Water balance estimation of the Campo de Cartagena watershed using hydrological modeling and remote sensing

J.E. Hunink(1), S. Contreras (1), A. Baille(2)

(1) FutureWater, Paseo Alfonso XIII, 48, Cartagena, email: j.hunink@futurewater.es
(2) Universidad Politécnica de Cartagena, Paseo Alfonso XIII, 48, Cartagena

Abstract

This work uses hydrological modeling and remote sensing techniques to estimate the spatial and temporal patterns of the water balance of an intensively irrigated agricultural watershed in south-eastern Spain. Remote sensing-based vegetation indexes were used to estimate crop evapotranspiration rates and as an input in the model. Model outcomes give insight in the overall water account of the watershed. They highlight the critical role of the groundwater system in the water balance, and the differences between abstractions and recharge, depending on the hydrological conditions.

Keywords: simulation models; earth observation data; water accounts; groundwater recharge

1. Introduction

Imbalances between water supply and demand and competition among different water sectors are increasing in many water-stressed basins in the world [1], [2]. However, in many cases, decision makers in the water sector lack good access to information on the basin scale where important decisions need to be made and a complete picture of the basins status is necessary[3], [4]. This information at the watershed level is a prerequisite for identifying, and for proposing strategies of water management compatible with the environmental constrains of semiarid agricultural Mediterranean watersheds [5], [6].

To build water balances for semiarid agricultural watersheds, many data on fluxes and stocks are often hardly or not available. Remote sensing methods can be of assistance in estimating some of these components in combination with hydrological modelling [7]–[9] and can in some cases be the only way to close the water budget [10], [11].

The overall aim is of this study is to assess how the water balance of an intensively irrigated watershed in south-eastern Spain is influenced by human interventions. The study uses a hydrological model in combination with remote sensing data to estimate the water balance of the Campo de Cartagena basin in south-eastern Spain. The analysis should provide insight in the spatial and temporal water balance patterns, with special emphasis on groundwater recharge and groundwater abstractions.

2. Methods

2.1 Study area

The Campo de Cartagena basin is located in SE Spain, in the Murcia region (Figure 1). It has a size of 1218 km^2 and drains to the Mar Menor lagoon. The NW and SW borders of the basin are mountainous areas of relatively low altitude (highest point at 1071 m a.s.l.). The basin has an average altitude of 151 m a.s.l. and is relatively flat (average slope 7.5%). Climate is semiarid with a strong Mediterranean regime. Mean annual precipitation is 300 mm, and mean annual temperature ranges from 14ºC to 17ºC. Potential evapotranspiration averages 1275 mm/y. For a more detailed description of the area see [12].

A major part of the basin is used for agriculture, of which 30% for irrigated agriculture (35,000 ha). The most important irrigated crops are citrus trees (oranges and lemon) and horticultural row crops (lettuce, broccoli, melon and others). In plots dominated by row crops, rotation of autumn-winter (e.g. lettuce, artichoke) and spring-summer (e.g. melon) crops is a very common practice. Drip irrigation is the main irrigation system in the study region.

2.2 Modeling approach

The soil-water balance model was built upon the SPHY (*Spatial Processes in Hydrology*) model [13]. SPHY is a raster-based soil bucket-water balance approach which simulates the soil water dynamics in the root zone based on the conservation mass equation. For more details on the model specifications, please refer to the model description in [13].

An algorithm for retrieving actual evapotranspiration rates based on a satellite-based vegetation index (VI) was developed within this study and integrated in SPHY. The approach combines observations of green foliage density with meteorological data to estimate evaporation from transpiring vegetation and has been applied for several applications [9], [14]. Here, the Normalized Difference Vegetation Index (NDVI) is used as a direct surrogate of the stress factors which affect the vegetation/crop performance and, thus, the crop coefficient (k_c). A simple linear parameterization for the VI-k_c relationship was used in which the minimum values for the crop coefficient ($k_{c,min}$) are reached in bare soils, and the maximum ones ($k_{c,max}$) are expected to be reached when vegetation/crop is growing at its optimum agronomic condition, i.e. when the NDVI is close to the maximum value observed for a non-stressed coverage.

Other input datasets into the model were the land use dataset from the SIOSE geodatabase (www.siose.es), detailed soil maps with different soil parameters prepared by the CEBAS-CSIC institute, and meteorological data from all operational meteorological stations in the basin managed by the Segura Basin Authority (CHS), the Regional Ministry of Agriculture (SIAM) and the Spanish Meteorological Agency (AEMET). The period covered was October-2000 to September-2012. The spatial resolution for the analysis was 250 m. Calibration of the hydrological model took place using data on evapotranspiration from two Eddy Covariance Systems in the basin. For more detail on the modelling approach, please refer to [11].

3. Results and Discussion

The hydrological model SPHY was applied using 10 years of remote sensing data and calibrated using the evapotranspiration data. Spatial and temporal outputs were analysed (see [11]) . The physical water balance was summarized at the basin scale. *Figure 2* shows the water accounting diagram for average conditions. The diagram shows the main fluxes and distinguishes between irrigated agriculture and the non-irrigated part of the basin (mix of rainfed agriculture and natural vegetation).

Figure 2 shows that during the study period, a mean annual volume of 61 hm^3/year was delivered from the Tajo-Segura aqueduct, while 104 hm^3/year was pumped from the groundwater system. The model estimated the potential recharge from irrigated areas at 66 hm^3/year. This recharges mainly the upper Quaternary aquifer, which is connected to the Mar Menor lagoon. It is known that there is some connection with the lower confined aquifers, but fluxes are yet insecure. Potential recharge is somewhat lower for the non-irrigated areas. Runoff is low (4 hm^3/year), assuming that finally most of the water entering the drainage network infiltrates.

On average, a little bit more than half of crop water consumption was met with irrigation inputs, while the remaining was met by rainfed soil moisture. The relative contribution of rainfed soil moisture to the total evapotranspiration ranged between 35-70% along the study period. As expected, a negative relationship was found between irrigation requirements and rainfall: the drier the year, the higher the requirements of irrigation inputs to the system.

Figure 3 shows the same diagram but for a dry year, with precipitation amounts about half of the average. For this particular year, surface water supply from the Tajo-Segura transfer was higher than average. But due to low rainfall amounts, groundwater abstractions were also higher than average (131 hm^3/year). Potential recharge is lower (30 hm^3/year), mainly due to low rainfall amounts.

4. Conclusions

Based on the remote sensing-based hydrological modelling exercise, this study showed that more than half of crop water consumption comes from irrigation water. Of this, a major part comes from groundwater (65%), while the rest comes from basin-transferred water. So the water balance estimation confirms that groundwater is a critical source for irrigation water in the Campo de Cartagena agroecosystem.

On average, groundwater abstractions are about similar to the potential groundwater recharge amounts. During a dry year, groundwater abstractions can be even about 4 times the recharge rate. However, recharge happens to the quaternary aquifer, which has a connection with the Mar Menor lagoon, while it is only slightly connected with the deeper aquifers.

6. References

[1] Wada Y., Bierkens M.F.P. 2014. Sustainability of global water use: past reconstruction and future projections. Environ. Res. Lett. 9: 104003.

[2] Green T.R., Taniguchi M., Kooi H., Gurdak J.J., Allen D.M., Hiscock K.M., Treidel H., Aureli A. 2011. Beneath the surface of global change:

Impacts of climate change on groundwater. J. Hydrol. 405: 532–560.

[3] Van Eekelen M.W., Bastiaanssen W.G.M., Jarmain C., Jackson B., Ferreira F., van der Zaag P., Saraiva Okello A., Bosch J., Dye P., Bastidas-Obando E., Dost R.J.J., Luxemburg W.M.J. 2015. A novel approach to estimate direct and indirect water withdrawals from satellite measurements: A case study from the Incomati basin. Agric. Ecosyst. Environ. 200: 126–142.

[4] Cheema M.J.M., Immerzeel W.W., Bastiaanssen W.G.M. 2014. Spatial quantification of groundwater abstraction in the irrigated Indus basin. Ground Water. 52: 25–36.

[5] Contreras S., Jobbágy E.G., Villagra P.E., Nosetto M.D., Puigdefábregas J. 2011. Remote sensing estimates of supplementary water consumption by arid ecosystems of central Argentina. J. Hydrol. 397: 10–22.

[6] Daccache A., Ciurana J.S., Rodriguez Diaz J.A., Knox J.W. 2014. Water and energy footprint of irrigated agriculture in the Mediterranean region. Environ. Res. Lett. 9: 124014.

[7] Ahmad M.D., Bastiaanssen W.G.M., Feddes R.A. 2004. A new technique to estimate net groundwater use across large irrigated areas by combining remote sensing and water balance approaches, Rechna Doab, Pakistan. Hydrogeol. J. 13: 653–664.

[8] Castaño S., Sanz D., Gómez-Alday J.J. 2009. Methodology for Quantifying Groundwater Abstractions for Agriculture via Remote Sensing and GIS. Water Resour. Manag. 24: 795–814.

[9] Contreras S., Jobbágy E.G., Villagra P.E., Nosetto M.D., Puigdefábregas J. 2011. Remote sensing estimates of supplementary water consumption by arid ecosystems of central Argentina. J. Hydrol. 397: 10–22.

[10] Taghvaeian S.C., Neale M.U. 2011. Water balance of irrigated areas: a remote sensing approach. Hydrol. Process. 25: 4132–4141.

[11] Contreras S., Hunink J.E., Baille A. 2014. Building a Watershed Information System fo.r the Campo de Cartagena basin (Spain) integrating hydrological modeling and remote sensing. FutureWater report 125.

[12] Baudron P., Barbecot F., Aróstegui J.L.G., Leduc C., Travi Y., Martinez-Vicente D. 2014. Impacts of human activities on recharge in a multilayered semiarid aquifer (Campo de Cartagena, SE Spain). Hydrol. Process. 28: 2223–2236.

[13] Terink W., Lutz A.F., Simons G.W.H., Immerzeel W.W., Droogers P. 2015. SPHY v2.0: Spatial Processes in HYdrology. Geosci. Model Dev. Discuss. 8, no. 2. : 1687–1748.

[14] Glenn E.P., Neale C.M.U., Hunsaker D.J., Nagler P.L. 2011. Vegetation index-based crop coefficients to estimate evapotranspiration by remote sensing in agricultural and natural ecosystems. Hydrol. Process. 25: 4050–4062.

Figures

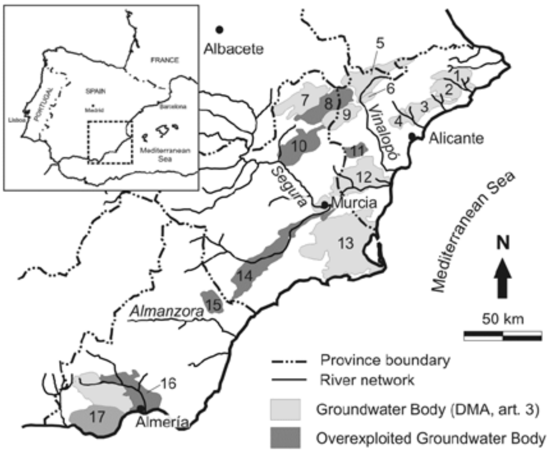

Figure 1. *Location of the Campo de Cartagena basin*

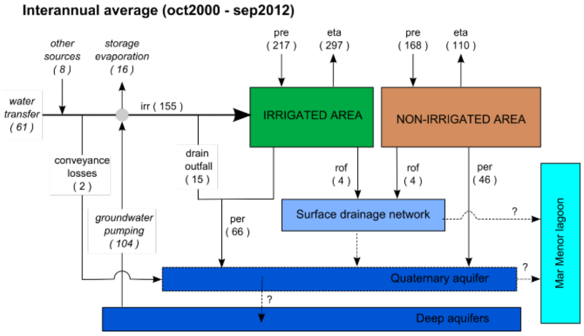

Figure 2*. Water accounting diagram for the Campo de Cartagena basin. Mean annual values for the Oct2000-Sep2012 period.*

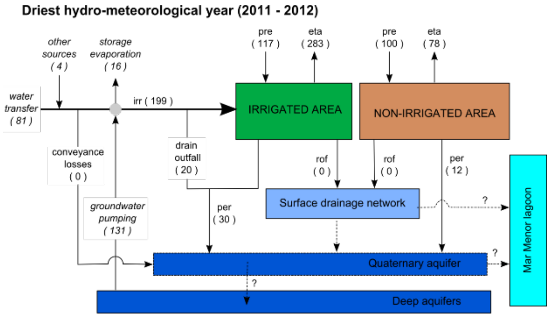

Figure 3*. Water accounting diagram for the Campo de Cartagena basin during the driest hydrological year.*