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Evaluation of Economical Aspects of Virtual Water in MENA Region

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Abstract

Water is the source of life, indeed the Holy Quoran says: "We made from water every living thing". Historians have been quick to point out that the migration of ancient civilizations was linked to sources of water. The Nile gave birth to the civilizations of the Egyptians whilst the Mediterranean cradled the ancient Greeks and provided the means for the Romans to flourish in their era of dominance.

Yet, at the dawn of the 21st century water is becoming an increasingly scarce resource. An ever growing population means ever more mouths to feed, and the demand being placed upon water resources from agriculture, industry and municipal requirements cannot be met in many regions of the world at the present rate.

The 21st century is called the "century of water" because there are regions where water scarcity results in poverty, poor sanitary conditions and disease. At the same time anticipated population growth increases the demand for potable water in urban areas and irrigation water for crop production. Economic growth will induce an increase in the consumption of cereal crops and also increase the water demand. Water should be considered as an economic good(14).

The first region in the world to be confronted by a water deficit to the extent that economic growth is being hampered and social stability is being threatened, is the Middle East and North Africa (MENA)(7). The purpose of this study is to highlight the key issues that a strategic level decision-maker will be confronted with when considering Virtual Water as a national coping strategy.

The concept of virtual water has been introduced by the British researcher Tony Allan in the early nineties of the last century(5).

Virtual water is defined, as the total quantity of water required for producing an agricultural product as well as the industrial products related to that agricultural crop.

Producing goods and services generally requires water. The water used in the production process of an agricultural or industrial product is called the virtual water contained in the product.

On the world average, agriculture uses about 70% of the total water withdrawals, making it, by far, the largest water user. This leads to an intrinsic relationship between a country's renewable water resources and the capacity for food production. In water scarce countries, increasing amounts of food have to be imported to substitute local water demand for food production. Among the imported food products, cereal grains are the dominant commodities in terms of the quantity and importance for food security to the importing countries. Water that is required for producing the imported food is termed virtual water. Cereal grains have been the major carrier of virtual water and their import has played a crucial role in compensating water in countries where the resources are scarce.

Main Study Objectives:

- To present an integrated view for the position of MENA Region from the water-scarcity border and consequently, the impact of that condition on water consumption.
- To determine the suitability of Virtual Water concept to be applied in MENA Region.
- To determine the economic feasibility resulted of application of virtual water concept on the main crops in MENA Region.
- To evaluate foot-prints and impacts of applying the strategic plans based on the virtual water concept in MENA Region.

For these objectives, a model based on the genetic algorithm is designed and a computer program is designed to calculate the virtual water of crops and to determine the economic impacts resulting of application of virtual water concept in MENA Region.

Introduction

According to UN statistics, there are now about 1.2 billion inhabitants living in areas lacking to adequate supplies of water in the world. In 1996 the UN predicted that by 2050, with the expanding world population that number would reach 2.4 billion inhabitants. The major problem in addition to population explosion and poor water practices is the corresponding increase in the amount of fresh water available. Since 1950, the world population has swelled from 2.5 billion to 6 billion inhabitants and this has resulted in falling of renewable supply of water by 58% per person.

The Middle East and North Africa (MENA) region is under tremendous strain and pressure to meet the growing water demands from its rapidly enlarging populations. This growing demand is compounding what was a critical situation already, for although the MENA region comprises more than 5% of the world’s population, it has access to only 1% of the world’s fresh water supply.

When dealing with the available water resources in an economically efficient way, there are three different levels at which decisions can be made and improvements be achieved(15). The first level is the user level, where price and technology play a key role. This is the level where the local water use efficiency can be increased by creating awareness among the water users, charging prices based on full marginal cost and by stimulating water-saving technology. Second, at the catchments or river basin level, in the choice that has to be made on how to allocate the available water resources to the different sectors of economy (including public health and the environment). The third level people allocate water to serve certain purposes, which generally imply that other, alternative purposes are not served. Choices on the allocation of water can be more or less efficient depending on the value of water in its alternative uses.

The volume of *virtual water* 'hidden' or 'embodied' in a particular product is defined as the volume of water used in the production process of that product (Hoekstra, 1998)[16]. Not only agricultural products contain virtual water. Although most studies have been limited to the study of *virtual water* in crops but also industrial products and services contain *virtual water*. As an example of *virtual water* content, one often refers to the *virtual water* content of grains. It is estimated that for producing one kilogram of grains, grown under rain with favorable climatic conditions, about (1-2) m^3 of water is needed. For the same amount of grains, but growing in an arid country, where the climatic conditions are not favorable (high temperature, high evapotranspiration) then, up to (3-5) m^3 of water[16] is needed.

When a country exports a water-intensive demanding product to another country, it actually exports water in a virtual form. In this way, countries support others in their water needs. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic. For water-scarce countries, it could therefore be attractive to achieve water security by importing water-intensive demanding products instead of producing all water-demanding products domestically. On the contrary, water-rich countries could profit from their abundance of water resources by producing water-intensive demanding products for export.

Definitions of Virtual Water

1 Virtual water content

The virtual water imbedded in a product is the volume of water used to produce the product, measured at the place where the product was actually produced (production site specific definition). The virtual water content of a product can also be defined as the volume of water that would have been required to produce the product in the place where the product is consumed (consumption site specific definition)[14,15]..

2 Virtual water export

The virtual water export of a country or region is the volume of virtual water associated with the export of goods or services from the country or region. It is the total volume of water required to produce the products for export[14,15].

3 Virtual water import

The virtual water import of a country or region is the volume of virtual water associated with the import of goods or services into the country or region. It is the total volume of water required (in the export countries) to produce the products for import. Viewed from the perspective of the importing country, this water can be seen as an additional source of water that comes on top of the domestically available water resources [14, 15].

4 Virtual water flow

The virtual water flow between two nations or regions is the volume of virtual water that is being transferred from one place to another as a result of product trade [14, 15].

5 Virtual water balance

The virtual water balance of a country over a certain time period is defined as the net import of virtual water over this period, which is equal to the gross import of virtual water minus the gross export. A positive virtual water balance implies net inflow of virtual water to the country from other countries. A negative balance means net outflow of virtual water [14, 15].

Definition of Water Footprints, Water Scarcity, Water Self-Sufficiency and Water Import Dependency

1 Water footprints

Water footprint of an individual, business or nation is defined as the total volume of fresh water that is used to produce the foods and services consumed by the individual, business or nation. A water footprint is generally expressed in terms of the volume of water use per year [8, 17].

2 Water scarcity

Water scarcity has often been defined as the ratio of actual water withdrawals to the available renewable water resources. This supply-oriented definition is useful from a production perspective, but does not express the scarcity from a demand perspective. In this study, water scarcity is defined as the ratio of the total water footprint of a country or region to the total renewable water resources. The national water scarcity can be more than 100% if a nation consumes more water than domestically available [8, 17]

3 Water self-sufficiency

Water self-sufficiency is the ratio of the internal water footprint to the total water footprint of a country or region. It denotes the national capability of supplying the water needed for the production of the domestic demand for goods and services. Self-sufficiency is 100% if all the water needed is available and indeed taken within the own territory. Water self-sufficiency approaches zero if the demand for goods and services in a country is largely met with virtual water imports [8, 17].

4 Water import dependency

Countries with import of virtual water depend, Fait accompli, on the water resources available in other parts of the world. The virtual water import dependency of a country or a region is defined as the ratio of the external water footprint of the country or region to its total water footprint [8,17].

Approach Methodology

1 Calculation of specific water demand per crop type

The average specific water demand per crop type was calculated separately for each relevant nation on the basis of the FAO data regarding crop water requirements and crop yields [11].

$$SWD\left[e,c\right]=\frac{CWR\left[e,c\right]}{CY\left[e,c\right]} \quad (1)$$

where:-

CWR [e,c] : the crop water requirement of crop c in country e (m^3/ha)
CY [e,c] : the crop yield (ton/ha).

The crop water requirement *CWR* (in m^3/ha) is calculated from the accumulated crop evapotranspiration amount ET_C (in mm/day) over the complete growing period. The crop evapotranspiration ET_C results of multiplying the ‘reference crop evapotranspiration’ ET_O by the crop coefficient K_c:

(2) $$ET_C = K_c \times ET_O$$

The concept of ‘reference crop evapotranspiration’ was introduced by the FAO to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. The only factors affecting ET_O are the climatic parameters. The reference crop evapotranspiration ET_O is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 12 cm, a fixed crop surface resistance of (70 sec/m) and an albedo of 0.23. This reference of crop evapotranspiration closely resembles the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water. The reference crop evapotranspiration is calculated on the basis of the FAO Penman-Monteith equation.

$$ET_o=\frac{0.408\,\Delta(R_n-G)+\gamma\frac{900}{T+273}U_2(e_a-e_d)}{\Delta+\gamma(1+0.34U_2)} \quad (3)$$

where:-

ET_o : reference crop evapotranspiration [mm/d].
R_n : net radiation at crop surface [MJ /m^2 /d].
G : soil heat flux [MJ/ m^2 /d].
T : average temperature [°C].
U_2 : wind speed measured at 2m height [m/sec].
(e_a-e_d) :vapour pressure deficit [kPa].

Δ : slope vapour pressure curve [kPa/ °C].
γ : psychrometric constant [kPa /°C].
900 : conversion factor.

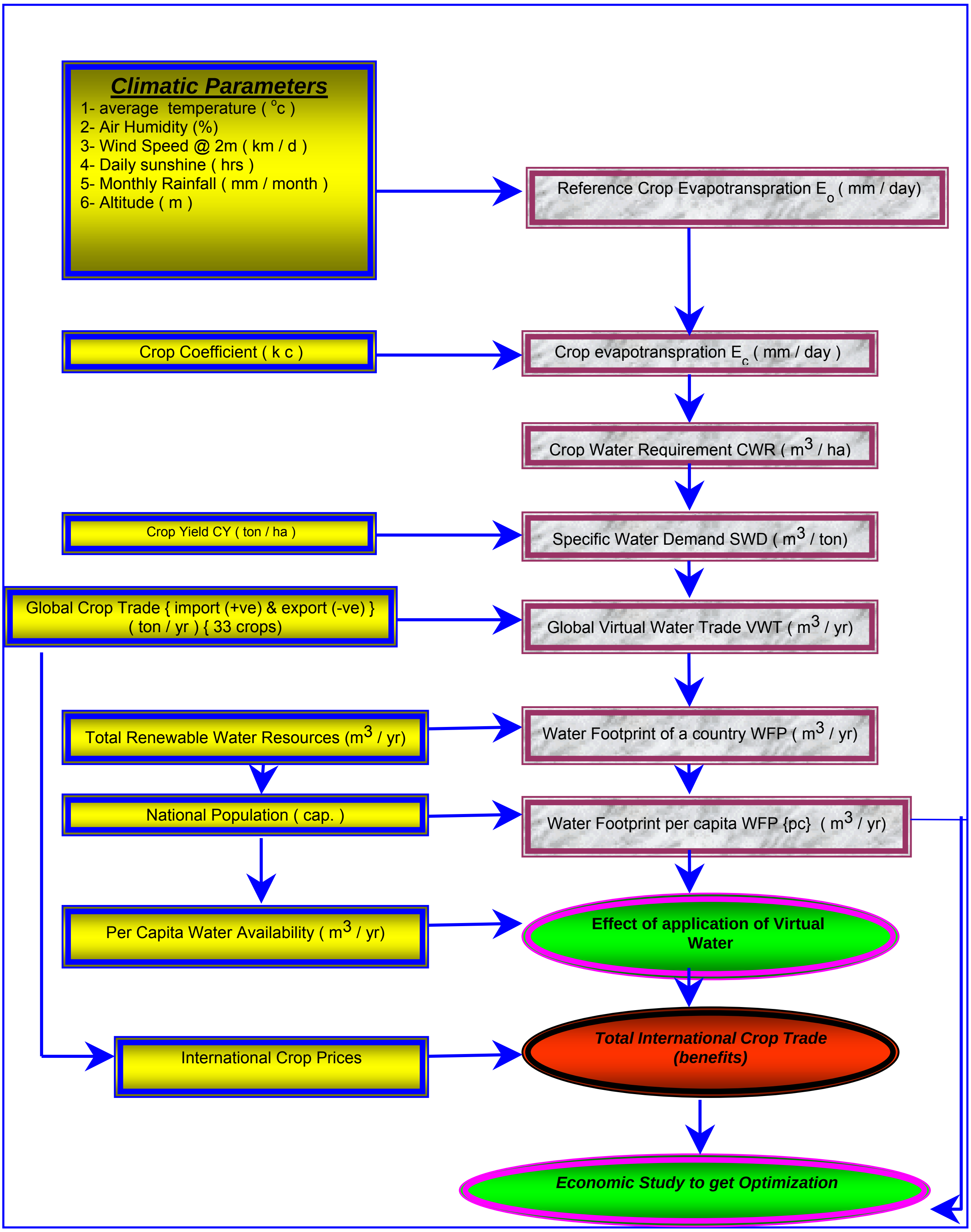

Figure (1). Flowchart showing Steps of the Calculation of Global Virtual Water Flows

The crop coefficient accounts for the actual crop canopy and aerodynamic resistance relative to the hypothetical reference crop. The crop coefficient serves as an aggregation of the physical and physiological differences between a certain crop and the reference crop.

The overall procedure for the calculation of specific water demand is given in Figure (1). This chart shows the steps for estimation of the virtual water trade flows between nations.

2 Calculation of virtual water trade flows and the national virtual water trade balance

Virtual water trade flows between nations have been calculated by multiplying international crop trade flows by their associated virtual water content. The latter depends on the specific water demand of the crop in the exporting country where the crop is produced. Virtual water trade is thus calculated by:

$$VWT\left[c,t\right]=CT\left[c,t\right]\times SWD\left[c\right] \quad (4)$$

where:

VWT : the virtual water trade (m^3/year) in year t as a result of trade in crop c.

CT : the crop trade (ton/year) in year t for crop c

SWD : the specific water demand (m^3/ton) of crop c

The gross virtual water import to a country is the sum of all imports:

$$GVWI\left[t\right]=\sum VWT\left[c,t\right] \quad (5)$$

where:

GVWI : The gross virtual water import (m^3/year) in year t for crop c.

The gross virtual water export from a country is the sum of all exports:

$$GVWE\left[t\right]=\sum VWT\left[c,t\right] \quad (6)$$

where:

GVWE : The gross virtual water import (m^3/year) in year t for crop c.

The net virtual water import of a country is equal to the gross virtual water import minus the gross virtual water export. The virtual water trade balance of country *x* for year *t* can thus be written as:

$$NVWI\left[x,t\right]=GVWI\left[x,t\right]-GVWE\left[x,t\right] \quad (7)$$

Where:

NVWI : The net virtual water import (m^3/year) to the country

Net virtual water import to a country has either a positive or a negative sign. The latter indicates that there is net virtual water export from the country.

3 Calculation of a nation's water footprint

The total water use within a country itself is not the right measure of a nation's actual appropriation of the global water resources. In the case of net import of virtual water import into a country, this virtual water volume should be added to the total domestic water use in order to get a picture of a nation's real call on the global water resources. Similarly, in the case of net export of virtual water from a country, this virtual water amount should be subtracted from the volume of domestic water use. The sum of domestic water use and net virtual water import can be seen as a kind of 'water footprint' of a country, on the analogy of the 'ecological footprint' of a nation. In simplified terms, the latter refers to the amount of land needed for the production of the goods and services consumed by the inhabitants of a country. Studies have shown that for some countries the ecological footprint is smaller than the area of the nation's territory, but in other cases much bigger (Wackernagel and Rees, 1996)[(22)]. The later means that apparently some nations need excessive land areas than their own territory to provide their goods and services.

The water footprint of a country (expressed as a volume of water per year) is defined as:

$$\textit{Water footprint} = WU + NVWI \qquad (8)$$

Where:

NVWI : The net virtual water import (m^3/year)to the country

WU : Total domestic water use *WU* should ideally refer to the sum of blue water use and green water use

Green water refers to the water in the unsaturated soil that is directly from the rainfall and used by the vegetation through the process of evapotranspiration.

Blue water is defined as the water in the lakes, rivers and aquifers.

However, since data on green water use on country basis are not easily obtainable, we have provisionally chosen in this paper to limit the definition of water use to blue water use.

4 Calculation of national water scarcity, water dependency and water self-sufficiency

One would logically assume that a country with high water scarcity would seek to profit from net virtual water import. On the other hand, countries with abundant water resources could make profit by exporting water in virtual form. In order to check this hypothesis we need indices of both water scarcity and virtual water import dependency. Plotting a graph for countries with water scarcity on the x-axis and virtual water import dependency on the y-axis would expectedly result in some positive relation, figure (10).

As an index of national water scarcity we use the ratio of total water use to water availability:

$$WS = \frac{WU}{WA} \times 100 \qquad (9)$$

where

WS : national water scarcity (%)

WU : the total water use in the country (m^3/year)

WA : the national water availability (m^3/year).

Defined in this way, water scarcity will generally range between zero and hundred per cent, but can in exceptional cases (e.g. groundwater mining) be above hundred per cent. As a measure of the national water availability *WA* we take the annual internal renewable water resources that are the average fresh water resources renewably available over a year from precipitation falling within country's borders.

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

$$WD = \begin{cases} \dfrac{NVWI}{WU + NVWI} \times 100 & if\ \ NVWI \geq 0 \\ 0 & if\ \ NVWI < 0 \end{cases} \qquad (10)$$

The value of the water dependency index will per definition vary between zero and 100%. A value of zero means that gross virtual water import and export are in balance or that there is net virtual water export. If on the other extreme the water dependency of a nation approaches hundred percent, the nation nearly completely relies on virtual water import.

As the counterpart of the water dependency index, the water self-sufficiency index is defined as follows:

$$WSS = \begin{cases} \dfrac{WU}{WU + NVWI} \times 100 & if\ \ NVWI \geq 0 \\ 100 & if\ \ NVWI < 0 \end{cases} \qquad (11)$$

The water self-sufficiency of a nation relates to the water dependency of a nation in the following simple way:

$$WSS = 100 - WD \qquad (12)$$

The level of water self-sufficiency *WSS* denotes the national capability of supplying the water needed for the production of the domestic demand for goods and services. Self-sufficiency is 100% if all the water needed is available and indeed taken from within the own territory. Water self-sufficiently approaches zero if a country heavily relies on virtual water imports.

Data Sources

Data on crop water requirements are calculated with the construction model (crop water requirement model). The model applies the FAO Penman-monteith equation for calculated reference crop evapotranspiration. In this study, the model calculates crop water requirement of different crop types on the basis of the following assumption:[25]

Crops are planted under optimum soil water conditions without any effective rainfall during their life; the crop is developed under irrigation conditions.

1) Plant evapotranspiration under standard conditions (ET_c), this is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields with 100% coverage.

2) Crop coefficients are selected depending on the single crop coefficient approach that means single cropping pattern, not dual or triple cropping pattern.

1 Climatic data

The climatic data needed is; the min temperature c^o, the max temperature c^o, air humidity in %, wind speed in km/day at 2m above ground level, daily sunshine in hrs, monthly rainfall in mm/month, altitude in m. This is taken as input to virtual water model which have been taken from:-

1- Food and Agriculture Organization of the United Nations, FAO's climatic database, which is also available through FAO's web site[25] .
2- IWMI (World Water and Climate Atlas) which is also available through web site[25].
3- EMA (Egyptian Meteorological Authority), is also available through web site[25].

However, the changes in crop water demand resulting from temperature and humidity changes were not taken into account in this study.

2 Crop parameters

The crop parameters used as input data to Virtual Water Model are the crop coefficients in different crop development stages (initial, middle and late stage), the length of each crop in each development stage, and the planting and harvesting dates. Crop parameters are based on Allen et al. (1998)[4] and Research Institute of the Ministry of Agriculture[19,25].

3 Crop yields

Data related to crop yields were taken from the FAOSTAT database[11], and the Research Institute of the Ministry of Agriculture in Egypt[19,25] In these calculations, the average of crop yields along the time period considered in the study is taken.

4 Global trade in crops

As a source for the global trade in crops, the data of 1990-2007 is used. These data are based on the Commodity Trade Statistics Data Base of the Food and Agriculture Organization of the United Nations (FAO)[12]. Estimation of the trade values from present year and up to 2050 is predicted by concerning the rate of increase in trade in the coming years which will result of the increase in consumption with the increase of population.

Specific Water Demand per Crop Type

The calculated crop water requirements for 33 different crops in countries of the MENA region and according to the FAO estimated water requirements are shown for 20 countries in Tables (1 to 4). The crop water requirements presented here refer to the evapotranspiration under optimal growth conditions. This means that the calculated values are overestimates, because in reality there are often water shortage conditions. On the other hand, the calculated values can also be seen as conservative, because they exclude inevitable losses (e.g. during transport and application of water) and required losses such as drainage. The calculated crop water requirements differ considerably over countries, which is mainly due to the differences in climatic conditions.

Specific water demand (m^3/ton) per crops' types in MENA region has been calculated by dividing the crop water requirement (m^3/ha) by the crop yield (ton/ha). These values are then compared with those estimated from the FAO.

Relative Water Requirement for Different Crops

The total volume of water use to produce crops (AWU, m^3/year) is calculated as:

$$AWU = \sum CWU \qquad (13)$$

where:

CWU : the total volume of water used in order to produce a particular crop (m^3/year)

$$CWU = CWR \times \frac{Production}{Yield} \qquad (14)$$

where:

CWR : the crop water requirement (m^3/ha)

Production : the total amount of crop produced (ton/year)

Yield : the produced amount of crop per unit area of productive land

Virtual Water Trade Balance in Countries of the MENA Region

The difference between total virtual water import and total virtual water export is the virtual water flow balance of the country in the time period concerned. If the balance is positive it implies net virtual water being imported and if it is negative then, there is net export of virtual water.

This section presents the virtual water trade balances in countries of the MENA region. The annual balances for each year 1990 and 2050 and the overall years balance are given. Figures (2 to 5) show the gross *Virtual Water Trade Balance.*

Table (1). Crop Water Requirements per Area and per Yield and estimated FAO Values in Countries of the MENA Region

	Crop	Egypt			Algeria			Bahrain			United Arab Emirates			Iran		
		Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements		
		m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha
1	Apples	14080	665	---	12724	3509	----	15439	1039	----	16015	2236	----	11357	1048	----
2	Bananas	10820	258	9680	11198	447	13690	11446	110	----	9973	165	9540	10247	747	13070
3	Barley	5720	2146	5620	3500	4599	3420	6153	922	----	5618	6362	5640	4925	3648	5800
4	Beans green	4840	475	4520	4573	1135	4260	5121	750	----	3655	19	3600	4151	415	4160
5	Beans dry	4160	1565	4200	5210	6007	6040	4393	218	----	4058	399	4080	3450	2387	----
6	Cottonseed	10550	9911	11430	6639	16598	6060	11307	11540	----	9052	9238	8830	8941	7545	9080
7	Dates	13130	393	13000	11622	4439	9000-13000	14416	252	9000-13000	14967	234	9000-13000	10529	2426	9000-13000
8	Grapefruit	11090	680	10000	9822	976	6500-10000	12139	470	6500-10000	12658	651	6500-10000	8863	822	6500-10000
9	Grapes	9120	420	10250	10195	3403	12360	10059	324	----	10516	316	10060	9387	1478	11240
10	Groundnuts	7200	2350	6930	6876	5532	7370	7768	1942	----	6403	1601	6390	6257	2162	5980
11	Lemons	11090	492	----	9822	840	----	12139	120	----	12658	65	----	8863	705	----
12	Maize	5090	627	4490	6365	3858	6860	5876	3266	----	4672	526	4120	5783	1335	6350
13	Nuts	15890	5452	---	14128	1999	----	17440	927	----	18080	2558	----	12823	6756	----
14	Oilseeds	6420	7134	---	6032	10360	----	6877	11812	----	7027	12069	----	5518	9065	----
15	Olives	11520	1821	---	10218	9773	----	12602	3065	----	13128	7517	----	9229	3962	----
16	Onions	5970	195	5570	5063	659	----	6511	22	----	6975	36	7120	4452	222	4980
17	Oranges	11230	552	----	9822	1298	----	12139	527	----	12658	593	----	8863	608	8210
18	Peas, dry	5140	2790	5420	4882	16172	----	5370	1083	----	5712	1152	6200	4381	20990	----
19	Peas, green	4950	478	5140	4380	1846	----	5655	1113	----	5546	960	----	4151	415	----
20	Pepper	3750	2500	4570	3195	363	3520	4306	489	----	5077	576	5420	5934	674	6170
21	Potatoes	3790	151	4730	6430	815	6920	4114	22	----	4426	20	4820	4976	294	4780
22	Rice	9440	945	9600	10431	3725	----	12093	403	----	10513	411	9340	9521	2520	10210
23	Sorghum	4850	864	4790	5232	3157	6550	5537	4476	----	4748	318	4680	3606	2915	3450
24	Soybeans	8350	2453	7790	5418	2126	5520	9050	3551	----	7316	2870	6910	6129	4707	5820
25	Spices	8270	2363	----	7720	468	----	8957	543	----	9184	557	----	7057	428	----
26	Sugar beet	8760	179	7580	5911	172	5710	9488	277	----	7360	215	6900	6129	179	6380
27	Sugar Cane	18390	146	21420	23892	340	23310	20064	286	----	19968	284	18270	21665	309	24710
28	Sunflower	6420	2634	7380	10042	19312	9100	6877	255	----	6909	256	6360	8970	332	9270
29	Sweet	6970	232	----	6644	211	----	7260	231	----	7789	248	----	5911	188	----
30	Tomatoes	5350	137	5890	7170	571	8350	5551	23	----	7335	23	7020	7900	338	8700
31	Vegetables	5630	318	5170	4973	789	4230	5981	103	----	4756	25	4630	4827	402	4400
32	Watermelons	6210	257	6740	5879	712	6250	6579	51	----	6848	48	6450	6819	351	6860
33	Wheat	6290	970	6380	5844	9254	5900	6842	1473	----	6064	274	5650	5780	4529	6100

Table (2). Crop Water Requirements per Area and per Yield and estimated FAO Values in Countries of the MENA Region

	Crop	Iraq			Israel			Jordan			Kuwait			Lebanon		
		Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements		
		m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha
1	Apples	12265	147	----	13374	514	----	12993	1814	----	12895	1800	----	12468	848	----
2	Bananas	12463	328	14920	13138	425	13070	10137	638	9740	9649	607	----	9475	407	7560
3	Barley	2013	209	1880	5880	11211	6800	4739	5366	4910	5026	1801	----	3589	2023	3710
4	Beans green	3139	514	3280	4935	331	4160	4741	695	5120	4274	626	----	2761	331	2040
5	Beans dry	5133	87	6530	1954	97	----	2771	272	2470	4080	734	----	4541	2185	4300
6	Cottonseed	4958	5060	4590	10518	4079	11920	10161	10370	10690	9479	9674	----	4590	4684	3470
7	Dates	11386	258	9000-	12161	1177	9000-13000	12057	3690	9000-	12061	3015	9000-	11521	1580	9000-
8	Grapefruit	9622	107	6500-	10286	179	6500-10000	10164	523	6500-	10224	526	6500-	9687	232	6500-
9	Grapes	12615	147	14990	13422	656	13240	9125	2195	9060	8468	23289	----	7702	985	7840
10	Groundnuts	6785	170	6180	5984	894	5980	4547	1137	4340	6514	1628	----	3838	1482	3590
11	Lemons	9622	163	----	10286	280	----	10164	288	----	10224	1136	----	9687	324	----
12	Maize	5994	242	5710	6571	476	6350	4619	519	4030	4580	434	----	3471	2053	3330
13	Nuts	13852	623	----	14811	12474	----	14680	2077	----	14546	2058	----	14098	3858	----
14	Oilseeds	5953	10223	----	6483	5885	----	6267	10764	----	5685	9763	----	6279	10783	----
15	Olives	10004	292	----	10701	3262	----	10571	6053	----	10606	8839	----	10088	6957	----
16	Onions	4951	66	4330	5233	146	5170	5177	402	5580	5695	342	----	4690	296	4760
17	Oranges	9622	80	----	10286	206	----	10164	476		10224	1461	----	9687	345	----
18	Peas, dry	4841	108	----	5298	4709	6120	5021	1013	5420	4631	934	----	4365	2281	3960
19	Peas, green	4243	835	----	4510	1394	----	4637	803		4380	758	----	4547	500	----
20	Pepper	2921	331	2310	6455	733	6170	3135	356	3100	3582	407	----	2762	313	2010
21	Potatoes	5608	34	5590	4998	146	4780	4059	128	4050	3645	182	----	3730	206	3360
22	Rice	10259	355	----	11133	435	12000	9086	355	8210	9722	380	----	9016	352	9900
23	Sorghum	6280	863	7840	3282	1176	3450	4522	302	4670	4300	288	----	4418	3535	3860
24	Soybeans	3853	264	3690	5349	2099	5820	3659	1436	3140	7414	2909	----	8077	3169	2680
25	Spices	7597	461	----	8241	500	----	8020	486	----	7406	65	----	7978	10637	----
26	Sugar beet	5760	25	5460	7054	206	6380	3877	113	3140	7788	227	----	3742	62	3470
27	Sugar Cane	23419	90	23840	25031	357	24710	24808	353	24640	24768	353	----	16420	763	12750
28	Sunflower	9911	367	10210	10164	6641	9270	6267	232	5770	5685	211	----	4820	2238	4840
29	Sweet	6564	209	----	5765	158	5620	6789	216	----	6353	202	----	5730	182	5860
30	Tomatoes	7026	53	7130	7710	114	8700	4856	117	4940	5115	162	----	4533	182	4090
31	Vegetables	2826	33	2880	4466	355	4400	2644	201	2400	4995	130	----	2197	173	2020
32	Watermelons	5817	44	5110	6350	630	6860	3432	110	3660	5538	451	----	3144	136	3030
33	Wheat	5061	500	4780	6223	1943	6100	3660	2531	3450	5546	1775	----	3202	1625	2850

Table (3). Crop Water Requirements per Area and per Yield and estimated FAO Values in Countries of the MENA Region

	Crop	Libyan Arab Jamahiriya			Morocco			Oman			Palestine			Qatar		
		Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements		
		m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha
1	Apples	13529	1337	----	12725	1209	----	15511	1044	----	13374	514	----	15278	1028	----
2	Bananas	10477	276	10520	9770	326	7560	10893	78	11130	13138	425	13070	9639	254	8530
3	Barley	2616	5487	2550	2462	2781	2400	4467	669	4490	5880	11211	6800	3963	132	4020
4	Beans green	3596	527	3200	2705	411	2570	4552	667	4300	4935	331	4160	3039	445	3040
5	Beans dry	5480	1781	6140	4445	7265	4150	5408	269	5960	1954	97	----	4520	225	4330
6	Cottonseed	5227	5335	4660	4868	4513	4210	7938	8101	7660	10518	4079	11920	6851	6992	6090
7	Dates	12418	2517	9000-13000	11649	2136	9000-13000	14642	305	9000-13000	12161	1177	9000-13000	14308	250	9000-13000
8	Grapefruit	10477	405	6500-10000	9855	845	6500-10000	12475	483	6500-10000	10286	179	6500-10000	12091	468	6500-10000
9	Grapes	12100	2420	11000	7989	1715	8080	10759	801	12450	13422	656	13240	10126	313	8740
10	Groundnuts	5743	2951	5540	4329	7098	4300	7008	1752	7040	5984	894	5980	5518	1380	5340
11	Lemons	10477	933	----	9855	986	----	12475	118	----	10286	280	----	12091	308	----
12	Maize	4755	4755	5150	4375	3772	4010	6233	3464	6560	6571	476	6350	5044	37	4970
13	Nuts	15086	2486	----	14125	1998	----	17463	2471	----	14811	12474	----	17239	2439	----
14	Oilseeds	6364	10929	----	5864	4887	----	6033	10362	----	6483	5885	----	6523	11204	----
15	Olives	10889	9608	----	10248	9446	----	12896	3137	----	10701	3262	----	12539	3050	----
16	Onions	6572	405	6630	4887	267	4450	7413	53	6550	5233	146	5170	6765	34	----
17	Oranges	10477	921	----	9855	657	----	12475	542	----	10286	206	----	12091	525	----
18	Peas, dry	5024	2955	4020	4772	5250	4200	5093	1027	6040	5298	4709	6120	5234	1056	----
19	Peas, green	4772	1976	----	4360	581	----	4935	971	----	4510	1394	----	5373	1058	----
20	Pepper	3336	379	2700	3081	350	2570	5110	580	4880	6455	733	6170	4489	509	3900
21	Potatoes	5388	669	5200	4145	241	4110	6953	27	6810	4998	146	4780	5377	56	5010
22	Rice	9227	448	----	8552	2048	----	11035	431	11670	11133	435	12000	9870	386	----
23	Sorghum	5597	4525	5720	4255	7743	4000	5815	183	5990	3282	1176	3450	3769	3047	3380
24	Soybeans	4593	1802	4130	3686	2278	3560	6765	2654	6300	5349	2099	5820	4961	1946	4490
25	Spices	8136	493	----	7557	9824	----	8051	488	----	8241	500	----	8561	519	----
26	Sugar beet	4537	132	4470	3822	82	3570	6595	192	6440	7054	206	6380	6912	202	6560
27	Sugar Cane	17479	249	17810	15883	231	13270	20025	285	20790	25031	357	24710	19825	282	20470
28	Sunflower	6364	255	6940	4640	4663	4720	6033	223	6810	10164	6641	9270	4864	180	4960
29	Sweet	6817	217	----	6518	419	----	7072	225	----	5765	158	5620	7137	227	----
30	Tomatoes	6201	455	6280	4942	147	4850	7457	32	7900	7710	114	8700	6388	35	6250
31	Vegetables	5577	465	3160	2512	163	2680	4881	33	4680	4466	355	4400	3731	34	3870
32	Watermelons	4887	305	4700	3529	153	3690	5941	29	6090	6350	630	6860	4967	55	4850
33	Wheat	4644	3770	4430	3576	2691	3480	5891	248	5760	6223	1943	6100	4224	184	3690

Table (4). Crop Water Requirements per Area and per Yield and estimated FAO Values in Countries of the MENA Region

	Crop	Saudi Arabia			Sudan			Syrian Arab Republic			Tunisia			Yemen		
		Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements			Crop Water Requirements		
		m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha	m^3/ha	m^3/ton	FAO m^3/ ha
1	Apples	13556	912	----	15282	1028	----	12323	1957	----	12880	2989	----	15478	10874	----
2	Bananas	9914	261	9540	9827	312	7520	9878	823	9540	8980	237	8110	9748	1524	9310
3	Barley	5011	751	5640	4061	608	3080	5551	17908	5640	3742	3991	3710	4070	3872	3590
4	Beans green	3694	541	3600	3792	556	3030	4740	524	4080	3807	552	3950	3761	1617	3340
5	Beans dry	4303	214	4080	3920	2614	3620	3802	2255	3600	2814	4679	2860	4880	822	4810
6	Cottonseed	8337	8508	8830	8684	16849	6830	8592	4913	8830	6782	8358	6540	8413	16850	6310
7	Dates	12751	1748	9000-13000	14502	2044	9000-13000	11381	6589	9000-13000	11719	3031	9000-13000	14720	10890	9000-13000
8	Grapefruit	10844	419	6500-10000	12387	1046	6500-10000	9575	768	6500-10000	9858	519	6500-10000	12586	487	6500-10000
9	Grapes	9667	719	10060	10891	810	9060	10959	2823	10060	8852	3313	8890	11019	1324	10160
10	Groundnuts	6518	1629	6390	5423	9835	4480	7073	3505	6390	4609	1152	4860	5390	1348	5490
11	Lemons	10844	277	----	12387	1332	----	9575	563	----	9858	708	----	12586	1673	----
12	Maize	4801	2669	4120	4923	10029	3690	4306	1440	4120	4454	2476	4520	5621	4413	5100
13	Nuts	15270	2160	----	17142	2425	----	13932	8249	----	14335	2028	----	17409	2463	----
14	Oilseeds	5660	9720	----	5417	9303	----	6246	10726	----	6416	11018	----	5529	9497	----
15	Olives	11230	2732	----	12765	3105	----	9974	8473	----	10270	17328	----	12978	3157	----
16	Onions	6078	938	4570	8061	1136	8710	4621	297	4620	5571	551	5520	8171	549	----
17	Oranges	10844	471	----	12387	2106	----	9575	532	----	9858	472	----	12586	6508	----
18	Peas, dry	4657	939	5640	4524	912	----	5841	4438	8410	4472	7593	4200	4655	3169	----
19	Peas, green	4464	879	----	4744	934	----	4464	951	----	4625	809	----	4794	944	----
20	Pepper	5451	619	5420	5693	646	5890	5863	333	5420	4650	528	4160	5673	644	4020
21	Potatoes	4169	210	4820	5460	195	5900	5022	1004	4820	4357	319	4630	5497	468	5300
22	Rice	10092	394	11600	9919	7935	12600	10313	21817	12000	8015	313	7200	8658	338	8670
23	Sorghum	4396	3554	4680	4736	11076	3520	4334	3414	4680	3761	8775	3760	4784	5495	4720
24	Soybeans	7000	2746	6910	6286	2466	4900	6655	2611	6910	4395	1724	4870	6460	2534	4960
25	Spices	7393	448	----	7280	441	----	7936	16593	----	8138	8138	----	7459	452	----
26	Sugar beet	6983	204	6900	6772	198	5560	6853	348	6900	6493	118	6000	6820	199	5430
27	Sugar Cane	17581	250	18270	18918	294	14110	17261	432	18270	16731	238	15340	19807	282	16990
28	Sunflower	5660	210	----	4699	12571	4170	6246	4509	6360	4385	6611	4590	5529	205	5480
29	Sweet	6392	203	----	6272	558	----	6744	215	----	6878	219	----	6501	748	----
30	Tomatoes	6823	320	7020	5705	442	5150	7342	483	7020	5870	233	5840	6523	420	6170
31	Vegetables	4974	175	4630	4060	1491	3450	4991	566	4630	3984	341	3930	4075	569	3660
32	Watermelons	5511	309	6450	4767	212	4130	6076	701	6450	4486	403	4430	4583	246	4740
33	Wheat	5538	1192	5650	4686	2955	4020	6041	3914	5650	4207	3307	4090	4644	2934	4480

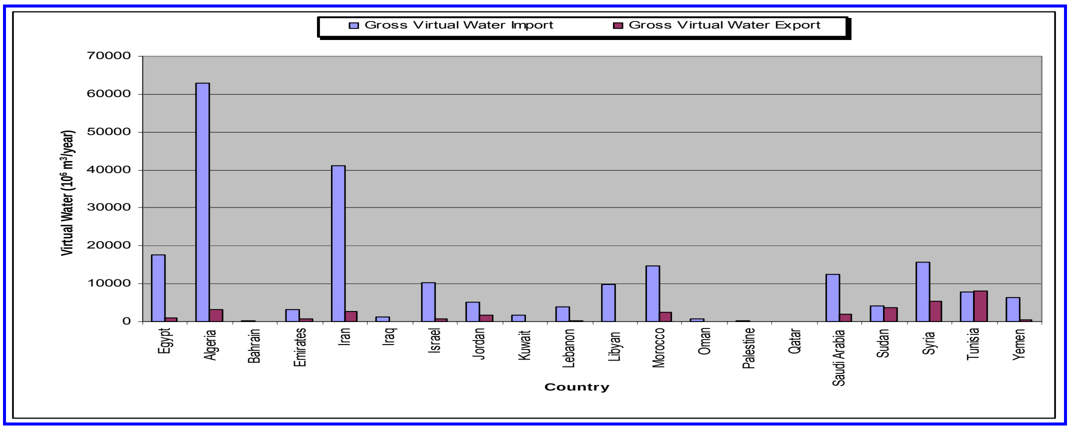

Figure (2). The Gross Virtual Water Trade Balance in MENA Region between 1990 and 1999

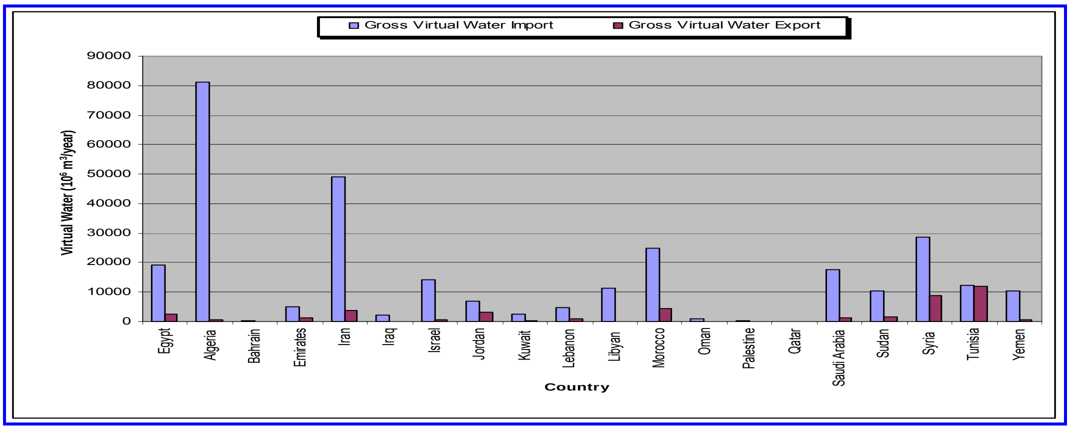

Figure (3). The Gross Virtual Water Trade Balance in MENA Region between 2000 and 2007

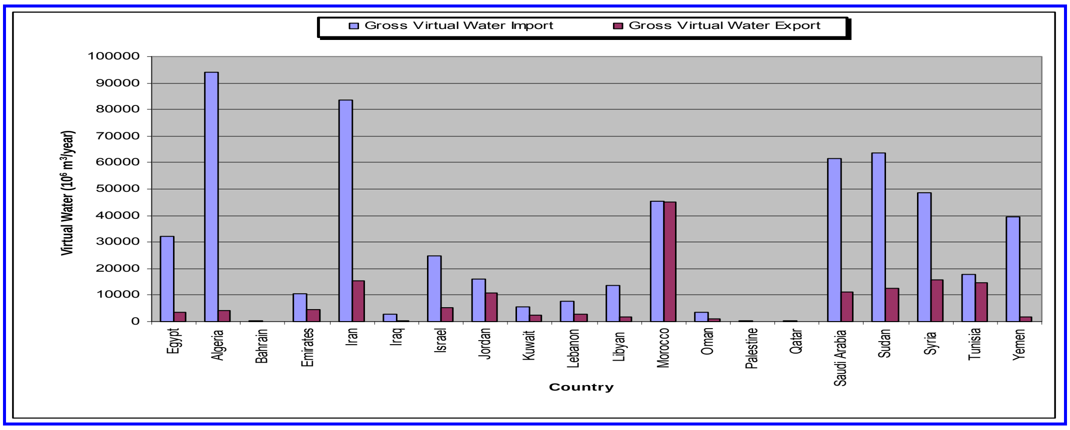

Figure (4). The Gross Virtual Water Trade Balance in MENA Region at 2025

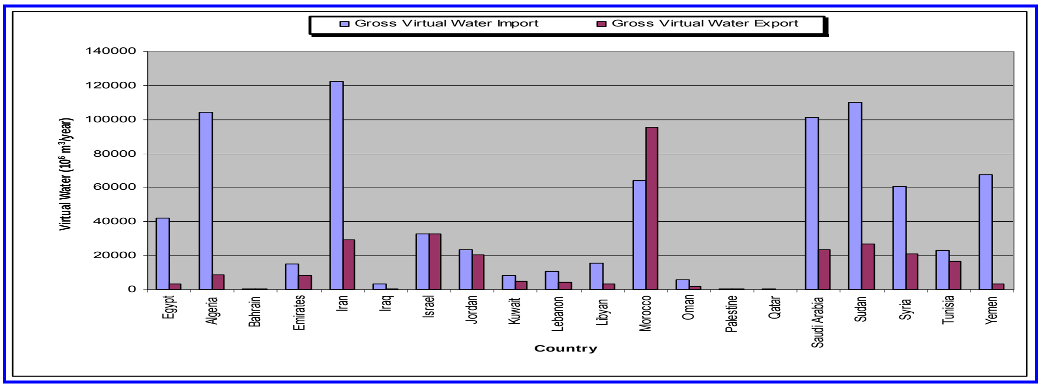

Figure (5). The Gross Virtual Water Trade Balance in MENA Region at 2050

Figures (2 to 5) show the gross virtual water trade balance in countries of the MENA region. From these Figures, it is obvious that the years which recorded less imported virtual water amounts are those following years of surplus agricultural crop production that resulted either from horizontal or from vertical increase in agricultural productivity.

It can also be concluded that continuous lack in agricultural production – which indicates continuous need of surplus virtual water amounts – results of increase of population against limited agricultural productivity.

Virtual Water Trade of Nations in Relation to National Water Needs and Availability

Using the definition previously presented, water footprint was calculated for each year using equations (9 to12). Indicators of countries of the MENA region which represent water scarcity, water self-sufficiency and water dependency were estimated.

Following, the appropriateness of applying the idea of virtual water in MENA region and determination of condition of all Countries from the water-scarcity border before and after application of the idea of virtual water are presented In Figures (6 to 9). Each figure shows for a parcel of years and the years 2025 and 2050, the water share per capita including virtual water compared to the water scarcity level. In Egypt, from 1990 to 1995, the water share per capita was above the water-scarcity border then, became below that level in the following years with exception of 2000 and 2001. By including the virtual water, the water share per capita will be above water scarcity border until 2025.

In Algeria, United Arab Emirates, Israel, Libyan Arab Jamahiriya and Palestine, the water amount per capita is under the water-scarcity border. By including the virtual water amounts then, the water amount per capita will be above the water scarcity border among all years of the study period.

In Bahrain and Qatar the water amount per capita is always under the water scarcity border.

In Iran, Iraq, Lebanon, Sudan and Syrian Arab Republic the water amount per capita is always above the water-scarcity border, even without including the virtual water amounts.

In Jordan, Kuwait and Yemen, the water amount per capita is below the water-scarcity border at all years in case that the virtual water amounts are not concerned. The border is oscillating around the water scarcity level when the virtual water amounts are included.

In Morocco and Tunisia, the water amount per capita is varying between water scarcity and water dependency regardless of adding the virtual water amounts.

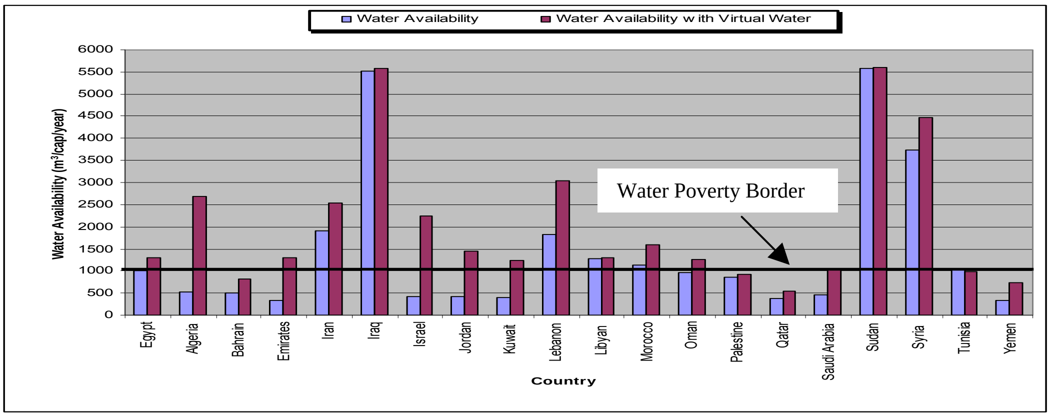

Figure (6). Virtual Water Trade in Relation to National Water Needs and Availability-between 1990 and 1999

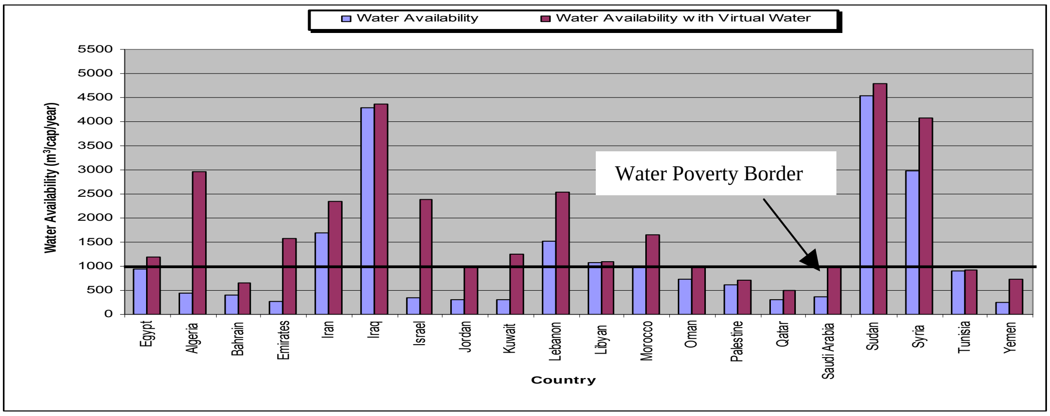

Figure (7). Virtual Water Trade in Relation to National Water Needs and Availability-between 2000 and 2007

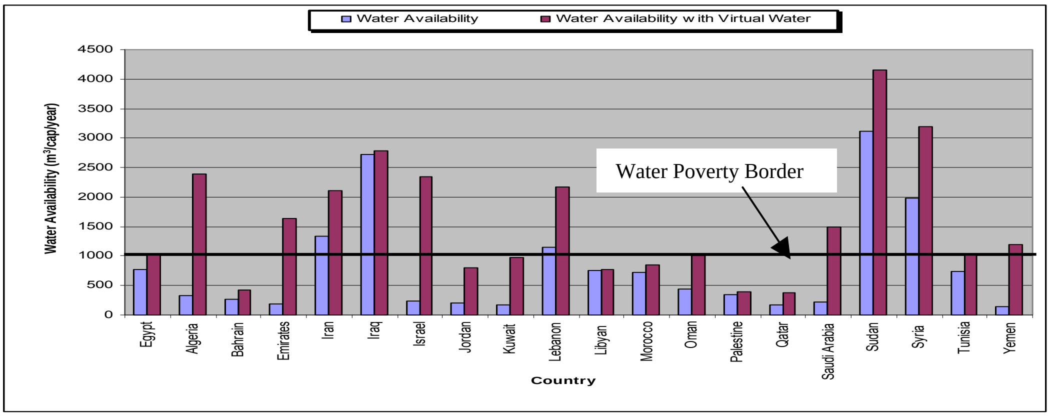

Figure (8). Virtual Water Trade in Relation to National Water Needs and Availability at 2025

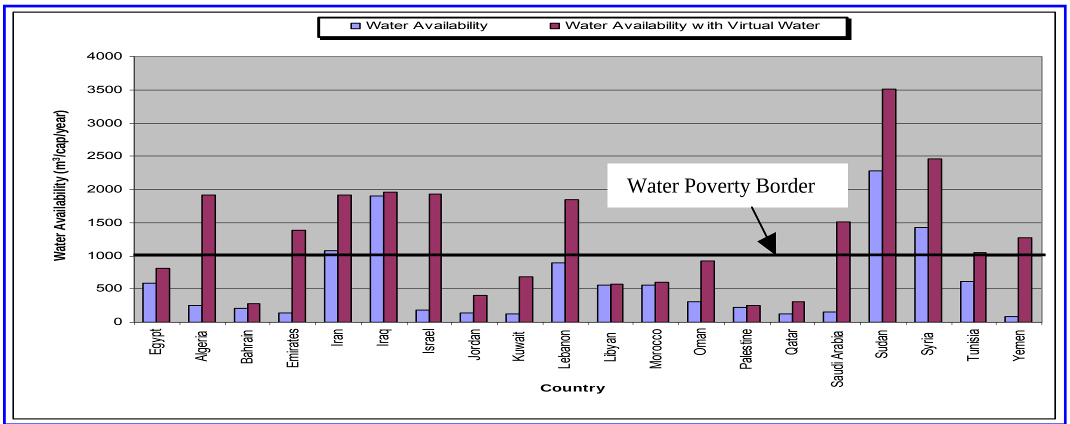

Figure (9). Virtual Water Trade in Relation to National Water Needs and Availability at 2050

Relation between Water Scarcity and Water Dependency

It could be expected that in general terms there is a positive relationship between water scarcity and water dependency, presuming that high water scarcity will lead decision maker to import virtual water and thus become a water dependent country. It is logical to suppose that the higher the scarcity within a country, the more dependency on water of other countries. To test this hypothesis, all countries of the world are plotted in a scarcity-dependency graph[8]. The results for the MENA region from 1990 to 2050 are shown in Figures (11 to 14). Actually, there seems to be no correlation as was supposed. The scarcity-dependency graph can be schematized into four areas or classes as presented in Figure (10) and Table (5)[8].

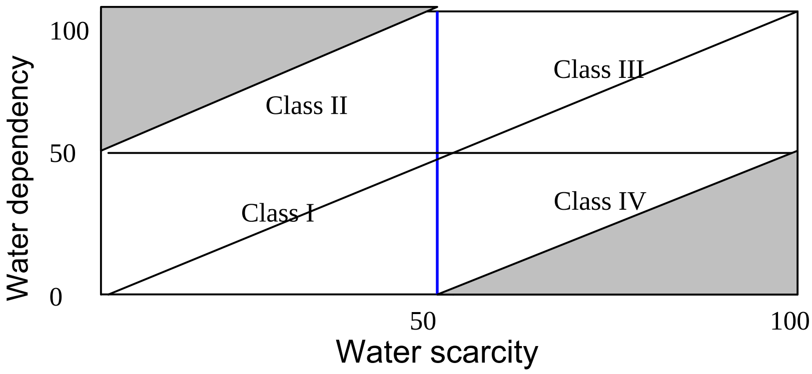

Figure (10). Four classes in the scarcity-dependency graph

The grey-shaded areas refer to combination of water scarcity and water dependency. This means that countries lying in these areas suffer of high water scarcity and at the same time have low water dependency. This actually means that some countries, although they are suffering from water scarcity, they do not depend on imported products to cover their water needs and they force themselves to use only their own products. The crops consumption in this case is linearly dependent on the national crop production.

Table (5). Position of MENA Countries in the Scarcity-Dependency Graph

Class I	**Class II**	**Class III**	**Class IV**
Iraq Tunisia	Algeria Lebanon Libyan Arab Jamahiriya Morocco Sudan Syrian Arab Republic	United Arab Emirates Israel Jordan Kuwait Oman Saudi Arabia Yemen	Bahrain Egypt Iran Palestine Qatar

Considering the definitions given in Section 4-1, a *water footprint* was estimated for each country of the MENA region. Then, using the definitions stated in Sections 2-4, 2-5 and 2-6, for the indicators of the national water scarcity, water self-sufficiency and water dependency were estimated for each country of the MENA region.

The basic data on national water withdrawal and water availability was taken from the FAO database. The water availability data in this case refers to the sum of internal and external water resources. Then, the data concerning net virtual water import figures for each country is estimated. The results are shown in figures 4 to 23 for the period 1990 to 2050.

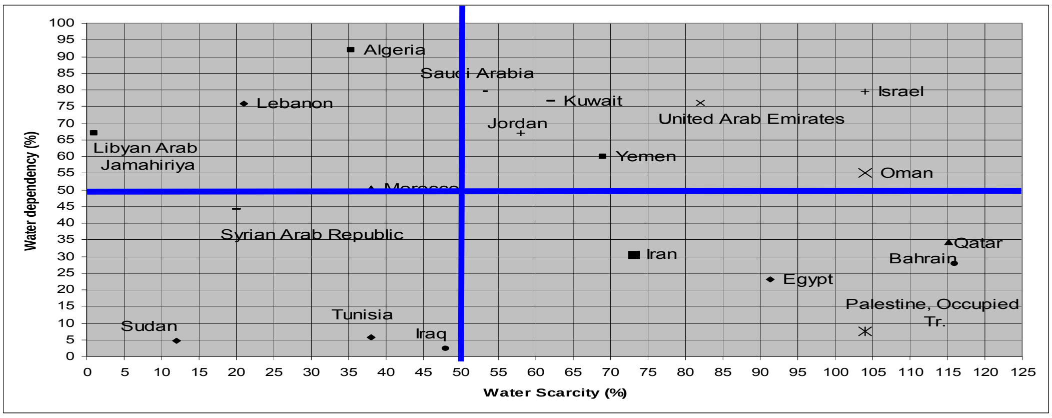

Figure (11). Water dependency versus Water Scarcity in MENA Region between1990 and 1999

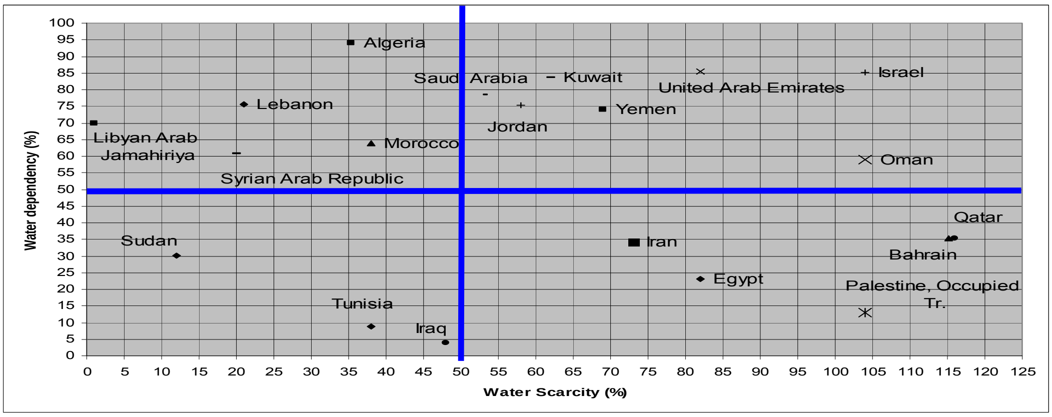

Figure (12). Water dependency versus Water Scarcity in MENA Region between2000 and 2007

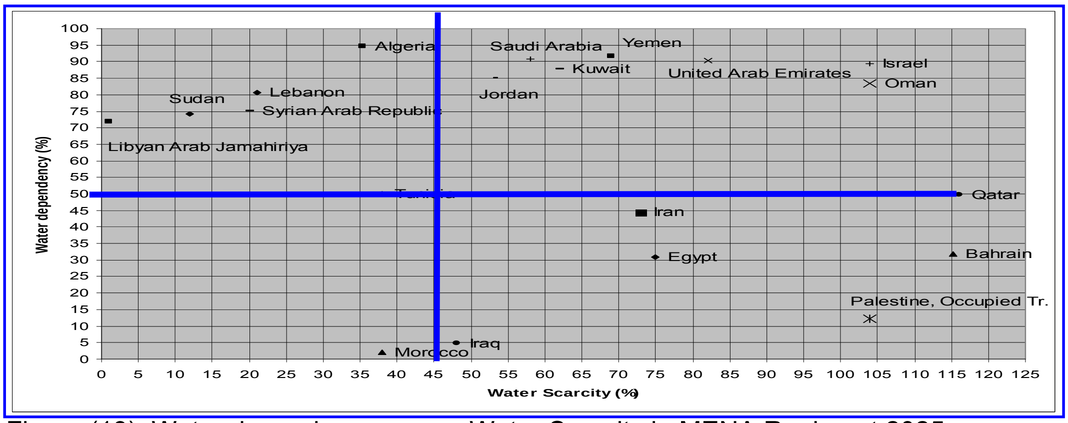

Figure (13). Water dependency versus Water Scarcity in MENA Region at 2025

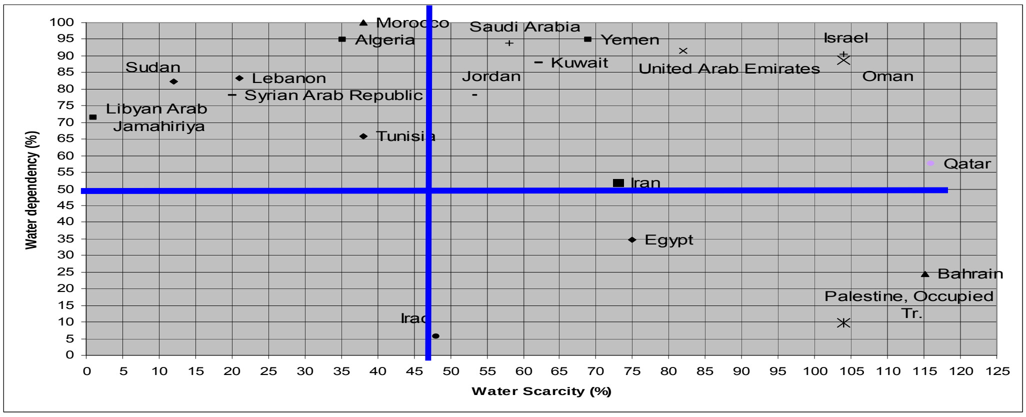

Figure (14). Water dependency versus Water Scarcity in MENA Region at 2050

Countries with relatively high water footprint per capita, roughly in the order of 2000m3/year per capita, are Algeria, Iran, Iraq, Lebanon, Libyan Arab Jamahiriya, Palestine, Sudan and Syrian Arab Republic. Countries with footprint above average; in the order of 1000m^3/year per capita; are for instance Egypt, United Arab Emirates, Israel, Jordan, Kuwait, Morocco and Oman. Countries with relatively low water footprint; below 1000m^3/year per capita; are Bahrain, Qatar, Saudi Arabia, Tunisia and Yemen.

The level of water self-sufficiency is classified; according to into 6 categories, which are 0-20%; 20-50%; 50-70%; 70-90%; 90-99%; and 100%. Table 6 shows the MENA countries classified according to their categories for the all years[8].

Table (6). MENA Countries Categorized into Different Levels of Water Self-Sufficiency

Level of Water Self-Sufficiency					
0-20%	20-50%	50-70%	70-90%	90-99%	100
Algeria United Arab Emirates Israel Jordan Kuwait	Lebanon Libyan Arab Jamahiriya Morocco Oman Saudi Arabia Syrian Arab Republic Yemen	Bahrain Iran	Egypt Palestine Qatar Sudan	Iraq Tunisia	

Conclusion

- Virtual water is a concept that is now being developed and refined for use by decision-makers at the strategic level in societies.
- Virtual water can be considered as an alternative source of water. Virtual water import can be used by national governments as a tool to release the pressure on their domestic water resources.
- Countries of the MENA region are not self-sufficient in producing food commodities to meet the national consumptive demand.
- Agricultural water policies regarding water use efficiency are highly needed to get optimal use of irrigation water for the aim of increasing crop productivity. Arab and MENA countries should plan to increase the exchange of agricultural crops. Each country has to focus on cultivated crops with lower water requirements and higher yield then to import

agricultural crops with higher water requirements and lower crop yield. This will help to improve the trade balance and create new job opportunities

- The Program implemented for this study, helps in identifying the actual water needs of different agricultural crops included in the study and therefore improves water distribution and consumption in the agricultural sector.
- The problem of greenhouse phenomenon is of high concern to all countries of the world because of it's negative impacts on all kinds of life on the Earth. It was found that the increase of temperature directly affects the crop water requirements which increases by 2.5% as a result of one degree increase in temperature and decreases by 0.97% as a result of 1% increase in humidity.
- The aim of the study of virtual water is providing food security. A market of virtual water within Arab and MENA countries will be highly appreciated.
- Import of virtual water from foreign countries is very risky and if the virtual water trade is not possible within countries of the same region, then it would be better to choose to be water independent rather than self sufficient.

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