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Estimating groundwater use patterns of perennial and seasonal crops in a Mediterranean irrigation scheme, using remote sensing

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ABSTRACT

This work explores the use of satellite-based vegetation indices (VI) to study groundwater use in a semi-arid agricultural irrigated area. The objective is to obtain insight in spatial and temporal patterns and differences in groundwater usage of perennial (mainly fruit trees) and seasonal crops (mainly row vegetable crops) under varying climatic conditions. Cropping intensities of seasonal crops are derived for each sector and irrigation water applied (IWA) is calculated using VI-based (NDVI from MODIS) actual evapotranspiration estimates and local efficiency factors. Groundwater use is then derived as the residual of total IWA and surface water supplies for each sector and crop type. The results of IWA following this methodology were compared with survey-based results for two crop types. Results correlated well, but deviate most during drought period, likely due to salt leaching practices. Monthly groundwater use patterns and spatial and temporal differences during normal water availability and drought conditions are reported. On average, about 50% of irrigation water is extracted from aquifers, but during droughts this percentage increases considerably. Perennial crops show sharper increases in groundwater use under such conditions than seasonal crops. Overall, seasonal crops put more pressure on the groundwater resource than perennial crops. Our results and methodology will be useful for water resource managers, and policy makers concerned with the role of groundwater resources on the sustainability of semiarid agricultural regions.

1. Introduction

Increasing demand on the limited source of water for irrigation is leading to over exploitation of groundwater resources in most Mediterranean basins (Daccache et al., 2014), which in turn threatens the sustainability of ecosystems and their economic services; including irrigated agriculture itself (Famiglietti, 2014). The pressure to use groundwater for irrigation is likely to increase over the next decades as a result of population growth, climate change and other factors (Green et al., 2011; Wada and Bierkens, 2014). Sustainable irrigation practices and adequate water allocation strategies at the right spatial scale are crucial to avoid overexploitation of various resources (Candela et al., 2012; Condon and Maxwell, 2014; Esnault et al., 2014).

Many studies have been done on groundwater abstractions on basin level. These studies were based on water table fluctuation methods (Cheng et al., 2009; Tsanis and Apostolaki, 2008), water balance methods (Castaño et al., 2009; Cheema et al., 2014; Ruud et al., 2004), or a combination of both (Jiménez-Martínez et al., 2009; Martínez-Santos and Martínez-Alfaro, 2010; Perrin et al., 2012). Water table fluctuation methods generally describe the groundwater balance and interactions at aquifer and basin level (Baudron et al., 2014a, 2013; Esnault et al., 2014; Jiménez-Martínez et al., 2010). However, at finer spatial scales, only water balance methods can provide the required level of detail but accurate information on evapotranspiration and irrigation efficiencies at the scale of interest is a prerequisite for their successful application (Alexandridis et al., 2014; Esnault et al., 2014; Taghvaeian and Neale, 2011).

It is important to understand irrigation practices and patterns at the spatial level of a particular irrigation scheme because it is at this level that sustainable water supply for agriculture can meaningfully be improved by active management (Alexandridis et al.,

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2014; Condon and Maxwell, 2014; Esnault et al., 2014). It is also at this level that different crop types can sensibly be included in water allocation and management decisions (Candela et al., 2012). Supplementing shortages in surface water supply with groundwater must be considered for conjunctive systems and be limited to what is physical and economic feasible.

Surface water demand for seasonal crops, to be considered by farmers, depends on a variety of short term factors, such as markets, water quality, weather forecasts and more (Tapsuwan et al., 2015; Lavee, 2010). The surface water demand of perennial crops on the other hand is less variable and farmers generally have a better grip on the shortfalls and usually supplement surface water supplies with groundwater. These differences in water management are reflected in the spatial and temporal patterns of groundwater usage within an irrigation scheme and they need to be addressed adequately to avoid over exploitation of groundwater in certain areas.

Estimating the water balance and especially the total amount of irrigation water applied through irrigation schemes is a complex task, particularly for schemes that utilise both surface and groundwater (Martínez-Santos and Martínez-Alfaro, 2010; Taghvaeian and Neale, 2011; Tsanis and Apostolaki, 2008). Metering is costly and often associated with practical and legal difficulties (Martínez-Santos and Martínez-Alfaro, 2010). Surveys of irrigation water use are likely to be biased and need to be repeated regularly to obtain temporal patterns. Data on surface water supplies are often readily available, but not so with groundwater data. Remote sensing methods can be of assistance in estimating groundwater usage in irrigated agricultural areas (Ahmad et al., 2004; Castaño et al., 2009; Contreras et al., 2011) and can in some cases be the only way to close the water budget (Contreras et al., 2014; Taghvaeian and Neale, 2011). Satellite-based vegetation indices have proven to be well correlated with evapotranspiration patterns (Glenn et al., 2011) and the study of their spatial anomalies and temporal dynamics have recently been proposed as indicators of the reliance of native ecosystems and agrosystems on groundwater (Barron et al., 2014; Contreras et al., 2013).

Several studies in the Mediterranean area and in parts of Spain, where this study was conducted, showed that groundwater is a critical resource and of concern to farmers (Baudron et al., 2014b, 2013; Contreras et al., 2014; IGME, 1994; Jiménez-Martínez et al., 2010); many aquifers are heavily over-exploited (Molina et al., 2009). It is not yet known which crop types are most dependant on groundwater. Results from a recent survey-based study (Martínez-Alvarez et al., 2014), which we also used in this study, showed that different crop types responded differently to droughts and depended to different degrees on groundwater. Alcon et al., (2011) reported similar phenomena based on earlier surveys carried out in the same area Affective management of the combined and interactive role of surface water and groundwater use by crops require a good understanding of (i) the spatial patterns of groundwater use by different irrigated crop types and (ii) the timing and amount of groundwater abstraction corresponding to each crop type (Condon and Maxwell, 2014; Esnault et al., 2014).

In this study a remote sensing-based water balance method was applied to quantify the relationship between cropping patterns and groundwater usage and the method was evaluated by comparing the results with survey-based values of irrigation water use. Spatial and temporal patterns of groundwater usage of perennial fruit orchards and seasonal horticultural row crops were determined for drought years and normal years by using monthly sector-level irrigation water applications.

2. Methodology

2.1. Study area

The study area is the Campo de Cartagena irrigation district located in south-east Spain (Fig. 1), which is representative of the intensive and export-oriented horticulture of the Murcia region. The climate is Mediterranean semiarid, with an average annual rainfall of 300 mm and a mean annual temperature of 18 °C. The total area under irrigation increased from 32,366 ha in 2011 to 41,065 ha currently, but it fluctuates based on annual water allocations. The total area comprises 23,498 plots which are managed by 2962 farmers. The theoretical annual water resources of the irrigation district amount to 141.6 hm^3, most of which comes from the Tagus–Segura Water Transfer (122 hm^3), and to a lesser degree

Fig. 1. Location of the Campo de Cartagena Irrigation District.