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Influence of precipitation and land cover changes in a Mediterranean mountain watershed (Guadalaviar River, Spain)

I. Melendez-Pastor*, E.I. Hernández, J. Navarro-Pedreño, I. Gómez and M.B. Almendro-Candel
Department of Agrochemistry and Environment, University Miguel Hernández of Elche, Av/ Universidad s/n Edifico Alcudia, 03202 Elche, Spain
* *e-mail: imelendez@umh.es*

Abstract: In this study the influence of recent (1984-2014) precipitation patterns and land cover changes in the water flow of the Guadalaviar River basin were analysed. The watershed is located in the southern Iberian Range (Spain) and is characterized by medium-high altitude (880-1849 m), extensive forest areas and low population density. This region is located in the confluence of the Tagus, Ebro and Turia great basins. The climate varies from cold continental sub-Mediterranean to mountain climate. Land cover maps were obtained from supervised classification of satellite imagery. Precipitation and water flow time series were obtained from official public institutions. Land covers dynamics in the study area seems to be more strongly influence by the process of rural abandonment than climatic variables. The expansion of shrubs and pine forest at expense of agricultural land is a quite slow process and the influence of short-term climate variability was not clearly revealed. The statistical analysis of precipitation and water flow time series anomalies revealed different water regimens and intense drought periods. A strong relationship between water flow and precipitation variability was evident for the portion of the river with a natural water flow. The significant relationship between precipitation and water flow after a reservoir was disrupted. Forestland expansion did not evidence a clear influence on precipitation or water flow patterns. However, other land cover changes (shrub vs. dryland agriculture) seemed to be greatly affected by precipitation variability along with other socio-economic factors.

Key words: Climate variability, land cover changes, Mediterranean mountain, remote sensing

1. INTRODUCTION

Climate variability and land cover changes have been identified as relevant factors affecting water flow dynamics in river watersheds (Wei et al. 2013). Climate change is affecting the hydrologic cycle by the intensification of extreme events (droughts and floods) and the increase of differences between dry and wet regions (Famiglietti and Rodell 2013). On the one hand, land cover changes influence many aspects of the water cycle such as the evapotranspiration, soil's water holding capacity, precipitation interception by vegetation stands and runoff parameters (Zhang et al. 2014). On the other hand, land cover changes not only affect the amount of water transported by rivers, but also their quality (Khare et al. 2012). Many research efforts are being focused in the determination of the influence of climate and land cover changes as drivers of water flow (Guo et al. 2016; Li et al. 2016) and quality (Delpla and Rodriguez 2014) worldwide.

In the case of the Iberian Peninsula, there are evidences that suggest a general trend of lower water flow in Spanish natural water courses (Martínez-Fernández et al. 2013). Several studies have shown the influence of land cover changes on the water flow from rivers (Morán-Tejeda et al. 2011; Lana-Renault et al. 2011), and the joint influence of climate and rural abandonment in surface hydrology of mountain areas (Beguería et al. 2003; Otero et al. 2011). Within the context of the province of Teruel (South of the Iberian Range, Spain), the Guadalaviar River (upper basin of the Turia River) is one of the main watersheds. Its basin encompasses most of the region of the "Sierra de Albarracín" and limits with the head of the Tagus. It is a watershed with remarkable sociocultural and environmental values, very low population density (about 3 inhabitants/km^2) and a dynamics of land cover changes induced by rural abandonment (Melendez-Pastor et al. 2014). The ecological status of the river is good and the river water is used by some traditional irrigation systems and as water supply from the “Arquillo de San Blas” reservoir.

The objective of this study was the analysis of the influence of precipitation variability and land cover changes in the Guadalaviar River’s water flow. Time series of precipitation and water flow, along with several land cover maps obtained from satellite imagery (1984-2014) were employed.

2. MATERIAL AND METHODS

The study area comprises the Guadalaviar River watershed with a total area of 845.6 km^2, a mean altitude of 1366 m a.s.l. and average slope of 9.6 degrees. The delimitation of the study area was based on the analysis of a 1:25,000 digital elevation model (Figure 1), provided by the Spanish National Geographic Institute (IGN). The basin was divided in three parts: upper, middle and lower. The water gauging stations of Tramacastilla limits the upper sub-basin, from this point to Arquillo de San Blas the middle sub-basin, and from this point to the confluence of Alfambra River and Guadalaviar the lower sub-basin. This is the starting point of the Turia River. The water gauging stations Yearbook Information System provided water flow data. Precipitation time series (1967-2014) from nine meteorological stations were also employed. Meteorological stations were located within or surrounding the study area at altitudes ranging from 920 m in San Blas to 1519 m in Guadalaviar. The State Agency of Meteorology (AEMET) provided precipitation time series.

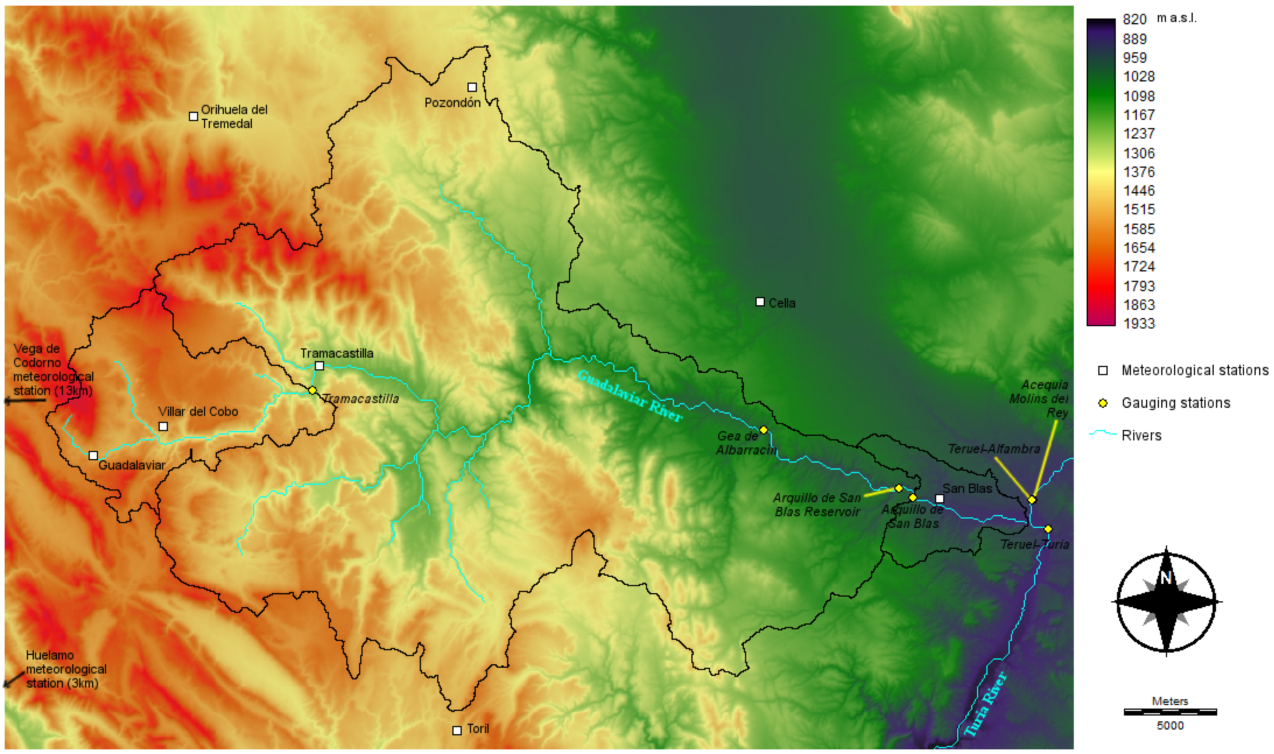

Figure 1. Digital elevation model of the study area. Meteorological and gauging stations are shown. Upper, middle and lower catchments are also shown.

Land cover maps were obtained from Landsat satellite images (summers of 1984, 2000 and 2014). The images were acquired from Landsat 5, 7 and 8 respectively. For this reason, an intensive pre-processing procedure including geometric, radiometric and atmospheric correction was done according to Melendez-Pastor et al. (2014). Field survey, aerial images and historical maps helped for the development of a training and test areas database. A total of 427 sampling points were considered. Those sampling points were located at unambiguous land cover classes for each date. A random division of the training (2/3) and test areas (1/3) dataset was performed. Seven land cover classes (i.e., pine forest, oak forest, rangeland, irrigation/river forest, drylands agriculture, water bodies and urban) that are representative of the entire study area and associated with different land cover were identified. The maximum likelihood classifier was applied to the non-urban areas (urban areas were previously masked because they are very small).

Precipitation and water flow time series were analysed for four different periods, namely 1967-1984, 1984-2000 and 2000-2014 and for the total length of the time series (1967-2014). Time series anomalies were computed for a monthly basis. The time series anomaly (z-score) was computed using the following expression:

$$z = \frac{x_i - \mu}{\sigma} \quad (1)$$

where x_i is the time series value for a given moment i, and μ and σ are respectively the mean value and the standard deviation value of the time series. When the z-score is negative, it indicates below-normal water flow conditions and when it is positive it indicates above normal water flow conditions thereby pointing to wet seasons or periods. Spearman rank correlation test was employed to analyse the relation between precipitation and water flow anomalies time series for the four time periods.

The influence among land cover changes, precipitation variability and water flow variations was evaluated for the upper and middle basins. Land cover changes were computed for the periods 1984-2000 and 2000-2014. Average precipitation maps for the periods 1967-1984, 1984-2000 and 2000-2014 were computed by developing multiple regression models combining precipitation data, altitude, aspect and geographical location. Average precipitation and water flow changes for the periods 1984-2000 and 2000-2014 were obtained and compared with the corresponding land cover changes.

3. RESULTS AND DISCUSSION

Average water flow of the Guadalaviar River (1967-2014) was 0.68 m^3/s for the upper basin (until Tramacastilla gauging station) and 1.37 m^3/s for the middle basin (limited by Arquillo de San Blas gauging station). Maximum water flow values were obtained for winter in both locations. A more intense variability between winter and summer was observed for the middle basin gauging station. Water flow just before the confluence of the Guadalaviar River with its major tributary (Alfambra) is unavailable. The development of the precipitation maps allowed the estimation of average precipitation and standard deviation for the upper (829±98 mm), middle (570±113 mm) and lower (375±12 mm) basins. The lower portion of the study area is relatively plain (altitude ranging from 880 to 1129 m a.s.l.) and small, with a cold continental sub-Mediterranean climate and intensively occupied by urban areas. The middle basin is the most extensive and diverse, with a mean altitude of 1354 m a.s.l. (ranging from 932 to 1849 m a.s.l.). The upper basin is basically mountainous, with a mean altitude of 1586 m a.s.l. (ranging from 1261 to 1845 m a.s.l.).

The first part of the research was focused in the analysis of the relations between precipitation and water flow at representative locations along the watershed. Three weather stations representative of the sub-basin were selected. The Guadalaviar village weather station was selected for the upper basin, and the Tramacastilla and San Blas weather stations were selected for the middle and lower basins respectively. Water flow was available for gauging stations located very close to the last two villages. Spearman values were similar for the three weather stations due to their time series anomalies were significantly correlated for all time periods. Intense precipitation events are usually associated to Atlantic fronts (Gobierno de Aragón 2007) thus explaining a great part of the correlations between the time series and the differences between the upper and western locations and the lower basin. Summer storms are very important too and even more frequent for the more mountainous areas. Water flow pattern for both locations were also significantly correlated for all time periods but with quite low significance values. The lower gauging station (Arquillo de San Blas) is located after the reservoir and its water flow is technically controlled according to water demands for irrigation and water supply. The Tramacastilla gauging station is monitoring a natural water flow region. It seemed relevant for the correlations between water flow and precipitation. The influence of precipitation in the upper and middle basins in the natural water flow river is significant for all time periods. Future scenarios of climate change in the region could lead to serious impacts on water management and river ecology (López-Moreno et al. 2013) thus requiring the development of strategic plans to minimize future environmental and socio-economic problems.

Table 1. Spearman rank correlation matrix between time series of precipitation and water flow anomalies. The maximum values for each cross between locations is in bold.

		Time periods	Precipitation			Water flow	
			Guadalaviar	**Tramacastilla**	**San Blas**	**Tramacastilla**	**Arquillo de San Blas**
Precipitation	**Guadalaviar**	TOTAL		0.730**	0.455**	0.379**	0.011 ns
		1967-1984		0.708**	0.325**	**0.441****	0.008 ns
		1984-2000		0.756**	**0.559****	0.420**	-0.089 ns
		2000-2014		**0.773****	0.445**	0.233**	0.110 ns
	Tramacastilla	TOTAL	0.730**		0.645**	0.331**	**0.143****
		1967-1984	0.708**		0.540**	**0.406****	0.124 ns
		1984-2000	0.756**		**0.725****	0.289**	0.074 ns
		2000-2014	**0.773****		0.658**	0.234**	0.111 ns
	San Blas	TOTAL	0.455**	0.645**		**0.111***	0.094 ns
		1967-1984	0.325**	0.540**		0.030 ns	0.112 ns
		1984-2000	**0.559****	**0.725****		0.128 ns	0.147 ns
		2000-2014	0.445**	0.658**		0.128 ns	0.062 ns
Water flow	**Tramacastilla**	TOTAL	0.379**	0.331**	**0.111***		0.241**
		1967-1984	**0.441****	**0.406****	0.030 ns		0.273**
		1984-2000	0.420**	0.289**	0.128 ns		0.204*
		2000-2014	0.233**	0.234**	0.128 ns		**0.298****
	Arquillo San Blas	TOTAL	0.011 ns	**0.143****	0.094 ns	0.241**	
		1967-1984	0.008 ns	0.124 ns	0.112 ns	0.273**	
		1984-2000	-0.089 ns	0.074 ns	0.147 ns	0.204*	
		2000-2014	0.110 ns	0.111 ns	0.062 ns	**0.298****	

Significance levels: **: $p \leq 0.01$; * : $p \leq 0.05$; ns : not significant

The second part of the research was focused in the analysis of land cover changes. Land cover maps were obtained from satellite images for the years 1984, 2000 and 2014. Major land covers in the upper basin are forest (48.5% in 2014) and rangeland areas (37.3% in 2014) that are frequently employed by cattle for grazing. The presence of dryland agriculture areas is less prominent (11.2% in 2014). The importance of rangeland increased in the middle basin (44.4% in 2014) due to the presence of poorer soils, lower precipitations and higher human activities pressure. Forest (38.2% in 2014) and dryland agriculture (14.4% in 2014) areas are very important too. The lower basin is dominated by the presence of dryland and irrigation agriculture (63.0% and 9.7% respectively), rangeland (12.5% in 2014) and urban areas (8.5 % in 2014). The importance of forest (6.3% in 2014) in the lower sector of the Guadalaviar River watershed is very limited.

The general trend was the expansion of rangeland and forest areas at expense of dryland agriculture. This general process has been observed for the this region (Melendez-Pastor et al. 2014) and similar Spanish mountainous areas (Arnaez et al. 2011) and it is related with the process of rural abandonment. However, this general pattern was slightly different for three sub-basins. Land covers and land uses in the lower basin are very influenced by the nearby urban area of Teruel city. Land cover dynamics in this portion of the study area are quite limited. Moreover, the middle and upper basins exhibited more intense land cover changes although their population is drastically reducing and migrating to the nearby cities (Melendez-Pastor et al. 2014).

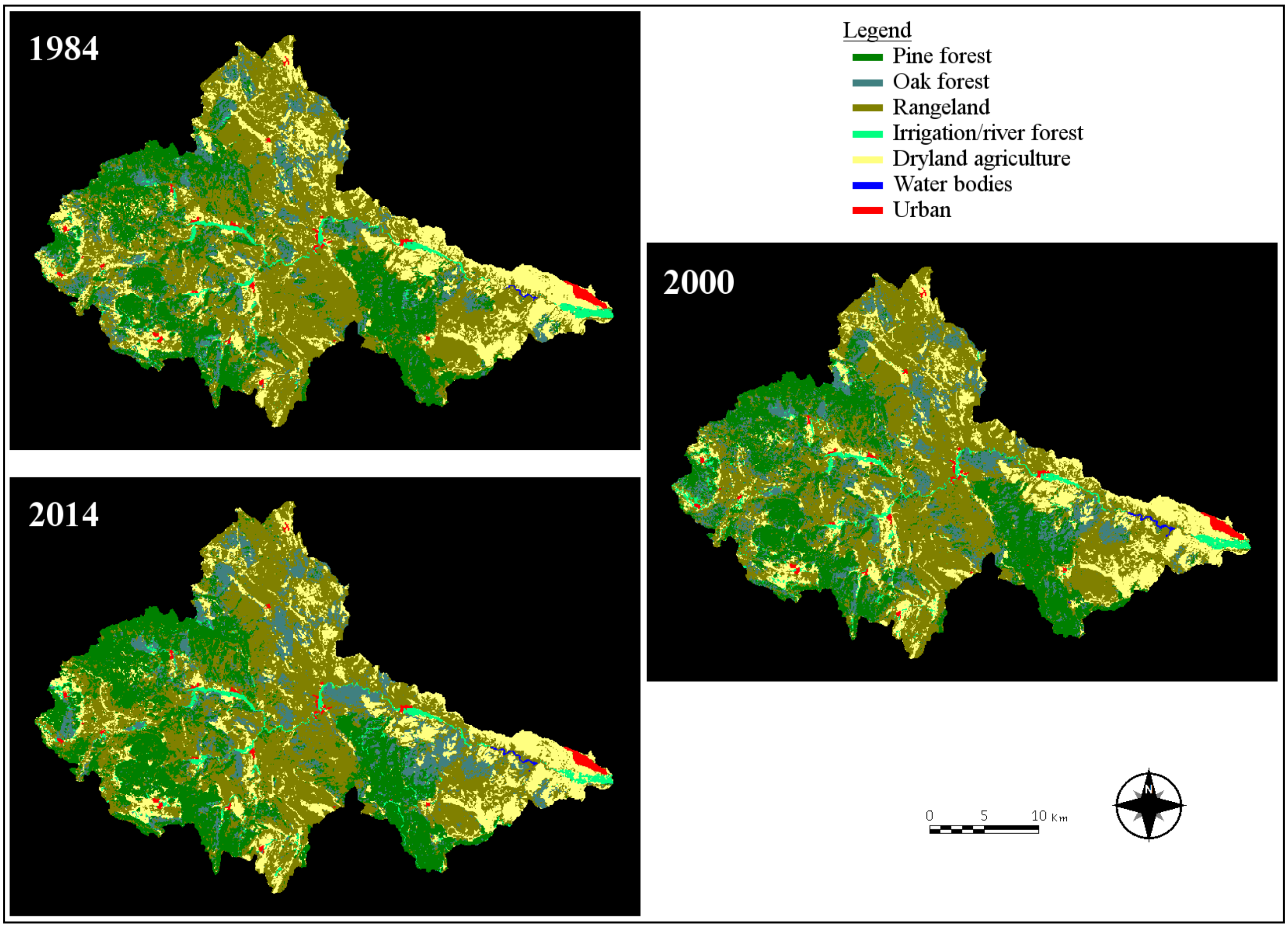

Figure 2. Land cover maps for 1984, 2000 and 2014.

Finally, the relation among land cover, water flow and precipitations changes was assessed. Land cover changes from 1984 to 2000 and 2000 to 2014 were related with comparable average precipitation and water flow changes (the period 1980-2000 respect to 1967-1984 and the period 2000-2014 respect to 1980-2000). These changes were analysed for the middle and upper basins where land cover, precipitation and water flow data were available. The upper basin experienced an almost synchronized reduction of water flow and precipitation in the first period (about -6%) and a notable increase in the second one (more than 20%). Land cover dynamics was characterized by a reduction of dryland agriculture and the corresponding increase of natural areas (forest + rangeland) in the first period. The increase of precipitation and water flow in the second period was associated with an increase of dryland agriculture at the expense of shrubs developed in temporally abandoned fields in the previous period. Forest areas continued their expansion dynamics. The middle basin water flow was controlled by the water level regulation at the reservoir and its association with the other variables was uncertain. Precipitation patterns were similar to the upper basin and land cover changes were dominated by the continuous expansion of forest and rangeland (with less intensity) at the expense of agriculture lands. This process of forestland expansion implies an homogenization and simplification of the landscape, with negative effects from the reduction in biodiversity and landscape variety and positive effects due to land re-vegetation that contributes to reducing soil degradation (Lasanta-Martínez et al. 2005). Also, the importance of water yield in headwaters is crucial to understand the evolution of water resources in major rivers (Morán-Tejeda et al. 2010). Our results area in accordance with previous studies at mountainous, densely forested areas (López-Moreno et al. 2013; Li et al. 2016) that suggested that the overall influence of land cover changes in water flow is less evident that the effect of precipitation variability for the whole study area.

4. CONCLUSIONS

This study analysed the influence of land cover, water flow and precipitations changes in the headwater of the Turia River. The Guadalaviar River watershed was characterized by a process of rural abandonment that implied an important expansion of forestland especially in the more inaccessible mountainous areas. The relationship between water flow and precipitation was highly evident for the portion of the river with a natural water flow. A reservoir in the lower portion of the river greatly affected the relationship between precipitation and water flow. The process of forestland expansion did not evidence a great influence on precipitation or water flow patterns. However, other land cover changes (shrub vs. dryland agriculture) seemed to be greatly affected by precipitation variability along with other socio-economic factors previously studied.

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