REMOTE SENSING AND EMPIRICAL METHODOLOGIES TO ASSESS GREEN WATER FOOTPRINT IN RIVER BASIN SCALE

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ABSTRACT

Fresh water, a scarce natural resource, is essential in every aspect of life. However, it seems to be the most affected environmental component by human activity. Overpopulation, overconsumption, pollution and climate change effects, in conjunction with issues such as conflicting water uses and increasing needs of human kind for fresh water, have led to the deterioration of water quality as well as its quantity, a fact that has a significant impact on the environment and the global ecological status. For this reason, it is urgent that we adopt tools and processes that will improve the current situation.

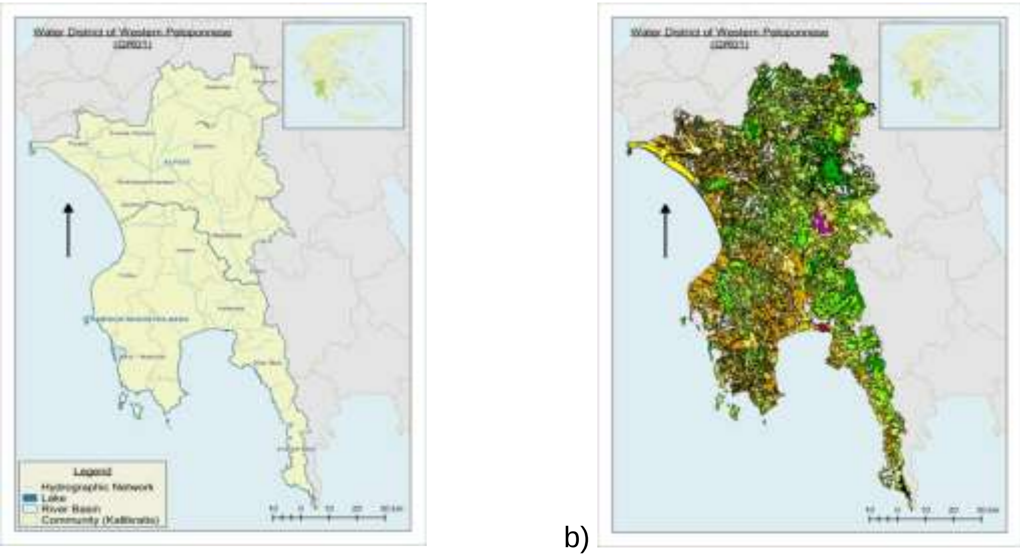
In this paper, empirical and remote sensing methodologies will be applied and compared to estimate the green component of water footprint (WF), in a period of four years, for three main land uses in a river basin: croplands, woodlands and pastures. The Water District of Western Peloponnese (GR01) which consists of two river basins was selected as the area of interest. Empirical methods were employed for estimating the contribution of evapotranspiration (ET) in green WF. In particular, the “Blaney – Criddle” approach was employed on croplands and pasture and the “Hargreaves” approach on woodlands (Marini *et al*., 2015). The analysis of the multitemporal remote sensing datasets was based on the MODIS Surface Resistance and ET (MOD 16) Level 4 product (Mu *et al*., 2011). The preliminary results which derived from the analysis and the quantitative comparison are presented so as to evaluate the green WF estimation obtained from the empirical and remote sensing approaches in a river basin scale.

Keywords: Water Resources Management, Water Footprint (WF), Remote Sensing, empirical methods, evapotranspiration (ET), river basin, water district of Western Peloponnese (GR01)

1. Background

Sustainable management of fresh water is required in order to meet water demand while protecting it. A response to this global need is the Water Footprint (WF) concept that was first introduced in 2002 by Hoekstra, as a multi-dimensional consumption-based water use indicator. WF is defined as the volume of fresh water consumed and/or polluted throughout the process of production of goods or services, taking the time and origin of its consumption into consideration (Hoekstra *et al*., 2011). It can be broken down to three components: blue, green and grey (Hoekstra and Chapagain, 2008) and it is usually assessed for products and services from a well-defined area (Ma *et al*., 2006; Hoekstra and Chapagain, 2007). This study focuses on the green component of WF which expresses the volume of water evaporated from the global green water resources (rainwater stored in soil). Greece, in particular, has one of the largest average national WF (Hoekstra and Chapagain, 2007) as result of inefficient water management policies that could not reduce the significant water losses. By examining various ET methods in the estimation of green WF (Charchousi *et al*., 2014), Charchousi concluded that the selected method of ET estimation does not significantly alter decisions regarding the possible management plan of water resources in a region scale at a policy making level.

This study deals with the water use estimated in the Water District of Western Peloponnese (GR01) in a 4-year period, from 2010 till 2013, for three main land uses, those of pastures, woodlands and croplands. The applied empirical and remote sensing methodologies used to estimate green WF are based on the volumetric approach proposed by Hoekstra. Furthermore, this research aims at analyzing, evaluating and comparing the applicability, benefits and drawbacks of these two approaches.



a) b)

Figure 1. a) River Basins and b) Corine 2000 Land Uses in Water District of Western Peloponnese (GR01)

Methodological approaches

According to the volumetric approach applied, 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 Mekonnen and Hoekstra (2011) the total WF (m^3 ton^{-1}) of land uses such as pastures, croplands and forests is the sum of those three components in all stages of their development process:

$$WF = WF_{green} + WF_{blue} + WF_{grey} \quad (1)$$

1.1. Empirical approach

The green water used for production represents the contribution of rainwater used in order to meet irrigation needs. It depends on specific evapotranspiration requirements and on the available soil moisture in the field. The necessary parameters involved to estimate the water footprint of a crop are crop type, yield and crop coefficient (Kc), average monthly rainfall (P), average monthly temperature (T), crop location and the applied amount of fertilizers (Allen *et al*., 1998). An indirect estimate of the green WF component is obtained using the "Blaney - Criddle" method that determines potential evapotranspiration for cultivated areas and pastures. As for the woodlands water needs that are covered by precipitation, they are estimated considering evapotranspiration requirements. In this analysis, “Hargreaves” method which uses limited climatic data (Hargreaves, 1973) was chosen to determine evapotranspiration requirements of woodlands.

1.2. Remote Sensing

Remote sensing-based techniques have the capability to estimate spatial and temporal variation of ET from catchment to global scales. Certain approaches have already validated different remote sensing techniques for the estimation of ET (Wang and Dickinson, 2012). In particular, remote sensing-based global estimations of ET have been produced by different algorithms, among which the MOD16 and the EUMETSAT MSG ET products are the most widely used. The MOD16 ET product has a spatial resolution of 1 km and is available on an eight-day, monthly and yearly basis. The EUMETSAT MSG ET product is available at 3 km spatial resolution every 30 min or daily. These products have been calibrated and validated mainly in the Northern hemisphere, with sites located in North and South America, Europe, Asia and sometimes Australia.

In this paper, the mean monthly MOD16 products have been employed towards the estimation of the WF for three land uses *i.e.,* pastures, croplands and woodlands, for a period of four years. These remote sensing observations were compared with the results from the empirical methods.

Result analysis

The aim of this analysis is to evaluate the two approaches and determine whether the assessment of the green WF is better quantified using empirical or remote sensing methods and whether this procedure could constitute a valid environmental indicator for the improved management and protection of water resources. It is vital that we highlight the equal importance of these two methods in the field of research on climate change and water management. The major drawback of the two approaches is the necessary assumptions that should be made in river basin scale related to the adequate climate data coverage and the exact location of the various croplands within the different river sub-basins. In Figure 2 indicative maps of green WF presenting the spatial distribution in the two river basins (Alfios and Pamissos) of the Western Peloponnese water district for pasture land use is shown for the entire 4-year period of interest.

a) b) c) d)

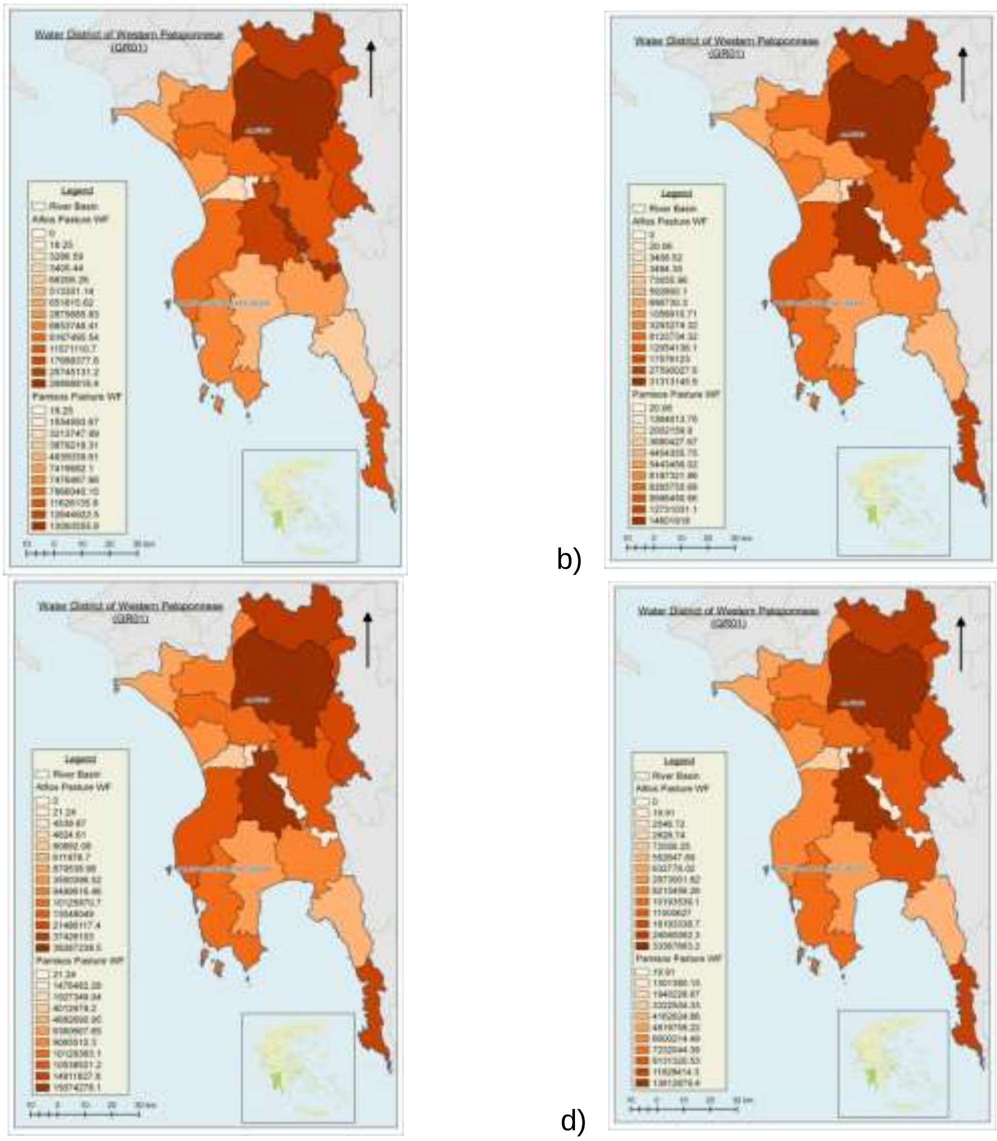


Figure 2. Green Water Footprint for Pasture land use in Water District of Western Peloponnese for a) 2010, b) 2011, c) 2012 and d) 2013 based on empirical methods

2. Discussion –conclusions

WF is a multidimensional indicator that refers not only to the water volume used to produce goods or services, but it also considers issues such as the location of the water footprint, the source of water used and the time when the water is used. The additional information is crucial to the assessment of the local environmental, social and economic impacts of a product with respect to its water footprint. At the same time, WF is greatly affected by the factors that contribute to its calculation. 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.

Surface and satellite-based measurement systems could provide accurate estimates of daily and annual variability of ET. Current land surface models provide widely different ratios of the vegetation transpiration to total ET. This source of uncertainty therefore limits the capability of models to provide the sensitivities of ET to precipitation deficits and land cover change (Wang and Dickinson, 2012)

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