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AN ENVIRONMENTAL APPROACH FOR THE MANAGEMENT AND PROTECTION OF HEAVILY IRRIGATED REGIONS

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ABSTRACT
In this paper the results of a preliminary study that investigates water footprint (WF) concept, as a useful tool to address water management problems in cultivated areas are presented. The two basic methodologies reported in the literature, their applicability, benefits and challenges were previously analyzed and evaluated by Tsoukala *et al*. (2011). A WF calculation for the crops of Messara valley in Crete is presented, so as to examine its contribution to achieving effective agricultural policies. Messara is one of the most important agricultural regions in Greece that faces serious problems in order to meet crop irrigation demand. The conclusions drawn from this analysis showed that WF can provide a transparent framework for the identification of potentially optimal alternatives for efficient water use at river basin catchment level.

KEYWORDS: Water footprint, environmental water resources management, effective fresh water use, irrigation needs, Messara valley, agricultural policy.

1. INTRODUCTION
The continuous population growth in recent decades combined with the accelerated rate of economic development have created significant impacts on agricultural and industrial sectors, resulting in a corresponding increase in fresh water demand. The focus on fresh water is important since fresh water is considered a scarce natural resource, the volume of which corresponds to 2.5% of the total amount of earth's water capital (Gleick, 1993). The WF is an indicator that measures the human appropriation of the globe's fresh water resources and its concept is similar to the ecological, energy and carbon footprint, as it translates human consumption into natural resources use (Hoekstra, 2009). The basic goal of the WF concept was to analyze the hidden links between human consumption and water use, as well as between international trade and water resources management (Hoekstra, 2009). The starting point for the research community was that water resources management is generally treated as a local issue or a problem limited to a river basin, whereas its global dimension is overlooked (Hoekstra, 2006). In this analysis, the close relationship between human consumption and consumers' choices is ignored.

The Water Footprint (WF) indicator was first introduced to the research community by Hoekstra (2003) and it measures the total use of fresh water resources in cubic meters per year. The WF of an individual or a community is defined as the total volume of fresh water that is used to produce goods and services consumed by the individual or the community and it can be broken down into three components, (i) blue, (ii) green and (iii) grey defined as (Hoekstra and Chapagain, 2008):

I. **Blue WF** is the volume of fresh water consumed from surface water and groundwater resources to produce goods and services towards an individual or a community. It excludes the part of the water abstracted from the ground or surface water system that returns to that system directly after the use or through leakage before it was used.
II. **Green WF** is the volume of water evaporated from the global green water resources (rainwater stored in the soil).
III. **Grey WF** expresses the polluted water that it is associated with the production of goods and services. It is the theoretical amount of water that would be required to dilute pollutants emitted during the production process to such an extent that the quality of the ambient water would remain below water quality standards (Chapagain and Orr, 2009).

A WF can be estimated for any well-defined group of consumers, including a family, a city or a nation (Ma *et al*., 2006; Hoekstra and Chapagain, 2007; Kampman *et al*., 2008). It can also be applied to a business or an organization (WBCSD, 2006; Gerbens-Leenes and Hoekstra, 2008). In previous work reported in the literature related to agricultural water consumption for agri-food production, Chapagain *et al*. (2006) were able to assess the WF of cotton consumption worldwide. According to their results, the WF related to pollution (grey component) is approximately about 20% of the total WF. About 85% of the total WF of cotton consumption in the European Union of 25 Member States (EU25) is located in other continents particular in Asia (India and Uzbekistan). Their study has shown the strong link between the consumption of a product at one place and the impacts on environment (i.e. water resources) at another. Chapagain and Orr (2009) used the WF concept to estimate water consumption in tomato crops grown partly in open systems and partly in greenhouses. Their analysis shows that the impacts of Spanish tomato consumption in the EU upon Spanish freshwater resources is location-oriented and it is mainly dependent upon the local agro-climatic characteristics, the local level of water resources, the total tomato production volumes and the production system. Ridoutt *et al*. (2010) proved in their analysis that significant improvement on freshwater resources availability, especially in areas suffering from water scarcity, will be obtained by reducing waste at all stages of the food chain. Efforts to reduce food chain waste will have greater impacts than improvements in irrigation practices. On the other hand, Ercin *et al*. (2011) showed in their analysis that the WF associated with the industrial production of a sugar containing carbonated beverage is rather negligible compared to the WF associated with the agricultural ingredients.

Greece has one of the largest average national WF, 2389 m^3/capita/yr (Hoekstra and Chapagain, 2007). Stamou (2010) analysed the percentage composition of Greek WF and concluded that the internal agricultural water use has the largest contribution to the final WF (about 59%). It may thus be concluded that current water management strategies in the agricultural sector are inefficient, resulting in significant water losses. In this paper, the preliminary results of an approach that uses WF as a tool to achieve efficient water resources management in the agricultural sector are presented. Furthermore, in this paper a tentative evaluation of alternative policies, based on the WF indicator is also presented.

2. WATER FOOTPRINT CALCULATION METHODOLOGIES

The volumetric approach proposed by Hoekstra (2003) and the stress-weighted index approach proposed by Ridoutt and Pfister (2010) are the two basic methodologies to calculate the WF of a good or a service. The applicability, benefits and challenges of those methodologies were analyzed and evaluated by Tsoukala *et al*. (2011). The focus of each methodology is limited to the calculation of the water volumes required in order to produce a good or a service. Parameters such as the origin of the water used or the associated environmental impacts are approached differently.

In this analysis, the volumetric approach is applied, according to which the blue and green components refer to the consumption of natural resources, while the grey component refers to the amount of water needed to assimilate possible pollution. According to Hoekstra (2009), by including natural resources use for waste assimilation (grey WF), the WF is a suitable indicator in order to understand and calculate the total human appropriation of natural resources. The uncertainty and subjectivity associated with the estimation of the grey WF is much higher than for the other two components, green and blue. This occurs due to the difficulty in the estimation of the parameters considered in the corresponding calculations, such as the pollutants' penetration in water bodies.

According to Hoekstra *et al*. (2011) the total WF (m^3 ton^{-1}) of the process of growing crops or trees is the sum of the green, blue and grey components:

$$WF = WF_{GREEN} + WF_{BLUE} + WF_{GREY} \tag{1}$$

The green WF (m^3 ton^{-1}) is calculated as the ratio of the volume of green water used for crop production, CWU_g (m^3 $acre^{-1}$), to the weight of crop produced, Y (ton $acre^{-1}$).

$$WF_{GREEN} = \frac{CWU_g}{Y} \tag{2}$$

The green water used for the production of the crop, CWU_g, represents the contribution of rainwater used in order to meet crop irrigation needs. It depends on the specific crop evapotranspiration requirement, PET_c (mm $month^{-1}$), and on the available soil moisture in the field. Soil moisture is maintained either by effective rainfall or by irrigation water supply. Effective rainfall, P_{eff} (mm $month^{-1}$), is estimated using the SCS method (USDA, 1980). The monthly green water use, u_g (mm $month^{-1}$), is equal to the minimum between effective rainfall, P_{eff}, and crop evapotranspiration requirement, PET_c.

$$u_g = \min[PET_c, P_{eff}] \tag{3}$$

The total green water use in crop production, CWU_g, is calculated as the sum of green water use for each month over the entire length of crop period (*k* months).

$$CWU_g = \sum_{i=1}^{k} u_g \tag{4}$$

The blue WF (m^3 ton^{-1}) is similarly defined to the green WF (Hoekstra *et al*., 2011).

$$WF_{BLUE} = \frac{CWU_b}{Y} \tag{5}$$

The blue water used for the production of a crop, CWU_b, represents the crop's irrigation requirement. It depends on crop evapotranspiration requirement, green water availability and irrigation water supply. The irrigation requirement, I_r (mm $month^{-1}$), is calculated as follows:

$$I_r = PET_c - u_g \tag{6}$$

Blue water use is considered zero, if the entire crop evapotranspiration requirement is met by the effective rainfall. The monthly blue water use, u_b (mm $month^{-1}$), is equal to the necessary irrigation requirement, I_r (mm $month^{-1}$), otherwise is zero.

$$u_b = \max[I_r, 0] \tag{7}$$

The total blue water use in crop production, CWU_b, is calculated as the sum of blue water use for each month over the entire length of crop period (*k* months).

$$CWU_b = \sum_{i=1}^{k} u_b \tag{8}$$

Annual crop yields were taken by yield statistics. In the case of perennial crops, the average annual yield over the crop lifetime should be considered. The grey WF (m^3 ton^{-1}) of a crop is calculated based on equation 9:

$$WF_{GREY} = \frac{(a * AR)/(c_{\max} - c_{nat})}{Y} \tag{9}$$

where AR (kg $acre^{-1}$) the chemical application rate to the field per acre, *a* the leaching-run-off fraction, c_{max} (mg l^{-1}) the maximum acceptable concentration, c_{nat} (mg l^{-1}) the natural concentration for the pollutant considered in the receiving water body, Y (ton $acre^{-1}$) the crop yield (Hoekstra *et al*., 2011).

Concerning the accurate calculation of WF, some critical issues are:

- the double inclusion of water volumes used in various products. For example, when a primary crop produces two or more products, the virtual water content of the primary grain is proportionally allocated to the various products. This is proportional to the value of the various products, or it may also be proportional to the weight of products (Hoekstra and Chapagain, 2008).

- the grey WF should be calculated based on the necessary water quantity for the dilution of the pollutant with the lowest acceptable concentration (Chapagain *et al*., 2006).

3. A CASE STUDY IN MESSARA VALLEY, CRETE

3.1 Current situation, deficiencies and proposed solution

Messara valley is located in the SW part of Crete's Heraklion Prefecture and is one of the most important Greek agricultural regions. The area of interest is part of Messara valley comprised by the municipalities of Tympaki and Moires, as shown in Figure 1. Due to the intense land cultivation and groundwater overexploitation, the area faces serious challenges in order to meet crop irrigation needs.

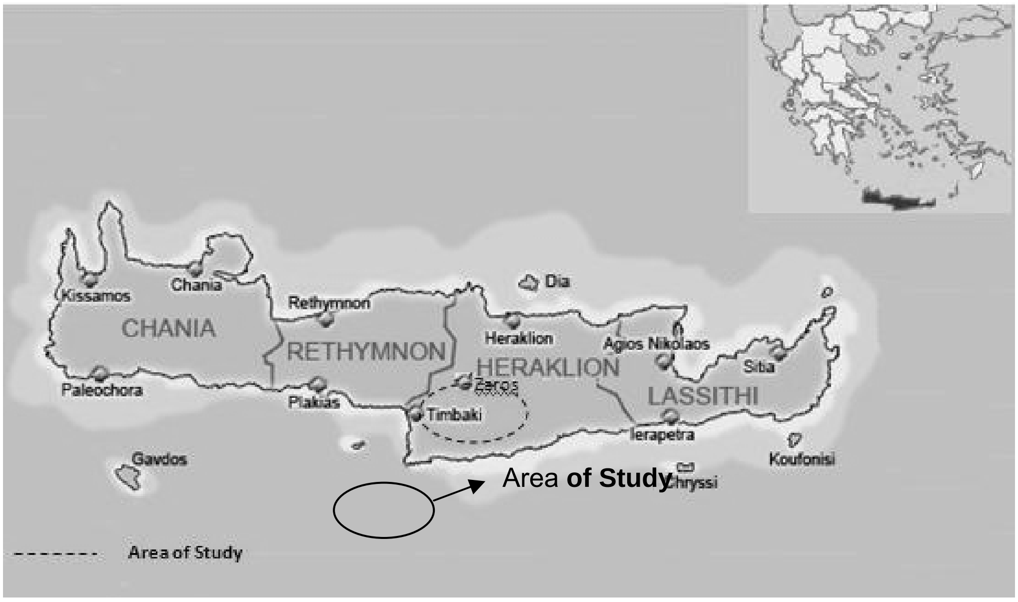

Figure 1. Area of interest in Messara Valley, Crete

The irrigation system in the area is mainly supplied by groundwater pumping wells. The continuous abstraction through the wells has caused groundwater depletion, and thus serious problems concerning deficit in water supply and degradation of water quantity have occurred. In order to solve the constantly increasing irrigation problem of the region, Local Authorities are planning to adopt a policy that proposes the construction of a dam at Faneromeni, located 7km north of Tympaki and 7km west of Zaros village, and also considers the improvement of the irrigation system and the reduction of currently cultivated crops from 15 to 5 (TEM SA, 2006). The present analysis evaluates and compares the WF of the currently applied agricultural practices to that of the proposed alternative, to indicate the differences between the two water resources management approaches requirements.

3.2 Methodology

In this analysis the evaluation of the WF is based on the volumetric method proposed by Hoekstra *et al*. (2011). The crop evapotranspiration requirement, PET_c (mm/month), is calculated using the Blaney-Criddle (1950) method. For the calculation of the grey WF the concentrations of nitrogen and phosphorus in both surface water bodies and groundwater were investigated and the pollutant with the lowest acceptable concentration was finally considered for the grey WF calculation. The leaching-run-off fraction was considered equal to 7% and the natural concentration for the pollutant in the receiving water body was considered equal to zero.

According to Chapagain and Orr (2009), in case of greenhouses the green water component is considered equal to zero. Based on observed climatic data inside greenhouses, the calculated PET_c is estimated at about 70-80% of the PET_c computed with the climatic parameters observed in crops cultivated outdoors (Fernandez, 2000; Fernandes *et al*., 2003; Harmato *et al*., 2004).

4. RESULTS AND DISCUSSION

The aim of this analysis is to investigate whether the WF could constitute a valid environmental indicator for the improved management and protection of heavily irrigated regions. To that end, the WF is used in order to (a) compare and evaluate different irrigation policies and (b) estimate the environmental cost of farming, with emphasis on groundwater resources (grey WF).

4.1 Evaluation of different irrigation policies

The total WF of the currently applied practices and the suggested policy are equal to the sum of the WF of the corresponding crops and their yields in open and covered production systems. In Table 1 and Figure 2 a comparison of the WF components for the two analysed policies is presented.

Table 1. WF of current applied and suggested policy

WF Components	WF ($m^3\ ton^{-1}$)		WF Reduction (%)
	Current Policy (15 Crops)	**Suggested Policy (5 Crops)**	
BLUE	11,512	2,812	75%
GREEN	13,288	5,930	55%
GREY	17,481	3,912	77%
TOTAL	**42,281**	**12,654**	**70%**

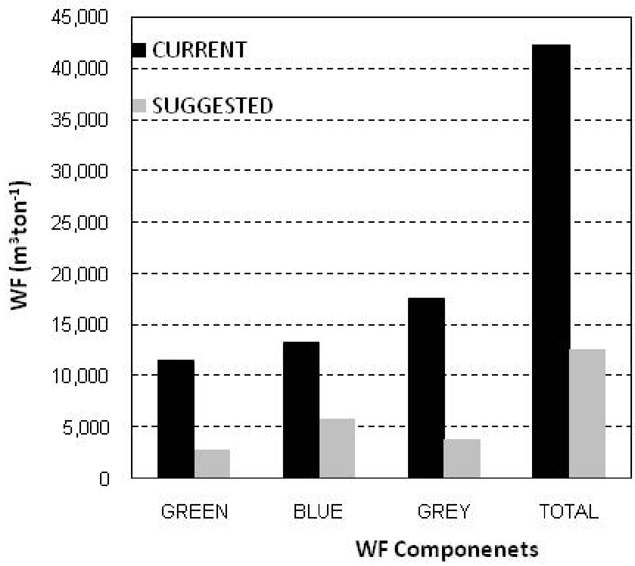

Figure 2. Comparison between currently applied and suggested policies

The proposed policy leads to a reduction of up to 70% in the total WF compared to the current policy (Figure 2). Individual components also present significant reductions (75%, 55% and 77% for the green, blue and grey components respectively).

In both cases, the grey WF is underestimated. The pollutant loads (kg of N, P) considered have been estimated based on the fertilizer guidelines for each crop. In reality, as farmers tend to apply greater amounts hoping to achieve higher yields resulting in the underestimation of grey WF component. In the current policy, the grey component has the largest contribution in the total WF (41%), whereas in the suggested alternative the blue component contributes the most (47%) (Table 2).

Table 2. Contribution of each WF component to the total WF

Policy	**WF Component**			
	GREEN	**BLUE**	**GREY**	**TOTAL**
Current	27%	32%	41%	100%
Suggested	22%	47%	31%	100%

The contribution of grey WF to the total WF is greater in the case of the current policy since the necessary water volume to assimilate the pollution is greater. The suggested policy performs better in terms of WF, as it involves reduced water use and consumption (blue and green WF) and requires less water for pollution dilution (grey WF).

4.2 Estimation of Environmental Cost in Groundwater

In this analysis, the concentrations of nitrogen and phosphorus in both surface bodies and groundwater were investigated and the pollutant with the lowest acceptable concentration was finally considered for the calculation of the grey WF. In the recent research literature related to WF crop calculations (Hoekstra *et al*., 2011), only nitrogen is considered as a potential pollutant with a maximum acceptable concentration value of 10 mg lit^{-1} without clarifying whether this value is referred to a surface or a groundwater water body. In order to identify the impact of the pollutants in the water bodies, two alternative scenarios were examined concerning the calculation of WF:

- Scenario A: Calculation of WF considering only nitrogen in surface water body as pollutant for the Current Policy (15 Crops) and
- Scenario B: Calculation of the WF considering only nitrogen in both surface and groundwater bodies as pollutant for the Current Policy (15 Crops).

In Figure 3, and Table 3 the total WF calculation for the two pollution scenarios is illustrated for the currently applied policy. The grey WF is reduced by 93% in the first scenario and by 69% in the second, in comparison with the current practices. The total WF was reduced by 38% and by 28% respectively.

Table 3. WF of Current Policy (CP) and of alternative Scenarios

WF Components	**WF of CP (m^3 ton^{-1})**	**Scenario A**	**Scenario B**	**WF Reduction between CP and**	
				Scenario A	**Scenario B**
GREEN	11,512	11,512	11,512		
BLUE	13,288	13,288	13,288		
GREY	17,481	1,225	5,420	93%	69%
TOTAL	42,281	26,025	30,220	38%	28%

This comparison illustrates that the environmental cost, expressed in terms of grey WF, is significantly depended by the water bodies under consideration. Acceptable concentrations of pollutants in groundwater bodies are smaller to those for surface water bodies, and as a result a greater amount of water is required for pollutant dilution if groundwater bodies are taken into consideration. In addition, acceptable concentrations of phosphorus in water bodies are lower than acceptable nitrogen concentrations; hence a larger water quantity is required to obtain acceptable pollutant limits. Consequently, the pollutant with the lowest acceptable concentration should be considered so as to achieve a better estimation of environmental cost.

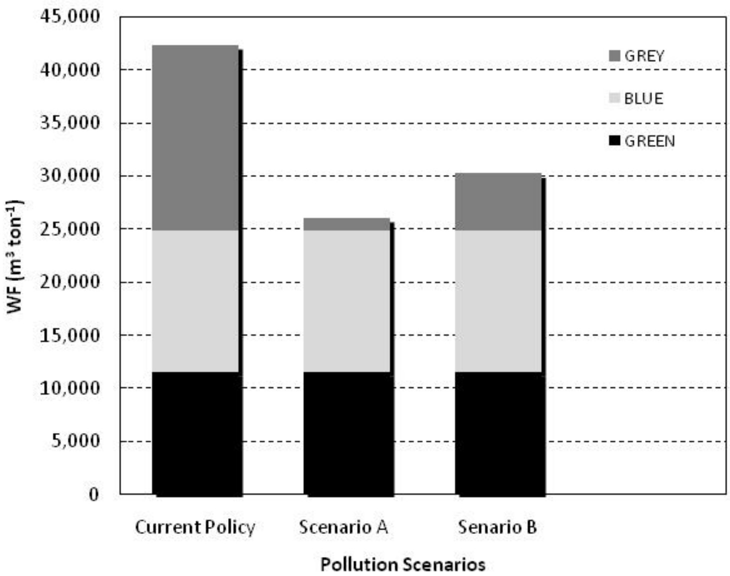

Figure 3. Comparison between currently applied situation and alternative scenarios

5. CONCLUSIONS

The WF is a multidimensional indicator that refers not only to the water volume used to produce a good or a service, but it also considers issues such as where the water footprint is located, what source of water is used and when the water is used. This additional information is crucial in order to assess the local environmental, social and economic impacts of a product with respect to its water footprint. The WF is greatly affected by the factors taken into consideration in the estimation calculation process. In general, greater yields result to a smaller WF.

For a reliable calculation of grey WF the pollutant with the lowest acceptable concentration should be considered as well as all the possibly affected water bodies, so that the farming environmental cost can be accurately estimated.

Despite the limitations of the methodology (the WF is a very recent indicator still under development), the WF can provide a transparent framework for the potential identification of optimal alternatives for efficient water use at the catchment level. The WF concept considers different scenarios that in conjunction with economic, environmental and social criteria could be a useful tool for the improvement of water resources management, while taking into consideration the conflicting goals of various sectors.

The WF indicator could constitute an environmental approach for the management and protection of heavily irrigated regions. It can be used as a basis for effective agricultural policy setting. National water footprint data could be included in national statistics, in order to create a reliable database where national water plans and river basin plans would be based. Such proposed water management plans would be also consistent with national policies with respect to the environment, agriculture, industry, energy, trade, foreign affairs and international cooperation.

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