Implications of Virtual Water Concept on Water Demand Management

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Abstract

The virtual water concept has been introduced to have a demand and consumer oriented indicators. Therefore, it would be imperative to implicate this concept on water demand management. The water demand management can save the national water through reallocating agriculture land-use patterns as freshwater systems are influenced by changing land-use patterns. This can be achieved if water intensive commodity is reallocated from an area where it is produced with low water productivity (resulting in products with high virtual water) to an area with higher water productivity. In Egypt, there are many different varieties of the same crop that has been cultivated in different regions of the country. This leads to production of the same crop with different virtual water content. Therefore, the main objective of this study is to measure the virtual water content of the main strategic crops in Egypt including Wheat, Rice, and Cotton with their different varieties at different regions to reallocate them appropriately within the crop pattern of Egypt. The data was prevailed that there are about 25 varieties of wheat. The most appropriate region for Wheat cultivation is Middle Egypt with crop variety of Gemmeza 9 with virtual water content equal to 572.45 m^3/ton. On the other hand, it was concluded that for Rice crop there are about 12 varieties. The most appropriate region for Rice cultivation is Lower Egypt with crop variety of Sakha 101 with virtual water content equal to 1319 m^3/ton. Finally, for Cotton crop there are about 10 varieties. It was also found that the most appropriate region for Cotton cultivation is Lower Egypt with crop variety of Giza 88 with virtual water content equal to 2261.85 m^3/ton.
Keywords: Virtual Water, Water Resources, Water Demands Management, and Crop Varieties

Introduction

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. The adjective 'virtual' refers to the fact that most of the water used to produce a product is, in the end, not contained in the product. The real water content of products is generally negligible if compared to the virtual water content. The term virtual water was introduced by Tony Allan in the early 1990s (Allan, 1993; 1994). It is defined as the volume of water that was in reality used to produce a commodity or service.

In more precise quantitative definition of the virtual water, principally two different approaches have been proposed and applied. In the first approach, the virtual water content of a product is defined as the volume of water that used to produce the product, measured at the place where the product was actually produced (production site specific definition). In the second approach, it can 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) (Hoekstra, 2003). In our study as we study the virtual water in the country base not as a national trade so we use the production site specific definition, which will depend on the production conditions, including place and type of production.

The practical use of the virtual water concept lies in the fact that the virtual water content of a product tells something about the environmental impact of the product consumption. Knowing the virtual water content of products creates awareness of the water volumes needed to produce the various goods, thus providing an idea of which goods impact most on the water system and where water savings could be achieved (Allan, 1997; 2002).

Public policies regarding economy and the prices of inputs and outputs influence farm-level decisions regarding crop production and marketing. National efforts to implement a virtual water strategy will have a greater likelihood of success if the impacts of public policies on farm-level decisions are considered when designing policies to encourage changes in farm-level management of land and water resources (Hoekstra, 2003).

It is clear that the virtual water concept has been introduced to have a demand and consumer oriented indicators. Therefore, it would be imperative to implicate this concept on water demand management on farm-level. The water demand management can save the national water through reallocating agriculture land-use patterns. This can be achieved if water intensive commodity is reallocated from an area where it is produced with low water productivity resulting in products with high virtual water to an area with higher water productivity resulting in products with low virtual water.

In arid and semi arid regions like in Egypt where a limited water supply constraints economic activity, national governments can enhance economic growth and development by adopting policies that enable water demands management in addition to water supply management to reflect water scarcity.

Egypt derives most of its water supply from the Nile River. The annual supply of water from the Nile is determined by 55.5 billion cubic meters. Nearly all agricultural production requires irrigation, given that the mean annual rainfall ranges from zero mm in the desert to 24 mm in Cairo and 200 mm in the northern coastal region and the mean annual rainfall in the Nile Delta is 150 mm (FAO, 1997).

The demand for water in agriculture, industry, and municipal uses has been increasing in Egypt due to population growth and increases in aggregate income. At present the total volume of water available each year is sufficient to satisfy aggregate demand. However, periodic droughts, regional shortages, localized capacity constraints, and inequitable sharing of water along canals reduce irrigation opportunities in some regions of the country (UNDP, 2002). Figure 1 indicates that Egypt is one of the countries that suffer of physical water scarcity due to its limited water resources and increasing population. To face this problem, Egypt would import more than 10% of its cereal consumption in 2025 (Chapagain et al, 2005).

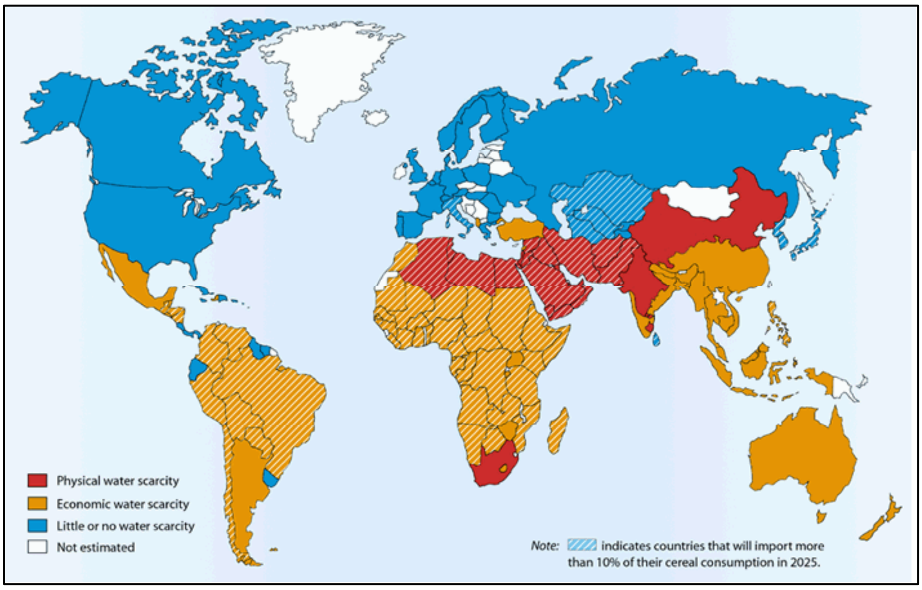

Figure 1: World Water Scarcity Map, year 2005 (Source: International Water Management Institute)

In Egypt, food security at the national level has been achieved and maintained by increasing the production of crops within the country. Domestic production of wheat has been increasing somewhat sharply since the middle 1980s. The faster rates of increase observed in recent years are due to policy changes that have allowed Egyptian farmers greater freedom in choosing crops with their different varieties and in selling their products in competitive markets (World Bank, 2001). Moreover, domestic production of rice in Egypt also increased sharply after 1988 for the same reason. However, the domestic production of cotton generally has been declining since 1980 (Hoekstra, 2003).

Policies that encourage farmers to acknowledge the scarcity value of Egypt's limited water supply will gain importance in future to ensure that water is used efficiently in domestic production and to motivate production of high valued crops with high water productivity and consequently low virtual water content. In Egypt, there are many different varieties of the same crop that has been cultivated in different regions of the country. This causes to produce the same crop with different virtual water content related to the crop variety and the region of cultivation. Therefore, it would be more effective for water demand management if the virtual water concept is implicated for production of the main strategic crops in Egypt including Wheat, Rice, and Cotton with their different varieties at different regions to reallocate them properly within the crop pattern of Egypt. This application of the concept at the national may generate substantial benefits for Egypt, in addition to water savings.

1. Assessing Virtual Water Content of Crops

Assessing virtual water content of a crop is not an easy task, because there are many factors influencing the amount of water used in production process. For instance producing 1 kg of grain in an arid country can require 2 or 3 times more water than producing the same amount in a humid country. So the following factors should at least be considered and preferably provided together with the estimates (Hoekstra, 2003):

- The place and period of production,
- The point of measurement (at the point of water withdrawal or at the field level), and
- The production method and associated efficiency of water use.

The Virtual Water Content [VWC] of a crop *c* in a country (m^3/ton) is calculated as the ratio of total water used for the production [CWU] to the total volume of production by that country (Chapagain and Hoekstra, 2004).

$$VWC_c = \frac{CWR_c}{P_c}$$

Where: CWR is the crop water requirement measured at field level (m^3/ha), and P_c the total volume of crop c produced per hectare in the country (ton/ha).

Crop water requirement is defined as the total water needed for evapotranspiration from planting to harvest for a given crop in a specific region, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Under standard conditions when a crop grows without any shortage of water, the crop evapotranspiration is equal to the CWR of a crop (Allen et al, 1998). The crop water requirement is calculated by accumulation of data on daily crop evapotranspiration ET_c (mm/day) over the complete growing period as following:

$$CWR_c = 10 \times \sum_{d=1}^{lp} ET_{c,d}$$

Where the factor 10 is meant to convert mm into m^3/ha and where the summation is done over the period from day 1 to the final day at the end of the growing period (l_p stands for length of growing period in days). The crop evapotranspiration per day follows from multiplying the reference crop evapotranspiration ET_0 with the crop coefficient K_c as following:

$$ET_c = K_c \times ET_0$$

The reference crop evapotranspiration is rate from a reference surface. The reference is a hypothetical surface with extensive green grass cover with specific characteristics. The only factors affecting ET_0 are climatic parameters. ET_0 expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The actual crop evapotranspiration differs distinctly from the reference evapotranspiration, as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). The major factors determining K_c are crop variety, climate and crop growth stage. More arid climates and conditions of greater wind speed will have higher values for K_c. More humid climates and conditions of lower wind speed will have lower values for K_c.

2. Implication of Virtual Water Content

Table 1 shows the crop water requirements (CWR) for the main strategic crops in Egypt measured in m^3/feddan (feddan = 0.42 hectare) according to the water duty tables of Ministry of Water Resources and Irrigation (MWRI, 2003). These crops include Wheat, Rice, and Cotton at different regions in Egypt including Upper Egypt, Middle Egypt, Lower Egypt and out valley.

Table 1: Crop Water Requirements (CWR m^3/feddan)

Crop Type	CWR (m^3/feddan) (MWRI)			
	Upper Egypt	Middle Egypt	Lower Egypt	Out Valley
Wheat	2008	1621	1464	1606
Rice	------	7085	5521	5548
Cotton	3665	3214	2863	2957

3. Virtual Water Content of Wheat

It was found that there are about 25 different varieties of wheat that are cultivated in the different regions of Egypt. Using the VWC equation, the virtual water content was calculated for the different varieties at the different regions as shown in Table 2. The productivity used in the equation was taking as an average of productivities for the period of 2000 to 2003 (MALR, 2001; 2002; 2003; 2004).

Table 2: Wheat Crop Varieties Productivity and Virtual Water Content (VWC)

Regions	Upper Egypt		Middle Egypt		Lower Egypt		Out Valley	
Crop varieties	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)
Giza 61	-----	-----	-----	-----	1.74	842.54	-----	-----
Giza 93	-----	-----	-----	-----	2.10	697.14	1.95	822.58
Giza 155	1.76	1139.49	1.20	1350.83	1.46	1001.11	1.38	1163.77
Giza 157	-----	-----	-----	-----	1.95	752.16	-----	-----
Giza 160	-----	-----	-----	-----	-----	-----	1.61	995.04
Giza 163	1.58	1270.28	-----	-----	2.04	717.65	-----	-----
Giza 164	2.01	997.44	2.14	756.20	2.21	663.40	0.73	2206.04
Giza 165	1.94	1034.75	-----	-----	-----	-----	-----	-----
Giza 167	1.90	1057.94	2.43	667.08	1.74	843.32	-----	-----
Giza 168	2.01	998.16	2.36	685.83	1.86	785.57	1.97	816.31
Sakha 8	2.32	864.57	1.80	898.79	1.95	749.13	1.87	858.27
Sakha 61	-----	-----	2.23	728.21	1.92	763.24	1.83	877.21
Sakha 63	-----	-----	-----	-----	2.04	717.65	-----	-----
Sakha 69	2.02	993.38	2.07	781.61	2.18	672.14	1.85	869.05
Sakha 93	-----	-----	2.44	664.75	2.04	718.20	1.99	807.20
Balady	1.77	1136.03	2.12	764.42	1.59	919.59	1.20	1342.81
Suhag 1	2.46	817.46	-----	-----	-----	-----	-----	-----
Suhag 2	2.67	753.41	-----	-----	-----	-----	2.02	793.79
Beni Suef 1	2.26	888.11	2.24	724.17	-----	-----	2.11	759.34
Beni Suef 3	-----	-----	2.58	629.47	-----	-----	-----	-----
Gemmeza 1	-----	-----	-----	-----	1.65	887.92	-----	-----
Gemmeza 5	-----	-----	-----	-----	1.71	856.96	1.88	852.44
Gemmeza 7	-----	-----	2.46	659.59	2.15	681.95	1.88	853.71
Gemmeza 9	-----	-----	2.83	572.45	2.23	655.28	1.96	820.22

The data revealed that for Lower Egypt region the most common cultivated variety of Wheat is Sakha 93 which covers about 30% of the total cultivated area of wheat in this region. It was also found that the most economic variety from the virtual water content (VWC) concept in this region is Gemmeza 9 with VWC of 655.28 m^3/ton where the VWC of Sakha 93 is 718.19 m^3/ton. So it is recommended to replace Sakha 93 and the other varieties with Gemmeza 9 type. On the other hand, for Middle Egypt region it was found that the most common cultivated variety of wheat is Beni Suef 1 which covers about 35% of the total cultivated area of wheat in this region. It was also found that for this region the most economic variety from the virtual water concept is Gemmeza 9 with VWC of 572.45 m^3/ton where the VWC of Beni Suef 1 variety is 724.17 m^3/ton. So it is also recommended to replace Beni Suef 1 and the other varieties with Gemmeza 9 type. In Upper Egypt region the most common cultivated variety of wheat is Giza 164 which covers about 62% of the total cultivated area of wheat. For this region, the most economic variety from the virtual water concept is Suhag 2 with virtual water content of 753.41 m^3/ton where Giza 164 variety has a virtual water content of 997.44 m^3/ton. Finally for the Out Valley region it was found that the most common variety is also Giza 164 which covers about 31% of the total cultivated area of wheat in this region. The most economic variety from virtual water concept is Beni Suef 1 with VWC of 759.34 m^3/ton where Giza 164 variety has a virtual water content of 2206 m^3/ton.

However, it could be concluded that the most proper region for Wheat cultivation in Egypt is Middle Egypt with crop variety of Gemmeza 9 (Figure 2). For the other three regions Lower Egypt, Upper Egypt, and Out Valley it is found that the most proper varieties are Gemmeza 9, Suhag 2 and Beni Suef 1 respectively. So it is recommended to replace the other varieties of wheat with these recommended varieties for each region to save water resources and activate water demands management.

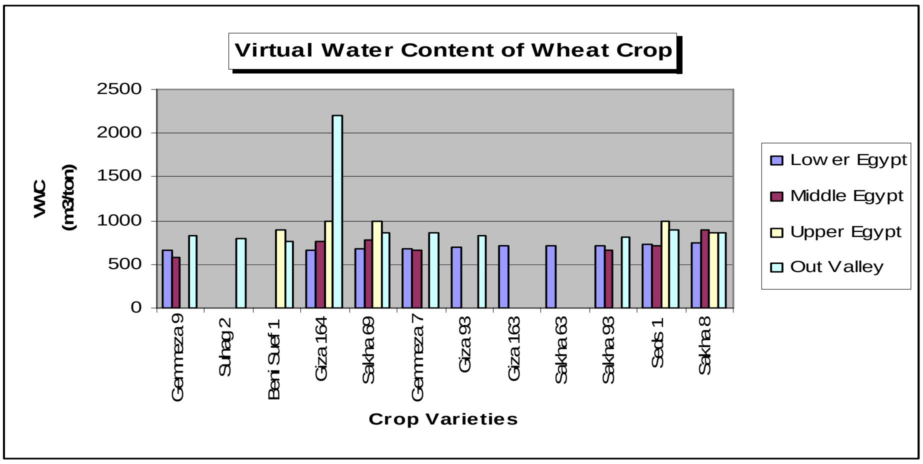

Figure 2: Wheat Virtual Water Content for Different Regions

3.1. Virtual Water Content of Rice

For Rice crop it was found that there are about 12 different varieties of rice that are cultivated in the different regions of Egypt. The rice crop is not cultivated in Upper Egypt region so there is no data for this region. Using the VWC equation, the virtual water content was calculated for the different varieties at the different regions as shown in Table 3. The productivity used in the equation was taking as an average of productivities for the period of 2000 to 2003 (MALR, 2001; 2002; 2003; 2004).

Table 3: Rice Crop Varieties Productivity and Virtual Water Content (VWC)

Regions	Lower Egypt		Middle Egypt		Out Valley	
Crop varieties	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)
Giza 171	3.48	1587.25	3.35	2113.03	1.96	2825.81
Giza 172	3.24	1705.59	------	------	------	------
Giza 173	3.26	1693.04	------	------	------	------
Giza 176	3.52	1567.80	3.63	1952.60	3.42	1622.46
Giza 177	3.79	1458.27	3.88	1826.74	3.50	1585.14
Giza 178	4.09	1351.09	3.97	1785.08	3.85	1441.04
Sakha 101	4.18	1319.66	4.09	1733.69	3.46	1601.62
Sakha 102	4.04	1366.16	3.98	1781.94	3.41	1625.07
Sakha 103	3.90	1416.73	3.85	1839.07	------	------
Sakha 104	4.00	1381.17	3.98	1781.05	------	------
Hybrid 1	4.11	1342.98	3.35	2113.03	------	------
Giza 159	------	------	------	------	3.8	1460.00

The data in table 3 shows that for Lower Egypt the Sakha 101 has the minimum virtual water content (1319.66 m^3/ton). So it is recommended to replace the other varieties with this variety of rice. On the other hand, for Middle Egypt region it was found that the most economic variety is also Sakha 101 with VWC of 1733.69 m^3/ton. Finally for the Out Valley region, Giza 178 was found to be the most suitable variety from the virtual water concept with VWC of 1441.04 m^3/ton. Therefore, it could be concluded that the most proper region for Rice cultivation in Egypt is Lower Egypt with crop variety of Sakha 101 (Figure 3). For the other regions Middle Egypt and Out Valley it is found that the most proper varieties are also Sakha 101 and Giza 178 respectively. So it is recommended to replace the other varieties of rice with these recommended varieties for each region to save water resources and activate water demands management.

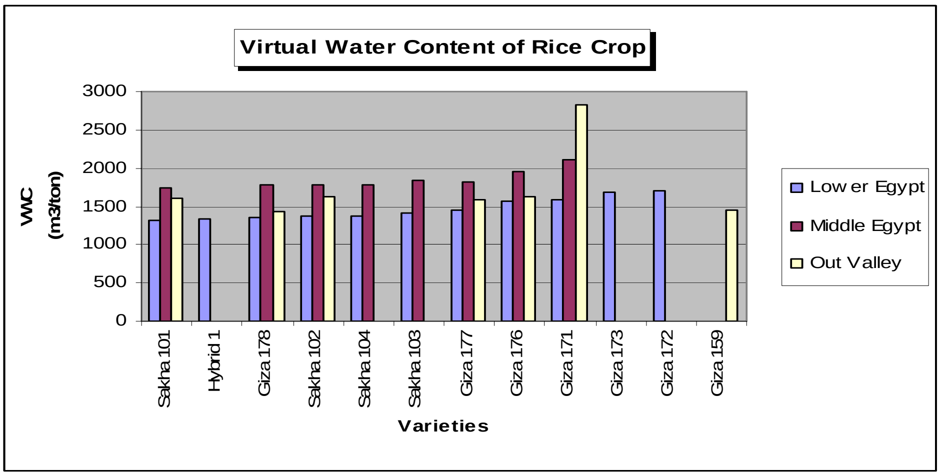

Figure 3: Rice Virtual Water Content for Different Regions

3.2. Virtual Water Content of Cotton

For Cotton crop it was found that there are about 10 different varieties of cotton that are cultivated in the different regions of Egypt. Using the VWC equation, the virtual water content was calculated for the different varieties at the different regions as shown in Table 4. The productivity used in the equation was taking as an average of productivities for the period of 2000 to 2003 (MALR, 2001; 2002; 2003; 2004).

Table 4: Cotton Crop Varieties Productivity and Virtual Water Content (VWC)

Regions	Lower Egypt		Middle Egypt		Upper Egypt	
Crop varieties	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)	Prod. (ton/fed.)	VWC (m^3/ton)
Giza 45	0.67	4287.21	------	------	------	------
Giza 70	1.04	2747.27	------	------	------	------
Giza 88	1.27	2261.86	------	------	------	------
Giza 85	1.04	2762.58	------	------	------	------
Giza 86	1.23	2323.53	------	------	1.10	3329.02
Giza 89	1.02	2811.00	------	------	1.24	2966.83
Giza 80	------	------	0.96	3347.13	------	------
Giza 83	------	------	1.00	3218.67	------	------
Giza 90	------	------	0.97	3304.67	------	------
Giza 87	0.99	2894.55	------	------	------	------

The data in table 4 shows that for Lower Egypt the most economic variety from the virtual water content (VWC) concept is Giza 88 with VWC of 2261.86 m^3/ton. So it is recommended to replace the other varieties with this variety of cotton. On the other hand, for Middle Egypt region it was found that the most economic variety from the virtual water concept is Giza 83 with VWC of 3218.67 m^3/ton. In Upper Egypt region, the most economic variety from the virtual water concept is Giza 89 with virtual water content of 2966.83 m^3/ton. Finally for the Out Valley region it was found that the only cultivated variety of cotton is Giza 83 with VWC of 5935.07 m^3/ton. Therefore, it could be concluded that the most proper region for Cotton cultivation is Lower Egypt also with crop variety of Giza 88 (Figure 4).

For the other regions Middle Egypt and Upper Egypt, it is found that the most proper varieties are Giza 83 and Giza 89 respectively. So it is recommended to replace the other varieties of cotton with these recommended varieties for each region to save water resources and activate water demands management. In spite of the high virtual water content of the cotton it could be recommended to cultivate it with the recommended variety at the appropriate region for exporting purpose and to improve the national income of the country.

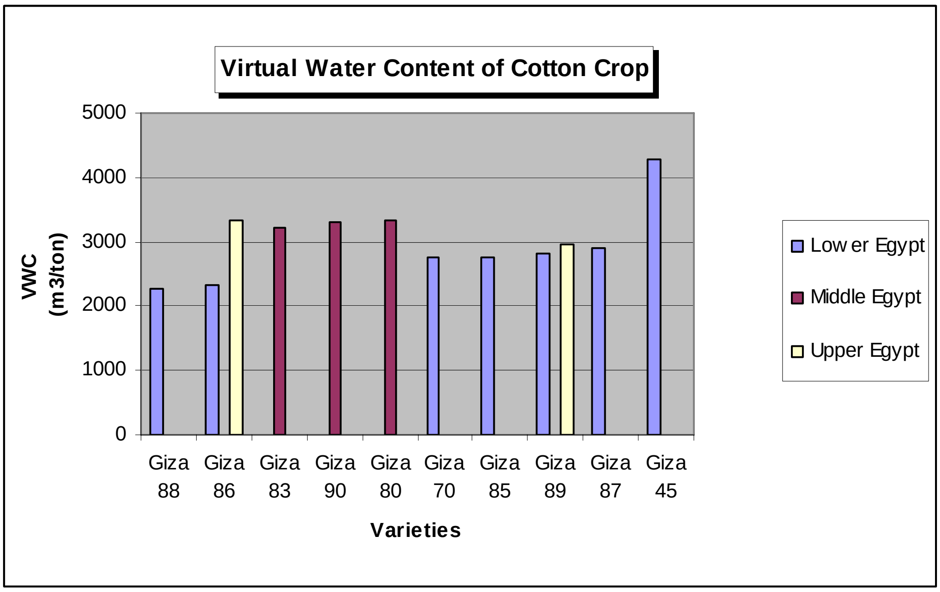

Figure 4: Cotton Virtual Water Content for Different Regions

Conclusions

The virtual water concept is a water demand management concept. However, there are many factors influencing the amount of water used in a production process of a crop. So at least the two factors of production location and crop variety should be considered and preferably provided together with the estimates to reallocate the water – intensive commodity from an area where it is produced with high virtual water content to an area with low virtual water content. This process of reallocating agriculture land-use patterns can save the national water.

It was observed that in Egypt, there are many different varieties of the same crop that has been cultivated in the different regions of the country. This causes to produce the same crop with different virtual water content related to the crop variety and the region of cultivation. The data was prevailed that:

- For Wheat there are about 25 varieties with average virtual water content of 864 m^3/ton. The most proper region for Wheat cultivation was found to be Middle Egypt with crop variety of Gemmeza 9 with virtual water content of 572.45 m^3/ton. For the other three regions Lower Egypt, Upper Egypt, and Out Valley it was found that the most proper varieties are Gemmeza 9 with virtual water content of 655.28 m^3/ton, Suhag 2 with virtual water content of 753.4 m^3/ton, and Beni Suef 1 with virtual water content of 759.34 m^3/ton respectively.
- For Rice crop there are about 12 varieties with average virtual water content of 1523 m^3/ton. It was found that the most proper region for Rice cultivation is Lower Egypt with crop variety of Sakha 101 with virtual water content of 1319 m^3/ton.
- Finally, for Cotton crop there are about 10 varieties with average virtual water content of 2992 m^3/ton. It was also found that the most proper region for Cotton cultivation is Lower Egypt with crop variety of Giza 88 with average virtual water content of 2261.85 m^3/ton.

It could be concluded that to deal 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. The three levels are local water use efficiency, water allocation efficiency and global water use efficiency. The global water use efficiency could be improved through international virtual water trade (import and export) between nations and countries. This could also achieve water security in water-scarce regions of the world.

It is a fact that some regions of the world are water scarce and other regions are water abundant. It is also a fact that in some regions there is a low demand for water and in other regions a high demand. A water-scarce country can import products that require a lot of water in their production and export products that require less water. This is called virtual water trade as opposed to real water trade, which is generally too expensive due to the large distances and associated costs.

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تطبيق مفهوم الماء الفعلي في إدارة الاحتياجات المائـــية

جيهان عبد الحكيم سلام و جمال عبد الناصر كامل

معهد بحوث الصرف – المركز القومي لبحوث المياه – القناطر الخيرية – مصر

تتأثر أنظمة المياه العذبة في العالم تبعا لتغير خريطة استخدامات الأراضي. تظهر إحصائيات اســتخدام المياه التقليدية كميات المياه المتاحة لكل قطاع مثل قطاعات الاستهلاك المترلي أو الزراعي أو الصناعي ولـــذلك فإن الطرق الإحصائية تتعامل دائما مع كميات المياه المتاحة وإمكانية الإنتاج المترتب عليها ولقد تم حديثا إدراج مفهوم محتوى الماء الفعلي للمنتج لإمكانية أخذ مؤشرات الاحتياجات الفعلية والاستهلاك في الاعتبار. ولـــذلك فإنه من الضروري تطبيق هذا المفهوم في إدارة الاحتياجات المائية حيث يمكن توفير المياه على المستوى القـــومي وذلك من خلال إعادة توزيع الخريطة المحصولية تبعا لمحتوى الماء الفعلي للنبات. ويمكن تحقيق ذلك بنقل زراعـــة المحاصيل ذات الاحتياجات المائية العالية من المناطق ذات الإنتاج المنخفض إلى المنـــاطق ذات الإنتـــاج العـــالي للوصول إلى أقل محتوى مائي فعلي. يوجد في مصر عدة أنواع من المحاصيل ذات أصناف متعددة يتم زراعتها في الأقاليم المختلفة مما يؤدى إلى إنتاج نفس المحصول بمحتوى مائي فعلى مختلف. ولذلك فإن الهدف الأساسي مـــن هذا البحث هو قياس المحتوى المائي الفعلي لأهم المحاصيل الإستراتيجية الرئيسية في مصر وهـــى القمـــح والأرز والقطن بأصنافها المختلفة في الأقاليم المتعددة وذلك لإعادة توزيعها بطريقة صحيحة. ولقد أثبتت النتـــائج أنـــه يوجد حوالي 25 صنف مختلف من القمح ويعتبر إقليم مصر الوسطى هو أنسب المناطق لزراعته وأنسب صـــنف يصل محتوى الماء الفعلي له إلى حوالي 572.45م^3/طن. وبالنسبة إلى الأرز يوجد له حوالي 10 أصناف ويعتـــبر إقليم مصر العليا هو أنسب الأقاليم لزراعته وأنسب صنف ذو محتوى مائي فعلى يصل إلى 1319م^3/طن. ومن ناحية أخرى أيضاً يوجد لمحصول القطن عشرة أصناف ويعتبر إقليم مصر العليا هو أنسب إقليم وأنسب صـــنف يصل محتواه الفعلي للمياه إلى 2261.85م^3/طن.