WATER FOOTPRINT ASSESSMENT OF APPLIED AGRICULTURAL POLICIES BASED ON CLIMATE CHANGE SCENARIOS

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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. Special concern was paid from United Nations to issues relate to adaptation process that should be mainly focusing on change in processes, practices and structures to moderate potential damages in all sectors e.g. agricultural, industry and tourism. 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.

In this concept, the Water Footprint (WF) could be used as a monitoring indicator to evaluate applied agricultural schemes and potentially 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 current agricultural scheme 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 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.

Keywords: Water footprint (WF), climate change, adaptation, irrigation policy, agricultural policy assessment, Chania plain, Messara plain

1. Introduction

In the last UN Climate Change Conference held in Warsaw, the participant countries decided to initiate domestic preparation for their intended national contributions towards a new universal climate agreement, which will come into force from 2020 [1]. Special concern was paid to issues relate to adaptation process that refers to adjustments in ecological and social-economical systems in response to expect 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, tourism. The main components of adaptation are observation, assessment of climate impacts and vulnerability, planning, implementation, monitoring and evaluation of adaptation actions [2].

Agriculture is a sector that needs to be adapted in the new climate conditions by adopting agricultural practices and policies to safeguard natural resources such as water and soil fertility for future generations and by protecting the environment, helping increase the agricultural productivity and contributing 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 [3].

In response to the current challenges in regards to the effects of climate change the Common Agricultural Policy (CAP) that has been established since 1962 as an integrated agricultural policy for all European Union (EU) Member States sets new rules regarding to agricultural practices, agricultural products transfer and all outcomes that arise, such as price stability, quality of products, product selection and land use [4]. 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. In any case, the shift toward organic farming that is done by young mainly farmers to crops which are resistant to new climate conditions that now prevail in the Greek territory is an important parameter of the applied and proposed agricultural policies in the country. Agricultural sector should be the first to respond to the 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 water demand in agriculture has altered the water balance in many watersheds and aquifers. In their analysis, Turral et al. [5] 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 current 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 of the region.

2. Methodology

2.1 Agricultural WF estimation

The Water Footprint (WF) indicator as it introduced by Hoekstra in 2002 measures the total use of fresh water resources that is used to produce a good and/or a service and it is 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) grey 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 [6].

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. [7] and Stathatou et al. [8] respectively. 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.

2.2 Development of climate change scenarios

Present and future model output from the RACMO2 regional climate model (RCM) was also 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 x 85 (lat x lon) grid and has a horizontal resolution of 25km. 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 24h 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].

3. Chania and Messara Plains, Crete

Chania plain is a relatively flat landform located southward from Chania Town in Crete (Figure 1). The agricultural land is estimated about 165ha [13] with an expended collaborative irrigation networks. The main crops that are cultivated in the area are olive trees (irrigated-rainfed), citrus and vines. In order to calculate the total water volume consumed for the cultivation of a crop, the corresponding WF is calculated. The total water consumption in Chania Plain is calculated as the sum of the water consumed by all crops cultivated in the area.

Messara plain is located in the Southwest part of Heraklion Prefecture in Crete (Figure 1) and it consists one of the most important agricultural regions in Greece. Due to the intense land cultivation and groundwater overexploitation, the area 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. The cultivated area is approximately 94ha.

Figure 1. Messara Plain and Chania Plain, Crete [14].

Both Chania and Messara plains are characterized as highly agricultural developed areas 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. Infrastructure improvement and crop restructuring are proposed as the major alternative actions to reduce impacts of continuous increasing freshwater demand in Crete.

4. Results Analysis

The findings of the report of the Bank of Greece [15] for the environmental, economic and social impacts of climate change in Greece notes that the average decline in agricultural production in Crete for representative crops such as olive trees, vines and vegetables is estimated around 10% under the various examined climate change scenarios. 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. Maintaining high levels of quality agricultural products such as olive oil, olives, wine, grapes and early vegetables soils rich in nutrients and sufficient water to meet their water needs 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.

Table 1. Annual crop production (ton)

Crop	Crop production (ton)	
	Chania Plain	*Messara Plain*
Irrigated olive trees	742	900
Rain-fed olive trees	1,576	20
Citrus	109,596	1,900
Avocado	5,070	-
Irrigated vines	891	1,200
Rain-fed vines	620	144
Hay	154	-
Alfalfa	3,312	104
Vegetables	16,951	7,500
TOTAL	**138,912**	**11,768**

4.1 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 (Figure 2):

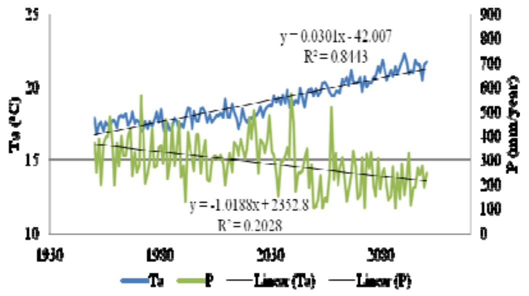
- The average annual temperature value is approximately one degree higher in Messara plain than Chania plain,

- There is a similar upward trend of average annual values of temperature in the two regions amounting to 0.3ºC per decade,

- The mean annual precipitation is higher in Chania (around 500mm/year) than in Messara plain (around 300mm/year),

- 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,

- The decreasing precipitation trend is higher in Chania plain (16mm/decade) where more rainfall events occurred than in Messara (10mm/decade). However, in Messara, the annual total precipitation reaches future values (around 200mm/year) typical of arid or semid-arid regions in the present climate period.


a)

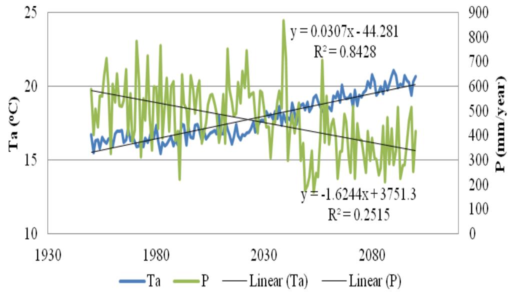

b)

Figure 2: Temperature and precipitation estimation based on examined climate change scenario for a) Messara Plain and b) Chania Plain

4.2 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 and are associated with fresh water consumption. For simplicity reason, it is assumed that crop yield and grey WF component that is associated with the pollution of water receptors due to the surface runoff of excessive quantities of chemical fertilizers applied to each crop are constant over the period of the present analysis.

Olives and vines are the two main crops found in the two areas of interest both in irrigated and rain-fed cultivation. 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. 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 bleu WF is estimated to be higher in Messara than in Chania Plain (Figure 3a and 3b). As far the total WF of rain-fed olive trees, it is progressively declined over the period of interest in both areas due to the reduction of precipitation rate and the increase of temperature based on the examined climatic change scenario affecting crop yield and quality characteristics of the final product (Figure 3c and 3d).

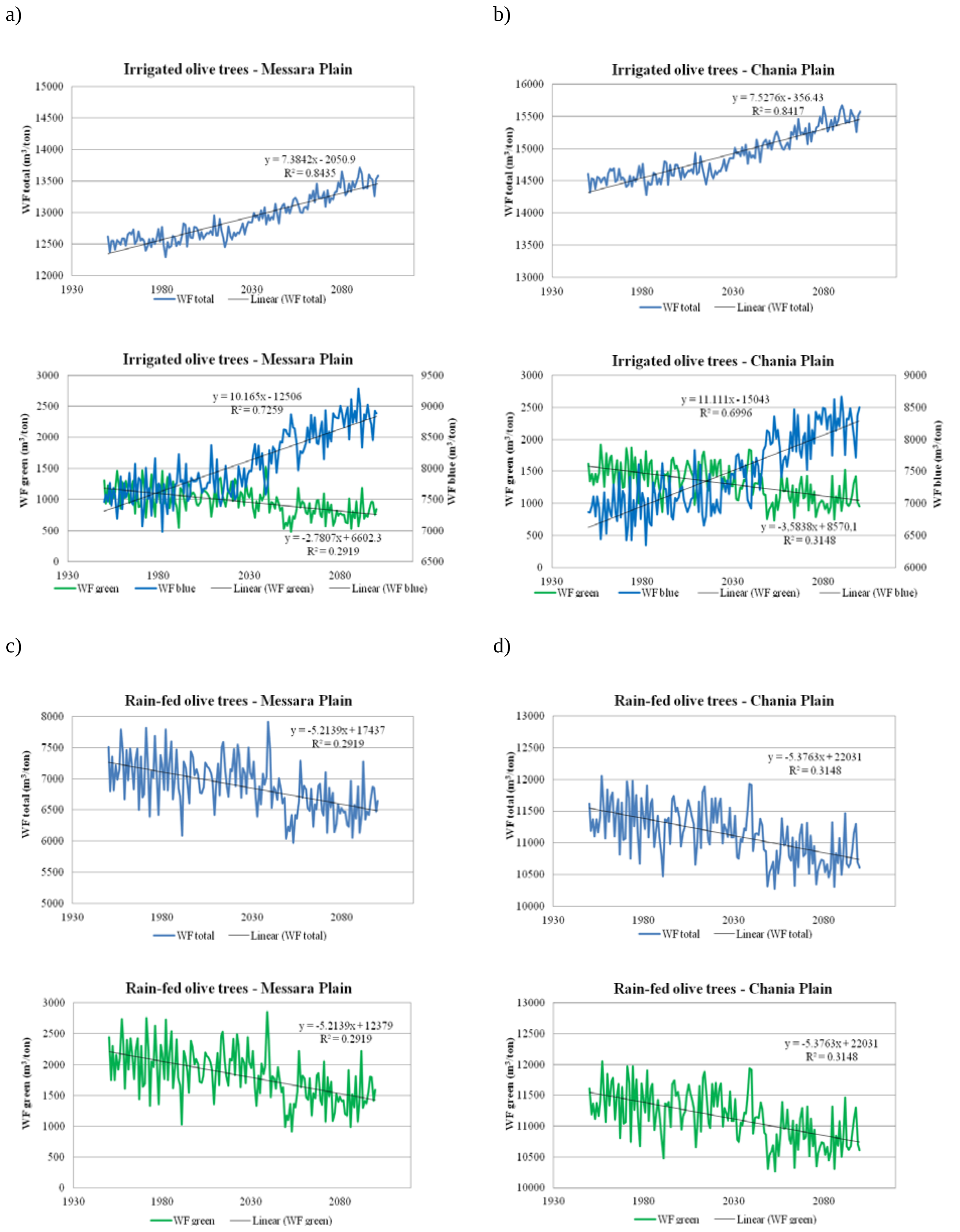


Figure 3: Olive trees WF in Messara Plain for irrigated (a) and rain-fed (c) and in Chania Plain (b and d) cultivations

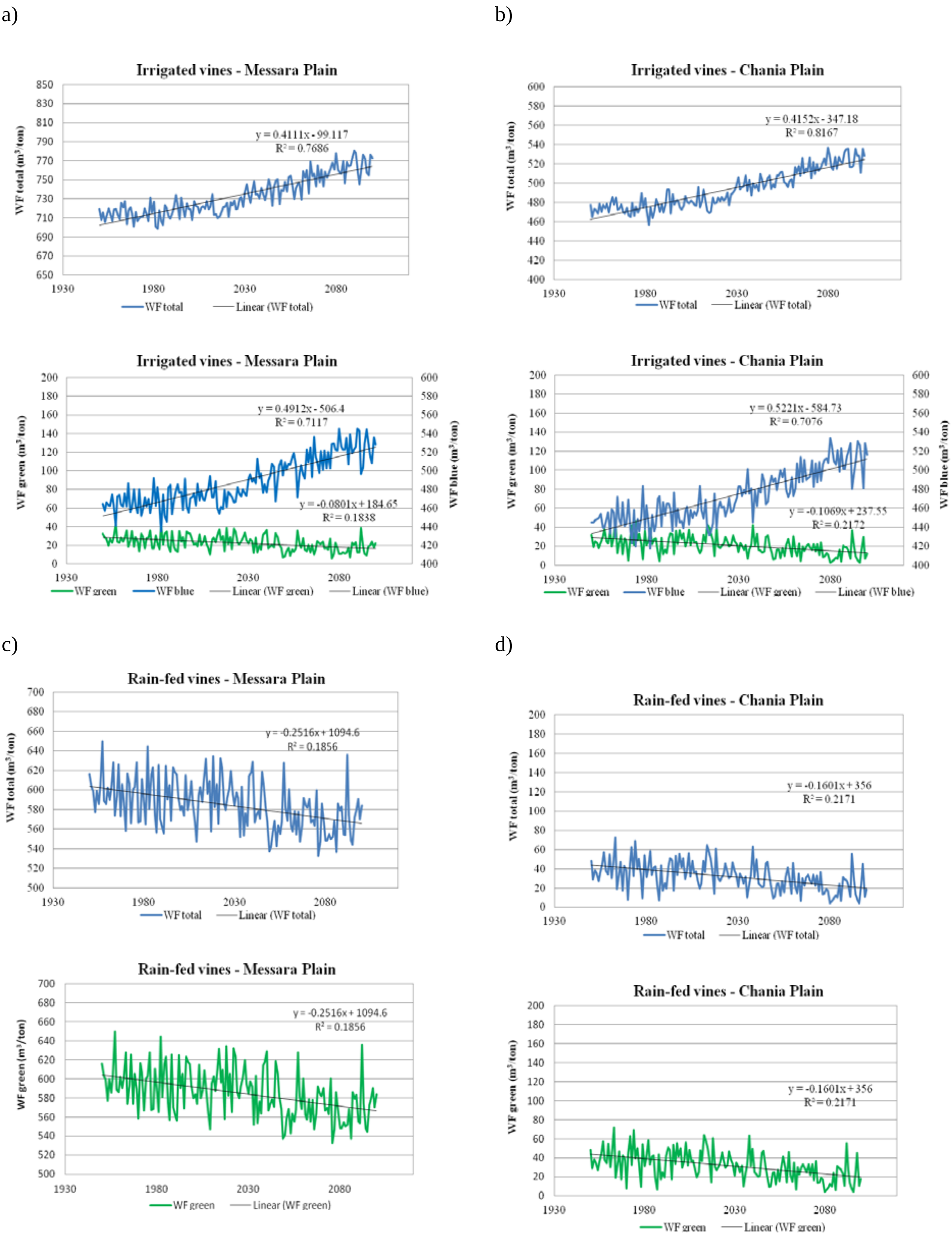


Figure 4: Vines WF in Messara Plain for irrigated (a) and rain-fed (c) and in Chania Plain (b and d) cultivations

In case of irrigated vines, a differentiation in total WF trend is observed in both areas of interest under the examined climate change scenario which coincides with the prediction of a relatively dry year like 2033

(Figures 4a and 4c). Similar behavior is observed in prediction curve of the total WF for irrigated olive trees (Figures 3a and 3c).

With respect to the WF components, it has been observed both in irrigated olive trees crops but most strongly in irrigated vines crops that during particularly wet years with high average annual rainfall like the one in 2039 the blue WF component is significantly reduced while the corresponding green one increases (Figures 4a and 4b). It is obvious during wet years that the water needs of these two irrigated crops are mainly covered by significant amounts of rainwater contributing this way to water resources saving in two very vulnerable areas with respect to water scarcity in Crete. However, there is significant variation in the decline rate of the green WF component based on the examined climate change scenario considering the irrigated crops. In the case of irrigated olive trees the rate of decline is more pronounced compared to irrigated vines and this is maybe due to significantly lower water needs of vines compared to irrigated olive trees (Figures 3a and 4a).

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 water footprint of rain-fed crops (Figures 3c, 3d, 4c and 4d). Although in this analysis the crop yield for all crops is assumed constant to the current ones, it is obvious that there will be an impact in the quality of cultivated agricultural products.

a) b)

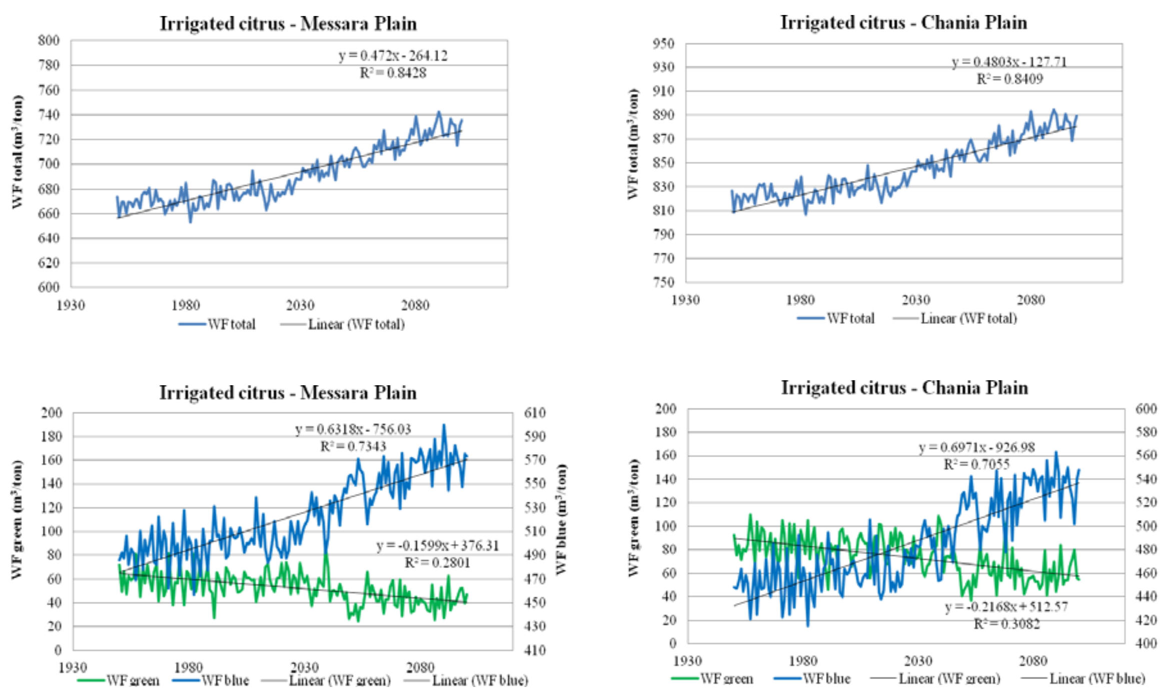


Figure 5: Irrigated citrus WF in Messara Plain (a) and in Chania Plain (b)

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. The high rate of precipitation historically observed in Chania until today has resulted in the limited consumption of fresh water resources for irrigation purposes of crops such as citrus and olive trees (Figure 3b and 5b). Nevertheless based on the examined climate change scenario the situation is expected to be reversed in Chania plain. After 2040 crops' water needs will be mainly covered by fresh water resources (Blue WF) than rainwater (Green WF) even though the annual mean rainfall in this region is estimated to be reduced about 20% from 2040 till 2100 (Figure5b).

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 (Figure 5a).

Based on the total WF estimation for any crop in the two areas of interest, significant amounts of fresh water 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 of temperature and corresponding decrease of 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. Special concern should be also pay by the research community in the inclusion of potential climate change impacts in the accurate estimation of grey WF.

5. Conclusions

WF is a newly entry indicator in research literature that tries to be established as a representative indicator of water consumption. It has been used so far to estimate water consumption of a product or a service by considering not only water needs but also the potential environmental pressure in water receptors. 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. However, to ensure agricultural production and farmers' income in two Cretan plains impacts of climate change such as desertification and seawater intrusion that decisively influencing the adequacy and the quality of fresh water 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. United Nations, Framework Convention on Climate Change, Focus: Adaptation, https://unfccc.int/focus/adaptation/items/6999.php (2013). Accessed 15 February 2014
3. Food and Agriculture Organization (FAO) of United Nations, Climate-Smart Agriculture Sourcebook, ISBN 978-92-5-107720-7 (2013).
4. P. Nowiski, European policy review Mid-Term Review of the EU Common Agricultural Policy, Journal of Nature Conservation, 10 (2002) 185–187.
5. H. Turral, J. Burke and J.M. Faures. Climate change, water and food security. FAO Water Report No. 36. Rome, FAO. http://www.unwater.org/downloads/unw_ccpol_web.pdf (2011). Accessed 15 February 2014
6. A.Y. Hoekstra, A.K. Chapagain, M.M Aldaya, and M.M. Mekonnen, The water footprint assessment manual: Setting the global standard, Earthscan, London, UK, (2011).
7. D. Charchousi, V.K. Tsoukala and M.P. Papadopoulou, How Evapotranspiration Process May Affect the Estimation of Water Footprint Indicator in Agriculture?, Desalination and Water Treatment (2014) (*accepted for publication*)
8. P.-M.G. Stathatou, V.K. Tsoukala, M.P. Papadopoulou, A. Stamou, N. Spiliotopoulou, C. Theoxari and S. Papagrigoriou, An Environmental Approach for the Management and Protection of Heavily Irrigated Regions, GLOBAL NEST Journal, 14 3 (2012) 276-283.
9. G. Lenderink, B. van den Hurk, E. van Meijgaard, A. P. van Ulden and 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 (www.ensembleseu.org).

11. N. Nakicenovic, J. Alcamo, D. Davis, B. de Vries, J. Fenhann, S. Gaffin, , K. Gregory, A. Grübler, Tae Yong 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, M.L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (Eds.), Cambridge University Press, Cambridge, UK, (2007), 541-580.
13. National Statistical Service of Greece http://statistics.gr Accessed 4 March 2014
14. http://www.explorecrete.com Accessed 4 March 2014
15. Bank of Greece, A comprehensive study of the impacts of climate change in Greece, Report pp. 468 http://www.bankofgreece.gr/Pages/en/klima/default.aspx (2011). Accessed 22 February 2014