RESTRUCTURING OF CROPS USING THE WATER FOOTPRINT IN LAKE KORONIA. A COMPARATIVE ASSESSMENT OF TWO METHODS

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ABSTRACT

As pressures on water resources have intensified lately, the impacts of water scarcity and pollution render the need of developing new "tools" to evaluate and communicate the risks to the wide audience. A debate has now emerged about the value, and the shortcomings of using water footprint to better support water resources management. Based on this concept, the restructuring of crops is studied in terms of water demand and WF of the different crops in Lake Koronia sub-basin. Lake Koronia, a rare Ramsar-protected wetland in Greece, represents a characteristic example of non-sustainable water management. In this paper the Water Footprint is used as a tool to evaluate the water resources management practices applied in agriculture, by determining the volume and the type of water use in Lake Koronia sub-basin. In particular, the blue, green and grey water footprint is calculated by using the methodology applied by Mekonnen and Hoekstra method. For the calculation of potential evapotranspiration, two methods are tested. The one applied by Penman – Monteith, which is used in CROPWAT model, and the Blaney – Criddle method. It is concluded that the calculated values of the water footprint and water demands of the crops are higher in the case of Penman – Monteith method in comparison to those calculated by using the Blaney – Criddle method. Major changes in crops are needed towards the improvement of water management in the area. Specifically, tobacco, sunflower, alfalfa and maize have the highest values of blue WF, which means that their intensive cultivation has a huge impact in the water balance of the WB and the cultivation of those crops should be reconsidered.

Keywords: water footprint, CROPWAT model, Hoekstra method, Lake Koronia basin, water resources management.

1. Introduction

Agriculture is strongly depended on the implemented irrigation systems and the availability of surface and groundwater resources. In many cases, the applied unsustainable irrigating techniques have led to severe environmental impacts regarding the water quality, the water availability and the food production (European Environment Agency, 2010; Fereres et al., 2011; Baveye, 2012; Pereira, 2015). Things are getting worse because the water allocation to irrigated agriculture will be reduced in the future due to the climate change and the expected increase in water demand for other economic sectors.

The Water Footprint (WF) is a useful indicator of water use which was firstly introduced by Hoekstra and Hung (2002) and afterwards it was elaborated by Chapagain and Hoekstra (2004) and looks at both direct and indirect water use. (Hoekstra et al., 2009).

"The interest in the water footprint is rooted in the recognition that human impacts on freshwater systems can ultimately be linked to human consumption, and that issues like water shortages and pollution can be better understood and addressed by considering production and supply chains as a whole" *(*Hoekstra 2009).

Chapagain et al. (2006) calculated the WF of cotton in global scale and they resulted that it consists of 42% blue water, 39% green water and 19% grey water. Also, Chapagain and Orr (2009) estimated the WF of tomato production in Spain as well as in whole Europan Union. Furthermore, Mekonnen and Hoekstra (2011) calculated the WF parts of several crops – including vegetables, fruits, oil crops and tobacco – in global scale by using the CROPWAT model and, finally, Chapagain and Hoekstra (2011) estimated the global WF of rice production. Charchousi et al. (2014) compared three empirical methods for the calculation of evapotranspiration in Chania (Crete) region in order to estimate the water footprint of nine crops.

2. Study area

Lake Koronia, a Ramsar protected area, is located 15 km north-east of the Thessaloniki in northern Greece. The Water Basin (WB) of the lake is about 2026 km^2 and it lies in the western part of Mygdonia river basin which also consists the water basin of Lake Volvi. The intense agricultural activity in the area cannot sustain the carrying capacity of the water system, resulting to water depletion, negative water balance and intense pollution. In particular, the annual water deficit of Lake Koronia basin was progressively reduced and, nowadays, it is about 20.3 x 10^6 m^3 (Greek Ministry of development, 2008). The major irrigated crops and their respective cultivated area in Lake Koronia basin for the year 2013 are presented in Table 1.

Table 1: Cultivated land (in 10^3 m^2) of basic crops in Lake Koronia water basin.

Crops	Cultivated land (10^3 m^2)	Cultivated land (%)
Alfalfa	19176	30.35 %
Grapes	832	1.32 %
Maize	9378	14.84 %
Maize for animals	12524	19.82 %
Olives	1262	2.00 %
Sunflower	14061	22.26 %
Trees (various)	1947	3.08 %
Tobacco	69	0.11 %
Vegetables	3929	6.22 %
Total	63178	100 %

3. Hoekstra method

The components of the water footprint (green, blue, grey) in m^3/tons were calculated using the methodology applied by Mekonnen and Hoekstra (2011) and they are presented in Table 2. Crop evapotranspiration and yield, required for the estimation of the green and blue water footprint have been also calculated following the modified Blaney - Criddle method (Doorembos and Pruitt, 1977).

The green component is given by the equation 1.

$$WF_{GREEN} = CWU_g/Y \qquad (1)$$

where: CWU_g: green water use ($m^3/10^3$ m^2)
Y: crop yield ($ton/10^3$ m^2)

The blue water footprint is calculated by the following equation:

$$WF_{BLUE} = CWU_b/Y \qquad (2)$$

where: CWU_b: blue water used by the crop ($m^3/10^3$ m^2)
Y: crop yield ($ton/10^3$ m^2)

and, finally, the grey water footprint is calculated by using the equation:8

$$WF_{GREY} = \{(a \times AR)/ (C_{max}-C_{nat})\}/Y \qquad (3)$$

where: a: contaminant that leaches or runs off
AR: contaminant application rate ($kg/10^3\ m^2$)
C_{max}: maximum acceptable concentration of contaminant (kg/m^3)
C_{nat}: the natural concentration of contaminant in the receiving water body (kg/m^3)
Y: actual crop yield ($ton/10^3\ m^2$).

Table 2: Blue, green and grey water footprint for each cultivation.

Crops	WF_{blue} (m^3/ton)	WF_{green} (m^3/ton)	WF_{grey} (m^3/ton)
Alfalfa*	52.13	30.33	284.03
Grapes	409.56	129.30	188.32
Maize	360.68	156.22	3876.15
Maize for animals	426.70	158.67	4856.32
Olives	251.27	82.93	196.92
Sunflower	833.10	360.30	192.00
Trees (various)	192.68	71.18	75.64
Tobacco	990.67	392.47	146.20
Vegetables	85.33	38.36	82.57
Total	3602.12	1419.76	9898.15

* first of five-cut alfalfa cutting

By analyzing the grey WF of the cultivations it is deduced that maize significantly contributes to the water degradation of Lake Koronia due to the massive use of fertilizers in order to achieve high crop production.

4. Cropwat model

As input data the model requires climatic, soil crop, as well as irrigation data. Climatic data (minimum/maximum temperature, precipitation, wind speed, humidity and solar radiation) for the year 2013 were derived from the Meteorological Station of Lagadas whose geographical coordinates are latitude = 40.75 and longitude = 23.07 (WGS84).

Also, the main soil characteristics (total available soil moisture, maximum rain infiltration rate, maximum rooting depth, readily available moisture and initial available moisture) are inserted to the CROPWAT model. Since loam soil type was selected in the present study the total available soil moisture (field capacity – permanent wilting point) and the maximum infiltration rate was set by the CROPWAT model to 30% and 300 mm/day respectively.

Table 3: Planting dates and dates of harvest for annual crops and crop's irrigation methods in Lake Koronia basin.

Crop	Planting Date	Harvest Date	Irrigation Method
Alfalfa*	Mid-April	Last week of May	100 % sprinklers
Grapes	-	-	100% drip systems
Maize	Mid-April	Mid-September	90% sprinklers 10% drip systems
Maize for animals	Mid-April	End of August	90% sprinklers 10% drip systems
Olives	-	-	100% drip systems
Sunflower	Last week of March	First week of August	100 % sprinklers
Trees (various)	-	-	100% drip systems
Tobacco	Last week of May	First week of September	100% drip systems
Vegetables	Mid-May	Mid-September	100% drip systems

* First of five-cut alfalfa cutting

As for the irrigation data, the values of root depth, depletion fraction, yield response and crop height that are used in CROPWAT were obtained from the literature and in accordance to the local agricultural authorities. The cultivating period for each annual crop is presented in Table 3 in parallel with their irrigation method (for both annual and multi-annual crops) (Management body of Lakes Koronia and Volvi, 2010).

By using the CROPWAT model, the blue and green WF per crop were calculated and presented in Table 4.

Table 4: Blue and green water footprint for each crop.

Crops	WF_{blue} (m^3/ton)	WF_{green} (m^3/ton)
Maize	293.2	249.5
Maize for animals	358.1	253.3
Alfalfa*	190.4	239.8
Trees (various)	249.7	54.5
Olives	248.5	158.5
Grapes	303.9	244.5
Sunflower	643.8	423.0
Vegetables	81.3	47.2
Tobacco	1063	403.3
Total	3658.9	2073.6

* whole cultivation period

5. Discussion and conclusions

The CROPWAT model, as it uses more parameters to estimate the evapotranspiration in a more detailed way, seems to be more accurate in comparison to the Hoekstra method. In particular, the first one takes into account additionally humidity, wind speed and solar radiation apart from the other meteorological parameters. In particular, as for the blue and green WF, the Hoekstra method and the CROPWAT model produce similar results for all crops. The average difference between the crop's water footprint using the two methods (CROPWAT and Hoekstra) is about 5%. These results are little higher than the results presented by Charchousi et al. (2014). The differences between the two methods in WF calculation doesn't alter the decision making policy of water resources management in a region like the sub-basin of Lake Koronia.

Major changes in crops are needed towards the improvement of water management in the area. Results have demonstrated that tobacco, sunflower, alfalfa and maize have the highest values of blue WF, which means that their intensive cultivation has a huge impact in the water balance of the WB. However, although tobacco has the highest blue WF, it is rarely cultivated so it causes minor impacts. On the contrary, maize, alfalfa and sunflower are the dominant crops in the area so their impact in the water balance is severe and the cultivation of those crops should be reconsidered.

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