Land Use Policy 61 (2017) 24–39

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Fostering integrated land and water management approaches: Evaluating the water footprint of a Mediterranean basin under different agricultural land use scenarios

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ARTICLE INFO

Article history:
Received 17 November 2015
Received in revised form
19 September 2016
Accepted 25 September 2016
Available online 14 November 2016

Keywords:
Unproductive water consumption
Water scarcity
Water pollution level
Soil erosion
Ecohydrological modelling
Common Agricultural Policy

ABSTRACT

In the Genil River Basin (southern Spain), agriculture is the greatest pressure on freshwater demand. Furthermore, water degradation caused by soil erosion is becoming a key environmental concern. This study aims to assess the water-related impacts of agriculture combining the use of an ecohydrological model (SWAT) with a spatiotemporal water footprint assessment to evaluate the current status of streamflow (blue water), soil water (green water) and the assimilability of sediments by streamflow (grey water footprint). The Common Agricultural Policy (CAP) requires farmers to adopt certain agricultural practices that are beneficial for the environment. Such practices could affect the conditions of available land and water resources. Because of the importance of applying the best land management practices for the maintenance of sustainable water resources, the study also infers probable water availability and water pollution level changes under different post-2013 CAP scenarios. The Genil streamflow is highly regulated, and, as a result, it is hard to discern significant changes ($p < 0.05$) under the proposed scenarios. However, there is a shift with afforestation measures from unproductive (i.e., direct soil evaporation) to productive water (i.e., evapotranspired water from agricultural and natural areas, excluding non-growing periods) consumption. The probability of annual evapotranspiration from natural areas being greater in afforestation scenarios than in the baseline scenario is 0.70 to 0.88, whereas the likelihood of soil water evaporation being lower is 0.60. Evapotranspiration in natural areas increases by about 521% from September to May under afforestation measures compared with the baseline scenario, whereas soil water evaporation decreases by 30% in winter. The grey water footprint and water pollution level decrease by 19% and 9%, respectively, with the highest streamflow conditions under afforestation as opposed to current conditions. However, water pollution levels of suspended solids greater than 1 indicate that the river flow is not capable of assimilating the existing sediment loads. Since land use changes and agricultural practices have a major impact on water resources, the post-2013 CAP reform can provide environmental benefits for water allocation and mitigation of water pollution. However, further efforts are required to better align the policy goals of the CAP and the Water Framework Directive.

1. Introduction

Land use and management greatly influences the hydrological functioning and water quality conditions within catchments (Dawson and Smith, 2010; Deasy et al., 2014; Dunn et al., 2015; Zhao et al., 2015). Agriculture is a major land use in Mediterranean basins, and much of the debate on how to address water scarcity and water quality problems revolves around improving agricultural water management, e.g., increasing water use efficiency and allocation within irrigated lands (Varela-Ortega et al., 2011; Martínez-Santos et al., 2014), as well as addressing chemical water pollution and soil erosion problems (Nikolaidis et al., 2013; Taguas et al., 2013; Bouraoui and Grizzetti, 2014). Several authors (Falkenmark et al., 2014; Fidelis and Roebeling, 2014; Murgue et al.,

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http://dx.doi.org/10.1016/j.landusepol.2016.09.027

2015) have, over the course of the last few years, argued the need to strengthen the links between land and water and the importance of promoting integrated land water resource management (ILWRM) strategies. Significant progress has been made to date in promoting integrated water resource management strategies (Ait Kadi, 2014; Savenije et al., 2014), but there is still a need to explicitly integrate the land use dimension in water resource management.

Achieving effective ILWRM in Mediterranean regions like Spain is a major challenge given the prevailing climate conditions and the growing water demand from the different socioeconomic sectors, particularly of agriculture. But beyond the biophysical and socioeconomic context of Spain, attention also needs to be paid to the existing environmental policy framework. The Common Agricultural Policy (CAP) is one of the main drivers of agricultural land use and management in Europe (Lefebvre et al., 2014), and its different instruments have an impact on the environment. Under the recently approved post-2013 CAP reform, more emphasis has been placed on sustainable natural resources management (e.g., water and land) (European Commission, 2013). Within this new policy scenario, farmers' basic payments are subject to compliance with certain environmental obligations (the so-called good agricultural and environmental conditions-GAEC) and "greening" measures (i.e., crop diversification, maintenance of ecological focus areas within the farm and/or management of permanent grasslands) (Pillar I). Also, a set of voluntary support measures, among them the Agri-Environment Climate (e.g., sustainable agroindustrial crops production), afforestation and organic agriculture measures, have also been included under the rural development program (Pillar II) to increase environmental sustainability in agriculture. The compulsory GAEC and greening requirements, as well as the voluntary measures, have been introduced with the aim of promoting agricultural practices that are beneficial for soils, water and biodiversity. Several studies have evaluated the anticipated impacts of some of these post-2013 CAP measures, e.g., the impacts of changing cropping patterns and input use on farmers' revenues (Giannoccaro and Berbel, 2013; Cortignani and Dono, 2015; Galán-Martín et al., 2015; Mahy et al., 2015; Solazzo et al., 2015), the inclusion of soil conservation practices (Taguas and Gómez, 2015) and the development of alternative strategies aimed at preventing abandonment of olive orchards (Rocamora-Montiel et al., 2014). Yet, there are no studies to our knowledge that have evaluated the possible impacts of the post-2013 CAP measures on water resources sustainability, a gap that this research aims to fill.

Water footprint (WF) assessment of a geographical region developed by the Water Footprint Network (Hoekstra et al., 2011) has emerged as a well-accepted methodology for accounting for water appropriation by humans and its impacts on the hydrological cycle, e.g., within basins. Overall, WF assessment is divided into four major phases: (1) goal setting and scoping; (2) accounting; (3) sustainability assessment; and (4) response formulation. The water accounting phase is not confined to the evaluation of water appropriation of surface or groundwater (blue water) within a basin; it also includes a quantification of the evapotranspired soil moisture (green water) and the volume of freshwater required to assimilate a pollutant load (grey water). The purpose of the sustainability phase is to contrast the green, blue and grey WF against available resources in space and time and determine the extent to which they are or are not compromising the sustainability of a basin. Different indices and methods have been proposed to assess blue water sustainability (Bayart et al., 2010; Hoekstra et al., 2012; Chico et al., 2013; Pfister et al., 2009; Pfister and Bayer, 2014), green water sustainability (Hoekstra et al., 2012; Palhares and Pezzopane, 2015) and the extent of grey water pollution by nitrogen (de Miguel et al., 2015) and phosphorus (Liu et al., 2012).

International Standard 14046 (ISO, 2014) was recently implemented by the International Organization for Standardization (ISO). This standard specifies the principles, requirements and guidelines for evaluating and reporting the water footprint based on life cycle assessments. WF assessment can round out ISO 14046 with the inclusion of green water assessment. Green water assessment is intrinsically linked to existing land uses and management, and water scarcity- and water pollution-related indicators. But perhaps one of the key contributions of WF assessment is the provision of more detailed spatiotemporal analyses of water footprints that are related to land management. There are in fact several arguments in favour of using WF assessment as a tool for linking land and water use and advancing towards the implementation of ILWRM within basins. Green water accounting, through the application of hydrological models, is capable of determining the volume of soil moisture that is consumed by different land uses, the water allocation shifts following changes in land use and management practices within basins and the likely effects on available blue water resources downstream. The basin-scale calculation of the grey water footprint is also capable of establishing a link between the water quality status, the land use configuration and ongoing agricultural practices. Nonetheless, there are still some limitations, since many of the WF assessments carried out so far (Chico et al., 2013; Palhares and Pezzopane, 2015) provide a rather static picture of the status of water consumption in relation to availability at a given time. This limitation can be overcome, for instance, by integrating the WF assessment into hydrological models that are able to simulate the spatial and temporal variability of water resources and the hydrological functioning within basins. Of the available hydrological models, SWAT (Soil Water Assessment Tool) (Arnold et al., 1998) has been successfully and widely applied to simulate green and blue water availability on a basin basis (Zang et al., 2012; Zeng et al., 2012), as well as water quality conditions in contrasting catchments (Li et al., 2011; Sommerlot et al., 2013).

The Genil River Basin (GRB) in southern Spain is currently facing major water challenges, particularly in the lower part of the basin. The current Guadalquivir River Basin Management Plan (GRBA, 2015a) foresees for 2027 a water deficit of 218 hm^3 in the main water management area (i.e., Regulacion General), equivalent to the 8% of the water demand for consumptive uses. Soil erosion is also becoming a worrying environmental concern in the GRB and is causing a high concentration of suspended solids in the river. Over the period 1999–2009, the median average value for suspended solids in the GRB was 138 mg L^{-1}. This is well above the standard of 25 mg L^{-1} set by the Freshwater Fish Directive (OJEU, 2006) and the standard of 35 mg L^{-1} defined by the Guadalquivir River Basin Authority (GRBA, 2007). Based on this, this study aims to develop a methodological framework for integrating a WF assessment into the ecohydrological SWAT model for two purposes: (1) assess the sustainability of the blue, green and grey water footprints in the GRB within the current scenario; and (2) develop different agricultural scenarios to explore the potential benefits of the post-2013 CAP in terms of water allocation and water pollution level reduction.

2. Materials and methods

2.1. Biogeographical conditions of the study area

The Genil River Basin (GRB) is the Guadalquivir's main tributary river and is located in the south of Spain. It has a drainage area of 8278 km^2. The climate is Mediterranean, characterized by warm temperatures (maximum and minimum average annual temperatures of 23 °C and 10 °C, respectively) and relatively low mean annual precipitation (480 ± 180 mm STD) over the period 1999–2009 (AEMET, 2013). This study focuses on the upper part of the GRB as far as the furthest downstream streamflow gaug-