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VIRTUAL WATER AND WATER PRODUCTIVITY AS A STRATEGIC PLAN FOR WATER GOVERNANCE IN THE ESCWA REGION.

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ABSTRACT

Producing food and fiber requires water. With the growing world population, demand on freshwater is rising. Meanwhile, a major issue is still ignored, this issue being whether there will be enough water in the ESCWA region for the next generations. Water supply in the region is unequally distributed in space and time, both at national and international level within each country. Some of ESCWA sub-regions have among the lowest per capita amount of water supply in the world. The intensive extraction and use of water for domestic, agricultural and industrial purposes, without proper provisions for the protection of the resource, has led to serious water pollution of surface and ground water bodies. Agriculture consumes 70-80% of water in the ESCWA region. Water deficit in water short countries arises from the lack of water governance among water users, governments and institutions to adapt to the resource scarcity and take measures to find solutions and implement alternatives.

One way to overcome this scarce water condition, in water-short countries, is to import water in food commodities. Water imported in this way is called "virtual water". The general objective of this paper is to determine, among the most demanded crops grown in a certain project and/or country, the crops having the highest water productivity and the optimal cropping pattern to be followed. This can be achieved by an optimization model that will yield the least water volume needed and generate the highest revenue. This model will aim at deciding on which crops to grow and on which crops to import. Knowing the national virtual water trade balance is essential for developing a rational national policy with respect to virtual water trade, it will also help the water governance decision makers finding a way for future strategic planning based on water availability and water productivity.

Keywords: Virtual water, water productivity, modeling, crop water use, water governance.

I. INTRODUCTION

Due to water resources scarcity, water-saving in agriculture should be emphasized since it consumes more than 70% of the water resources in the ESCWA region. Water management and saving in the other two domains (domestic and industrial) should not be neglected, but the net saving is less than that in agriculture. The ongoing approach for water saving recommended by the international organizations and governmental agencies is to adopt so-called 'water-saving' irrigation methods such as localized irrigation versus gravitational irrigation. This approach does not justify this shift from traditional surface irrigation to localized irrigation as found by Vidal et al (2001); who concluded that drip irrigation is not a miracle technology, since excellent as well as poor results were obtained and adoption of drip irrigation requires the ability of farmers to finance the purchase. Moreover the farmers should be trained to understand the soil-plant- water- climatic relationship in order to appropriately manage and operate this new adopted technology. Another approach was introduced by Seckler (1996), who used the expression 'more crop per drop' to mean that increasing crop water productivity was more relevant than just saving water. In most cases localized irrigation has shown to increase crop water productivity, by increasing yields and decreasing the amount of water used (Cetin and Bilgel (2002), Fedaku and Teshome (1998), Nimah (2005) and Nimah et al (2003)). This new concept "more crop per drop' is linked to more integrated concepts that led to the new approach of combining "Virtual Water and Water Productivity".

The water used in the production process of an agricultural commodity is called 'virtual water' contained in the product. (Hoekstra et al 2002). The concept could be expanded to include the water needed to produce non-agricultural commodities. Virtual water is the water embodied in a product, not in real sense, but in virtual sense. Virtual water has also been called 'embedded water' this term did not capture the attention of the water managing community. (Allan 1993; 1994). The term "virtual water" was coined at a seminar at the School of Oriental and African Studies (SOAS) in about 1993. Allan 2003 cited the following example:

"It requires about 1,000 cubic meters of water to produce a ton of grain. If the ton of grain is conveyed to a political economy short of freshwater and/or soil water, then that economy is spared the economic, and more importantly, the political stress of mobilizing about 1,000 cubic meters of water. The author observed that by the millennium the ESCWA region was importing at least 50 million tons of grain annually. This tonnage required 50 cubic kilometers (billion cubic meters) of water to produce it, which is the volume of freshwater that flows into Egypt each year down the Nile."

Net import of water in a water scarce nation can relieve the pressure on the nation's own water resources. Virtual water can be seen as an alternative source of water. Using this additional source can be an instrument to achieve regional water security.

The other segment of this paper is water productivity. (Malano and Burton, 2001 and Molden et al., 1998) defined the gross productivity as the value of crop productivity expressed in monetary unit (MU) per unit surface (hectare, ha) or per unit of water consumed (m^3).

The net productivity or gross margin is the value of crop productivity (MU / ha^{-1} or MU/ m^3) minus all applicable charges consisting of equipment price (considered per hectare and per year of life length), water price (usually known per cubic meter or per hectare), and other production charges. In this article water productivity is defined as monetary units per unit of water (MU/ m^3).

Virtual water and water productivity combine agronomic and economic concepts, with emphasis on water as a key factor of production. The agronomic component involves the amount of water used to produce crops, while the economic component involves the opportunity cost of water, which is its value in other uses that may include production of alternative crops or use in municipal, industrial and or recreational activities. The virtual water perspective is consistent with the concept of integrated water management, in which many aspects of water supply and demand are considered when determining the optimal use of limited water resources (Bouwer, 2000). This concept might also reduce the financial burden in developing a new infrastructure on water distribution.

The general objective of this study is to combine the virtual water and water productivity concepts as a solution to expand the use of the scarce available water resource, in a country, by improving its economical return from agriculture.

II. METHODOLOGY

In order to meet the objective defined before, two scenarios are considered. The first one: not allowing import of crops from foreign countries; and the second, one allowing the import.

A. SCENARIO ONE:

In this scenario, the status quo is: no import is allowed in the region under study. It is assumed that the crops needed, will be grown in the country without importing any of the national requirements.

The most demanded crops in the region under study will be selected. This will be done by adding the amount of locally produced crops, and the imported ones. After adding them, they will be arranged in descending order from the highly demanded to the lowest demanded. Then, the total water amount needed for their production will be estimated on the following basis:

1. Calculation of specific water demand per crop type

Per crop type, average specific water demand (SWD)[1] will be calculated separately on the basis of FAO and local data on crop water requirements and crop yields.

The crop water requirement CWR (in m^3 ha-1) is calculated from the accumulated crop evapotranspiration Etc (in mm/day)[2] over the complete growing period. The crop evapotranspiration ETc follows from multiplying the 'reference crop evapotranspiration' ETo with the crop coefficient Kc.

The ETo values are obtained either from local available data and research stations or calculated using the FAO CROPWAT method as described in the FAO publications (Smith et al., 1992; Allen et al., 1994a, 1994b; Allen et al., 1998):

2. Calculating water productivity

The water productivity (WP)[3] in MU per m^3 of each crop will then be calculated by first calculating the water use efficiency (WUE) [4] and then multiplying it by the farm gate price of that crop.
After calculating the following economic values, it is obvious that the crops having the least water productivity are the crops that consume the more water and that generate the lowest amounts of profit. These are therefore the crops that should be avoided to be produced in the study region.

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[1] $SWD[c] = \frac{CWR[c]}{CY[c]}$, Where: *SWD* denotes the specific water demand (m^3 ton-1) of crop *c* in the country under study, *CWR* the crop water requirement (m^3 ha-1); and *CY* the crop yield (ton ha-1).

[2] Etc = Kc * ETo

[3] Water productivity = WUE (Kg/m^3) * Price (MU/kg), Where:Water productivity is expressed in MU per m^3, WUE is the water use efficiency expressed in Kg per m^3, Price is the farm gate selling price in MU per Kg

[4] $WUE = \frac{Yield(Kg/ha)}{GIR(m^3/ha)}$, Where: WUE is the Water use efficiency in kg per m^3, *Yield* is the yield in kg per hectare (kg/ha)and, GIR is the net irrigation requirement in m^3 for one hectare

In the status quo, it is not allowed to import crops from out of the study region. After determining the crops planted in that region, the considered crop's values will be evaluated. This value will be expressed per volume m^3 which results from multiplying the quantity of product (Kg) by the unit value per product, expressed as volume of water per Kg of product (m^3/kg). This value is the virtual water value (VWV)[1] .

This virtual water value will be multiplied by the farm gate price of the crop and this way, the MU value of virtual water will be obtained.

After setting the status quo, it will be allowed to import crops from foreign countries. It is therefore necessary to compute as well the virtual water value of those same crops in the country of origin and then choose the crops to grow in study region as well as those to import.

B. Allow Import of Crops from Foreign Countries

Sections 1.a and 1.b described above will be applied to calculate the water use efficiency and the virtual water value on a crop by crop basis.

1. Calculation of Virtual Water Trade Flows and the National Virtual Water Trade Balance

Virtual water trade flows[2] between nations will be 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.

The above equation assumes that if a certain crop is exported from a certain country, this crop is actually grown in this country (and not in another country from which the crop was just imported for further export).

2. Decision Basis Considering Comparative Advantages

After determining the required amounts of water to grow our necessary crops in study region without allowing import, it will be allowed to import some of national needs from foreign countries. Therefore, the same procedure will be followed to calculate the water productivity of crops outside the study region. First, for each crop imported to the study region, the countries of origin will be determined and the water productivity for these crops in study region will be determined.

The farm gate prices of the crops will therefore be considered the price of the crops arriving to the import outlet of the study region port (sea port, airport...) and the amount of water needed to grow them will be null since, this water needed will not be affecting study region water resource but foreign water resources which are not of our concern in this paper.

The selection criteria in this case will therefore be only centered on the prices needed for importing the crops into the region and thus, the crops originating from the countries charging the least cost for selling as well as the least cost of export will be the most profitable for study region authorities to import.

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[1] $VWV = \dfrac{ET_a(m^3)}{Yield(Kg)}$,Where: ET_a is the quantity of water evapotranspired at field level and, Yield is the increment or total yield (Kg)

[2] VWT[ne,ni,c,t] = CT[ne,ni,c,t] * SWD[ne,c], Where: VWT [ne,ni,c,t] denotes the virtual water trade (m^3yr-1) from exporting countries *ne* to importing country *ni* in year *t* as a result of trade in crop *c*, *CT* represents the crop trade (ton yr-1) from exporting countries *ne* to importing country *ni* in year *t* for crop *c* and, *SWD* represents the specific water demand (m^3 ton-1) of crop *c* in the exporting country.

C. Minimizing Costs of Production

In order to minimize the cost of production of crops for the authority concerned in the study region, in terms of money as well as in terms of water resources. Therefore, the choice will be based on water productivity basis. This way, while deciding on whether to import or grow crops in the study region will be in the same time a procedure that will save money as well as a very important resource that is going scarce in the ESCWA region, this resource being water. The decision criteria will therefore be based on comparative advantages. For each crop, the water productivity from different sources will be opposed to that of the study region. The source having the highest water productivity will be the one that should be imported. If producing the crop generates more productivity than any other country, then the crop in question should be grown on site.

D. Optimization Model Development

Based on a mathematical optimization model, the optimal combination of crops to be grown will be selected as well as those that should be imported. This will be performed by using the General Algebraic Modeling System (GAMS) with an objective of maximizing the return from the amount of water used subject to different constraints such as water availability and land constraint. This optimization model will be done for each crop separately in such a way that determines the amounts to grow locally, as well as, the amounts to imports from each of the exporting countries.

The MODEL is defined as such:

$$MaxZ = \sum_{i=1}^{n} r_i p_i x_i$$

Where:

Z= Total return from water used in monetary unit
i = Index of crop type
r_i= Gross water requirement per Kg of crop i in m^3 per Kg
p_i = Price of selling one Kg of crop i in MU per Kg
x_i = Quantity of crop i to be grown in Kg
n= Total number of crops

The model is subject to a set of constraints:

a) Water availability constraint: The total quantity of water used should not exceed the quantity of water available in the specific region under study. This can be represented by:

$$\sum_{i=1}^{n} r_i x_i \le \alpha$$

Where α is the quantity of water available for the irrigation of the proposed crops.

b) Land availability constraint: The total area under study should be used to the maximum with the crops to be grown. This can be represented by:

$$\sum_{i=1}^{n} l_i x_i \ge \beta$$

Where l_i is the land productivity in Kg per m^2 of crop i and β is the total land available for growing the proposed crops.

III. DISCUSSION

The estimated amount of Virtual Water in some agricultural products is as tabulated in table 1. In the table, both values for virtual water on global as well as case study in Lebanon are presented as reported by Hoekstra 2003 and Nimah et al 2001.

Table 1. Virtual Water content of few selected agricultural products in m3/ton.

	Zimmer and Renault 2003	Nimah et al 2001
Beef	13500	27100
Lamb	-	17300
Eggs	2700	5550
Poultry	4100	3530
Wheat	1160	1260
Lentils	-	1250
Milk	790	1210
Citrus	-	450
Grapes	-	430
Apple	-	350
Cucumber	-	310
Potatoes	105	250
Tomato	-	200

In calculating the virtual water content of a product, Zimmer and Renault 2003 made a distinction between primary products, (such as sugar, vegetables, vegetable oil and alcoholic beverages), transformed products including animal products; while Nimah et al calculation was based on the amount of water needed from seedling to harvest for primary products and for transformed products the calculation was based on the amount of water consumed throughout the life cycle. We can deduce from table 1 that the amount of water that can be saved trough the import of beef is equal to 13,600 m^3per ton. If this amount is multiplied by the total consumption of beef meat in Lebanon, then the volume of virtual water that can be imported will be significant. Data presented in table 1 should be collected in each ESCWA country in order to apply the virtual water- water productivity concept. This data can then be used in any optimization model.

The national virtual water trade balances in the ESCWA region in 2003 are presented in table 2.

Table 2. Virtual water trade balances in the MENA region including ESCWA member countries in billion m^3 per year (Extracted from, A.Y Hoekstra 2003)

Country	Gross virtual water import	Gross virtual water export	Net virtual water import
Algeria	-	-	10.5
Bahrain	-	-	-
Egypt	19.4	1.0	19.4
Iraq	-	-	-
Jordan	5.3	0.8	4.5
Kuwait	-	-	-
Lebanon	1.93	0.03	1.90
Libya	-	-	1.3
Morocco	-	-	5.7
Oman	-	-	-
Palestine	-	-	-
Qatar	-	-	-
Saudi Arabia	-	-	-
Syria	-	-	-
Tunisia	-	-	4.0
UAE	-	-	-
Yemen	-	-	-

In table 2 the net virtual water import is calculated as the difference between the gross virtual water import and the gross virtual water export for a country X. When it is negative, it means that the country is exporting virtual water, otherwise it is importing it.

The virtual water concept was proposed by Tony Allan about 10 years ago, one cannot expect that established methods of research and shared data sets exist. This concept of virtual water linked to water productivity is a new concept which relates the import- export of virtual water to the economics of trade as interconnected indirectly to the stakeholders. This concept might affect the socio- economic implications and will have direct impacts on farmers, water user associations and other stakeholders. This is due to the involvement of the price of goods or products on the farm gates as stated in the definition of water productivity. Also , this concept saves on the financing of infrastructures because of the import of virtual water that will lead directly or indirectly to the appropriate carriers of water to the end users.

This new method will help meeting water resource challenges if a series of steps are implemented in the water governance procedures.

- Integrated supply and demand management: In most of the ESCWA countries, the supply decision makers do not coordinate their activities with the demand sector especially in agriculture. Experience showed this to be a major error, for economic, social and environmental reasons. Therefore the emerging view is that both the management improvements and priority infrastructure have an essential and complementary role in contributing to sustainable growth and poverty reduction. Also, integrated water resource management including rainwater, desalination, ground and surface water, etc., as well as storage and distribution, treatment, recycling and disposal, and the protection, conservation and exploitation of water resources at their origin is necessary for proper planning and use.

- Cooperation among stakeholders (institutions on national, regional and international basis). Growing demand for water for domestic, industrial and the environmental means that there is a growing need for cooperation procedures (from the local to the international level) for dispute resolution, and for re-allocating water in response to changing demands and values. Water governance is moving from being just a local issue to a national issue and from a national to an international one, requiring new approaches to financing, dispute prevention and resource management.

- Water Audits & Data Base. Water audits provide a comprehensive appraisal of natural water resource base. It assists in water policy assessment and development, investment decisions, monitoring and evaluating program and policy performance; and direct resource management, particularly by local governments. Availability of information and the capacity to use it to make policy and predict responses is necessary. This implies forming a database that have sufficient information on hydrological, bio-physical, economic, social and environmental characteristics of the region under study to allow informed policy choices to be made.

- Capacity building, awareness and participation. For the implementation of this new concept, water user's capacity building and understanding of the concept of soil- water - plant relationship and the economical revenue for any change is a must. Thus training at all levels of water users should be conducted; coupled with an effective extension program. Empowering local communities to decide on the level of access to safe water and hygienic living conditions, the need to produce more food, and the need to create more sustainable livelihoods per unit of water, and the need to manage human water use to conserve the quantity and quality of freshwater and terrestrial ecosystems that provide services to humans and all living things. Consequently, community education and awareness-building is a critical component in water demand management, as is effective stakeholder participation in decision-making and policy development (Full participation by all stakeholders, including workers and the community); this will involve new institutional arrangements. There must be a high level of autonomy, but this must at the same time be associated with transparency and accountability for all decisions. It is also important to ensure that representatives provide feedback to the constituencies they represent.

- Water pricing. The principle of full-cost pricing complemented by targeted subsidies. The rationale behind this is that users do not value water provided free or almost free and have no incentives to conserve water. The economic sustainability of water and sanitation services depends largely and appropriately on the recovery of costs through user fees or tariffs that are equitably assigned. The recognition of water as an economic good is central to achieving equitable allocation and sustainable usage. Water allocations should be optimized by benefit and cost, and aim to maximize water benefits to society per unit cost.

IV. CONCLUSION

An optimization model was developed relating water productivity to virtual water trade to help overcoming the water scarcity in the ESCWA region and thus sustain agricultural productivity. The model addresses the issue of maximizing water productivity and selecting crops that will lead to the best virtual water import trade balance for the region under consideration based on realistic economical constraints. To benefit the socio- economic implications and impacts on stakeholders certain steps were described to make stakeholders receptive and engage them in the process of implementation.

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