As an indicator of national water scarcity, the ratio of total water use to water availability is used:

$$WS = \frac{WU}{WA} \; X \; 100$$

WS is the national water scarcity (%), WU the total water use in the country ($m^3\ yr^{-1}$) and WA the national water availability ($m^3\ yr^{-1}$). Values above 100 percent indicate withdrawal of nonrenewable groundwater resources or use of desalinated and other supplemental water resources that are not included in the total annual water resources.

As the counterpart of the water dependency, the water self-sufficiency measure is used to reflect the level which a nation relies on foreign water resources through import of water in virtual form. The water self-sufficiency (WSS) is defined as follows:

$$WSS = 100 - WD$$

WD is the virtual water import dependency of a nation and calculated as the ratio of the net virtual water import into a country to the total national water appropriation:

$$WD = \begin{cases} \dfrac{NVWI}{WU + NVWI} \, x\, 100 & if \;\; NVWI \geq 0 \\ 0 & if \;\; NVWI \langle \, 0 \end{cases}$$

NVWI is the net virtual water import of a country (m^3 yr^{-1}). Self-sufficiency is a hundred per cent if all water needed is available and taken from within the national territory. Water self-sufficiency approaches zero if a country relies heavily on virtual water imports.

In order to provide information on the efficiency of water use, indicators of water use intensity/productivity by sector are considered. They are important inputs when designing policies of strategic allocation of water. The economic characteristics considered most frequently in indicators of water use intensity/productivity are output, value added or number of employees (UN, 2006). As a relationship between the proportion of GDP derived from agriculture or industry sector, and the proportion of water used, Water use efficiency (for each sector) is defined as follows:

$$\begin{pmatrix} Water\ use\ Efficiency \\ (\%)\ by\ Sector \end{pmatrix} = \begin{pmatrix} Water\ Use\ Intensity \\ by\ Sector \end{pmatrix} x \begin{pmatrix} Water\ Use\ \mathrm{Pr}oductivity \\ Total \end{pmatrix}$$

Water use intensity by sector is defined as the ratio of the volume of water used and value added. The indicator of water productivity is similar to the "productivity" indicators used in economic analysis and it is computed as a reciprocal of water intensity. This indicator is computed for the whole economy as a ratio of GDP and total volume of water used.

In order to study health impacts of environmental degradation, Disability Adjusted Life Years (DALYs) has been used to provide a common measure of disease burden for various illnesses and premature mortality. Illnesses are weighted by severity, so that a relatively mild illness or disability represents a small fraction of a DALY, while a severe illness represents a larger fraction of a DALY. For waterborne illnesses – associated with inadequate water and sanitation services and hygiene - the loss of DALYs presented in this study are estimated by cause of Diarrhoeal diseases (FAO, 2007).

Two more measures are used to capture water stress based on indicator of fertilizer consumption per hectare of arable land and capacity for sustaining access based on percentage of the population with access to safe water and sanitation (FAO, 2007). The latter indicator is recognizing that domestic and human consumption is as important as for water availability for growing food. Access to adequate sanitation has a greater influence on health than safe water supply. Development of water and sanitation facilities, and provision of equitable and universal accesses to such services, is considered as a basic human right and cornerstone for economic and social development.

Principal Components Analysis

An (*n* x *p*) data matrix ($X_{n,p}$) is generated in this study, where *n* is the number of countries (*n*=22) and *p* equals the number of indicators (*p*=8). The elements of this matrix are $x_{i,j}$, where $x_{i,j}$ is the value of the *j*th indicator for the *i*th country. This data matrix is standardized prior to the next statistical analyses which leads to a matrix (Z_{nxp}) consisting of z scores.

$$Z_{i,j} = \frac{(x_{i,j} - \bar{x}_j)}{s_j}$$

where

$$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{i,j}$$

and

$$s_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{i,j} - \bar{x}_j)^2}$$

The standardization procedure results in a variance of one for each column, thereby assigning the same influence to each of the variables. The sample correlation matrix (R) is related to the Z matrix as

$$R = \frac{1}{n-1} Z^T Z$$

Principal Components Analysis is designed to provide information on the most meaningful parameters, which describe whole data set affording data reduction with minimum loss of original information (Helena et al., 2000). While preserving the variation in the data to the maximum extent possible, the principal components analysis is used transforming the p-dimensional dataset into smaller number of dimensions which are linear combinations of the original variables and independent of each other. Each dimension captures a successively smaller amount of the total variation in the data.

With PCA based multivariate statistical model, a data matrix is approximated using the product of two smaller matrices called PC scores (*S*) and PC loadings

(*L*). These lower dimensional data matrices capture the underlying patterns within the original data. The dominant patterns present within the samples (eg. countries) are illustrated by plotting the columns of the score matrix and the patterns within the variables (eg. indicators) are shown by plotting the columns of the loadings matrix. For this study, using a two principal component model, the standardized 22 x 8 data matrix, ($Z_{22,8}$) is modeled using the two dimensional scores and loadings matrices as follows:

$$Z_{22,8} = S_{22,8} \ L^T{}_{22,8} + E_{22,8}$$

where E is the residual matrix containing the variation not explained by the model. The goal of PCA is to extract the principal components such that the remaining unexplained variance (E) describes only noise. Hidden patterns can then be amplified and the noise discarded (Gauch, 1993).

The data matrices (scores and loadings) are obtained through eigenanalysis of the correlation (R) or covariance (C) matrix. For the purpose of this study, the PCA is performed using the R matrix because the scales of measurement are different for the variables and the variances are quite different. Eigenanalysis of R involves finding unique pairs of vectors I, and scalars A, called eigenvectors and eigenvalues respectively, such that $R * I = \lambda * I$ which is solved by finding the *p* roots of the polynomial equation $|R - \lambda I| = 0$ (where *I* is the *p x p* identity matrix).

Eigenanalysis of a *p* x *p* correlation matrix produces *p* pairs of eigenvalues $(\lambda_1, \lambda_2, ..., \lambda_p)$ and eigenvectors $(I_1, I_2, ..., I_p)$. The eigenvectors are generally normalized to unit length. Each eigenvalue/eigenvector pair describes a principal component. The eigenvalues describe the amount of variance explained by each principal component and the loadings (*I*) are the coordinates of the eigenvector. Principal components are extracted so that the maximum amount of variance is explained in (has the largest eigenvalue associated with) the first principal component and progressively less variance is explained for each subsequent component. The principal components account for the correlations present within the original data, but are independent of one another. Because PCA is simply eigenanalysis of the correlation matrix, the data does not need to be normally distributed (Johnson and Wichern, 2002).

The principal component scores (s) are then given as linear combinations of the original standardized data (z) with the loadings (I) as the coefficients

$$s_{i,c} = \sum_{j=1}^{p} z_{i,j} \ * I_{j,c}$$

where *i* identifies the country, *j* identifies the indicator, *c* identifies the principal component, and *p* represents the total number of indicators. In other words, the PC score combines information on all indicators values for a given country into a single number. The loadings, on the other hand, indicate the relative contribution each indicator makes to that score.

Results and Discussion

From the identification of a core set of variables based on water issues, Table 1 shows the mean (with standard deviation), units, minimum and maximum of the AWSI indicators. Comparison of data shows that imbalance between the increasing water demand and the limited water resources is being experienced by most Arab countries. The Gulf council countries are able to alleviate the prevailing water deficit through non-conventional means, mainly desalination. However, the quantity of water available in the region on per capita basis from the combined conventional and non conventional sources still remains considerably below the 1000 m^3/capita/year threshold.

A suitable comparison among the different indicators requires the need to calculate the indicator value based on the following formula: $(x_i – x_{min})$ (100)/ $(x_{max} – x_{min})$, where x_i, x_{max} and x_{min} are the original values for country i, the highest value country, and the lowest value country. The indicators therefore show a country's relative position and for any one indicator this lies between 0% and 100%. The maximum and minimum values are adjusted to represent the best and worse values of the indicator, respectively.

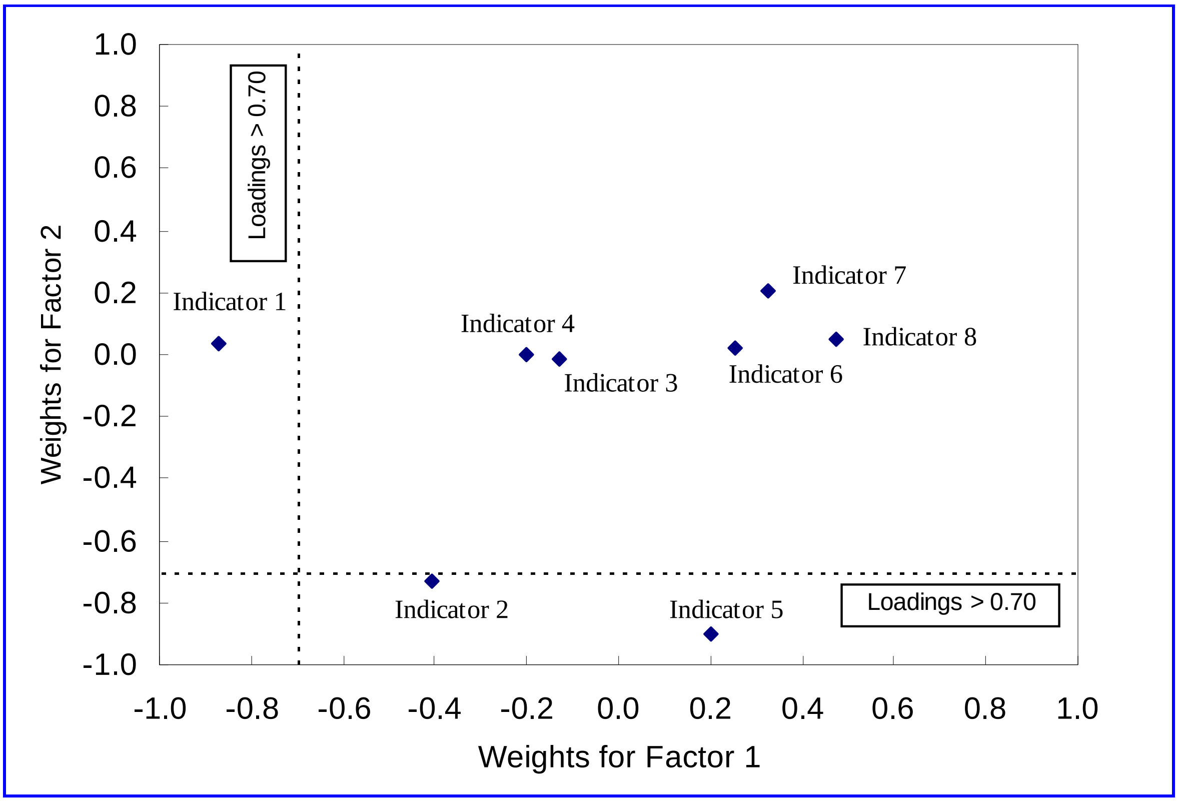
The results of the Principal Component Analysis indicate the existence of four components (categories) for the 8 indicators, which explain more than 82% of the variation in the data. Although the number of components selected depends to a certain extent on the decision criteria chosen to determine the cut-off point for adding more components, the scree-plot, $\lambda > 0.7$, and explained variance criteria all support the choice of four principal components (Table 2). After deciding to keep four principal components, the multivariate statistical model is repeated to re-allocate the indicator loadings on the selected components. For better interpretability of the results, the Varimax rotation is chosen, which rotates the principal components in four-dimensional space in such a way that maximizes each indicator's loadings on only one of the four directions. Based on the extraction of principal components amounting to a variance maximizing (varimax) rotation of the original variable space, the results of the rotated component loading matrix are shown in Figure 1.

Table 1. Mean (with standard deviation), minimum, maximum and units of the eight AWSI indicators
Source of variables data is the Food and Agriculture Organization (FAO, 2007)

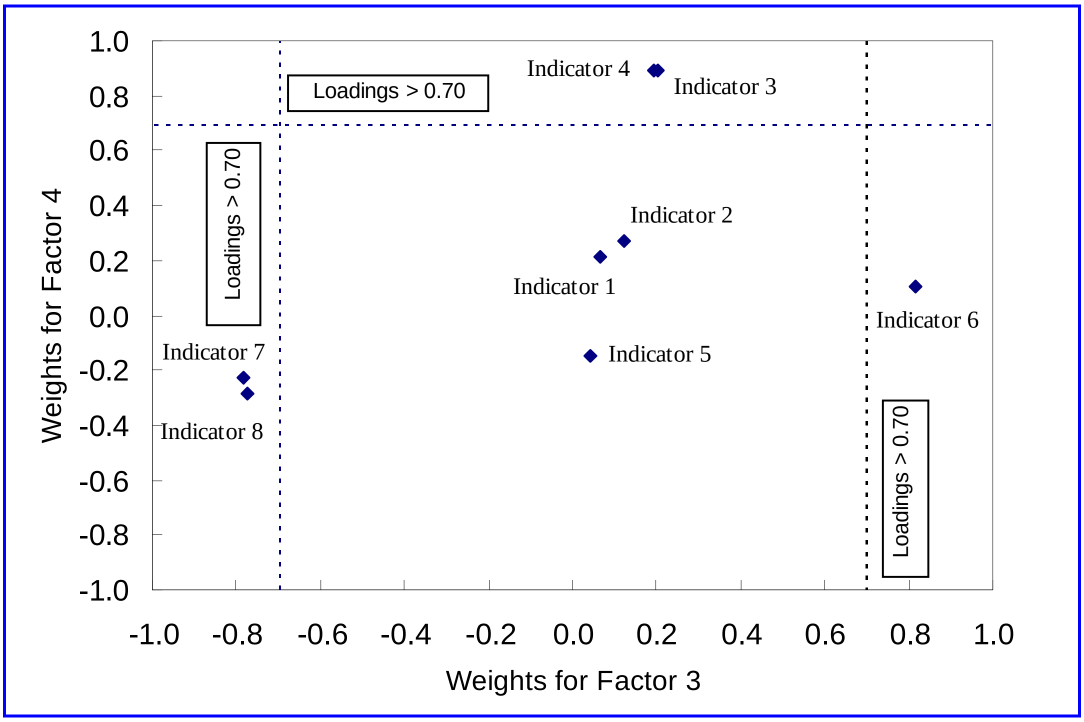
Indicators	No.	Units	Average (standard deviation)	Minimum (country)	Maximum (country)
Water crowding	1	Capita per million cubic meters per year	3158.7 (2499.2)	508.51 (Iraq)	9658.73 (Libya)
Water self-sufficiency	2	Percentage	54.1 (30.5)	9.00 (Comoros)	100.00 (Sudan, Syria)
Water scarcity	3	Percentage	314.8 (554.6)	0.83 (Comoros)	2200.00 (Kuwait)
Agricultural water use efficiency	4	Percentage	19.0 (24.9)	0.92 (Comoros)	104.00 (Kuwait)
Industrial water use efficiency	5	Percentage	0.1 (0.1)	0.02 (Saudi Arabia)	0.45 (Comoros)
Fertilizer use intensity	6	Kilograms per hectare of arable land	109.8 (135.6)	0.50 (Somalia)	466.70 (UAE)
Adjusted Life Years by cause of Diarrhoeal diseases	7	Diarrhoea DALYs /1000 capita per year	11.8 (14.0)	0.60 (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE)	48.00 (Somalia)
Population with access to safe water and sanitation	8	Percentage	79.6 (22.7)	26.90 (Somalia)	100.00 (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia)

Table 2. The Number of Principal Components – Cumulative Variance Explained

Principle Components	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	3.35	41.95	3.35	41.95
2	1.33	16.63	4.68	58.58
3	1.09	13.64	5.77	72.23
4	0.79	9.88	6.56	82.12
5	0.62	7.77	7.19	89.89
6	0.58	7.34	7.77	97.24
7	0.15	1.93	7.93	99.17
8	0.06	0.82	8.00	100.00



(a)



(b)

Figure 1. Extraction of (a) first and second Principle Components and (b) third and fourth Principle Components (Rotation: Varimax normalized)

Since the eigenvalues are calculated using the correlation matrix of the input data, they represent the variance explained by each principal component. The factor loadings matrix highlights which indicators load together on the same component as well as which indicators do not load strongly on any of the four components (Figure 1). The results demonstrate several important characteristics of the AWSI: Firstly, the index is a multidimensional measure and water sustainability is a multidimensional concept. Although the number of principal components is smaller than the number of indicators, four components are required to capture at least 80% of the variation in the data. The rotated principal components also load strongly on distinct sets of indicators, which corroborate the assumption that if the developed index were based on a small number of indicators such, it would not fully describe all dimensions of water sustainability. Secondly, the analysis of the component loadings matrix as presented by Figure 1 suggests that some indicators relate more closely to each other than others. These sets of indicators have high loadings on the same principal component and in the same direction along the component.

Thirdly, since no indicator has low loadings on all four principal components, it can be concluded that none of them is redundant in the calculation of the AWSI. Principal component 1 is determined predominantly by water crowding indicator which demonstrates the dependence on fresh water. It is one of the most influential indicators selected in this study, a result that confirms the findings of the correlation analysis. While the second component correlates strongly with water self-sufficiency and Industrial Water use efficiency, the third component is determined by water scarcity and agricultural water use efficiency. Given that all axes are orthogonal to each other, this means that the remaining three indicators loading on the fourth principal component measure distinctly different environmental aspects of water sustainability than are captured by components 1, 2 and 3.

The second important application of principal component analysis to the AWSI consists of its ability to determine the statistical weights of the indicators. Using the Varimax rotated component loading matrix, the four factor loadings of each indicator were squared to avoid negative weights and added together, thereby reflecting the total squared loadings across the four principal components. The sum of squared loadings for the 8 indicators was then re-scaled so that the final weights add up to 1. If an indicator has comparatively strong capacity to explain the variation in the data, it would be expected to receive a relatively high weight, and vice versa. The four policy categories are, therefore, calculated as the PCA derived weights of their constituent indicators. The weights from the PCA are given in Table 3.

Table 3. PCA Derived Weights of the AWSI Indicators

Objective	Index Category	Indicators	Weight within Category	Weight within AWSI
Water Sustainability		Water crowding	1.00	0.15
	Water Dependency	Water self-sufficiency	0.50	0.23
		Industrial water use efficiency	0.50	
	Water Scarcity	Water scarcity	0.48	0.27
		Agricultural water use efficiency	52	
Environmental Sustainability		Fertilizer use intensity	0.25	0.35
		Diarrhea DALYs	0.37	
		Drinking and sanitation facilities	0.38	

All of these have been converted into an index between 0 and 100 and a higher score is “better” for all measures. The individual Arab country scores and ranking are shown in Figure 2. With the highest summation of weighted scores, Syria and Sudan show up in the top two of AWSI distribution having the lowest variance in sustainability performance. They are the only Arab countries which do not rely on foreign water resources through import of water in virtual form. Countries with lower indices' scores show less strong water sustainability performance. However Kuwait and the United Arab Emirates have different challenge by augmenting supplies through desalination technology investments, they have the lowest ranking according to sustainability performance of the others.

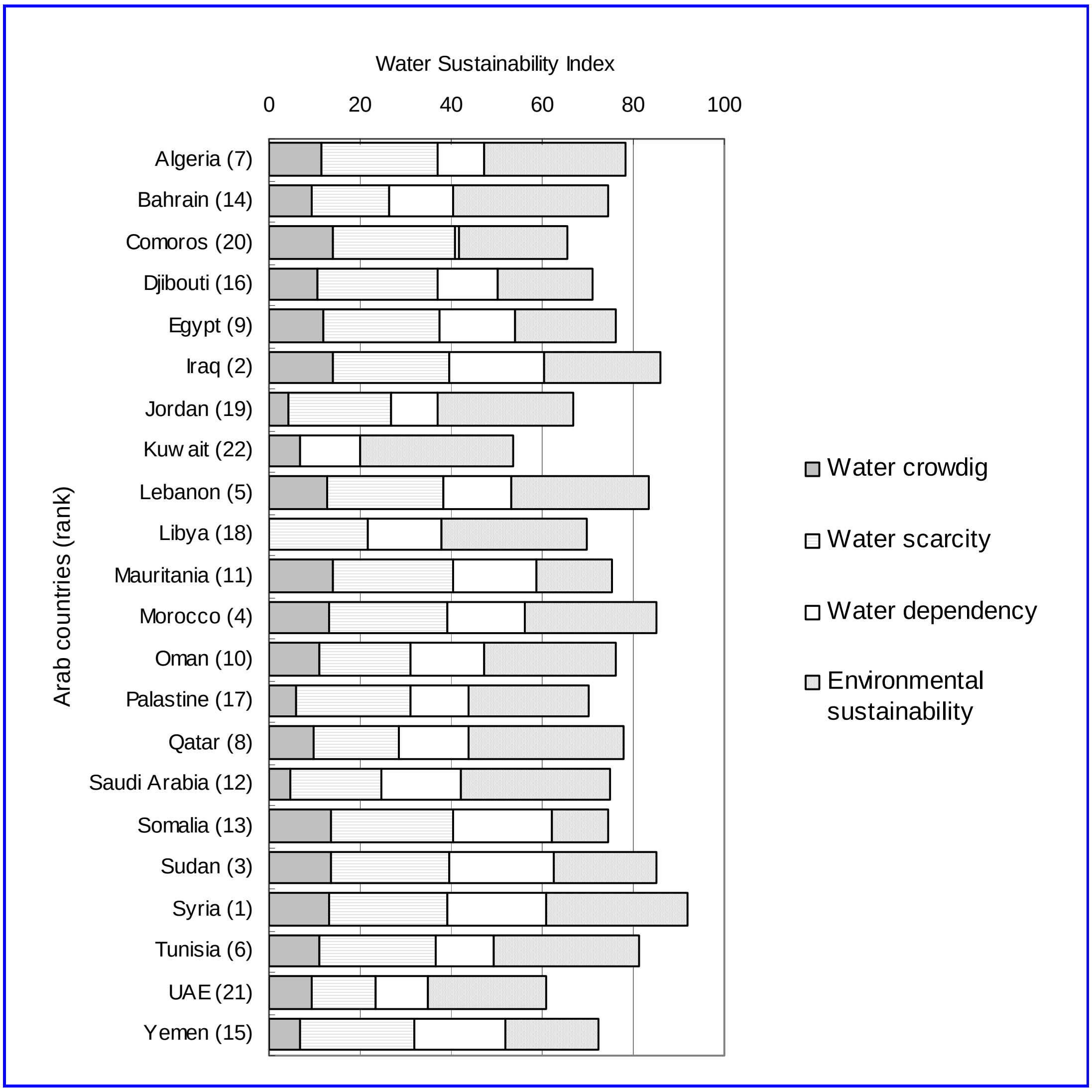


Figure 2 AWSI ranking for each country under PCA weighting of four categories

To compare the effect of used aggregated indicators on the Arab water availability index, each of the weighted categories was standardized for zero mean and unit variance. The zero level implies the average of all the Arab countries included in this analysis. Level positive 1 denotes one standard deviation above the average and negative 1 represent one standard deviation below the average. Values higher than zero imply a better condition for the indicator while negative values represent an adverse state. Figure 3 shows the scaled four categories for three countries Syria, Egypt and Kuwait.

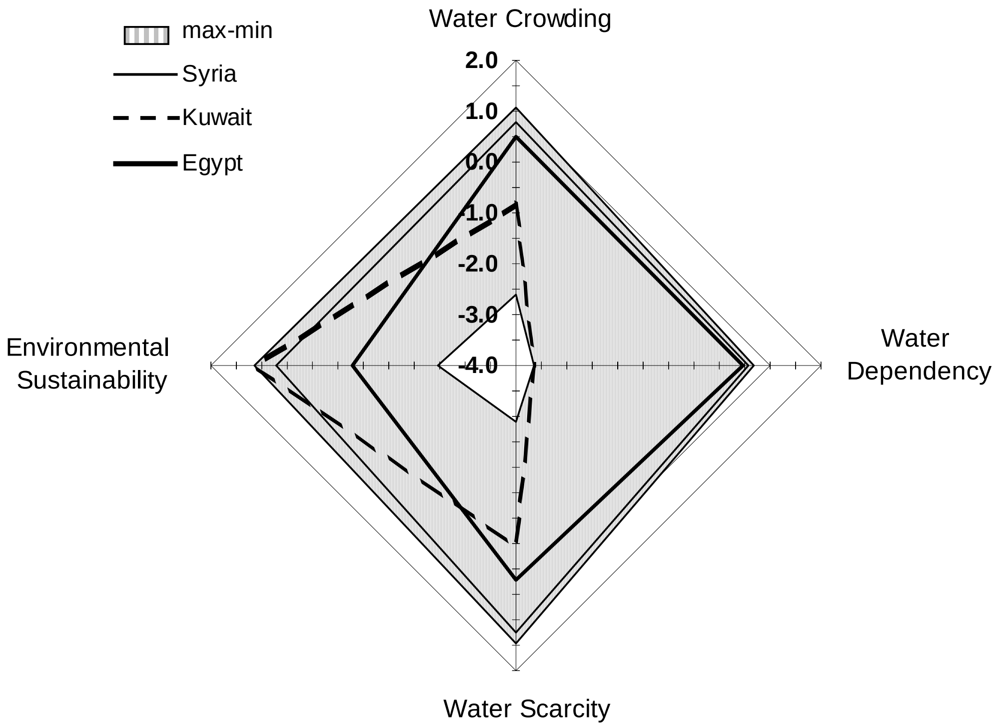


Figure 3 The scaled four categories for Syria (rank=1), Egypt (rank=9) and Kuwait (rank=22)

Syria and Sudan are the only Arab countries to obtain the highest score in water self-sufficiency. All other Arab countries are net importers of water embedded in food, due to lack of sufficient rain or irrigation water to grow crops domestically. With higher scores than the regional average in water use efficiency by industry sector, Syria and Sudan are the best two countries in the category of water dependency. Since Syria is the only Arab country with all indicators above the regional average, it is located on the top list of AWSI distribution. Iraq and Sudan - In spite of a dependency ratio of 53.3 % and 76.9 %, respectively which expresses the share of the total renewable water resources originating outside the country, are rated as the top two of AWSI distribution in water crowding and water dependency, respectively. Category of Environmental sustainability in both countries is closely lower than the regional average.

While the region has low water availability on average, the quantity of water available varies considerably among countries in the region. Morocco, Lebanon, Tunisia and Algeria are ranked fourth, fifth, sixth and seventh, respectively. They represent a group of countries that has adequate quantities of renewable water at the national level, but with variation between different parts of the country and over time. Excluding Syria, Morocco is the only Arab country with all four categories above the regional average. Both categories: water dependency and environmental health are slightly above the regional average because both indicators: the percentage of the population with access to safe water and sanitation, and the water use efficiency in the industry sector are slightly below the regional average. The Water dependency category for Lebanon, Tunisia and Algeria is the only category lower than regional average because they shared in lower values of water self-sufficiency indicator than regional average. Starting from Tunisia followed by Algeria, water crowding category begins to get lower values towards the regional average.

By occupying the eighth rank, Qatar is leading the group of countries that has consistently low levels of renewable water resources. This group depends heavily on nonrenewable groundwater and augments supplies by desalination of sea or brackish water. The water crowding category is slightly lower than the regional average. Over the region, Qatar is located on the top list of environmental health category distribution because of the highest score in water and sanitation coverage and Diarrhea DALYs. Therefore, Qatar has an advanced ranking, in spite of lower score of the water sacristy category than the regional average. Within the top eleven courtiers of AWSI distribution, Qatar is the only country with a clear lower water use efficiency score in the agriculture sector than the regional average.

With managing complex irrigation and drainage networks and high dependency ratio of the total renewable water resources, Egypt has achieved comparable high of agricultural water use efficiency and self sufficiency. Egypt is one of the countries with the lowest scores below the regional average in fertilizer use Intensity and water use efficiency by industry sector. That led to lower the values of both categories: environmental health and water dependency. In Oman, both agricultural water use efficiency and fertilizer consumption are clearly lower than the regional average decreasing the scores of water scarcity and environmental health. Oman has the highest score in water supply and sanitation coverage and DALYs. Mauritania is one the best two countries in water crowding and water sacristy categories. Despite this, Mauritania is ranked lower rank in the AWSI distribution because it scores significantly below the regional average for the environmental health.

Saudi Arabia is clearly below the Arab regional average in water crowding, and water scarcity categories. Saudi Arabia achieved the maximum score of water supply and sanitation coverage and DALYs. Somalia has the minimum score in environmental health category. Somalia is considered one of the best two countries in both categories: water scarcity and water dependency. The water crowding, scarcity and dependency categories are lower than the regional average. Over the region, Bahrain has the highest score in environmental health category. Yemen is significantly below the regional average in water crowding and environmental health category. Yemen is well above average in water self-sufficiency and water use efficiency in the industry and agriculture sector. Djibouti scores well below the regional average in water dependency and environmental health. Djibouti has high score in water scarcity category. Palestine is below the regional average of water crowding, water dependence and environmental health. Libya has the lowest score in water crowding category and is clearly below the regional average for water scarcity indicator.

Jordan is clearly below the regional average in five indicators: water crowding, water self-sufficiency, water use efficiency by industry and agriculture sectors and fertilizer use intensity. Although Comoros has a high score of water crowding, water scarcity categories; it has the lowest score over the region in water dependency. It has clearly lower water supply and sanitation coverage and DALYs than the regional average. United Arab Emirates is below the regional average in the four categories. United Arab Emirates represents the worst case of fertilizer use intensity lowering the final score of the environmental health category. Kuwait represents the worst case of water scarcity category where both indicator water use efficiency by agriculture sector and water scarcity are the lowest. The environmental health category has a high score since it has the best case of drinking water and sanitation coverage and DALYs.

Unless serious efforts are made to increase water use efficiency, non conventional water resources, and cultivation of crops that do not require large amount of water, it is expected that the agriculture sector would continue to consume water amounts beyond the available capacity. This water overuse would threaten other economic sectors (due to diminishing availability) and eventually subject the heath and welfare of people in the region to serious risk. Accordingly, decreasing water use in agriculture and reallocation of some conserved resources to domestic and industrial sectors is necessary to ensure the availability of basic water needs for malignance of public heath and economic development in most of the region's countries.

The results demonstrate several important characteristics of the AWSI. As a multidimensional index based on a multivariate statistical model, it is a useful tool to investigate the multidimensional concept of water sustainability. The index draws on suitable information already available from several sources, including the United Nations Development Programme and Food and Agriculture Organization. This makes it easy to update without having to create new data gathering systems. The index permits international comparisons of various types of information: descriptive, communication, assessment, showing trends and predicting the future. In general, the index is developed as a policy tool to measure a sustainability state relative to a base condition or period, which allows for comparison between regions and for comparison over time.

Conclusion and Recommendations

The complexity of linking multidimensional aspects of water management together has been taken into account in such a way as to construct a holistic water management tool to address the problems of sustainability, and its relation to water access and use. The methodology based on the principal component analysis was successfully tested in the Arab region, and this has shown that there is great potential for the useful application of the index in a variety of locations.

The composite index proposed herein is presented by a mathematical aggregation of eight indicators based on 22 variables and condensed into manageable information sets, which are then further condensed into an index that can then be translated into policy-oriented measure. It is furthermore used to determine a set of weights for the indicators based on their statistical importance. The weights are used to adjust for unequal variances of the indicators, and hence their unequal levels of certainty. The results of the principal component analysis indicate the existence of four components: water crowding, scarcity, dependency and environmental sustainability for the indicator matrix. This aggregation explains more than 82% of the variation in the data. For better interpretability of the results, the varimax rotation is chosen, by rotating the principal components in four-dimensional space in such a way that maximizes each indicator's loadings on only one of the four directions.

The four categories are, therefore, calculated as the principal component analysis derived weights of their constituent indicators. All of these have been converted into an index between 0% and 1% and a higher score is "better" for all measures. With the highest summation of weighted scores, Syria and Sudan show up in the top two of AWSI distribution having the lowest variance in sustainability performance. They are the only Arab countries which do not rely on foreign water resources through import of water in virtual form. Countries with lower indices' scores show less strong water sustainability performance. However Kuwait and the United Arab Emirates have different challenge by augmenting supplies through desalination technology investments, these two countries have the lowest ranking according to sustainability performance of the others.

By highlighting the fact that AWSI is a helpful tool to investigate the multidimensional concept of water sustainability, it is believed that integration of different attributes is possible and useful. To upgrade the structure of the index, it is recommended to combine categories based on infrastructure, environment protection, and culture. The infrastructure component focuses on the type, state and reliability of the infrastructure as well as the ability to operate and maintain it. The environment comment can include two subcomponents: water Quality status and environment protection. The water quality index provides a measure of the overall chemical water quality based on the International Water Quality Guidelines in terms of representing different variables of non-compliance (scope, frequency and amplitude). The protection component can be included to reflect institutional efforts and initiatives being taken to protect their surrounding environment. The culture component based on participation which can include measures of the level of involvement in conservation groups (e.g., watershed associations) and the overall awareness environmental and health issues with respect to water.

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