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Developing and Evaluating A Tool for Assessment Economic Water Productivity (Eco-Wp Tool)

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ABSTRACT

The substance of worldwide water scarcity is the geographic and temporal inconsistency among freshwater demand ,water resource availability and *the un-efficient use of water resources*. Water footprint (WFP) and economic water productivity are considered a solution to global water stress and water scarcity. This study aims *to develop a tool of the assessment of* the economic water productivity (Eco-WP) and evaluate different methods of water productivity (WP) and their relationship with WFP . The WFP and Eco-WP were estimated in year *2017* for the major crops in Egypt. The results showed that there were two analyzes for Eco-WP: first, analysis per crop, the average of Crop Water Productivity was taken for each crop to compare crop's water productivity for overall Egypt. Second, analysis per governorate, the average governorate Water Productivity for all crops planted in this governorate. Also, the relationship between Eco-WP and WFP was a reverse relationship (power equation). For the first analysis, the most suitable method to judge Eco-WP was the Energy Price Method with 0.98 (R^2). However, the appropriate method to assess Eco-WP was the net revenue method with 0.56 (R^2).

Key words: Economic water productivity, Crop water footprint, and Egypt.

INTRODUCTION

Water productivity (WP) is the net return for a unit of water used. Improving water productivity aims to produce more food, income, better livelihoods, and ecosystem services with less water. The Eco-WP is defined as the net revenue per unit of water used. It has also been used to link water use in agriculture to feed and the environment Moldena *et al*., (2010).

There are many articles that used Eco-WP with WFP using the Crop Price Method such as Chouchane *et al.*, (2015) quantify and analyze the WFP of Tunisia at the national and sub-national level, and assess economic water and land productivities related to crop production for irrigated and rain-fed agriculture, and water scarcity. Hai *et al.*, (2020) developed an indicator named WFP of crop values and evaluated comprehensively the water-use efficiency (WUE) under the complex planting structure. Wangab, (2014) calculated and compared the *WFP* of each grain crop and the integrated WFs of grain products with actual and virtual crop patterns in different regions of China for 2010. Also optimize the spatial distribution of crops and develop agricultural water savings to increase crop water productivity. Paolo *et al.*, (2018), Schyns and Hoekstra, (2014), and Garrido *et al.*, (2010) were used the Crop Price Method to assess economic water and land productivities related to crop production.

However, the energy price method was used in the following articles: quantify the volumes of all virtual water trade flows over the period 2008-2012 in Egypt for some crops from hydrological and economic perspectives and put the virtual water trade balances of these crops within the context on national water needs and water availability (Khalil and Ibrahim 2015). Ramadan *et al.*, (2015) promote the most suitable governorate to plant each crop and adjust crops planted areas to decrease irrigation water consumption and save water. Ibrahim and Khalil (2021) enhance water use efficiency and overcome water scarcity problems using the WFP , virtual water trade and the Eco-WP during the period from 2012 to 2016.

The aim of this study is to provide a tool for assessing the Eco-WP tool using three approaches and comparing these approaches to choose the most appropriate method for estimating of Eco-WP. To achieve this aim, the field-scale WFP s of rice, maize, cotton, soybean, wheat, potato, tomato, sunflower, groundnut, clover, and flax were calculated using the Eco-WP tool for each governorate in Egypt in the year 2017.

MATERIALS AND METHODS

Study area:

Egypt is located in the northeastern corner of the African continent. The area of Egypt is about 1,002,450 km^2, and the altitude of Egypt ranges from 133 m below sea level in the Libyan Desert to 2,629 m above sea level in the Sinai Peninsula. The area of agricultural land in Egypt is confined to the Nile Valley and delta, with a few oases and some arable land in Sinai. The total cultivated area is 3.108 million ha, accounting for only 3% of total land area. The entire crop area is irrigated, except for some rain-fed areas on the mediterranean coast (Ouda 2016).

Data collection:

The data required by the Eco-WP tool includes location data, cop data, and soil data. The simplemaps.com

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website was used to obtain location data (latitude, longitude, and altitude for each governorate in Egypt). The daily climate data includes minimum and maximum air temperature, relative humidity, sunshine duration, wind speed, and daily rainfall.

The crop data includes values of Kc for each crop over the length of the growing period and growth stages. FAO Irrigation and Drainage Paper No. 24 provides general lengths for the four distinct growth stages and the total growing period for various types of climates and locations, and also provides typical values for Kc_{ini}, Kc_{mid}, and Kc_{end} for various crops. Soil data was required to estimate gross irrigation (Allen and Pruitt, 2009). Typical soil water characteristics for different soil types was estimated according to FAO 56 (Allen *et al.*, 1998). The food balance sheet of each crop includes crop production, planted area, crop yield, crop price and total costs. The preceding information was obtained from the Economic Affairs Sector-Ministry of Agriculture and Land Reclamation EAS-MALR (Volumes 2017-2018). To estimate the grey WFP , fertilizer application rates for each crop were obtained from FAO (2005).

Economic water productivity (Eco-WP) estimation:

The Eco-WP was developed using Microsoft visual studio 2019 (C sharp language). Building on the concept of Eco-WP expressed WP as physical-economic output per unit of water consumed (in kg m^3 or $\$/m^3$). If the whole fraction of dry or wet matter or crop production can be used as economic or physical terms in the fraction, then amount of irrigation water and input water at different scales, and WFP , etc. can be used. The Eco-WP could be estimated using three methods: according to energy output, crop unit price, net revenue (this analysis was conducted using the Eco-WP tool).

a) Energy output method:

The energetic water productivity (En_g) may be calculated by dividing the energy output of the crop in kcal/ton (En_{output}) by total WFP in m^3/ton. After that, water economic productivity was computed as multiplying the energetic water productivity by energy price in \$/kcal as the same approach as Khalil *et al.,* (2015).

$$En_g = \frac{En_{output}}{WF_{tot}}$$

Water economic productivity was calculated as follows:

$$\mathbf{Eco-WP} = En_g * P_{EN}$$

Where:

Eco-WP = The economic water productivity in [\$/m³] and;

P_{EN} = Energy price in [\$/kcal].

b) Crop unit price method:

Economic water productivity (Eco-WP in $\$/m^3$) represents the economic value of farm output per unit of water consumed and is calculated as the average producer price as approach (Paolo *et al.,* 2018), (Schyns and Hoekstra, 2014), and (Garrido *et al.,* 2010).

$$\mathbf{Eco-WP} = \frac{P_{crop}}{WF_{tot}}$$

Where:

P_{crop} = Crop price in [\$/ton].

c) Net revenue method:

Total costs by hectare (\$/ha) were computed as the summation of land preparation, seeding, irrigation, fertilization, weeding, pest control, harvesting, and transportation costs. Then, total costs by hectare divided by crop yield (ton/ ha) to calculate total costs by ton (C_{ton} in \$/ton). So, Water economic productivity was calculated as follows:

$$\mathbf{Eco-WP} = \frac{\mathbf{P_{crop} - C_{ton}}}{\mathbf{WF_{tot}}}$$

Before estimating the Eco-WP, the total WFP of crops, which is the summation of green, blue, and grey WFP s has to compute first. The green, blue, and grey WFP s was estimated according to Hoekstra *et al.,* (2012) as follows:

$$\mathbf{WF_{green}} = \frac{\sum \mathbf{CWR_{green}}}{\mathbf{Y}}$$

$$\mathbf{WF_{blue}} = \frac{\sum \mathbf{CWR_{blue}}}{\mathbf{Y}}$$

$$WF_{grey} = \frac{\left[\frac{Appl * \alpha}{C_{max} - C_{nat}}\right]}{Y}$$

Where:

Y = The crop yield in ton/ha;

WF_{green} = Green WFP in m³/ton;

WF_{blue} = Blue WFP in m³/ton;

c_{max} = The maximum acceptable concentration for Nitrogen in kg/m³;

c_{nat} = The natural concentration for Nitrogen in kg/m³; and

α = The leaching-run-off fraction.

RESULTS AND DISCUSSIONS

The study analyses the Eco-WP of major crops in Egypt in 2017 under different assessment methods (Energy Price Method, Net Revenue Method, and Crop Price Method) using the Eco-WP tool. To implement this analysis, the WFP was calculated for all crops per governorate. In this section, the results were compared according to two sectors as follows:

- **Economic water productivity per crop:**

As shown in Fig. 1, clover, potato (summer, nili, and winter), and tomato (summer, nili, and winter) had the highest Eco-WP in Egypt. Under using energy price method, clover had the highest economic WP (about 0.66 $\$/m^3$) followed by, winter potato and winter tomato. Tomato had the highest Eco-WP using the Net Revenue Method during the winter, at around 0.424 $\$/m^3$. On the other hand, the crop price method agreed with the energy price method in clover had the highest Eco-WP (1.4 $\$/m^3$). The lowest Eco-WP crop for Energy Price Method was cotton (0.012 $\$/m^3$) , in the Net Revenue Method was soybeans (0.0109 $\$/m^3$), and in the crop price method was Sorghum (0.012 $\$/m^3$).

According to previous results, it is recommended to planted clover in the winter season and potato in summer and nili season due to the highest Eco-WP in the energy price method and crop price method. This finding does not similar to Badawy *et al.,* (2022) who assess the average clover productivity in Egypt (0.311 $\$/m^3$) according to net revenue. According to the same method El-gafy *et al.,* (2014) found that, average clover productivity (Giza ,and Gharbia) was 0.14 $\$/m^3$ in 2008. While, Kheira, (2009) estimated average clover water productivity (0.133 $\$/m^3$) during the winter of 2002/2003 and 2003/2004 in Kafr El-Sheikh according to Unit Price Method. Previous studies do not include grey water consumption. On the other hand, it preferred to cultivate winter, nili, and summer tomato due to the highest Eco-WP in the Net Revenue Method. This suggest agreed with El-Marsafawy and Mohamed, (2021) where average tomato productivity was 0.95 $\$/m^3$ according to net revenue and it's not include grey water consumption in Egypt.

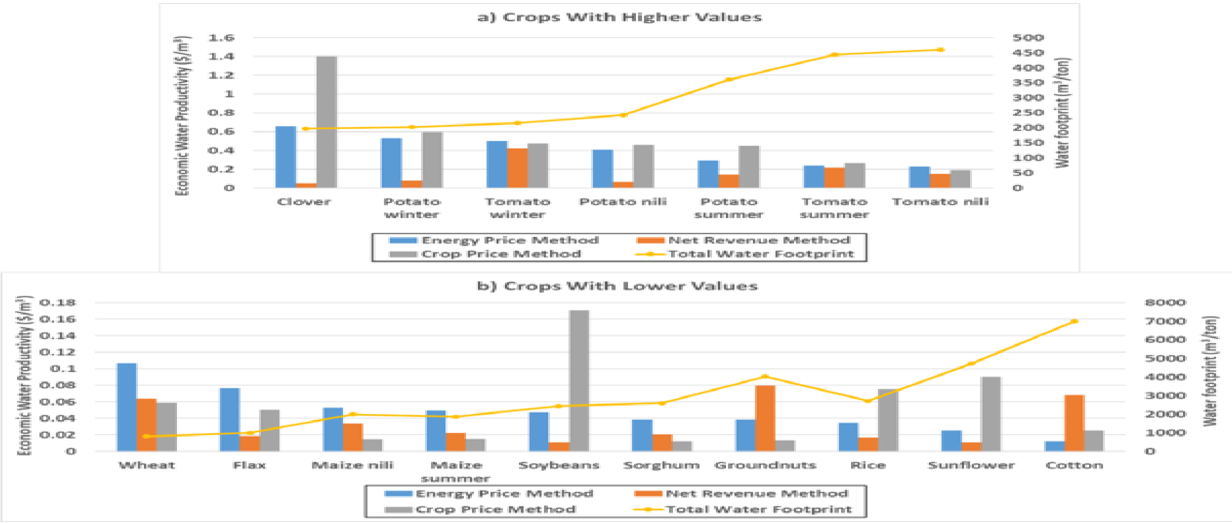

Fig. 1. The Eco-WP for major crops in Egypt in 2017 using three different methods

As observed before, there is not a clear relationship between results from these three different methods at calculated Eco-WP. So, the appropriate method to estimate the Eco-WP could be chosen according to the correlation factor between WFP and output results from each method. Fig. 2 showed the comparing between Energy Price Method, Net Revenue Method, and Crop Price Method. The R^2 for Net Revenue Method was the lowest one; however, the highest was o.9798 for Energy Price Method.

Clover and (summer, nili, and winter) potato Eco-WP shown in Fig. 3.

According to the Energy Price Method, its preferred to planted clover in Kafer El-Sheikh governorate due to it having the highest Eco-WP. While North Saini had the lowest economic value for one cubic meters of water, it's suggested to not plant clover in this governorate. For potato (summer), the highest Eco-WP was observed in Kafer El-Shiekh governorate While the lowest one was located in South Sinai governorate (0.16 $/m^3). While Gharbia had the highest economic value for one cubic meters of water, its suggested to plant potato (nili) in this governorate. Bahira and Giza (0.35 and 0.37 $/m^3) had the lowest Eco-WP for potato (nili). Otherwise, the highest and lowest Eco-WP for potato (winter) was in Sharika and south Sinai, respectively.

According to the Net Revenue Method, Asyut and Gharbia (0.036 and 0.066 $/m^3) have the lowest and highest Eco-WP for clover, respectively. Otherwise, for summer potato, highest Eco-WP wad observed in Gharbia and Kafer El-Shiekh (0.1824 and 0.1823 $/m^3,resepectively), whereas the lowest one was in Asyut and Giza (0.111 and 0.119 $/m^3,resepectively). The lowest and highest Eco-WP for nili potato were 0.054 and 0.079 $/m^3, respectively in Asyut and Gharbia. For winter potato, North Sinai had the highest Eco-WP about 0.097 $/m^3 and South Sinai had the lowest Eco-WP about 0.06 $/m^3.

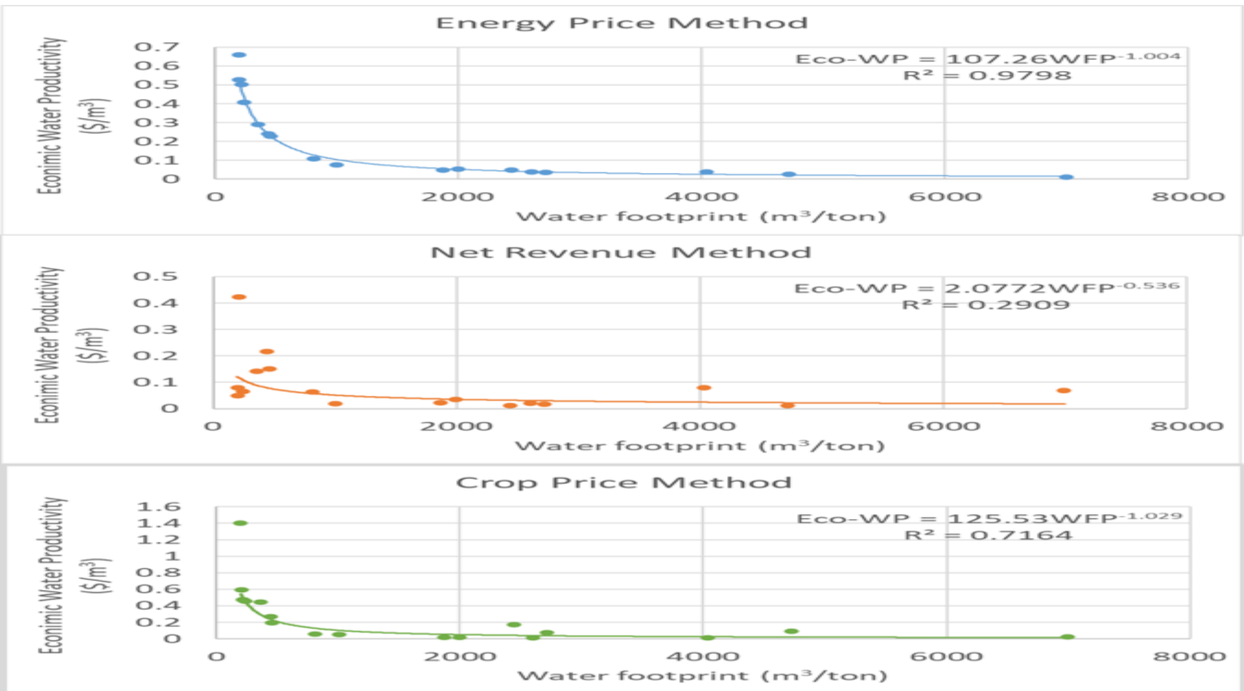

Fig. 2. The correlation factor between average of WFP and Eco-WP for Crops using three different methods

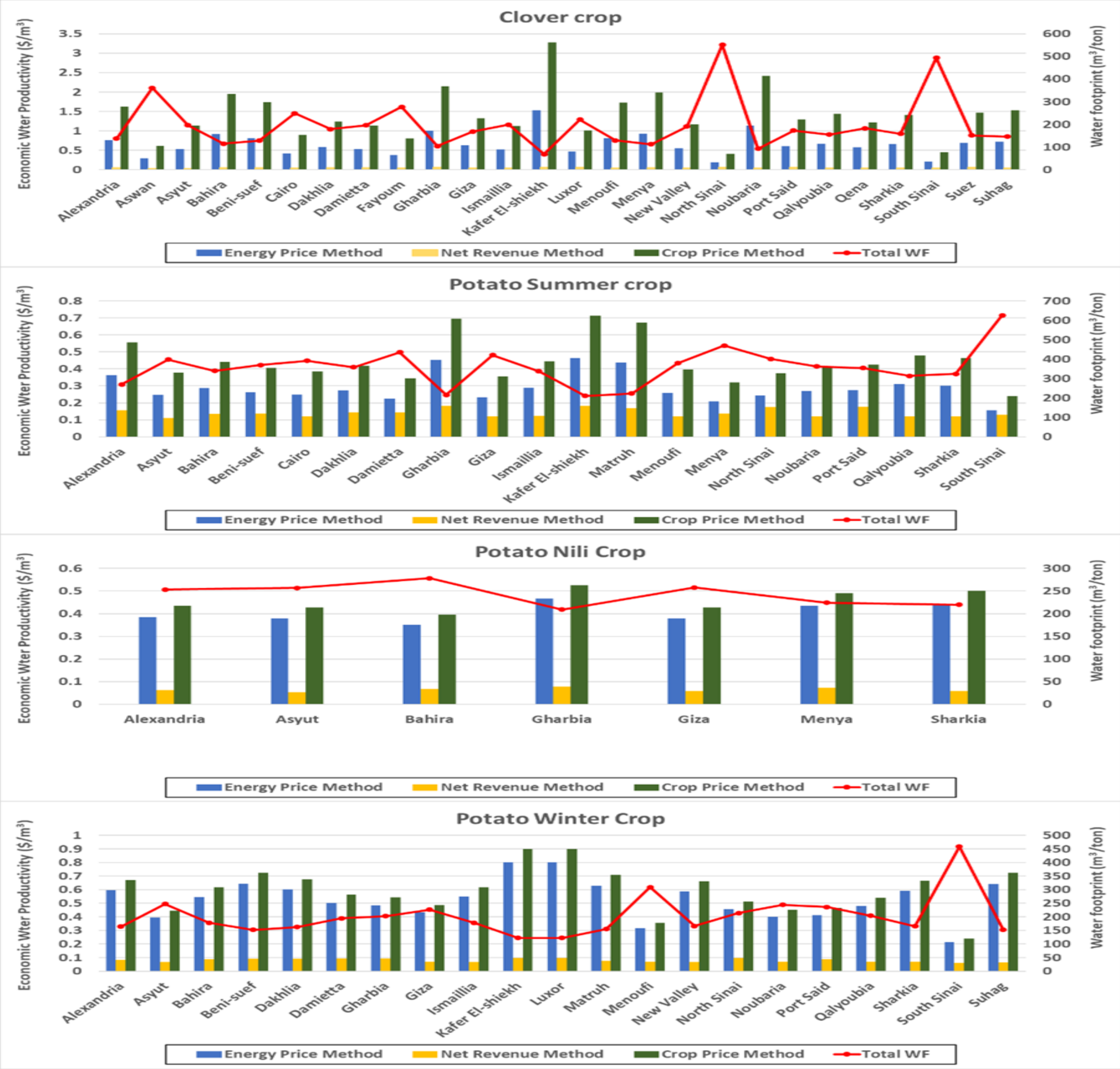

Fig. 3. The Eco-WP using three different methods for clover, and winter potato, nili potato, and summer

According to the Unit Price Method, Kafer El-Shiekh had the highest Eco-WP for clover (3.28 $/m^3$) while North Sinai had the lowest one (0.45 $/m^3$). The highest and lowest Eco-WP for winter potato was observed in Luxor and South Sinai about 0.9 and 0.24 $/m^3$, respectively. For nili potato, the highest and lowest economic water were in Gharbia and Giza (about 0.53 and 0.43 $/m^3$), respectively. Kafer El-Shiekh had the highest Eco-WP for summer potato (0.711 $/m^3$) while South Sinai had the lowest one (0.23 $/m^3$).

Economic Water Productivity per Governorate

As illustrated in Fig. 4, Kafer-El Shiekh, Matruh, and Menya had the largest Eco-WP in Egypt. Under using Crop Price Method, Kafer-El Shiekh had the highest Eco-WP (0.49 $/m^3$), however the lowest one was in Aswan about 0.11 $/m^3$. While North Sinai had the largest Eco-WP using Net Revenue Method about 0.2 $/m^3$. On the other hand, in the Energy Price Method the governorate that had the highest Eco-WP was Matruh (0.38 $/m^3$). The lowest Eco-WP crop for Energy Price Method, and Net Revenue Method were Aswan (0.089 $/m^3$), and New Valley (0.075 $/m^3$), respectively. The Value of output data from Crop Price Method was the highest one for all governorates, followed by Energy Price Method, and the lowest output data obtained from Net Revenue Method.

As stated in previous results, Energy Price Method recommended to cultivate crops under study in Matruh. While Net Revenue Method and Crop Price Method preferred Kafer El-Shiekh agreed with El-gafy *et al.*, (2014) (not include grey WFP). The results from each method were different. To choose the most suitable method, the relationship between Eco-WP and WFP .

The correlation factor between Eco-WP and average WFP for each governorate was illustrated in Fig. 5. The lowest R^2 was founded with using Crop Price Method (about 0.19). The Net Revenue Method has the highest value of R2 about 0.56. While the R square for Energy Price Method was 0.25.

Comparing between crops in governorates to choose the most appropriate crop get high revenue and the most efficient water use illustrated in Fig. 6.

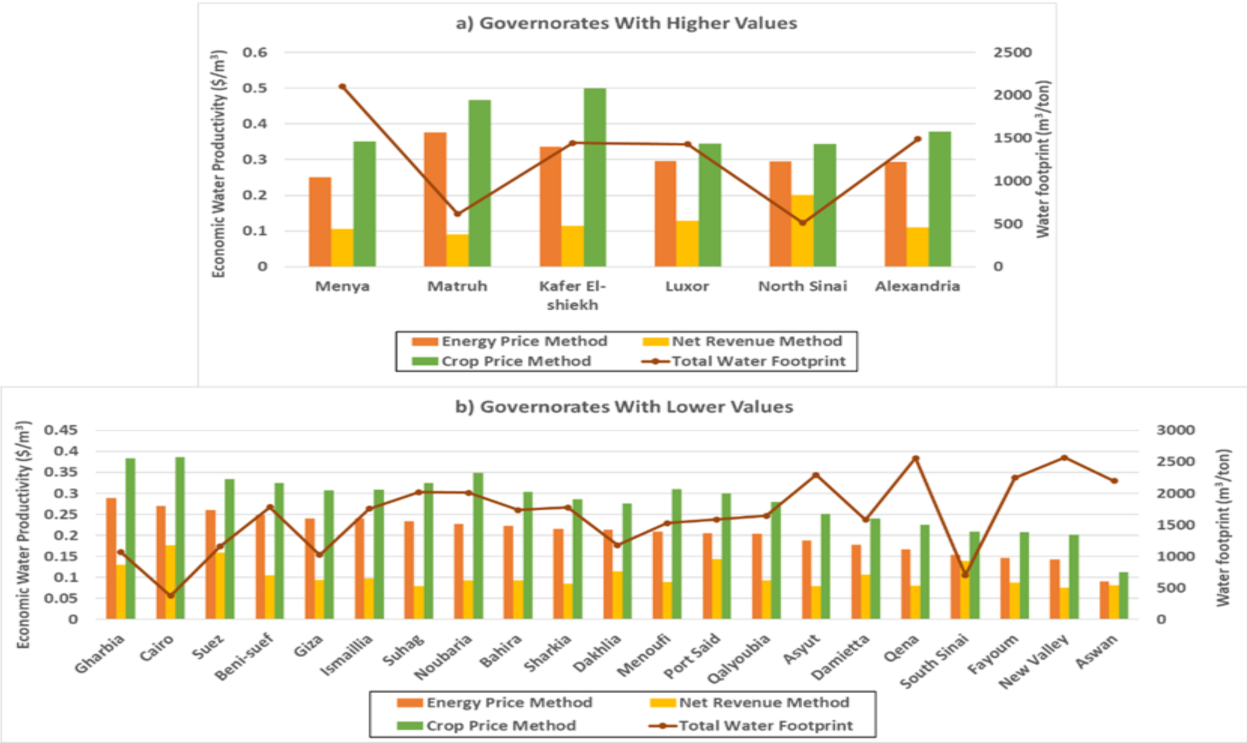

Fig. 4. The Eco-WP for Governorates in Egypt in 2017 using three different methods

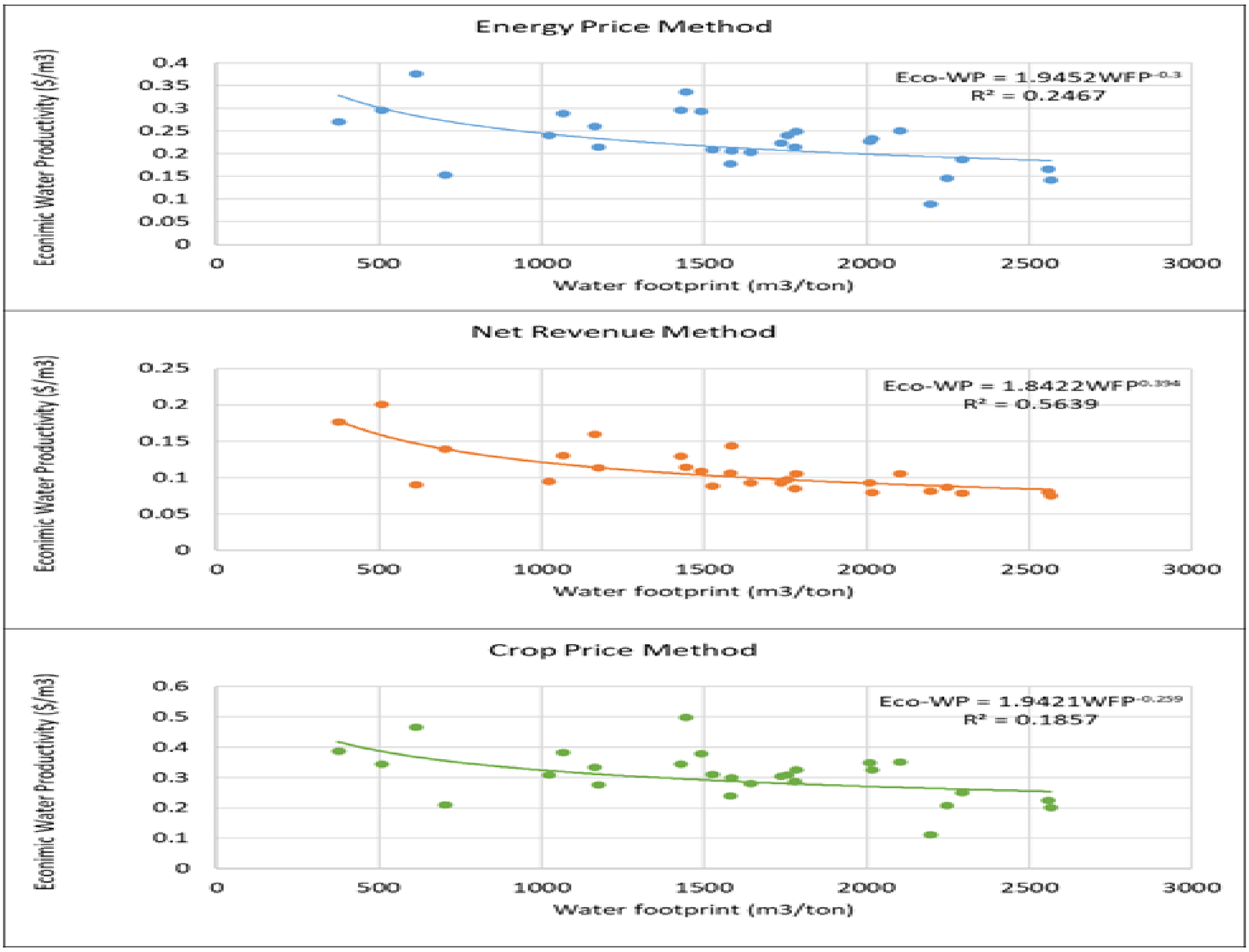

Fig. 5. The correlation factor between average of WFP and Eco-WP for Governorates using three different methods

Fig. 6. The Eco-WP using three different methods for Menya, Matruh, Luxor, Kafer El-Shiekh, and North Sinai

According to Energy Price Method, it's preferred to planted clover in Kafer El-Shiekh and Menya while, however planting cotton in Kafer El-Shiekh and Menya get the lowest economic value per one cubic meter. Otherwise, Matruh get the highest Eco-WP in planting Winter potato. But it is not suggested to plant Summer maize on Matruh. In North Sinai and Luxor, winter tomato had the highest Eco-WP about 0.54 and 0.88 $\$/m^3$, respectively.

According to Net Revenue Method, Kafer El-Shiekh, Menya, and Luxor get the highest Eco-WP in planting tomato Winter. It is not preferred to planted sunflower in Kafer El-Shiekh due to the low Eco-WP for it. In Menya and Luxor, the lowest Eco-WP was for planting soybeans about 0.011and 0.0133 $\$/m^3$. Planting clover and maize Summer in North Sinai and Matruh get the lowest revenue per one cubic meter due to high WFP .

According to Price Crop Method, the highest and lowest Eco-WP were obtained when planting clover and wheat in Kafer El-Sheikh, respectively. It is not preferred to plant groundnut in Menya and Luxor due to lowest Eco-WP. It is preferred to planting winter potato in North Sinai.

CONCLUSION

Economic water productivity has no single definition that suits all situations. In general terms, productivity is a ratio referring to the unit of output (s) per unit of input (s). Obviously, the unit the Unit of input was the one cubic meter of WFP used to produce the crop or product, but the output was different according to the understanding of each researcher. The output may be directly crop price or net revenue after subscribing costs during production process or choose stable index from economic perspective such as energy and related it with crop or product WFP .

So, the study aims are to provide a tool for assessment the Eco-WP tool using three approaches and compare these approaches to choose the most appropriate method for estimating the Eco-WP. According to the results, it's important to identify the Eco-WP analysis objectives. Finally, the most suitable approach to estimate the Eco-WP analysis for crops or products was the energy price method with a high value of R^2 about 0.9798. While for Eco-WP analysis for Governorates , the most appropriate method was Net Revenue due to its more related to WFP than other methods.

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تطويروتقييم أداة لتقييم الإنتاجية الاقتصادية للمياه (Eco-WP)

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الملخص

جوهر ندرة المياه الدولية هو التناقض الجغرافي والزمني بين الطلب على المياه العذبة وتوافر موارد المياه والاستخدام غير الفعال لموارد المياه. تعتبر البصمة المائية والإنتاجية الاقتصادية للمياه حلاً للإجهاد المائي العالمي وندرة المياه. تهدف هذه الدراسة إلى تطوير أداة لتقييم الإنتاجية الاقتصادية للمياه (Eco-WP) وتقييم الطرق المختلفة لإنتاجية المياه وعلاقتها بالبصمة المائية. تم تقدير البصمة المائية والإنتاجية الاقتصادية للمياه للمحاصيل الرئيسية في مصر عام 2017. وقد أظهرت النتائج أن هناك تحليلين للإنتاجية الاقتصادية للمياه. أولاً التحليل الكمي لكل محصول: العامل المؤثر ان هذا التحليل هو الاحتياجات المائية لكل محصول . ثانيا التحليل لكل محافظة:وهو متوسط إنتاجية المياه بالمحافظة لجميع المحاصيل المزروعة بها والعامل المؤثر على هذا التحليل هو الفروق المكانيه وتوزيع المحاصيل في المحافظات. كما كانت العلاقة بين الإنتاجية الاقتصادية للمياه والبصمة المائية علاقة عكسية (معادلة القوة). بالنسبة للتحليل الأول ، كانت الطريقة الأكثر ملاءمة لتقييم الإنتاجية الاقتصادية للمياه هي طريقة مؤشر سعر الطاقة مع معامل ارتباط حوالي 0.98. وذلك نتيجة لعدم ثبات الاسعار داخل مصر وزيادة معدل التضخم فكانت طريقه مؤشر سعر الطاقه هي الاكثر ارتباطا بالبصمه المائية للمحاصيل تحت الدراسة. اما بالنسبة للتحليل الثاني فكانت الطريقة الأكثر ملاءمة لتقييم الإنتاجية الاقتصادية للمياه هي طريقة مؤشر صافي العائد مع معامل ارتباط حوالي 0.56. وتلك الطريقه هي الاكثر ارتباطا بالبصمه المائية للمحافظات تحت الدراسة.