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Water Resources Vulnerability Assessment of MENA Countries Considering Energy and Virtual Water Interactions

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Abstract

Scarce water resources of MENA countries are under multiple stressors: population growth, growing economies, land use changes, changing lifestyles or climatic variability. The vulnerability of such resources is often analysed using simple, sector-specific indicators. This study develops a holistic country-based vulnerability assessment of water resources using an integrated index. This Country Vulnerability Index of Water Resources (CVIW) considers cross-sectoral linkages as a way to mitigate vulnerability. The index provides a macro-level overview of the status of water resources in the MENA region using regional analysis and individual country vulnerability profiles. The index is a composite of the socio-economic and natural components. It considers solutions to reduce vulnerability by importing virtual water or using available energy resources. The assessment provides an overview of water resources threats in the region considering the capacity of the water management to absorb such threats.

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Keywords: Vulnerability Assessment, Water Scarcity, Water Energy Food Nexus; MENA Region

1. Introduction

Over the half past century, accelerating development has created global and regional pressures on ecosystem functions and services. Thresholds for resilient water systems are being crossed globally and regionally with severe effects on land use [1, 2, 3]. Dryland countries face greater challenges because of natural resource scarcity. In the

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Middle East and North Africa (MENA) region, natural boundaries of resource use are even more exacerbated due to population growth, economic development and water demands associated with changing lifestyles. Coupled with unsustainable management practices, current development pathways are leading to deterioration of the resources base and increasing scarcity crises. The MENA region has thus become an especially vulnerable region in recent years. Alongside extreme water scarcity, recent climate change studies point out that the MENA region will be largely affected by climate change reducing precipitation patterns and increasing temperatures [4, 5, 6]. In this region with the largest water deficit in the world, water demands have exceeded the local capacity to be self-sufficient in the production of food [7]. Increasing water scarcity has highlighted the trade-offs and opportunities in water resources use. For example, increases in agricultural production to satisfy food security requirements in the region directly affect water demands. In contrast, importing virtual water embedded in trade of food products or other consumables saves scarce water resources. Further, any biofuel strategies demand more land to produce fuel crops, which will in turn increase demands for water and energy. According to such a scenario, the Middle East, for instance, would double its primary energy demand 2030 [8]. On the other hand, increasing demands for water can be satisfied through the use of abundant energy reserves, e.g. water desalination.

This study develops a Country Vulnerability Index of Water Resources (CVIW) which provides a multi-facetted and cross-sectoral view on the vulnerability of national water resources. This approach of inter-country comparisons provides insights on varying socio-economic, developmental and natural threats to water resources in the MENA region. Such interdisciplinary and 'complicated' view on vulnerability has been developed in earlier studies focusing on water resources vulnerability in river basins [9, 10]. In this paper, such vulnerability measurement approach has been modified to incorporate a country level view considering related energy and food issues that can help reduce water resources vulnerability.

2. Methods and Data

2.1. Index Concept and Composition

The proposed index, CVIW, is applied to MENA region countries, whereas the non-MENA country of Turkey is added to this analysis due to regional relevance. Palestine was excluded for the lack of data. The CVIW proposes six vulnerability categories: governance, socio-economic, environmental risk, water scarcity, external water footprint and energy for water. Table 1 gives an overview of the categories, indicators and data sources. Note that socio-economic issues are represented by one category using the Human Development Index (HDI) as measure of a society's capacity to react to increasing scarcity. In the category of environmental risks, four indicators were used that capture water disasters (floods and droughts) and water supply variability (seasonal and inter-annual). Arguably, these are most crucial future climate threats in the region. The category of energy for water depicts the ability of a country to react to increasing water scarcity by mobilizing its energy reserves for water production. The indicator developed here investigates whether a country will be able to devote its energy reserves for water production (e.g. desalination) on the long-run. This will depend on the size of energy reserves, the dependency of the country's economy on such reserves and the economic power of the country to release itself from such dependency. Finally, the category of external water footprint illustrates the ability of a country to save water resources by importing water-intensive products. The index used here considers how much virtual water is imported and also consumed relative to the water scarcity situation in a specific country.

Table 1. Description of the CVIW Sub-indices

Sub-Index *(Source)*	Index Description	Data Source
Governance *(CIFP 2007)*	Political Instability Index (PII): Economic distress and vulnerability to unrest	The Economist Intelligence Unit [12]
Socio-Economic (UNDP)	Human Development Index (HDI): Geometric mean of Life expectancy; Income and Education Indices at the individual level	UNDP [13]
Environmental Risk	Drought severity (Average length of droughts times the dryness of the	Gassert et al. [14]

(Gassert et al. 2013)	droughts from 1901 to 2008); Flood occurrence (Number of floods recorded from 1985 to 2011); Inter-annual variability (Variation in water supply between years); Seasonal variability (Variation in water supply between months of the year)	
Water Scarcity *(Pfister et al. 2009)*	Water Stress (Ratio of water withdrawals to hydrological availability, along with a variation factor to account for variability of precipitation)†	Pfister et al. [15]
External Water Footprint *(original index based on Mekonnen & Hoekstra 2011)*	Ratio external to total water footprint multiplied by the value of water scarcity‡	Mekonnen & Hoekstra [16]
Energy for Water *(original index)*	Three steps-index: 1- Long-term energy sufficiency: energy reserves transformed into number of years of sufficiency to accommodate for electricity consumption and energy for water production; 2- Fossil revenues dependency: fossil revenues weighted by the GDP of the country; 3- Economic power: income level scale the World Bank	IEA [17], EIA [18], Fichtner [19], The Global Economy [20], UN-Water [21], World Bank [22]

While in the categories governance and socio-economic data were used directly from the Political Instability Index (PII) and the HDI, data for the new indices in the other four categories were collected from diverse sources. All the data used in the assessment are easily accessible for the majority of countries around the world. The used data were transformed to the CVIW final scale from 0-1 by using minimum and maximum values in the available global dataset except for the energy for water category. For determining the final level of vulnerability, the CVIW uses the following ranges: 0,76-1 (extreme vulnerability); 0,51-0,75 (high vulnerability); 0,26-0,5 (moderate vulnerability); 0-0,25 (low vulnerability).

2.2. Cross-Sectoral Indices

The proposed vulnerability index 'CVIW' introduces two original cross-sectoral indices to capture the close interlinks of water resources to energy and trade. While virtual water imports provide opportunities to relieve stress on water resources, energy reserves can accommodate new water demands. The two indices are described in this place. *Energy for Water*

Options to use water for energy production and vice verse are receiving much attention in recent years by illustrating different technologies and embedded footprints of both resources [23]. The index developed here only looks at energy use for water production as a way to mitigate scarcity and reduce vulnerability. Further, the use of water for energy production in the MENA region is highly heterogeneous. In general, the energy system in the MENA region is largely decoupled from freshwater in comparison to other world regions [24]. CVIW uses an original energy for water vulnerability index which is composed in three steps. Firstly, a long-term energy sufficiency indicator of a country is calculated. This assesses the ability of a country to provide, by its own means, enough energy for water production in the next 25, 50 and 100 years. The indicator calculates the number of years in which the available energy reserves (fossil fuel reserves and hydro-energy production) can satisfy the energy consumption and energy consumption for water production in a country. Secondly, a fossil fuels revenues dependency indicator evaluates the dependency of the country's economy on fossil energy revenues assuming that countries with high dependency will be restricted in using energy reserves for water production. Finally, the income level of a country is considered to further examine the country's ability to free energy reserves for water production.

† For Bahrain data from Gassert et al. (2013) were used due to a lack of data in Pfister (2009). In this case, water stress represents the annual water withdrawals and annual availability, without considering precipitation variability.

‡ Bahrain, Iraq, Oman and Qatar were not considered in Mekonnen & Hoekstra (2011). However the missing countries were listed in Chapagain and Hoekstra (2004), that used the indicator "water import dependency" instead. Thus, data for the four countries was used from Chapagain and Hoekstra (2004) and calibrated with the average deviation to project the values for 2011.

For low-income country with high dependency on energy revenues, currency from energy exports are indispensable for fighting poverty and provide for basic governmental services. They thus cannot be allocated for water production without suffering from heavy socio-economic consequences.

External Water Footprint

Countries with limited water resources such as the MENA countries, in general, are increasingly depending on imported virtual water due to goods, products, commodities and services to fulfill the needs of their populations [25]. The index used here calculates the external water footprint of a country relative to the water scarcity in the country. In this sense, water resources of water-scarce countries are vulnerable if an external water footprint (water used in other nations to produce products consumed locally) is relatively low.

3. Results

3.1. Vulnerability Categories

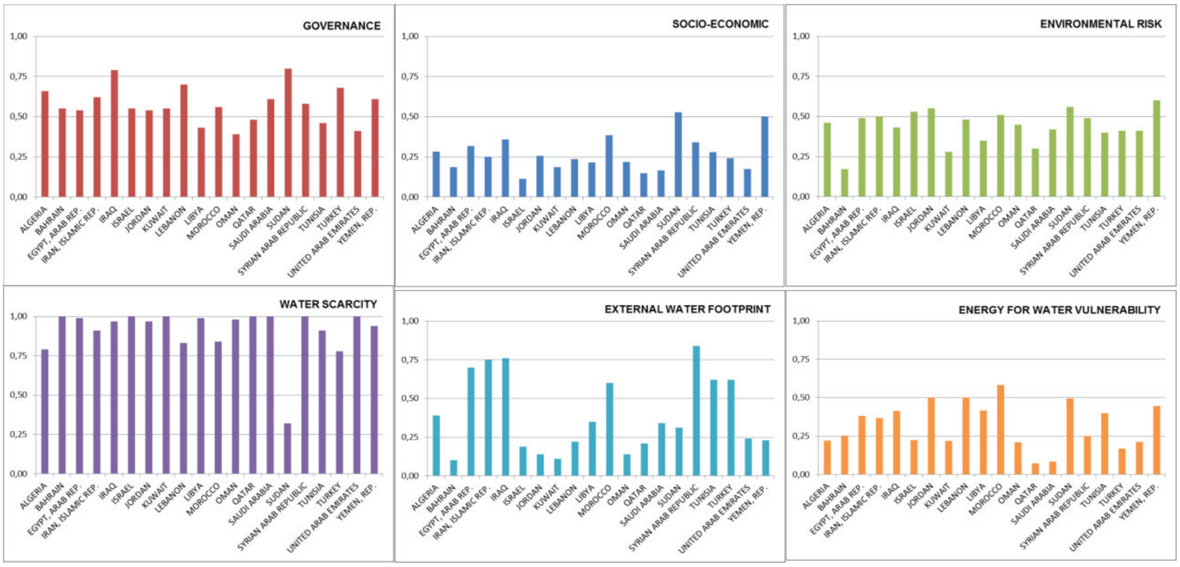

Fig. 1. Water resources vulnerability by category in the MENA region

Governance. Freedom from violence and conflict-free access to natural resources are crucial for development. In the MENA context, the impact of conflicts on the access to natural resources and on the water-food-energy nexus has being recently emphasized [26, 27]. As shown in Figure 1, none of the countries has a low vulnerability score in regard to governance. The data used are from the period 2009/2010. The situation is expected to be even worse after the political turmoil since 2011. We assume that this transformative phase will pass putting the countries again on comparable basis in regard governance.

Socio-Economic. Based on HDI data of 2013, socioeconomic vulnerability is high in Sudan and Yemen. However it is important to mention, that no MENA countries obtained a very high vulnerability score.

Environmental Risk. Results in this category show that the majority of the MENA countries are moderately vulnerable to environmental risks. However, Israel, Jordan, Morocco, Sudan and Yemen show a high vulnerability.

Water Scarcity. Water stress is a common indicator of water scarcity. Evidently, regional vulnerability is very high in this regard. 13 of the MENA countries appear in the top 30 of 176 countries in the total dataset.

External Water Footprint. Water-rich countries in the region can show to use their water resources for supply essential goods like food. This is the case of Sudan for example since the low external water footprint is justified by the low water scarcity. Still, Sudan is performing worse in this category than the countries of Bahrain and Kuwait for example which have high values in terms of water scarcity, but import most of their virtual water. At the same time, countries like Iraq, Iran, Egypt, Morocco and Syria depend more on their own water resources mainly for food security. The low external water footprint together with the high level of water scarcity in these countries lead to high vulnerability of local water resources.

Energy for Water. The majority of countries are moderately or low vulnerable in this category due rich energy reserves. Countries like Jordan, Morocco and Lebanon are not rich in energy resources or in economic terms and thus cannot compensate for increasing scarcity. Although certain countries like Yemen have enough energy reserves to satisfy future demands, their economic dependency on the reserves for basic development is high. Further, while Iraq disposes of rich reserves, the energy consumption and demand for the water sector are very high jeopardizing its ability to reallocate reserves for water production.

3.2. Country Profiles and Overall Vulnerability

In this section, a selection of country profiles are described in order to show the key differences among countries, presenting the most vulnerable ones and the best performers. Additionally, countries will be analyzed that face less water scarcity but are under risk because of other factors.

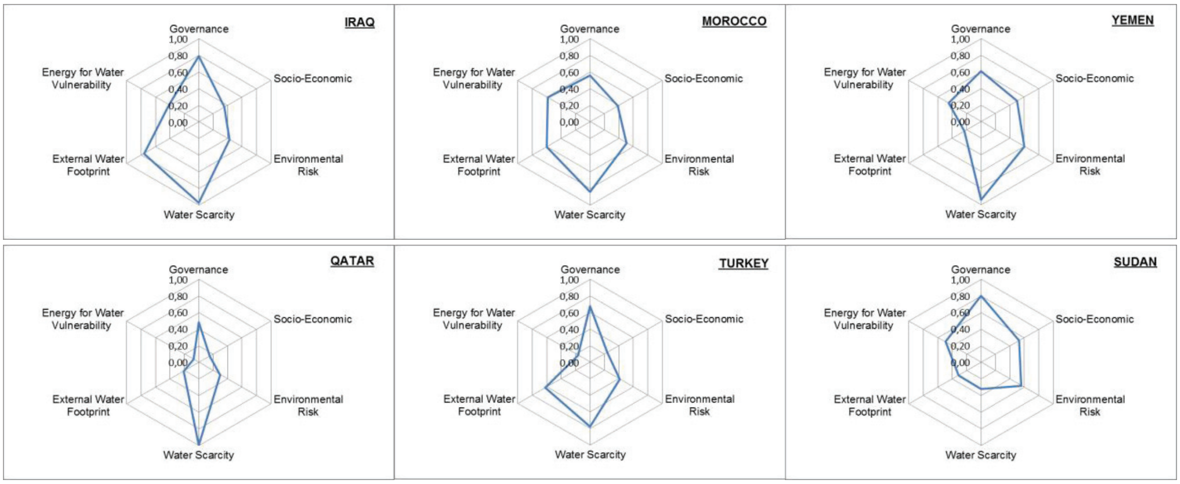

Fig. 2. Vulnerability Profiles of Selected Countries

Highly vulnerable countries in MENA region

Iraq. The results set Iraq as the most vulnerable country in the region, ranking in the very high vulnerability range. The main difficulties Iraq is facing based on the assessment are external water footprint, governance and water scarcity. Iraq has a high water scarcity but it does not ease the scarcity by enough importing water goods. This situation is similar in regard as in Syria, Egypt, Tunisia, Turkey or Iran. Besides, Iraq will be less able to use its energy reserves (the same reserves as of the United Arab Emirates), to reduce water scarcity problems due to a high energy footprint. Syria is next in terms of vulnerability to Iraq with relatively a similar profile.

Morocco and Yemen. In addition to high water scarcity, Morocco exhibits a sizable internal water footprint and low energy revenues. These factors combined makes increasing scarcity an eminent risk for the country. Another country that also lacks viable alternatives is Yemen. Yemen's extreme scarcity situation is exacerbated by bad scores in on governance and socio-economic performance. Besides, energy reserves are not freely disposable for water production. Yemen is mitigating water scarcity mainly importing virtual water.

Less vulnerable countries in the region

Qatar and Bahrain. Qatar is the least vulnerable country in the MENA region despite extreme scarcity. Good socio-economic performance and rich energy reserves means that the country can manage its way out of scarcity and environmental risks. Similarly Bahrain is a good performer for the same reasons while it is even less vulnerable to environmental risks according to available historic data. Both countries are however vulnerable to instability and political unrest as other countries in the region.

Non-consequent performers

Sudan. Sudan is the least water scarce country in the MENA region. It has a moderate vulnerability in the external water footprint. Nonetheless, the country is almost reaching high vulnerability because of a very high vulnerability in governance and in socio-economic aspects. Furthermore, the country shows the second highest result concerning in regard to environmental risks. For the case of energy vulnerability Sudan is on the border to be highly vulnerable because of limited resources and economic means to provide to for alternative water production technologies.

Turkey. Turkey is the second least water scarce country although water scarcity is still a serious issue. The country shows high vulnerability in regard to governance and water footprint. Turkey compensates for this via energy reserves and a high socio-economic development.

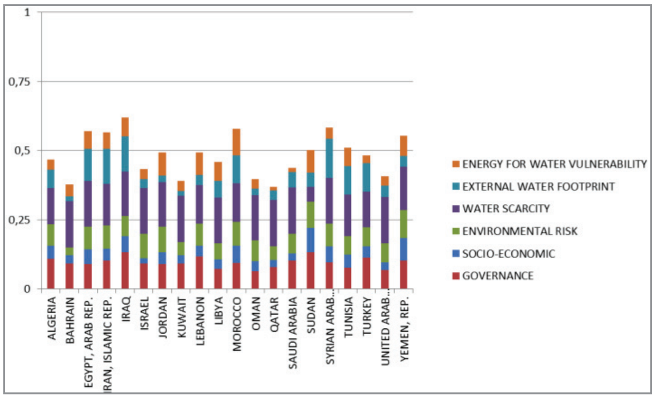

Fig. 3. Total CVIW results for MENA Region

The overall results of the vulnerability assessment are shown in figure 3. None of the MENA countries is extremely vulnerable because none reaches 0.76-1 on the NEXUS scale. But seven countries show high vulnerable (0.51-0.75) which are the following countries: Egypt, Iran, Iraq Morocco, Syria, Tunisia and Yemen. The rest of the countries show moderate vulnerability as they reach to values on the scale between 0.25-0.50: Algeria, Bahrain, Israel, Jordan, Kuwait, Lebanon, Libya, Oman, Qatar, Saudi Arabia, Sudan, Turkey and the United Arab Emirates.

4. Discussion

CVIW represents an index capable of capturing the multidimensionality and interdisciplinary of water resources vulnerability beyond physical scarcity. In applying it to the MENA region, interesting patterns can be noted. High level of vulnerability is associated with those big-sized MENA countries with little virtual water imports. These two common characteristics are however related. Relatively big countries are less likely to be able to satisfy local (water) demands through imports alone. Another factor is presumably the big size of agricultural sectors in these countries. Arguably, this explains the relatively low external water footprint. However, this paper did not consider virtual water related to trade of agricultural products but virtual water imports of all products. In fact, the linkages between water security and food security have traditionally not taken studied in terms of mutual impacts and externalities [28]. While the CVIW links water vulnerability to energy resources and trade (including food-related trade), substituting virtual water imports of all products with only food-related water imports will not change the relative vulnerability of the countries. This is because of the high positive correlation between the total external water footprint and the food-related external footprint of the region's countries, according to our analysis. A modification of the CVIW to incorporate only direct interactions related to the 'Water, Energy and Food Nexus' is not necessary, yet feasible. In any case, the focus of the CVIW on water vulnerability remains justifiable. Water plays a central role in Nexus since it is main cause of competition and most vulnerable resource to pressures from other sectors [29, 30]. By analyzing vulnerability of water resources considering food and energy, "untapped opportunities" can be revealed by for example outlining alternatives to current use pattern through virtual water imports and energy and food trade [31].

Another modification might be related to weighting of the indices. In this paper, the selected parameters are all weighted in the same way although some of them might play a less important role regarding water vulnerability.

Furthermore, the index might have a bias towards the developmental or economic capacity of a country. Economic development, resource-richness and political stability are directly positively correlated in many of the analyzed countries. However, there are enough examples in the region of resource mismanagement and success despite natural scarcity. Thus, weighting the different vulnerability categories is a debatable method as favoring specific parameters over others cannot be scientifically justified in many cases [32].

5. Conclusions

This study analyzes the water vulnerability of 20 countries in the MENA-Region using global data sets using a comprehensive, interdisciplinary index. The index also accommodate for adaptation capacity to increasing scarcity considering the close links of the water, energy and trade. MENA countries seem to be able to compensate extreme water scarcity in the future through trade, energy use and technology. Yet regional water resources will remain vulnerable with natural scarcity in face of socio-economic growth as the major risk. Furthermore, political instability is another outstanding factor in the region which puts an additional burden on eco-systems and societies. Besides, environmental climate risks in the region are significant and bring about uncertainties regarding future supply.

While almost all MENA countries share same vulnerability characteristic in regard to supply scarcity, fragile governance and high variability of supply, their adaptation strategies and capacities to mitigate this situation vary significantly. Resource-rich countries of the gulf region seem to utilize most of available measures in terms of importing more embedded water, desalinating seawater or investing in technologies. Traditional agricultural societies in the region are having difficulties to decrease the internal water footprint in face of resource depletion. Instead, internal water footprint is rather tackled through socio-economic development, which can provide water saving technologies and know-how to increase resource use efficiency. Regional food trade can be an option to mitigate extreme scarcity in certain countries. Yet, this option is quite limited and trade must be expanded beyond the region in order to make significant virtual water gains. Finally, future research can be useful in applying the CVIW method using more recent, and consistent data sets, comparing this vulnerabilities of different world regions, or applying this Nexus-based approach to other spatial units relevant for allocation and planning.

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