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How evapotranspiration process may affect the estimation of water footprint indicator in agriculture?

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ABSTRACT

A critical component of water footprint (WF) indicator is the green WF that refers to the total rainwater evapotranspiration (ET) plus the water incorporated into the crop. From the definition of the WF the ET rate of an irrigated cropland needs to be reliably quantified especially in water scarce regions like Chania Valley in Crete. Based on this concept, different scenarios in terms of water consumption (basic and future) and hydrological conditions (average and dry) were evaluated. Furthermore, the WF was estimated, by applying different methods to calculate ET and effective rainfall, in order to determine whether the choice of the applied method may affect the agricultural WF estimation and lead to different outcomes as far irrigation water management practices. In this analysis, the WF was proven to be a useful tool as it is a multidimensional indicator [1], by determining the volume and the type of water use per ton of agricultural product. Furthermore, it was proved that the classification of crops (in terms of water consumption) varies slightly depending on the calculation method of different WF parameters. The actual ET is the most accurate option, since it takes into account the frequency and amount of irrigation and the soil moisture used by the crop. Finally, the variations between the various ET methods in the estimation of WF does not significantly alter the decisions related to the possible management plan of water resources of a region and the restructuring plan of crops in the policy-maker level.

Keywords: Water footprint (WF); Actual evapotranspiration (ET); Blaney–Criddle; Hargreaves; FAO Penman–Monteith; CROPWAT; Effective rainfall; Irrigation water management practices

1. Background

Freshwater is considered in many places to be a scarce and overexploited natural resource that needs to be properly managed. In order to achieve an optimum water resources management in a region, it is crucial to measure the level of human appropriation of fresh water capital. In Greece, the agriculture domain is one of the most significant domains regarding the water consumption. The water consumed in agriculture is

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87%, in tourism 10%, and in industry 3%. During dry summer periods, the irrigation needs are greater and as a result the pressure in water resources is increased [2].

The water footprint (WF) of a crop is an empirical indicator introduced by Hoekstra that estimates when, where, and how much freshwater is consumed and could be used as a tool for evaluating an agricultural policy plan [3]. WF of a product or a service consists of three components: (a) the blue WF which is the volume of freshwater that is consumed from the global blue water resources (surface water and ground water) to produce goods, (b) the green WF which is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture), and (c) the grey WF which is the volume of polluted water that is associated with the production of goods. The latter can be estimated as the volume of water that is required to dilute pollutants to such an extent that the quality of water recipient remains at or above agreed water quality standards [1]. Based on WF calculation the most water intensive crops (with the largest total WF), the most polluted (with the largest grey WF), and those that put extensive pressure on water resources of a region (with the largest blue WF) could be identified. The evapotranspiration (ET) of crop as well as the effective rainfall during cultivation period have to be calculated in order to estimate the agricultural WF of a region. Numerous empirical or semi-empirical equations have been developed to estimate the ET based on climate data.

In the present paper, the WF is used as a tool to evaluate water resources management practices in Chania Plain, which is considered one of the most developed agricultural areas in Greece. The aim of this study is to explore and assess the potential of the WF concept to be used as a reliable and convenient indicator for the development of an optimal agricultural policy focusing on the optimal water resources management of the region. Based on this concept, the restructuring of cropland is studied in terms of water consumption which was calculated for four different scenarios (basic-dry (BD), basic-average (BA), future-dry (FD), and future-average (FA)). Furthermore, the WF is calculated, for each crop, by applying different empirical methods to calculate ET (e.g. Blaney–Criddle, Hargreaves, Penman–Monteith) and effective rainfall, in order to determine whether the choice of the applied method may lead to different conclusions regarding water resources management.

2. The Chania plain

The Chania plain is a relatively level landform spreading southward from the city of Chania on the island of Crete, as shown in Fig. 1. This plain is considered to be one of the most developed agricultural areas of Greece that faces impacts of water scarcity due to the extended irrigation networks. The expansion of tourism facilities and the intense construction of main residence leave no space for expansion of collaborative irrigation networks. However, some networks expansions will have been completed until 2016. In addition, restructuring of the irrigated land is in progress [4]. The area of agricultural land in Chania plain according to National Statistical Service of Greece is about $165 \times 10^6\,m^2$. The crops mainly cultivated in the area are olives, citrus, and grapes. According to the proposed restructuring of the irrigated land [4], citrus will be replaced by avocado crops and most of irrigated olives will be turned into rain-fed olives. The present analysis compares the water consumption in agriculture for the currently applied agriculture policy (basic scenario) and the proposed one (future scenario when restructuring of irrigated land is completed) in order to determine if the proposed scenario leads to optimum water use. The water consumption is calculated based on the WF. Each scenario is studied for two hydrological conditions scenarios, a dry and an average one.

3. WF estimation based on ET and rainfall methodologies

In order to calculate the volume of water consumed in agriculture in each scenario, the WF of each crop is calculated. The water consumption is calculated by multiplying the WF ($m^3\,ton^{-1}$) by the weight of crops produced (ton) in a yearly basis (Table 1). The total water consumption in Chania Plain is calculated as the sum of the water consumed by all crops cultivated in the area. There are two different approaches for calculating the WF based on: (a) the irrigation requirements of the crop that should be fully met and (b) the water consumption for each crop that should be considered equal to actual ET [1]. In the present paper, the WF is calculated both ways, in order to determine the accuracy of each approach.

3.1. Estimation of the green WF

The green WF of a crop is calculated as the ratio of the volume of green water used for crop production, CWU_g (m^3/m^2), to the weight of crop produced, Y (ton/m^2).

$$WF_{green} = CWU_g / Y \quad (1)$$

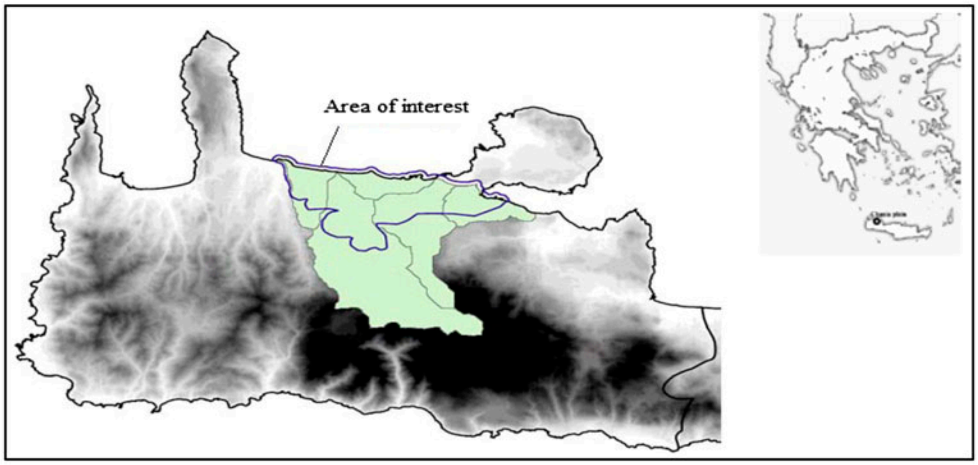

Fig. 1. Area of interest [5].

Table 1
Annual crop production (ton)

Crop	Crop production (ton)	
	Basic scenario	Future scenario
Irrigated olives	742	944
Rain-fed olives	1,576	1,421
Citrus	109,596	104,910
Avocado	5,070	7,760
Irrigated grapes	891	938
Rain-fed grapes	620	596
Hay	154	154
Alfalfa	3,312	3,323
Vegetables	16,951	16,951

The green water is calculated as the sum of green water use for each month, u_g (mm month^{-1}), over the entire crop period. Assuming that the irrigation requirements of the crop are fully met, the monthly water use is equal to the minimum between effective rainfall, P_{eff}, and crop evapotranspiration, ET_c [6].

$$u_g = \min\ (P_{\text{eff}}, \text{ET}_c) \tag{2}$$

3.1.1. Evapotranspiration

The aim of this analysis is to determine whether the choice of the method to estimate ET may lead to different conclusions regarding the water management needs. In Chania Plain, three different empirical methods to calculate ET (Blaney–Criddle, Hargreaves, FAO Penman–Monteith) were applied.

The Blaney–Criddle method is based on an empirical equation and is the most common method for calculating ET. The ET of a crop, ET_c (mm d^{-1}), according to Blaney–Criddle equation [7], depends on the crop coefficient, K_c, the mean daily temperature, T_α (°C), and the mean daily percentage of annual daytime hours, P. However, according to Brouwer and Heibloem, this method provides only a rough estimate or "order of magnitude" [8].

$$\text{ET}_c = K_c\ (32 + 1.8T_\alpha) \cdot P/3.94 \tag{3}$$

The Hargreaves equation is also based on an empirical method that estimates the reference potential ET of a crop, ET_o (mm d^{-1}) and is a temperature-based method [9]. The ET is a function of the extraterrestrial solar radiation, RA (mm d^{-1}), the maximum daily air temperature, $T_{\max}$ (°C), the minimum daily air temperature, $T_{\min}$ (°C), and the mean daily temperature, T_α (°C). According to Tabari [10], the Hargreaves equation is a precise model under warm humid and semi-arid climatic conditions, but a less accurate model in estimating ET in cold humid climate.

$$\text{ET}_o = 0.0023\ \text{RA}\ (T_\alpha + 17.8)\ \sqrt{(T_{\max} - T_{\min})}] \tag{4}$$

The Penman–Monteith method is the most widely used method but also the one that demands precise climatic data such as the mean temperature, T_α (°C), humidity, U (%), sunshine, n (h/d), wind speed, u (m/s). The method requires many data components which may result in complex calculations. CROPWAT model uses this method to estimate ET of crops [11].

3.1.2. Effective rainfall

In this analysis, there are also applied different methods to estimate effective rainfall. The first method applied is based on Eq. (5), proposed by the USDA. According to this equation, the monthly effective rainfall depends on rainfall, P_t (mm/month), and the monthly ET_c [12]. This method was chosen to be applied in combination with Blaney–Criddle and Hargreaves ET equations where the factor $f(D)$ is considered to be equal to 1.

$$P_{\text{eff}} = f(D)\ [1.25\ P_t^{0.824} - 2.93]\ [10^{0.000955\ \text{ET}_c}] \tag{5}$$

When Penman–Monteith equation is used to estimate ET effective rainfall then is calculated based on monthly rainfall only data [13].

$$P_{\text{eff}} = P_t\ \frac{125 - 0.2P_t}{125},\ P_t \leq\ 250\ \text{mm} \tag{6}$$

$$P_{\text{eff}} = 125 + 0.1\ P_t, P_t > 250\ \text{mm} \tag{7}$$

3.2. Estimation of the blue WF

The blue WF ($m^3\,ton^{-1}$) is similarly defined to the green WF [1].

$$\text{WF}_{\text{blue}} = \text{CWU}_b/Y \tag{8}$$

The blue water used for the production of a crop, CWU_b, represents the crop's irrigation requirement. The monthly blue water used for the production of a crop, assuming that the irrigation requirements of the crop are fully met, is considered zero, if the entire crop ET requirement is met by the effective rainfall [1].

$$u_b = \max\ (0, \text{ET}_c - P_{\text{eff}}) \tag{9}$$

3.3. Estimation of the blue and green WF, based on the actual ET

For irrigated agriculture, it is assumed that the irrigation requirements of the crop are fully met. However, farmers may apply less than the amount of water needed, in particular in those regions where water is scarce. The assumption that the irrigation water applied is sufficient enough to meet the irrigation requirements may lead to an overestimation of the blue WF [14].

In case that the irrigation requirements of the crop are not fully met, the blue water use should not be calculated through Eq. (9). Instead, CROPWAT model can be used to calculate the green and blue water used in agriculture, considering the applied irrigation practices. In the area of study, the irrigation depth per month does not satisfy irrigation requirements of each crop. For this reason, the 'irrigation schedule CROPWAT option' is used to estimate green and blue water, in order to calculate the actual WF. The model does not work with the concept of effective precipitation. Instead, the model includes a soil water balance which keeps track of soil moisture content over time using a daily time step [1]. Consequently, using this option, the soil moisture is taken into account while estimating the green water use, CWU_g. For example, for a period with rainfall higher than the one needed in order to cover the water needs of the crop, then an amount of the water that is not used by the crop is stored as soil moisture and it can be used by the crop later.

The green water evapotranspiration, ET_{green}, the blue water evapotranspiration, ET_{blue}, and the total evapotranspiration, ET_a, are estimated based on the CROPWAT's results. The total evapotranspiration, ET_a, is equal to what is called 'actual water use by crop' in the model output.

$$\text{ET}_a = \text{actual water use by crop} \tag{10}$$

Rain-fed conditions are simulated by the model by choosing the 'no irrigation' schedule option.

$$\text{ET}_{\text{green}} = \text{ET}_a \tag{11}$$

$$\text{ET}_{\text{blue}} = 0 \tag{12}$$

Irrigated conditions can be simulated by specifying the irrigation schedule. The blue and green water, consumed by the crop, can be calculated through Eqs. (13) and (14) [1]. Total net irrigation and irrigation requirements are defined by CROPWAT model.

$$\text{ET}_{\text{blue}} = \min\ (\text{total net irrigation, actual irrigation requirement}) \tag{13}$$

$$\text{ET}_{\text{green}} = \text{ET}_a - \text{ET}_{\text{blue}} \tag{14}$$

The input data to CROPWAT, required for the calculation of actual ET, are related to the climate (mean temperature, T_α (°C), the humidity, U (%), the sunshine,

n (h/d), and the wind speed, u (m/s)), the soil type (total available water, the infiltration rate, the maximum rooting depth, and the initial soil moisture depletion), the irrigation system (irrigation frequencies, irrigation application depths, and maximum crop height), the rainfall (monthly rainfall, P (mm/month)), and the crop (crop coefficient, K_c, the stages length, the planting date, the critical depletion factor, p, rooting depth, yield response factors, K_y) [15].

3.4. Estimation of the grey WF

The grey WF ($m^3\,ton^{-1}$) of a crop depends on fertilization rate applied to the field per acre, AR (kg/m^2) where α is the leaching-run-off fraction, c_{max} ($mg\,l^{-1}$) is the maximum acceptable concentration, c_{nat} ($mg\,l^{-1}$) is the natural concentration for the pollutant considered in the receiving water body, and Y is the crop yield [1].

$$WT_{grey} = (\alpha \cdot \ AR)/(c_{max} - c_{nat})/Y \qquad (15)$$

4. Results analysis

The WF of crops in Chania Plain is calculated for different scenarios in terms of water consumption (basic and future) and hydrological conditions (average-dry) were evaluated. The water consumption in the basic scenario refers to the water consumed for the production of crops cultivated in the Chania Plain, according to the applied agriculture policy. The water consumption is also estimated for the future scenario in order to study the restructuring of the cropland in terms of water consumption; in other words, in the future scenario, citrus are replaced by avocado crops and most of irrigated olives are turned into rain-fed olives and, as a result, the annual crop production in a yearly base differs from annual crop production on the basic scenario. The basic and the future scenarios are studied for two different hydrological conditions (average and dry). In the average hydrological conditions, the monthly amount of rainfall is equal to the mean monthly rainfall, whereas for the dry hydrological conditions, the monthly rainfall is considered 20% less than the average.

4.1. WF and water consumption in agriculture based on Blaney–Criddle equation

In Table 2, the WF of each crop is estimated, assuming that the irrigation needs of crops are fully met, for the average (A) and the dry (D) hydrological conditions, respectively. The estimation of ET and effective rainfall was based on Eqs. (3) and (5) respectively. Blue WF is calculated only for the irrigation season.

As shown in Fig. 2, comparing the water consumed under dry and average hydrological conditions, the green water consumed in dry conditions (D) is about 15% less than the green water consumed in average conditions (A) for both scenarios. On the contrary, the blue water consumed is about 3% increased. The grey water consumption is not affected by the hydrological conditions.

Comparing the future (F) and the basic (B) scenario based on water consumption, it is observed that the restructuring of the irrigated land leads to reduction of green and grey water consumption in the Chania plain. However, the reduction is limited to 1% concerning green water consumption and about 2.5% concerning the grey water consumption. The blue water consumption is increased about 1%. Thus, the future scenario seems to be a better scenario based on the total water consumption.

4.2. WF and water consumption in agriculture based on Hargreaves equation

In Table 3, the WF of each crop is estimated for the average (A) and dry (D) hydrological conditions, based on the Hargreaves equation in order to estimate the monthly ET of the crop. For the irrigation period, it is assumed that the irrigation water applied in the area is sufficient enough to cover crop's water needs. As a result, the effective rainfall is calculated based on Eq. (5).

Fig. 3 shows that in dry periods, the green water consumed is about 10% less than the green water consumed in average conditions. On the contrary, an increase of 5% is observed, concerning the blue water. The reduction of the rain water consumption implies the increase of the irrigation water consumption, in order to satisfy the crop needs. Comparing the future and the basic scenarios with respect to water consumption not only dry hydrological conditions put additional pressure on the surface and groundwater resources but also the restructuring of cropland in the future scenario reduces the green and grey water consumption approximately 1% and 2.5%, respectively.

4.3. WF and water consumption in agriculture based on Penman–Monteith equation

In Table 4 the WFs of crops are estimated, based on the methods adopted by CROPWAT model. The Penman–Monteith equation is used for calculating the

Table 2
WF (m^3/ton) and water consumption in agriculture based on Blaney–Criddle equation for average and dry hydrological conditions

Crop	WF_{green}		WF_{blue}		WF_{grey}	WF_{total}	
	Average	Dry	Average	Dry	Average/Dry	Average	Dry
Irrigated olives	3,990.17	3,525.11	2,751.01	2,910.25	6,116.21	12,857.39	12,551.56
Rain-fed olives	5,985.26	5,287.66			9,174.31	15,159.57	14,461.97
Citrus	196.39	162.00	246.37	253.54	286.70	729.46	702.23
Avocado	236.90	199.45	406.35	419.44		643.26	618.89
Irrigated grapes	60.40	52.53	388.93	396.80		449.33	449.33
Rain-fed grapes	90.61	78.80				90.61	78.80
Hay	709.17	630.61				709.17	630.61
Alfalfa	108.54	86.97	925.31	946.88		1,033.85	1,033.85
Vegetables	13.10	11.14	165.46	167.42	196.59	375.15	375.15

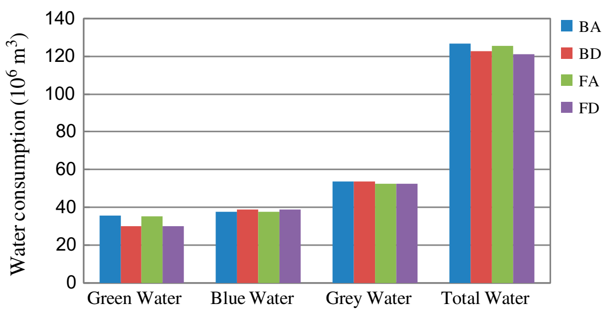

Fig. 2. Comparison of water consumption for basic (B) and future (F) scenarios, average (A) and dry (D) hydrological conditions—Blaney–Criddle method.

ET and Eqs. (6) and (7) for calculating the effective rainfall. As the irrigation water is sufficient enough to meet water needs, the blue water use is estimated through Eq. (9). Comparing the average and dry hydrological scenarios (Fig. 4), the conclusion is similar to previous ones based on Hargreaves and Blaney–Criddle equations. For the dry period, the green water consumed is about 7% less and the blue water about 2% more than the water consumed during the average period. Regarding the future and the basic scenario, the green water consumed is reduced about 1% and the grey water about 2.5%. Concerning the irrigation water, the future scenario proved to be more water intensive. The increase of the blue water consumption is about 7% for the average hydrological conditions and about 2% for the dry conditions. As a result, the evaluation of the water policy in Chania Plain leads to the conclusion that the crop restructuring causes less environmental stress (pollution), as less grey water is consumed in future scenario (Fig. 4), but requires greater use of the available water resources, as the blue water consumption is increased.

Table 3
WF (m^3/ton) and water consumption in agriculture based on Hargreaves equation for average and dry hydrological conditions

Crop	WF_{green}		WF_{blue}		WF_{grey}	WF_{total}	
	Average	Dry	Average	Dry	Average/Dry	Average	Dry
Irrigated olives	2,446.85	2,305.77	3,741.36	3,882.43	6,116.21	12,304.41	12,304.41
Rain-fed olives	3,670.27	3,458.66			9,174.31	12,884.58	12,632.97
Citrus	139.33	123.87	254.56	270.02	286.70	680.58	680.58
Avocado	164.80	147.18	306.56	324.19		471.37	471.37
Irrigated grapes	46.94	41.89	306.15	311.19		353.09	353.09
Rain-fed grapes	70.41	62.84				70.41	62.84
Hay	515.69	442.04				515.69	442.04
Alfalfa	97.48	81.80	713.13	728.81		810.61	810.61
Vegetables	11.17	9.30	130.79	132.66	196.59	338.55	338.55

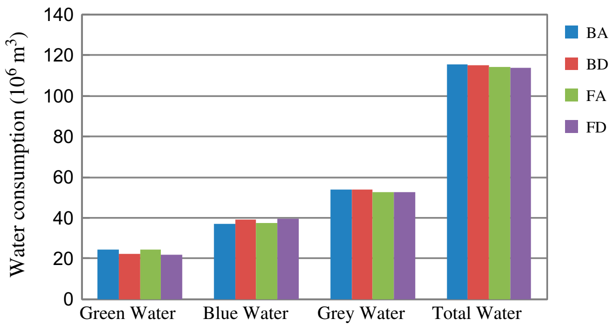

Fig. 3. Comparison of water consumption for basic (B) and future (F) scenarios, average (A) and dry (D) hydrological conditions—Hargreaves method.

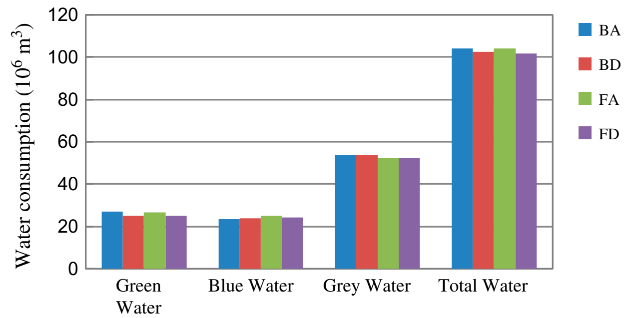

Fig. 4. Comparison of water consumption for basic (B) and future (F) scenarios, average (A) and dry (D) hydrological conditions—Penman–Monteith method.

4.4. WF and water consumption in agriculture based on actual ET

In Table 5 the WF for all crops is estimated via CROPWAT model. In this case, the calculated WF is the actual WF of crop, as the water used by crops is not calculated by assuming that the crop's water needs are fully met, but by considering the irrigation schedule and the soil moisture content.

As shown in Fig. 5, the green water consumed in dry conditions is about 1% less than the green water consumed in average conditions and blue water is increased about 2%. Regarding the future and the basic scenario, the green water consumed is reduced about 1% and the grey water about 2.5%. The increase of the blue water consumption is about 4% for the average hydrological conditions and about 2% for the dry conditions.

4.5. Benchmarking the WF calculation methods

In Fig. 6, the WF for nine crops estimated based on the various ET methods (Blaney–Criddle (Blan.), Hargreaves (Harg.), Penman–Monteith (Pen.), and actual ET (actual)) for average hydrological conditions are presented. Regardless of the ET method, rain-fed olives have the greater WF, whereas for the rest eight crops the corresponding WFs are significantly lower. The water consumption does not considerably vary depending upon the applied ET calculation methodology and it does not lead to different conclusions regarding water policy implementation. Actual ET seems to be the more accurate method as it is based on irrigation schedule and soil moisture. However, the data required by the CROPWAT model, mentioned in Section 3.3, proved difficult to be collected. Consequently, assumptions have been made such as the maximum infiltration rate is considered to be 50 mm/d, as proposed by FAO, and the initial soil moisture depletion is considered to be 10%. The influence of ET methodology in the estimation of WF for each crop is examined based on the current (basic) and the proposed (future) scenarios. Similar are the results for the dry hydrological conditions.

Table 4
WF (m^3/ton) and water consumption in agriculture based on Penman–Monteith equation for average and dry hydrological conditions

Crop	WF_{green}		WF_{blue}		WF_{grey}	WF_{total}	
	Average	Dry	Average	Dry	Average/Dry	Average	Dry
Irrigated olives	3,418.67	3,156.00	2,486.67	2,540.00	6,116.21	12,021.55	11,812.21
Rain-fed olives	5,128.00	4,734.00			9,174.31	14,302.31	13,908.31
Citrus	130.50	123.65	130.95	133.55	286.70	548.15	543.90
Avocado	181.94	173.38	295.44	304.00		477.38	477.38
Irrigated grapes	45.20	38.87	275.00	281.33		320.20	320.20
Rain-fed grapes	67.80	58.30				67.80	58.30
Hay	775.50	684.00				775.50	684.00
Alfalfa	133.50	108.90	672.70	697.30		806.20	806.20
Vegetables	16.40	13.31	176.03	179.11	196.59	389.02	389.02

Table 5
WF (m^3/ton) and water consumption in agriculture using CROPWAT model for average and dry hydrological conditions

Crop	WF_{green}		WF_{blue}		WF_{grey}	WF_{total}	
	Average	Dry	Average	Dry	Average/Dry	Average	Dry
Irrigated olives	4,793.64	4,806.79	2,823.40	2,597.52	6,116.21	13,733.25	13,520.52
Rain-fed olives	9,202.00	8,594.00			9,174.31	18,376.31	17,768.31
Citrus	165.87	156.16	130.93	134.45	286.70	853.50	577.31
Avocado	198.51	187.23	238.75	250.72		437.26	437.95
Irrigated grapes	134.79	125.48	166.63	166.60		301.42	292.08
Rain-fed grapes	272.80	265.60				272.80	265.60
Hay	1,126.00	1,126.00				1,126.00	1,126.00
Alfalfa	217.12	238.47	521.06	498.70		738.18	737.17
Vegetables	26.28	23.11	78.51	88.11	196.59	301.38	307.81

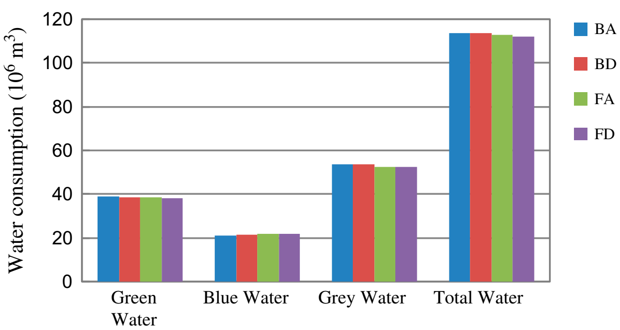

Fig. 5. Comparison of water consumption for basic (B) and future (F) scenarios, average (A) and dry (D) hydrological conditions—actual evapotranspiration.

As shown in Fig. 7, the water consumption in the future scenario (F) is slightly lower than the one in the basic scenario (B), for average (A) hydrological conditions. Similar are the results for the dry conditions also. As a result, the comparison of basic and future water consumption leads to the conclusion that the future scenario is less water intensive, no matter the ET method used. In Table 6, the percentage of variation between the basic and the future water consumption is shown. The percentage variation of the blue, the green, and total water consumption differs due to the applied ET method. The grey water consumption is decreased about 2.5% due to the variation of crops' production, regardless the ET method, since the grey WF is not a function of ET and effective rainfall (Table 6).

5. Discussion

Sustainable water resources management in a highly cultivated region requires knowledge of physical processes (e.g. evapotraspiration) and also assumes adequate hydrological data collection (e.g. temperature, soil water content, and humidity). The use of WF

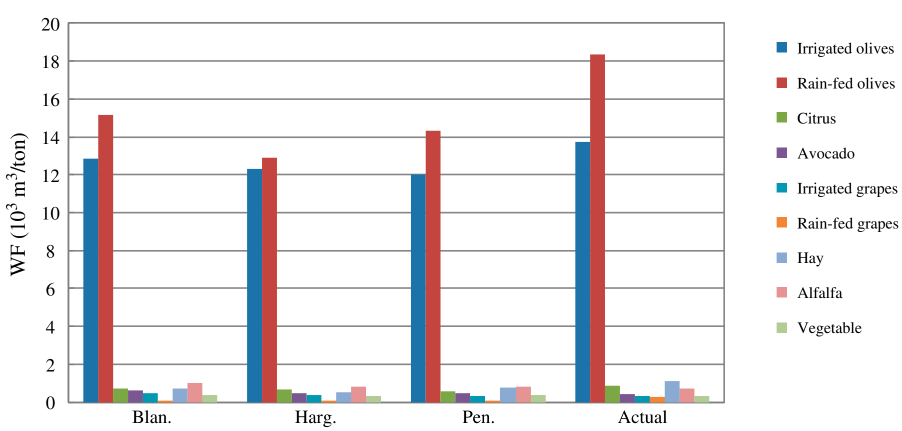

Fig. 6. WF of crops (10^3 m^3/ton), calculated through different methods for average hydrological conditions (after [5]).

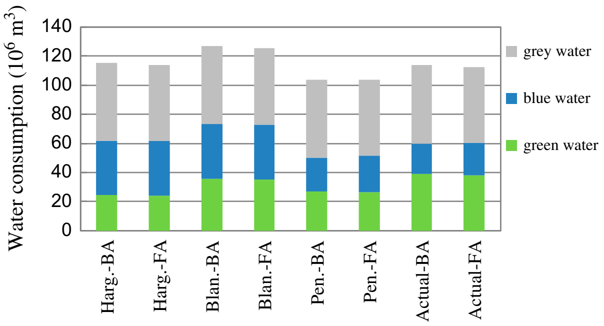

Fig. 7. Water consumption (10^6 m^3) in agriculture—average hydrological conditions.

concept to evaluate alternative agricultural policies in a water sensitive region has been evaluated by Stathatou et al. (2012) showing that each component of WF has to be studied separately in order to achieve a sustainable irrigation policy [16]. ET rather than actual ET is a common input for hydrologic models because it offers an upper limit to evapotranspirative water losses [17].

Special attention has been given by many researchers in the estimation of ET showing that it is a very sensitive procedure to parameters' measurements and data collection; therefore, the uncertainty associated with ET estimates could not be ignored. In the work of Douglas et al. (2009) for a range of land covers such as citrus, forest, grass in Florida, the Turc method significantly overestimates low daily PET values and underestimates high values, whereas the Priestley–Taylor method appears to best estimate PET in these regions [17].

Gagulas et al. (2013) applied the Turc and modified Thornthwaite, two main empirical methods for the estimation of the ET rate in an environmentally sensitive basin in Western Macedonia, Greece. Their analysis showed that the calculated values of real ET based on Turc method were slightly higher than the ones calculated by Thornthwaite [18]. The comparison also of the Priestley–Taylor and Penman–Monteith methods for wet sloping grassland proved that by imposing an annual cycle in the surface resistance parameter and the alpha factor, an improvement in the estimated ET rate may occur [19]. The simplified method proposed by FAO Penman–Monteith and the Priestley–Taylor model showed a comparable fit to the observed data in a region located in Southern Italy. An over-prediction of about, respectively, 17% and 14% is calculated [20].

Maeda et al. (2011) evaluated three temperature-based ET methods (Blaney–Criddle, Hargreaves, and Thornthwaite) in Southeast Kenya where intense agricultural activity takes place. The land surface temperature (LST) data were retrieved from MODIS/Terra sensor. Based on their analysis Hargreaves method is considered the most appropriate for this area and the MODIS LST data were satisfactorily incorporated into this method [21]. Earth Observation data and the CROPWAT model were also used in two sites in Romania in order to estimate actual ET values based on the energy balance of the surface. The analysis showed that the ET_c values estimated based on the energy balance of the surface which uses NOAA–AVHRR satellite-derived data, are generally greater than those simulated by the CROPWAT model with relative errors of ± 10–15% [22].

Table 6
Water consumption differentiation of future scenario with respect to basic scenario for average and dry hydrological conditions

	Green water variation (%)	Blue water variation (%)	Grey water variation (%)	Total water variation (%)
Average hydrological conditions				
Blaney–Criddle	−1.0	+0.8	−2.5	−1.1
Hargreaves	−1.2	+0.7	−2.5	−1.2
Penman–Monteith	−0.7	+6.7	−2.5	~0
Actual evapotranspiration	−1.6	+4.3	−2.5	−1.0
Dry hydrological conditions				
Blaney–Criddle	−1.0	+0.9	−2.5	−1.1
Hargreaves	−1.1	+0.6	−2.5	−1.2
Penman–Monteith	−0.7	+2.4	−2.5	−1.0
Actual evapotranspiration	−1.2	+2.0	−2.5	−1.2

6. Conclusions

The WF was proven to be a useful tool to assess water use, by estimating the green, blue, and grey water consumption as a function of space and time. Therefore, the total WF on a crop level could be used as a rough indicator, in order to identify water pressures and propose restructuring strategies. The WF analysis in the Chania Plain led to the conclusion that the restructuring of the cropland leads to a better water resources management in the area of interest, as the total water consumption based on crops' WF tends to be smaller in the future scenario. Also, the reduction of grey water consumption obtained by the restructuring of the cropland confirms the reduced environmental pressure imposed in regional water resources.

The critical role of ET process in the hydrological water balance of a region remains still critical since ET fluxes are difficult to be predicted and quantified. Our analysis answers the imposed research question in the title by showing that variations between the various ET methods in the estimation of WF does not significantly alter the decisions in the policy-maker level related to the possible management plan of water resources of a region and the restructuring plan of crops.

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