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Water footprint assessment considering climate change effects on future agricultural production in Mediterranean region

M.P. Papadopoulou[a,*], D. Charchousi[b], V.K. Tsoukala[b], C. Giannakopoulos[c], M. Petrakis[c]

[a] *School of Rural and Surveying Engineering, National Technical University of Athens, Zografou 15780, Greece, email: mpapadop@mail.ntua.gr*
[b] *School of Civil Engineering, National Technical University of Athens, Zografou 15780, Greece*
[c] *Institute of Environmental Research and Sustainable Development, National Observatory of Athens, Palaia Penteli 15236, Greece*

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ABSTRACT

Climate change significantly affects every day's human activities such as agriculture and tourism by altering the composition and parameters of global atmosphere over long period of time. In Greece, a substantial part of the national gross domestic product comes from agricultural production the efficiency (e.g. crop yield) of which mainly depends on adequacy and sufficiency of resources such as water and soil fertility. In this concept, the water footprint (WF) could be used as a monitoring indicator to evaluate applied agricultural schemes and potential adaptation measures in cultivated regions in Greece with respect to consumption of freshwater resources and deterioration of water receptors considering climate change scenarios. In the present paper, agricultural WF in two plains in Crete, Messara and Chania, are calculated in order to estimate the environmental impacts of the currently applied agricultural schemes on freshwater resources and soil productivity in the two plains. The analysis was based on a climate change scenario that has been developed up to 2100 to assess the effects of precipitation and temperature variability on crop yield and consumption of freshwater resources in the two plains. The results analysis showed that for all the crops in both Messara and Chania plains the two components of WF, blue and green have a substantial contribution to the overall WF of crops. However, the changes in mean annual temperature and precipitation as they are estimated in the examined climate change scenario may affect the evolution of blue and green WF till 2100 by alternating the source of consumed water between water reserves and rainfall. In both also Cretan plains is observed that an estimation of future water needs based on WF indicator could be obtained considering the particular climate scenario only for irrigated crops due to the similar trend that is followed by temperature and total WF. A similar estimation could not be made for rain-fed crops due to the high variability in future precipitation values (low R^2). Finally, the impact of climate change with respect to WF estimation is considerably higher in water scarce areas like Messara plain. The crop yield sensitivity analysis for citrus demonstrated that there is no pattern by which it is possible to estimate their crop yield considering only mean monthly temperature and precipitation values. The crop yield is

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*Corresponding author.

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decisively influenced by the timing that the different rainfall and temperature events happened during the growing season. By concluding special concern should be paid on adaptation measures in local, regional, and national level in order to control the impact of climate change on crop yields.

Keywords: Water footprint (WF); Agricultural policy assessment; Climate change; Adaptation; Crop yield; Mediterranean region

1. Introduction

In the last United Nation Climate Change Conference held in Warsaw, the participating countries decided to initiate domestic preparation for their intended national contributions towards a new universal climate agreement, which will come into force in 2020 [1]. Special concern was paid to issues related to adaptation process that refers to adjustments in ecological and social-economical systems in response to expected or actual climate change and their impacts. The goal of the proposed adaptation activities should be mainly focusing on change in processes, practices, and structures to moderate potential damages in all sectors e.g. agricultural, industry, and tourism.

Agriculture is a sector that needs to be adapted in the new climate conditions by adopting agricultural practices and policies that will primarily safeguard natural resources for future generations and then help increase agricultural productivity (e.g. crop yield) in order to contribute to eradication of poverty. The most crucial impact of climate change on agriculture is related to changes in the water cycle and it needs to be considered within a wide context that includes water demand increase, degradation of water quality, and competitive water use at various levels [2]. In Greece, a substantial part of the national gross domestic product comes from agricultural production the efficiency of which mainly depends on adequacy and sufficiency of resources such as water and soil fertility. Agricultural sector should be the first to respond to challenges imposed by the accelerated increase of human activities on water resources.

Adaptation measures with respect to water management in agricultural sector could be established at various levels (e.g. farm, irrigation scheme, watershed/aquifer, river basin, and national levels). The increase in water demand in agriculture has altered the water balance in many watersheds and aquifers. In their analysis, Turral et al. [3] argued that adaptation practices at national level could only be obtained mainly throughout reallocation of water between or within sectors and strengthening of water right access. In this concept, the water footprint (WF) indicator could be used to evaluate applied agricultural schemes with respect to consumption of freshwater resources and deterioration of water receptors considering climate change scenarios. In the present paper, the agricultural WF in two highly cultivated regions in Crete e.g. Messara plain and Chania plain are estimated considering the two currently applied agricultural schemes. A developed climate change scenario up to 2100 has been also developed to estimate the potential effects of precipitation and temperature variability on freshwater resources and agricultural crop yield in the region.

2. Methodology

2.1. Agricultural WF estimation

The WF indicator as it introduced by Hoekstra in 2002 measures the total use of freshwater resources that is used to produce a good and/or a service and it consists of three components: (i) blue WF referring to the freshwater volume consumed from surface and subsurface water resources, (ii) green WF referring to the volume of rainwater consumed during the production process and (iii) gray WF referring to the volume of water that is required to dilute pollutants to such an extent that the quality of the water receptors remains above existing water quality standards [4].

A detailed analysis of the agricultural WF estimation in the two areas of interest, Chania plain and Messara plain are presented in Charchousi et al. [5] and Stathatou et al. [6] respectively. Chania plain is a relatively flat landform located southward from Chania Town in Crete (Fig. 1) with a cultivated land of 165 ha [7] and an expended collaborative irrigation networks with no serious water management issues. On the other hand, Messara Plain is located in the southwest part of Heraklion prefecture in Crete (Fig. 1) and it consists one of the most important agricultural regions in Greece with a cultivated area of 94 ha approximately. Due to the intense land cultivation and groundwater overexploitation, Messara plain faces serious water related problem e.g. water scarcity, groundwater level depletion, and water quality degradation. The irrigation needs are mainly covered by groundwater pumping wells.

Fig. 1. Messara plain and Chania plain, Crete [8].

In order to calculate the total water volume consumed for the cultivation of each crop, the corresponding WF is calculated. The total water consumption in both plains is calculated as the sum of the water consumed by all crops cultivated in each area of interest. Both plains are characterized as highly cultivated regions in Crete with serious water resources and soil fertility related issues. In Table 1, the most representative crops and their corresponding annual crop production are presented.

In the present paper, an assessment of current agricultural schemes applied to the two different plains in Crete is obtained based on the performance of WF indicator with respect to the developed climate change scenario described in the next section. A sensitivity analysis of crop yield variability due to climate change effects is also performed that considers monthly climate averages for certain dry and wet years.

2.2. Development of climate change scenarios

Present and future model output from the RACMO2 regional climate model (RCM) was used. This model was developed within the framework of the EU project ENSEMBLES where the National Observatory of Athens participated. RACMO2 was provided by the Royal Netherlands Meteorological Institute widely known as KNMI. The KNMI-RACMO2 regional climate model [9] is forced with output from a transient run conducted with the ECHAM5 Global Climate Model. The RCM model uses 40 vertical levels on a horizontal 95 × 85 (lat × lon) grid and has a horizontal resolution of 25 km. The selection of this specific model was based on an assessment performed within the ENSEMBLES project. All the models' ability to simulate the present climate was assessed and KNMI-RACMO2 was found to more accurately simulate climate and extremes for the Mediterranean region [10]. The model daily values of air maximum and minimum temperature, relative humidity, wind speed, and 24 h accumulated precipitation were used to calculate mean monthly output. In this study, a transient model simulation running from 1950 up to 2100 was utilized. The future period simulations are based on the IPCC SRES A1B scenario [11], which provides a good mid-line estimate for carbon dioxide emissions and economic growth [12].

Table 1
Annual crop production (ton)

	Crop production (ton)		Mean crop yield (ton/ha)	
Crop	Chania plain	Messara plain	Chania plain	Messara plain
Irrigated olive trees	742	900	0.75	0.75
Rain-fed olive trees	1,576	20	0.5	0.4
Citrus	109,596	1,900	20	20
Avocado	5,070	–	16	–
Irrigated vines	891	1,200	15	15
Rain-fed vines	620	144	10	4.8
Hay	154	–	2	–
Alfalfa	3,312	104	10	8
Vegetables	16,951	7,500	35	50
Total	138,912	11,768		

3. Results analysis

Agricultural production in both areas of interest are characterized by the cultivation of representative crops for the climate and soil characteristics of Crete such as olive trees and vines rain-fed and irrigated-citrus and vegetables. The qualitative characteristics of the species grown in these areas are particularly high that significant amounts of them are promoted to domestic and international markets. To maintain high levels of quality agricultural products such as olive oil, olives, wine, grapes, and early vegetables soils rich in nutrients and sufficient water quantities are set as prerequisites. Actions such as restructuring of agricultural production and integrated water management plans for the proper use and management of existing water resources are necessary to be immediately adopted. In this analysis, the suitability of WF indicator to assess climate change impacts to agricultural production in Crete is examined considering the effects on freshwater consumption.

3.1. Climatic parameters analysis

Based on the prevailing climate change scenario which has been previously analyzed and refers to the provision by 2100 of climatic parameters of temperature and precipitation in the two areas of interest, it is observed that (Fig. 2):

(1) The average annual temperature value is approximately one degree higher in Messara plain than Chania plain.
(2) There is a similar upward trend of average annual values of temperature in the two regions amounting to 0.3˚C/decade.
(3) The mean annual precipitation is higher in Chania (around 500 mm/years) than in Messara plain (around 300 mm/years).
(4) In contrast, the decreasing trend in annual total precipitation is higher in Chania plain with significant inter-annual variability, thus affecting the rate of evapotranspiration.
(5) The decreasing precipitation trend is higher in Chania plain (16 mm/decade) where more rainfall events occurred than in Messara (10 mm/decade). However, in Messara, the annual total precipitation reaches future values (around 200 mm/years) typical of arid or semi-arid regions in the present climate period.
(6) The average annual temperature over the period of study seem to conform to a linear relationship (R^2 ~ 0.8) in both plains, whereas R^2 values regarding the corresponding mean annual precipitation are significantly lower (~0.2). The R^2 values are expected due to the rather small inter-annual variability (year-to-year variation) of temperature and to the significantly larger inter-annual variability of precipitation.

This fact does not change our conclusions for a downward trend in precipitation but just indicates that as we are moving towards a warmer and drier climate, there will be years in-between with rather high precipitation amounts but the overall trend will still be a reduction in precipitation.

3.2. WF analysis

The main focus of this analysis is given to the impacts of climatic change parameters e.g. temperature and precipitation that may affect the blue and green WF components of a crop which are associated with freshwater consumption. For the purposes of this analysis, it is first assumed that crop yield will not vary in the future and also gray WF component that is

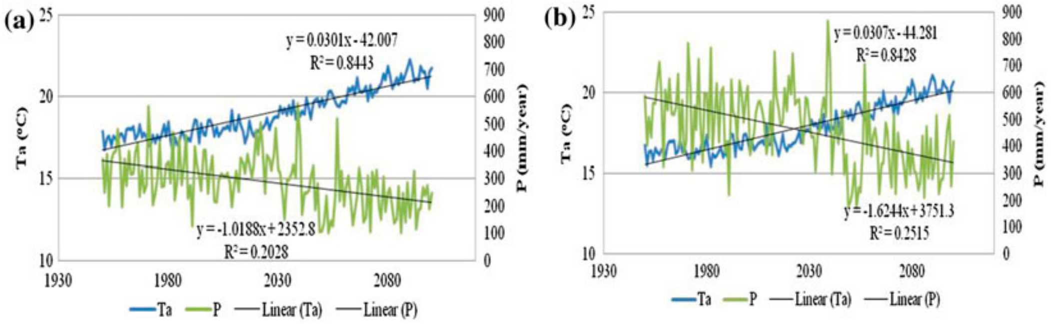

Fig. 2. Temperature and precipitation estimation based on examined climate change scenario for (a) Messara plain and (b) Chania plain.

associated with the pollution of water receptors due to the surface run-off of excessive quantities of chemical fertilizers applied to each crop will be constant over the period of the analysis. Then a sensitivity analysis concerning the climate change impacts on crop yield is also performed in Section 3.3.

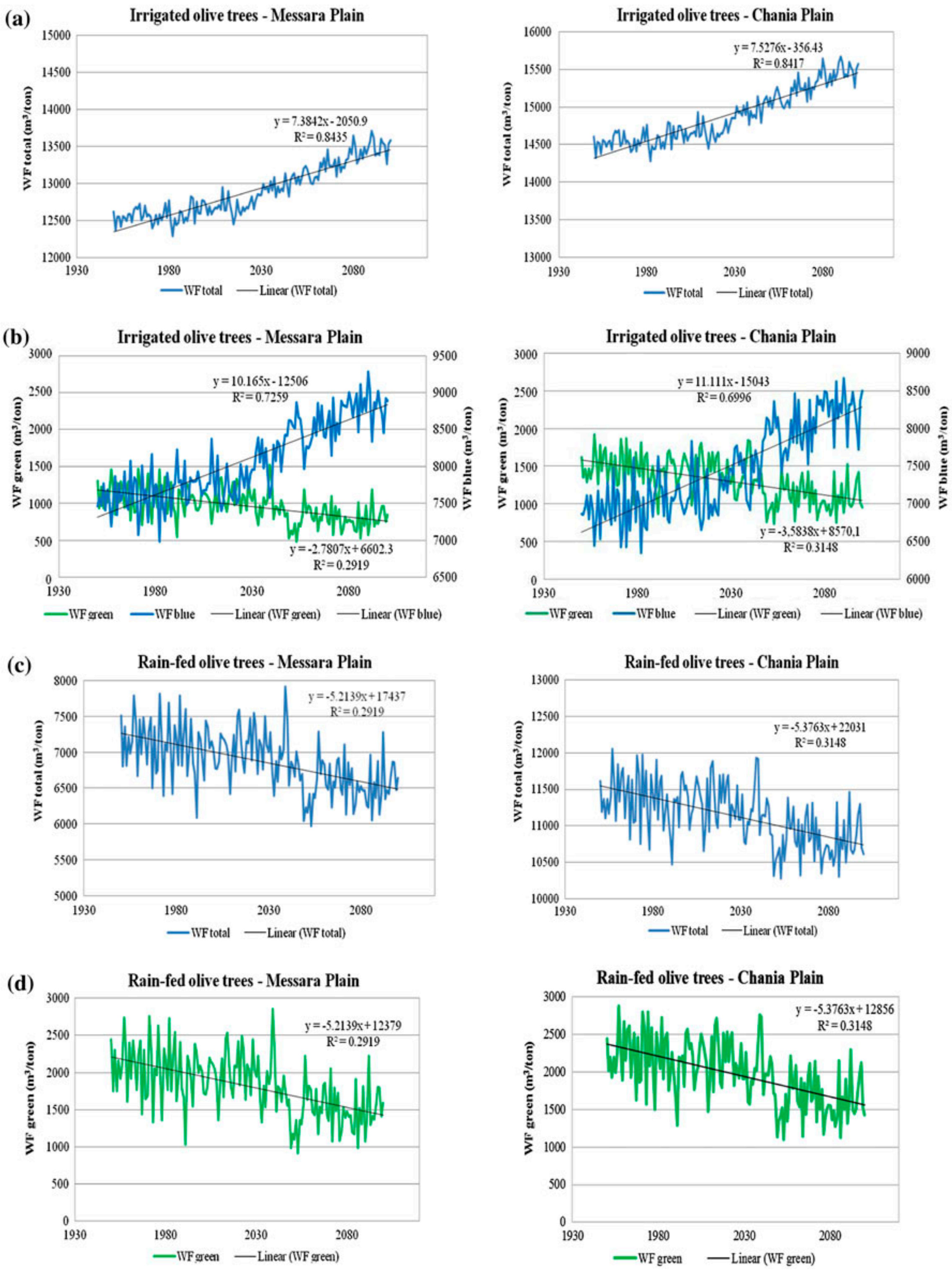

Fig. 3. Olive trees WF in Messara plain for irrigated (a) and rain-fed (c) and in Chania plain (b and d) cultivations.

Irrigated and rain-fed olives and vines are the two main crops found in the two plains. Based on the analysis of the prevailing climate change scenario, irrigated olive trees in both areas show an upward trend in terms of total WF estimations, whereas the total WF for rain-fed olives follows a downward trend similar to the corresponding decline trend of precipitation observed at each area of interest (Fig. 3(a) and (b)). Similar behavior is observed for vines (Fig. 4(a) and (b)). However, considering each component of WF separately, the blue WF component for the irrigated olive trees is characterized quite striking compared to the growth trend that temperature follows during the same period in both areas. At the same time, a significant reduction on yearly mean values of precipitation is observed affecting the green WF of rain-fed olive trees that follows a more rapid decline. On the other hand, the total WF for the irrigated olives increases in both areas following an identical trend even though the blue WF is estimated to be higher in Messara than in Chania plain (Fig. 3(a) and (b)). The analysis in both Cretan plains showed that an estimation of future water needs based on WF indicator could be obtained considering the particular climate scenario only for irrigated crops due to the similar trend that is followed by temperature and total WF. A similar estimation could not be made for rain-fed crops due to the high variability in future precipitation values (low R^2).

Regarding rain-fed crops, the decreasing precipitation rate as it is estimated by the examined climate change scenario for the coming years up to 2100 in conjunction with the observed gradual temperature increase for the same period contribute to a strong reduction of the corresponding WF of rain-fed crops (Figs. 3(c) and (d), and 4(c) and (d)). In particular, for rain-fed vines the water needs estimated by WF, are much higher in areas such as Messara plain with low crop yield (Fig. 4(c) and (d)). Although in this step of the analysis, the yield for all crops is assumed

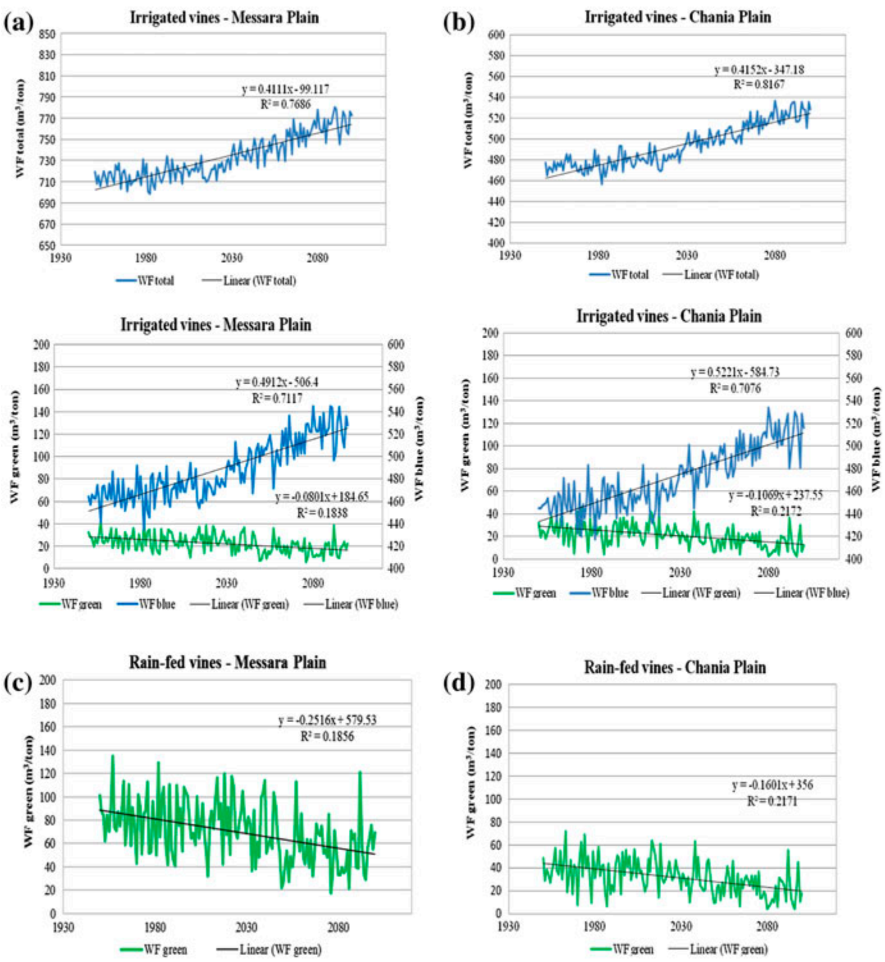

Fig. 4. Vines WF in Messara plain for irrigated (a) and rain-fed (c) and in Chania plain (b and d) cultivations.

constant to the current ones, however an impact in the quality of cultivated rain-fed agricultural products is expected in the future.

A key element of Cretan agricultural production and farmers' income is the cultivation of citrus especially in Chania plain where the annual production exceeds 100,000 tons. In a particularly rainfall poor region such as Messara plain, the water needs of irrigated crops are historically covered mainly by freshwater resources. The situation is aggravated over the years based on the examined climate change scenario due to continuing rainfall decrease that is estimated for the region (Fig. 5(a)). On the other hand, the high rate of precipitation historically observed in Chania until today has resulted in the limited consumption of freshwater resources for irrigation purposes of crops such as citrus and olive trees (Figs. 3(b) and 5(b)).

Based on the total WF estimation for every crop examined in the two areas of interest, significant amounts of freshwater resources are consumed. A common conclusion of the analysis for all the crops in both Messara and Chania plains is that the two components of WF, blue and green, have a substantial contribution to the overall WF of crops. However, the mean annual increase in temperature and corresponding decrease in precipitation as they are estimated in the examined climate change scenario may affect the evolution of blue and green WF till 2100 by alternating the source origin of consumed water between water reserves and rainfall.

3.3. Crop yield sensitivity analysis

Climate change affects not only water resources quality and availability but also introduces changes in plant productivity. The severity of climate change effects on plants will vary between regions depending upon the preexisting climatic conditions and the adaptation potential of local cultivated species [13]. The findings of the report of the Bank of Greece [14] for the environmental, economic, and social impacts of climate change in Greece noted that the average decline in agricultural production in Crete for representative crops such as olive trees, vines, and vegetables was estimated around 10% under the various examined climate change scenarios.

Previous research works have shown that climate change had a considerable negative impact globally on agricultural production of several crops such as wheat, maize, and barley [15]. The uncertainty associated with rainfall variability due to climate change is still significant and it is difficult to assess its impact on agricultural production [16]. However, many studies have emphasized that on warmer and drier years decreased yields are expected [16–18]. Also rising temperature alters the duration of crops growth stages and as a result final crop yield is reduced [19,20]. As

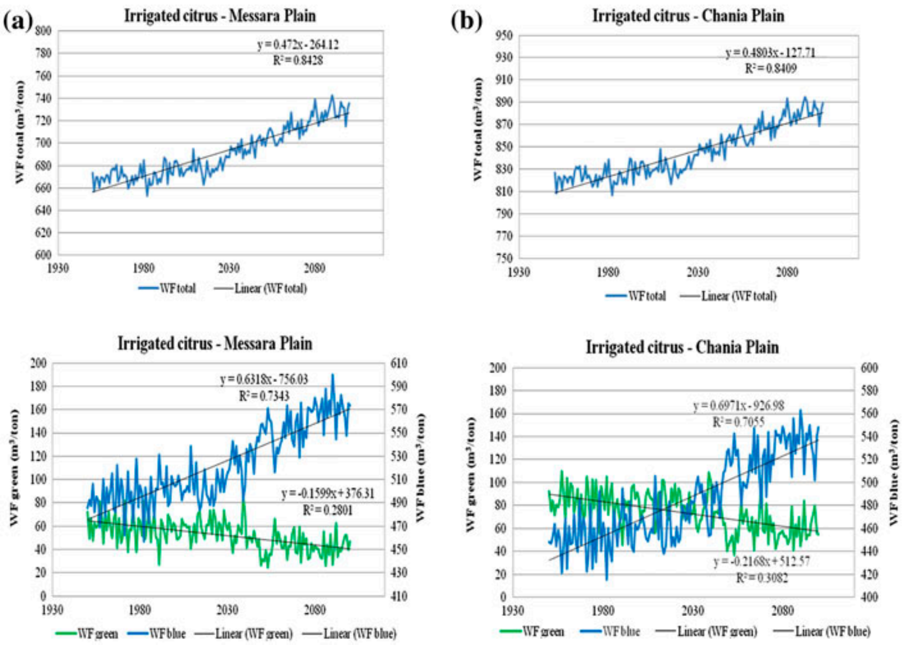

Fig. 5. Irrigated citrus WF in Messara plain (a) and in Chania plain (b).

far southern Europe, Supit et al. [21] proved that by the end of the century yields will decline and production may only be possible on the basis of irrigation water availability. Climate change impacts depend on species and region so adaptation measures such as changes in farm planning and developing new breeding lines should consider regional differences. Based on the review of Kang et al. [22], existing model results have shown that crop yield is more sensitive to precipitation than temperature future differentiation.

WF of a crop depends not only on water consumption, but on crop yield as well [4]. Also climate variation affects both water consumption and crop yield. It is therefore important to assess the impact of crop yield variability due to climate change on WF estimation. The response of yield to changes on temperature and precipitation can be estimated through empirical crop models. Lobell et al. [17] have developed a statistical model to estimate agricultural yield anomaly in crops cultivated in California based on temperature and precipitation. Due to similarities in climatic and agricultural parameters between the two regions (e.g. Crete and California), the proposed statistical crop yield anomaly model has been used in this analysis in order to get an estimate of citrus variability yield through time due to climate change effects. Then the impact on WF estimation due to the use of a modeled annual yield and a reference annual yield is quantified.

Based on the proposed model [17], citrus yield anomaly (Y, ton/ha) is calculated for future years based on precipitation and minimum temperature data according to the following empirical equation.

$$Y = 2.67T_{n-12} - 0.49T_{n-12}^2 + 12.3P_5^2 - 6.10 \tag{1}$$

where Y the yield anomaly (ton/ha), T_{n-12} the minimum temperature of the 12th month from the year prior to harvest (°C), and P_5 the precipitation of the 5th month (mm).

The adjusted citrus yield for different years is then calculated considering the computed citrus yield anomaly (Eq. (1)) and the corresponding reference yield for citrus which in this case is taken equal to the current one (20 ton/ha) as it is described in Section 3.2. Considering the adjusted citrus yield value, citrus WF in Chania and Messara plain was then estimated for the driest past years (1959, 1991) and the driest future years (2049, 2053 for Chania plain and 2053, 2086 for Messara plain) based on the developed climate change scenarios for the two plains.

The results analyses have shown that during dry years (1959, 1991) citrus yield was estimated lower than the reference one resulting in higher WF (Fig. 6). In 2049, a slightly increase in citrus yield is estimated in Chania resulting in lower WF compared to the WF estimated based on reference yield (Fig. 7(b)).

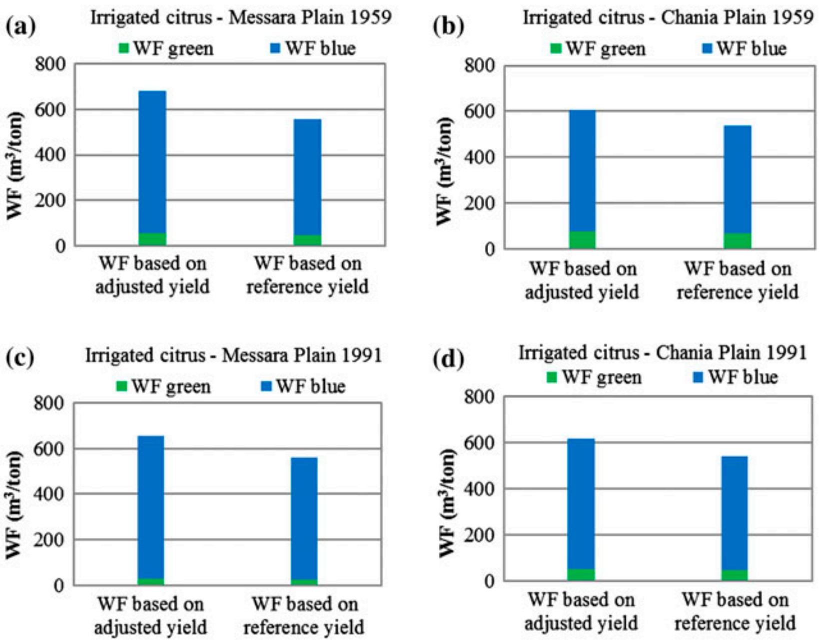

Fig. 6. Irrigated citrus WF calculated based on adjusted and reference citrus yield for Messara plain (a, c) and in Chania plain (b, d).

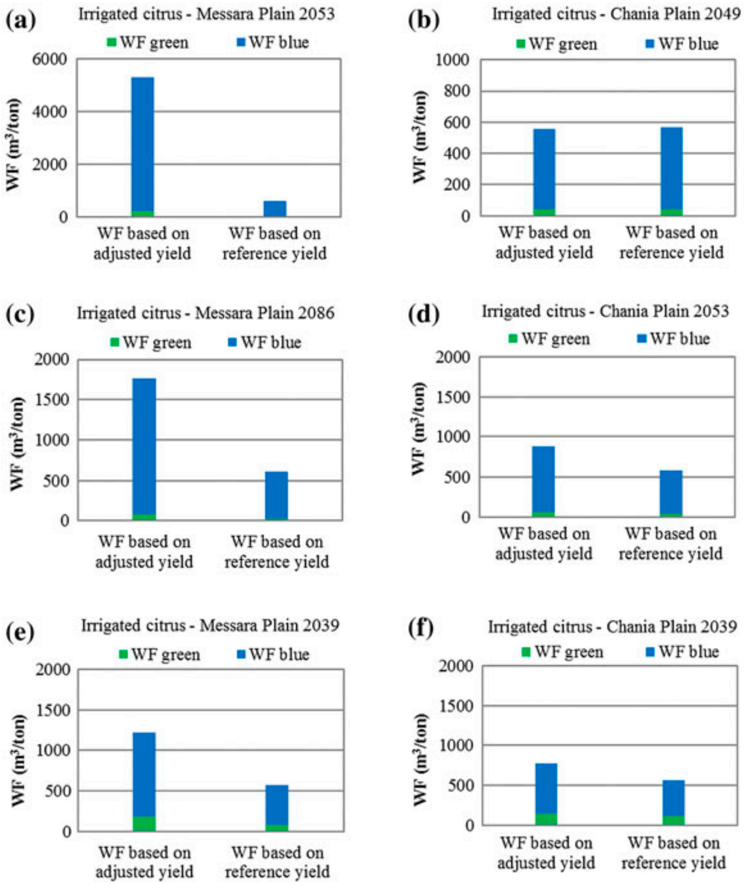

Fig. 7. Irrigated citrus WF calculated based on adjusted and reference citrus yield for Messara plain (a, c, e) and in Chania plain (b, d, f).

Although 2049 is estimated to be dry year, the increased yield is explained as an increase in precipitation in the 5th month of the year is estimated. In 2053, a significant low yield is calculated based on the expected climate condition, high temperature, and low precipitation rate, and as a result the corresponding WF of citrus cultivated in Messara plain is significantly increased (Fig. 7(a)). Finally, 2039 is estimated to be an extremely wet year. However, citrus yield is lower compared to the reference crop yield as the 12th month from the year prior to harvest is a particularly warm month and consequently an increased WF is expected (Fig. 7(e) and (f)).

It is clear from the analysis, that the influence of crop yield variability due to climate change conditions on WF estimation is crucial. In Table 2, the percentage

Table 2
Citrus WF variation for selected years considering yield variability

	Chania plain		Messara plain	
Year	WF_{total} variation (%)	Yield variation (%)	WF_{total} variation (%)	Yield variation (%)
1959 (dry year)	+13	−12	+22	−18
1991 (very dry year)	+14	−12	+17	−14
2039 (wet year)	+37	−27	+111	−53
2049 (dry year)	−2	+2		
2053 (very dry year)	+51	−34	+789	−89
2086 (dry year)			+188	−65

of variation, mainly increase for dry and wet years, of citrus WF that is estimated based on adjusted and reference crop yield is summarized. It is obvious that the impact of climate change with respect to WF estimation is considerably higher in water scarce areas like Messara plain. The analysis for citrus crops demonstrated that there is no pattern by which it is possible to estimate their crop yield considering only mean monthly temperature and precipitation values. The crop yield is decisively influenced by the timing that the different rainfall and temperature events happened during the growing season.

4. Conclusions

The current analysis showed that WF could be potential used as a monitoring indicator to evaluate applied agricultural schemes and potentially adaptation measures in highly cultivated regions in Greece e.g. Messara and Chania plains with respect to consumption of freshwater resources and deterioration of water receptors considering climate change scenarios. As Chuku and Okoye [23] proposed, adaptation measures such as (a) income/asset management, (b) government programs and insurance, (c) farm production practices, and (d) technological development should be adopted in different scales in order to assess the impact of climate change on yield especially on water scarce regions such the ones in Mediterranean basin and effectively limit future yield losses.

However, to ensure agricultural production and farmers' income in the two under consideration Cretan plains, climate change impacts such as desertification and seawater intrusion that decisively influencing the adequacy and the quality of freshwater resources should be immediately addressed.

References

[1] United Nations Climate Change Secretariat, UN Climate Change Conference in Warsaw keeps governments on a track towards 2015 climate agreement, Press Release (2013) 1–4.

[2] Food and Agriculture Organization (FAO) of United Nations, Climate-Smart Agriculture Sourcebook, FAO, Rome, 2013.

[3] H. Turral, J. Burke, J.M. Faures, Climate Change, Water and Food Security, FAO Water Report No. 36, FAO, Rome, 2011. Available from: <http://www.unwater.org/downloads/unw_ccpol_web.pdf. Accessed 15 February 2014>.

[4] A.Y. Hoekstra, A.K. Chapagain, M.M. Aldaya, M.M. Mekonnen, The Water Footprint Assessment Manual: Setting the Global Standard, Earthscan, London, 2011.

[5] D. Charchousi, V.K. Tsoukala, M.P. Papadopoulou, How evapotranspiration process may affect the estimation of water footprint indicator in agriculture? Desalin. Water Treat. 53(12) (2014) 3234–3243.

[6] P.-M.G. Stathatou, V.K. Tsoukala, M.P. Papadopoulou, A. Stamou, N. Spiliotopoulou, C. Theoxari, S. Papagrigoriou, An environmental approach for the management and protection of heavily irrigated regions, Global Nest J. 14(3) (2012) 276–283.

[7] National Statistical Service of Greece. Available from: <http://statistics.gr>. Accessed 4 March 2014.

[8] Available from: <http://www.travelinfo.gr/maps/crete.htm>. Accessed 31 May 2014.

[9] G. Lenderink, B. Van den Hurk, E. Van Meijgaard, A.P. Van Ulden, J.H. Cuijpers, Simulation of Present-day Climate in RACMO2: First Results and Model Developments, KNMI Technical Report 252, 2003, 24 pp.

[10] ENSEMBLES Deliverable D3.2.2: RCM-specific Weights Based on their Ability to Simulate the Present Climate, Calibrated for the ERA40-based Simulations. Available from: <www.ensembleseu.org>.

[11] N. Nakicenovic, J. Alcamo, D. Davis, B. De Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L Price, K. Riahi, A. Roehrl, H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. Van Rooijen, N. Victor, Z. Dadi, Special Report on Emission Scenarios, Working Group III of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, 2000, 595 pp.

[12] J. Alcamo, J.M. Moreno, B. Nováky, M. Bindi, R. Corobov, R.J.N. Devoy, C. Giannakopoulos, E. Martin, J.E. Olesen, A. Shvidenko, Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, in: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. Van der Linden, C.E. Hanson (Eds.), Cambridge University Press, Cambridge, 2007, pp. 541–580.

[13] K. Chartzoulakis, G. Psarras, Global change effects on crop photosynthesis and production in Mediterranean: the case of Crete, Greece, Agric. Ecosyst. Environ. 106 (2005) 147–157.

[14] Bank of Greece-Climate Change Impacts Study Committee, The Environmental, Economic and Social Impacts of Climate Change in Greece, Report, pp. 494. Available from: <http://www.bankofgreece.gr/BoGEkdoseis/ClimateChange_FullReport_bm.pdf 2011>. Accessed 22 February 2014.

[15] D.B. Lobell, Ch.B. Field, Global scale climate–crop yield relationships and the impacts of recent warming, Environ. Res. Lett. 2014002 (2007) 7 pp.

[16] P. Roudier, B. Sultan, P. Quirion, A. Berg, The impact of future climate change on West African crop yields: What does the recent literature say? Global Environ. Change 21 (2011) 1073–1083.

[17] D.B. Lobell, C.B. Field, K.N. Cahill, C. Bonfils, Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties, Agric. For. Meteorol. 141 (2006) 208–218.

[18] J. Hui, L. Er-da, T. Wheeler, A. Challinor, S. Jiang, Climate change modelling and its roles to Chinese crops yield, J. Integr. Agric. 12(5) 2013 892–902.

[19] A. Dalla Marta, M. Mancini, F. Natali, F. Orlando, S. Orlandini, From water to bioethanol: The impact of climate variability on the water footprint, J. Hydrol. 444–445 (2012) 180–186.

[20] L. Carlo, M. Fabio, D.H. Tracy, C. Andrea, H. Roland, L. Catalin, C. Costanza, A. Giuseppe, G. Giampiero, Climate change in Europe. 3. Impact on agriculture and forestry—A review, Agron. Sustainable Dev. 29 (2009) 433–446.

[21] I. Supit, C.A. Van Diepen, A.J.W. De Wit, J. Wolf, P. Kabat, B. Baruth, F. Ludwig, Assessing climate change effects on European crop yields using the crop growth monitoring system and a weather generator, Agric. For. Meteorol. 164 (2012) 96–111.

[22] Y. Kang, S. Khan, X. Ma, Climate change impacts on crop yield, crop water productivity and food security—A review, Prog. Nat. Sci. 19(12) (2009) 1665–1674.

[23] C.A. Chuku, C. Okoye, Increasing resilience reducing vulnerability in sub-Saharan African agriculture: Strategies for risk coping and management, Afr. J. Agric. Res. 4 (2009) 1524–1535.