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Water Footprint As A Tool Of Water Resources Management – Review

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Abstract

Water is essential for live, freshwater supplies around the world are under significant pressure because of increasing consumption and pollution. Egypt suffers from water scarcity due to the increase in the population and the lack of integrated management of water resources, resulting in a gap between the available water resources and the required water consumption. Many studies were done to improve irrigated agriculture's efficiency on water consumption and crop yields for saving water in irrigated agriculture to achieve water management sustainability. Therefore, the aim of this work is reviewing of the previous studies of crop water footprint accounting as a diagnostic tool to identify the hotspots of irrigated agricultural systems Water footprint as one of the tools of integrated water management. The water footprint (WF), which is an indicator that includes both direct and indirect water use, is a metric for determining how much freshwater a product consumes during its life cycle. It helps in providing water quantities to obtain the highest water efficiency to obtain the highest return of one cubic meter of water. And, it also helps to improve the strategies of sustainable agricultural and the structure of international trade. Water footprint necessitates the need to integrate water resources management policies agricultural and trade policies to feed in a comprehensive country water accounting system.

Key words: Water footprint, Water management, Agricultural crops, Food security

Introduction:

Water scarcity is affecting many countries due to the unequal distribution of water resources, as well as increased demand. Therefore, improving the management and efficiency of water resources has become very important [1]. Growing populations and continuous socioeconomic development increase the pressure on the world's scarce water resources, which facing the challenges of water scarcity and water quality deterioration [2].

Not only Egypt but worldwide as well, the total people are living in severe water scarcity regions ranges from 1.8 to 2.9 billion during 4-6 months per year. Moreover, half billion people live in areas that are suffering from severe water scarcity in the whole year [3]. Egypt lies in a dry region of the world. The management of water resources in dry areas is necessary to maintain the limited quantities of water available in these areas and to achieve an appropriate level of development, food security and stability [4].

The aim of this work is reviewing of the previous studies of crop water footprint accounting as a diagnostic tool to identify the hotspots of irrigated agricultural systems. Based on this analysis specific actions can be defined to improve water use efficiency, reduce water abstractions, polluted water returns, and maintain production rates.

1. Water situation in Egypt:

Egypt suffers from water scarcity due to the increase in the population and the lack of integrated management of water resources, resulting in a gap between the available water resources and the required water consumption. Egypt is a very arid country with only 1.18% of annual water resources comes from rainfall and 9.03% from underground sources, The Nile River as the main reliable source of water in Egypt [5].

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Under the 1959 Nile Waters Agreement between Egypt and Sudan, Egypt receives a constant amount of water (55,500 billionCM) through the Nile River annually, This amount of water accounts for 72.64% of the Egyptian annual water resources [6]. Agriculture sector consumes 81.6% of Egypt annual water resources, (followed by family use (13.5%), and industry use (1.57%) [5]

To face the water shortage challenges, Egypt national water resources management strategy included policies and action plans to manage water demand and supply considering the protection of its water resources [2]. The challenge is to produce more yields with less water and so reduce the water footprint of each unit of the crops produced [7].

The climate change plays a vital role in the water resources utilization related to crop yield [8, 9]. Temperature raise as projected by many climatological studies will lead to highly increased evapotranspiration on the territory of Egypt especially because of the traditionally irrigated agriculture. Besides, the projected high temperature would increase the local water demands especially on the agricultural sector [10].

As the result of the climate change, all crops are projected to have a decrease in yields and an increase in irrigation needs. Some crops only decrease a few percent while others have a reduction of more than one-fourth [11].

In order to study the relationship between agricultural water consumption and water resources evaluation there are several methods have been applied such as water use efficiency, water scarcity and water footprint (WF) that considered the main indicators for sustainable evaluation of irrigated agriculture [12].

2. Water footprint

WF has been primarily used to study wise water management based on water consumption and pollution for human production or consumption along the supply chain of a product [13, 14].

Hoekstra [15], introduced the concept of "water footprint" and subsequently elaborated by Hoekstra and Chapagain [16] provides a framework to analyze the link between human consumption and the appropriation of the globe's freshwater. The water footprint of a product (alternatively known as "virtual water content") expressed in water volume per unit of product usually (m^3 ton^{-1}) is the sum of the water footprints of the process steps taken to produce the product.

The water footprint thus offers a wider perspective on how a consumer or producer relates to the use of fresh water systems. It is a volumetric measure of water consumption and pollution.

Water footprint accounts give spatiotemporally explicit information on how water is appropriated for various human purposes. They can feed the discussion about sustainable and equitable water use and allocation and also form a good basis for a local assessment of environmental, social and economic impacts [17].

Water footprint is defined as the volume of fresh water used to produce the product, summed over the various steps of the production chain. The water footprint (WF) is a multi-dimensional freshwater consumption whether directly and indirectly by a producer or a consumer, it helps to analyze the relationship between water consumption by human and the appropriated water for industrial sector [18]. The water footprint of a product can be used to give policy makers on idea of how much water is being traded through imports and exports of the product [19]. The volume of water used during the crop growing season is linked to production this is the final goal of all agricultural activity. Water footprint accounting is a suitable procedure to assess the relationship between water use and crop yield [20]. A 33.3% reduction in water volume relative to current practice did not result in a major decline in maize yield, but water footprint was decreased by 23.9% [21].Water footprint (WF) studies are primarily concerned with reducing the global average of freshwater consumption [22]. The water footprint is expected to increase by up to 22% as a result of climatic changes and change in land use by 2090 [23]. Accurate and precise quantification of WF is the basis for management of regional agricultural water resources. The magnitude of WF is significantly affected by climate, soil types, and water management practices, which causes the obvious spatiotemporal variability of WF [24, 25]. Local conditions, geographical area, atmosphere, and technology are all taken into account by the WF [26, 27].

In addition, Kim and Kim [28] added that, because food cannot be produced without water, demand-driven water management of agricultural and livestock products applying water footprint is needed for food security. El-gafy [29] investigated wheat production, water footprint, and virtual water nexus using a System Dynamic model. . It was found that the water footprint of wheat production and consumption in Egypt changes according to changes in the crop production, foreign trade, per capita consumption, population, and climate effects. In line with this study Gafy et al. [30] also used system dynamics to calculate a water-food-energy nexus index and the energy and water footprints for 43 Egyptian agricultural crops, based on production and consumption amounts.

Also, they calculated the virtual water and energy imports and exports of the same crops.

2.1. Water footprint components

The water footprint as a usable metric for assessing the current and future water use is water footprint (WF) accounting, which consists of three components of water (green, blue, and grey). Moreover, it offers a quantifiable indicator to measure the aforementioned three components per unit of crop production [31, 32]. Green water is defined as the fraction of rainwater stored in soil and available for the crop to be evapotranspiration during growing stages (ET_{green}), which is equivalent to the effective precipitation (P_{eff}) concept [33].

Blue water refers to all water used for irrigation from aquifers and surface water sources that are evapotranspiration during the cropping practices [34, 35]. Grey water is the volume of freshwater needed to dilute a certain amount of pollution such that it meets ambient water quality standards or is equivalent to natural background concentrations [36, 37]. In several studies, the grey component is not assessed, due to difficulties in evaluating the pollutants and in integrating the component in real water volumes [38].

BWF calculated with water use data could reflect water use efficiency in fields and irrigation efficiency simultaneously. Moreover, it will be able to distinguish how much is GWF and BWF with spatial and temporal dimensions, respectively [39].

Under Egyptian conditions (Khalil, et al. [10], introduced an overview of the water footprint of rice, wheat and maize (m^3/ton) in the different sections of the Egypt over different years. As shown in fig.1, water footprint of rice in New Areas containing larger amounts of water footprint (about 2246 m^3/ton) and Middle Egypt (about 1918 m^3/ton), however, Lower Egypt containing smaller amounts of water footprint (about 1435.9 m^3/ton). While the water footprint of wheat fig.2 showed that New Areas containing larger amounts of water footprint (about 3189 m^3/ton), Upper Egypt (about 2076 m^3/ton) and Middle Egypt (about 1708 m^3/ton), however, Lower Egypt containing smaller amounts of water footprint (1511 m^3/ton). It was also documented that the water footprint of maize in New Areas containing larger amounts of water footprint (about 3464 m^3/ton), Upper Egypt (about 2486 m^3/ton) and Middle Egypt (about 1822 m^3/ton), however, Lower Egypt containing smaller amounts of water footprint (about 1601.6 m3/ton) fig.3.

2.2. Blue, green, and grey water footprint calculation

Hoekstra et al.[17] indicated that, the total water footprint of the process of growing crops or trees (WF_{total}) is the sum of the green, blue and grey components.

The calculation of WF of crop products is crop ET per unit area divided by the average yield per unit area in the same period. The use of average meteorology and crop yield data makes it hard to reflect the temporal change of WF of grain products, a point noted by Hoekstra and Mekonnen [40].

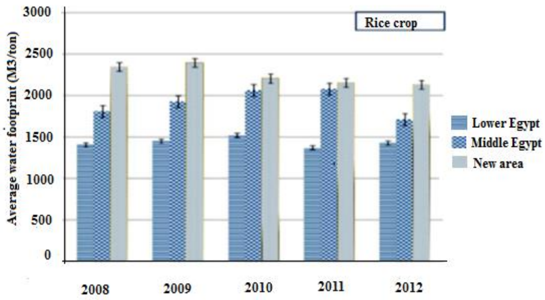

Fig. 1 Total water footprint of rice over the period (2008-2012).

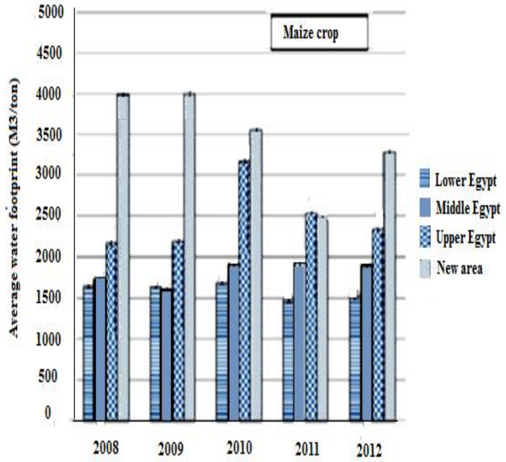

Fig. 2 Total water footprint of wheat over the period 2008-2012

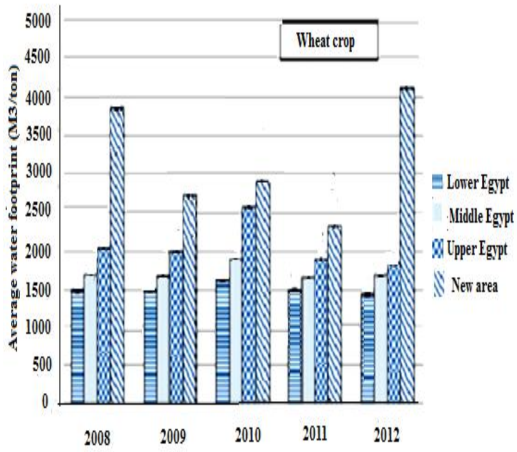

Fig.3 Total water footprint of Maize over the period 2008-2012

The first parameter, potential crop evapotranspiration, is essential in water footprint calculations. Various mathematical models are used to estimate reference evapotranspiration (ET_O) [41, 42, 43]. However, the Food and Agriculture Organization's (FAO) FAO-56 Penman-Monteith method [44] is more effective than other.

Reference evapotranspiration with Penman-Monteith equation, it is the most widely used for water footprint calculations [30, 45, 46]. Although Penman-Monteith method is the most reliable, it requires a large number of meteorological parameters at various spatiotemporal scales (maximum and minimum air temperatures, wind speed, solar radiation, and vapor pressure deficit), which are often unavailable in many developing countries due to a lack of meteorological stations and weather data records [47, 48, 49].

Hoekstra et al.[17] said that, the blue water footprint is an indicator of consumptive use of so-called blue water, in other words, fresh surface or groundwater. The blue water footprint in a process step is calculated as:

WF proc, blue (m3/ton) = Blue Water Evaporation
+ Blue Water Incorporation
+ Lost Return flow

Hoekstra and Chapagain [16] said that, the grey water component in the process water footprint of a primary crop (m3/ton) is calculated as the load of pollutants that enters the water system (kg/yr) divided by the difference between the maximum acceptable concentration of the water pollutant (cmax) and its natural concentration in the receiving water body (cnat). They also stated that, 10 percent of the applied fertilization rate has assumed to be the quantity of nitrogen that reaches free flowing water bodies (in kg/ha/year). As recommended by The Water Footprint Assessment manual and the Expert panel, the values used for the maximum concentration for Nitrogen were the ambient water quality standards USEPA [50].

Natural concentrations for all chemicals of concern were assumed to be zero. This may lead to an underestimation of the grey water footprint, since water bodies that have a natural background concentration of a certain substance will actually have less assimilation capacity for this substance. Therefore the value used for nitrogen was 4333 μg/l and for phosphorous 12 μg/l. For pesticides the natural background concentration used was zero [51]. While, the leaching runoff fraction values used for the recalculation were the default global average values suggested by the experts was 10% for nitrogen.

The effect of the use of nitrogen has been analyzed but other nutrients, pesticides and herbicides to the environment have not been analyzed Hoekstra et al.[17]. 10 mg/liters (measured as N) have been used, as ambient water quality standard for nitrogen. To calculate the volume of freshwater required assimilating the load of pollutants, ambient water quality standard for nitrogen was used.

El Fetyany et al.[2] calculated the average water footprint per ton of each commodity for Egypt for the 10 years (1995- 2006) for different crops to estimate the national agricultural water footprint for Egypt. These data are elaborated in Fig. 4. Also, the average values of green, blue, and grey water footprint (m^3/ton) calculated for some crops in Egypt are shown in Fig.5.

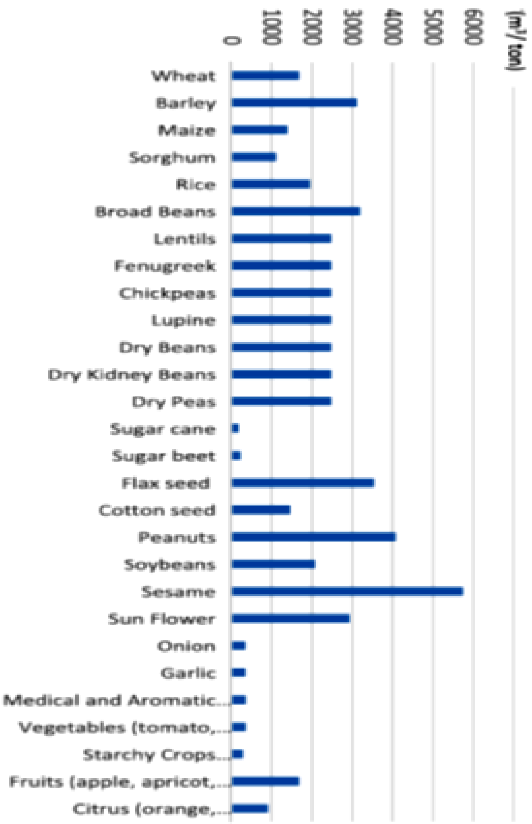

Fig.4 Average Water footprint values (m^3/ton) for different crops in Egypt (1995–2006).

3. Water footprint as a tool of water resources management:

Water footprint is put forward as a tool for assisting policy development in the water sector by showing the extent of interdependence of individual countries on the water resources of other countries [52] and thus allowing countries to assess their national food security and develop environmental policy [40]. Water footprint can help governments understand the extent to which the size of their national water footprint is due to consumption patterns or inefficient production and thus to priorities policy actions such as changing consumption patterns or improving the water efficiency of production [53, 54].

While water is clearly an input to production, it cannot be the sole criterion for judging the rationality of trading 10 patterns, as trade between countries is determined by a variety of factors such as land, labour, technology, trade agreements and other factors [55]. Considering gross value added to the economy per litre of water used, and thus bringing in a socio-economic dimension, is one idea for widening the criteria considered as part of a water footprint analysis [54].

Conclusion:

According to Egyptian sustainable development strategy 2030, the promotion of food security, nutrition, and sustainable agricultural growth. Irrigated agriculture has been enhanced food security however it increased the pressure on water resources especially with the huge food demand due to population growth and socio-economic development. To solve this problem, water footprint and virtual water analysis were used to enhance water use efficiency and recover water scarcity problems in Egypt. Water footprint measures the actual occupancies of water resources from the perspective of consumption. It connects water use consumption patterns, and it can be regarded as the best indicator for measuring the influences of agriculture activities on water resource environmental, because the concept of water footprint has expanded water issues into economic field. The findings from this research can help the government and policy makers to mitigate the side effect of the climate change on crop yield and to enhance and sustainable the water resources management in Egypt for major crop production region. Therefore, this investigation can present a pioneering modeling strategy that would lead to improvement of efforts to address the WFP prediction, which in turn may assist in mitigation plans such as policies for sustainable water-use and development plans for food security.

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