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Streamflow Response to Climate Variability and Land-Cover Changes in the River Beça Watershed, Northern Portugal

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Additional information is available at the end of the chapter

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Abstract

This work analyses changes in the River Beça basin streamflow, an area with a typically Mediterranean climate, since the second half of the last century, evaluating trends in annual, monthly and extreme streamflow in the River Beça basin and relating them to precipitation variability and changes in land use and vegetation. Annual streamflow and precipitation are highly irregular, both in intra and inter annual terms. During the period analysed, which covers the last six decades, a consistent negative trend was observed, both in mean annual streamflow and amount of annual precipitation. The results also demonstrate that precipitation greatly influences streamflow dynamics, accounting for around 85% of the variability observed in mean annual streamflow. In addition, the results show that the changes detected in land use/cover may have affected the water discharges of the river, although it is difficult to evaluate the magnitude of impact. The findings demonstrate that the impacts of climate variability and land use/cover change on streamflow are challenging and crucial to the management of water resources in Mediterranean river basins.

Keywords: Streamflow, Precipitation, land use/cover change, River Beça, Northern Portugal

1. Introduction

Water is a natural resource which has great economic, environmental and social value and is fundamental to the livelihood and welfare of human beings and the earth's ecosystems. A decrease in streamflow can have severe consequences for the water supply, both for ecosys-

tems and societies. Thus, management of the river basin is a key factor affecting the volume of water required to cope with the increasing demands of the population and several specific activities such tourism, agriculture and the energy sector, which directly depend on water resources.

Climate and land use/cover changes can have a profound influence on hydrological processes. The effect of climate variables, such as precipitation, temperature and evapotranspiration, is crucial to understanding the availability of water in any given territory [1]. Nowadays, it is recognised that the climate system is being subjected to natural as well as man-made changes [2], affecting the global cycle as well as the quantity and quality of water resources [3–5]. Observation of the climate in mainland Portugal from the 1970s onwards shows that the mean annual temperature has increased in all regions by about 0.5°C per decade, more than twice the global warming rate [6]. With regard to precipitation, analyses of spatial variability and trends in annual and monthly precipitation based on data from 42 stations in mainland Portugal during the period 1960–2011 show that annual precipitation has decreased in all stations and that this trend is statistically significant for most of the time series (70% of the stations showed negative trends with at least a 0.1 significance level) [7]. In many cases these changes in climatological variables can be identified as the cause of trends detected in the hydrological time series [8–25].

Moreover, in order to understand water resources, which are closely related to the production of runoff, at regional/local level the role of the whole tributary basin should be taken into consideration, particularly with regard to land use and plant cover [17, 18]. Several authors have reviewed catchment experiments to determine the effect of vegetation change on water yield [26–30]. In general, they concluded that surface runoff and river discharge tend to increase when natural vegetation (especially forest land) is cleared [31, 32], since deforestation reduces canopy interception storage, transpiration, and infiltration capacity [33]. Conversely, compared with a deforested area, a dense forest cover implies less surface runoff, due to the interception of the rain by leaves and the water requirements of the trees themselves [16, 17, 19–23, 34–37].

On the other hand, in Portugal, important socio-economic and political changes in the 1970s led to migration from the countryside. In fact, the introduction of modern agriculture, the opening up of international markets and the lowering of crop prices, market-oriented cultivation of cereals became unprofitable in most marginal areas of the country. As a consequence, several areas were abandoned, especially in marginal, semi-mountainous and mountainous areas, which significantly reduced the cultivated land and resulted in important transformations to the landscape, characterised by the spread of natural vegetation, including both shrub and forest land. Moreover, the implementation of CAP measures in Mediterranean countries has reinforced the extensification of farming in the “Less-Favoured Areas” (i.e., abandonment or marginalization and collapse of traditional farming systems), which has been going on for the last decades. Changes in land use characteristic of extensification include fewer cultivated fields, more shrub patches, larger areas of natural pastures, and the abandonment of some patches, followed by the development of stratified bush communities [37].

Thus, water resources in the Portuguese mountains, as well as in the Mediterranean mountains in general, are facing the effects of a changing climate, higher temperatures and lower precipitation, together with the consequences of a socioeconomic process that has led to the abandonment of rural activities and consequent changes in land use and land cover [20, 38].

It is therefore important to understand the hydrological responses to these changes in order to develop sustainable catchment management strategies. In fact, management is a key element in terms of the volume of water required to cope with increasing demand [39]. This factor is crucial in countries with a Mediterranean climate, such as Portugal, where the greatest demands for water are concentrated in the summer months (associated with tourism, irrigation and the return of emigrants for holidays), namely the season when it is least available [17].

The main aim of this study was to investigate the changes in the River Beça basin streamflow since the second half of the last century. Two objectives were defined: (i) to determine changes and trends in annual, monthly and extreme streamflow in the River Beça basin; (ii) to estimate the effects of climate variability and human activities, particularly those related to changes in land use and cover change, on streamflow. The environmental conditions of this basin are typical of Mediterranean mountain regions and the river is not regulated, thus presenting a natural regime.

2. Study area

Located in the North of Portugal, the Beça watershed is a third-order watershed that flows into to the Tâmega River (**Figure 1**), a tributary in the northwest sector of the Douro basin. The substratum mainly comprises two important lithic types: granitic rocks (granitoids) and metasedimentary rocks (schists and graywackes). The soils are classified as humic cambisols.

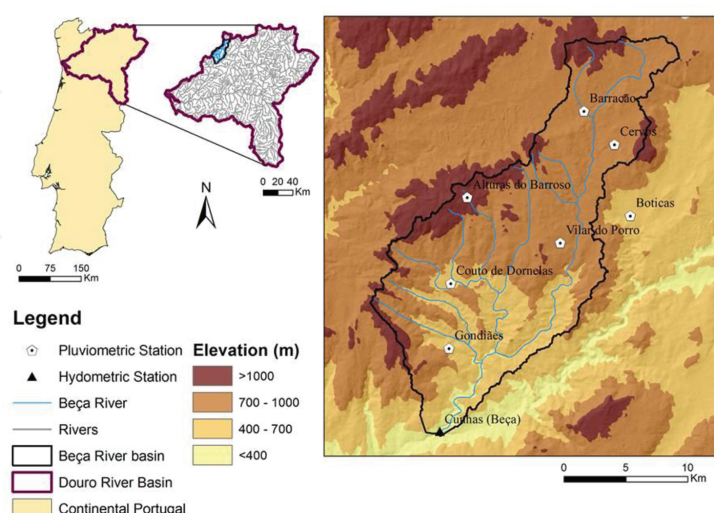


Figure 1. Location of the Beça River watershed.

It is characterized by a rugged topography, in which the altimetric gradient exceed 800 m asl, and drains over 338 km².

Like other Mediterranean river systems, there is a marked variability in the inner and inter annual streamflow responses of the River Beça. **Table 1** presents the monthly and annual variability. It is no surprise that autumn and winter (the humid season) river flows account for the majority of runoff (around 80%), followed by a relatively long dry period. During the remaining six months of the year, 17% of the streamflow occurs during the spring and only 3% in the summer season. The river flow is also characterized by large disparities between wet and dry years (with a maximum of 21.5 m³s⁻¹ and a minimum of 1.3 m³s⁻¹, St. deviation of 4.6 m³s⁻¹). This situation presents a major problem for water resources management.

The mean annual rainfall is around 1150 mm yr⁻¹. The area is also characterized by great inter-annual variability in precipitation, with a standard deviation of 458.8 mm. Thus, there is marked seasonality, with rainfall dominant in autumn-winter and concentrated in the period October-May, whereas July and August are very dry months (**Table 1**).

River flow (m ³ s ⁻¹)	O	N	D	J	F	M	A	M	J	J	A	S	Year
Maximum	28.2	43.3	64.7	70.7	75.2	78.6	30.1	25.8	11.5	5.9	3.3	7.2	21.5
Mean	4.2	9.5	16.7	19.2	18.3	14.2	9.5	6.4	3.6	1.5	0.7	1.1	8.7
Minimum	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.5	0.5	0.4	0.4	0.4	1.3
St. deviation	5.9	9.5	15.8	16.1	16	13.5	6.8	5.1	2.6	1.3	0.4	1.1	4.6
Prec. (mm)													
Maximum	382.5	474.9	827.0	474.5	582.8	618.5	328.6	251.0	221.5	88.7	97.0	196.0	2411.2
Mean	106.4	144.2	172.6	155.8	135.5	119.8	93.9	81.1	45.1	17.1	20.4	54.9	1146.7
Minimum	1.0	0.0	7.0	1.0	5.2	0.0	6.5	1.9	0.0	0.0	0.0	1.3	336.4
St. deviation	90.1	110.5	175.1	118.6	127.6	123.0	71.4	55.3	43.4	18.9	20.8	45.4	458.8

Table 1. Variations in monthly streamflow and precipitation in the study area.

3. Methodology

The streamflow data used in the study was obtained from the Portuguese National Institute for Water (INAG), which has kept records for the last six decades in daily time steps (m³s⁻¹). Annual, monthly and daily data were examined for the period 1950/51–2010/11, using data from a hydrological station in Cunhas, located near the lower point of the catchment area (222 m asl) by the mouth of the River Beça. The streamflow follows a natural, unmanaged regime. A number of different statistics were chosen to describe the characteristics of the streamflow and test for any change in the flow regime at the streamflow gauging station. Trends were also calculated for selected quantiles of discharge, namely the <10th and >90th percentiles, in order

to evaluate the differences between low and high-flow regimes during the six decades analysed.

Rainfall data was also obtained from the INAG. Although precipitation data was collected from seven rainfall gauges distributed within the study area, only the data series for the Cervos rain gauge (842 m asl) was used. The Cervos station was the only one that had collected rainfall data for over five decades (1950/51-2008/09) and is classified as offering high quality and reliability. The annual rainfall data at this station also showed a statistically highly significant correlation with the annual precipitation of all other stations (with a Pearson-correlation coefficient of over $r = 0.77$). The data from this station was therefore considered representative of the average rainfall for the whole of the watershed.

Two non-parametric methods (Mann-Kendall and Sen's slope estimator) were applied to detect trends in the annual and monthly precipitation and streamflow variables. As the Mann-Kendall (MK) trend test [40, 41] can detect trends in a time series without requiring normality or linearity [42], it is highly recommended by the World Meteorological Organization [43] and therefore widely used to detect trends in hydrological and meteorological series [44].

According to the MK trend test, the null hypothesis H_0 is that the data in a time series $\{Y_i, i = 1, 2, \dots, n\}$ is independent and identically distributed over random variables and the hypothesis H_1 implies is that there is a trend in the series. The MK trend test starts by computing the test statistic S given by equation 1:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(Y_j - Y_i) \quad (1)$$

where $\text{sgn}()$ is the signum function. The S statistic, in cases where the sample size n is larger than 10, is assumed to be asymptotically normal, with $E(S)=0$ and

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)}{18} \quad (2)$$

where t refers to the extent of any given tie and \sum_t states the summation over all ties (equation 2). The standard normal variate Z is computed by Equation 3:

$$z = \begin{cases} \frac{(S-1)}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{(S+1)}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (3)$$

Therefore, in case $|Z| \leq Z_{1-\alpha/2}$ in a two-sided test for trend, the null hypothesis H_0 should be accepted at the α level of significance. A positive value of S denotes an “upward trend”, while a negative value of S indicates a “downward trend”.

The Sen slope estimator is useful in cases where the trend is assumed to be linear, depicting the quantification of change per unit of time [45, 46]. De Lima et al. [47] highlight the use of this estimator in cases where there are missing values or other gaps in the data, as it remains unaffected by outliers or gross errors. The slope estimates Q_i of N pairs of data are calculated as (equation 4):

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, 2, \dots, N \quad (4)$$

where x_j and x_k are data values at times j and k ($j > k$) respectively. The Sen slope estimator derives from the above N values of Q_i and equals their median. When there is only one datum in each time period, then $N = n(n-1)/2$, where n corresponds to the number of time periods. The N values of slopes are ranked from the smallest to largest and if N is odd, the Sen slope estimator is calculated as equation 5:

$$Q_{median} = Q[(N+1)/2] \quad (5)$$

On the other hand, if N is even, the estimator is produced by equation 6:

$$Q_{median} = \left(Q_{[N/2]} + Q_{[N/2+1]} \right) / 2 \quad (6)$$

A simple relationship between streamflow and rainfall was also established, excluding temperature since several studies have shown that this variable is not significant in explaining the variance observed in streamflow [17, 22, 48].

In order to evaluate changes in land use and land cover, two different cartographic sources were used:

- i. A map of the soil, land use and capacity of the Nordeste Transmontano region, 1980, 1:100,000 [49],
- ii. A map of land use in Portugal, 2007, 1:25000 (source: Direção Geral do Território; <http://www.dgterritorio.pt/>)

As the two sources have different land use/cover classifications, a simplified legend was established by combining classes, in order to capture the main land use/cover changes. A simple description of the land use and cover classes identified in the River Beça basin are described in **Table 2**.

Land use/cover	Description
Urban areas	Includes built-up land and other recreational areas (gardens, parks, etc.)
Agricultural areas	Areas used for cultivating both annual (vineyards, olives) and perennial (cereals) crops
Agroforestry systems	Areas used as pasture and grassland, as well as mosaic farmland.
Forest and woodlands	Areas covered with dense trees that form almost complete canopies (70%–100%). This category includes forest plantations, mainly pinus, and mixed forest, largely associated with the regeneration of “autochthonous” species such as oak trees.
Shrubland	Areas covered with shrubs, small trees and bare land that has very little or no grass cover (exposed rocks)

Table 2. Description of the land use/cover classes identified in the Beça watershed.

4. Results

4.1. Trends in annual and monthly precipitation and streamflow

The annual mean rainfall and streamflow over the period for which records exist were 1150 mm and $8.7 \text{ m}^3 \text{ s}^{-1}$ respectively. Significant inter-annual variations in rainfall and streamflow are shown in **Figure 2**, corroborated by the respective coefficients of variations, namely 40% for rainfall and 52% for streamflow, showing that streamflow was generally more variable than rainfall.

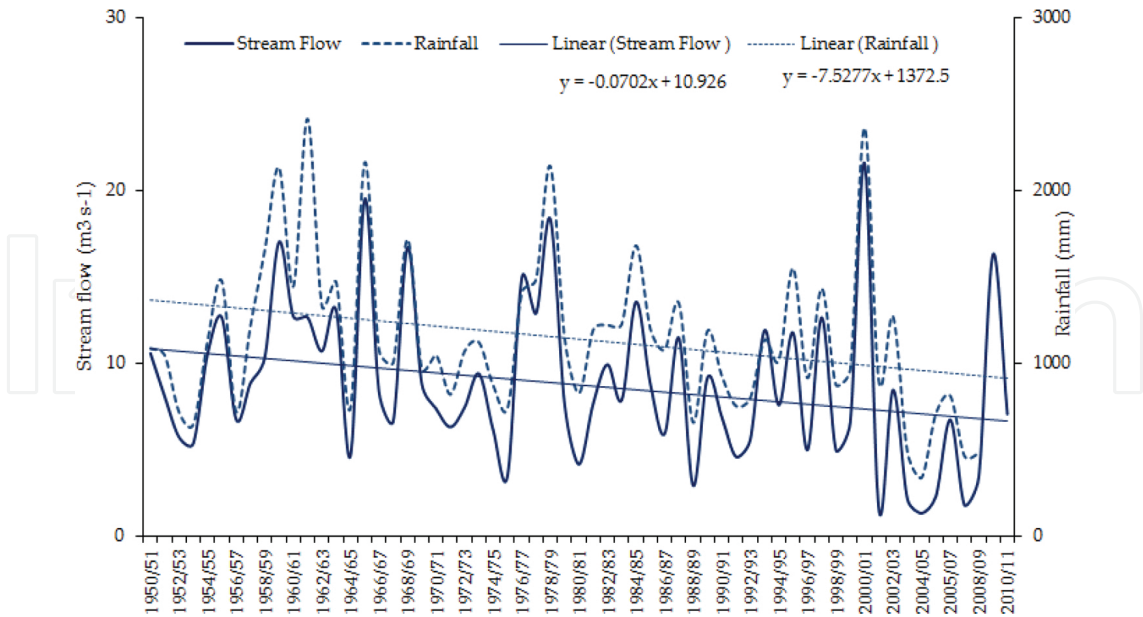


Figure 2. Inter-annual variability of rainfall and mean stream flow at the Cervos and Cunhas station.

Linear trend curves were fitted to the annual rainfall and mean annual streamflow to evaluate the long-term temporal changes (**Figure 2**). These linear regression models show that over the

60-year period both annual rainfall and streamflow decreased, 7.5 mm and 0.07 m³ s⁻¹ respectively per year. These annual rates of change accounted for 32% and 39% of the variation in the rainfall and streamflow rates of change for the study period. The results of the Mann-Kendall method confirm the significant negative annual trend for both variables with a significance level of 5% (**Table 3**).

Rainfall			Stream flow			
	Mann–Kendall score (S)	P-value	Sen's slope	Mann–Kendall score (S)	P-value	Sen's slope
O	-14.000	0.931	-0.024	-50.000	0.755	-0.004
N	-161.000	0.283	-0.952	-168.000	0.287	-0.048
D	-73.000	0.629	-0.367	-70.000	0.660	-0.029
J	-198.000	0.186	-0.971	-84.000	0.597	-0.056
F	-246.000	0.100	-1.283	-380.000	0.016	-0.192
M	-420.000	0.005	-2.000	-690.000	0.0001	-0.270
A	-116.000	0.440	-0.370	-544.000	0.001	-0.140
M	-65.000	0.668	-0.194	-600.000	0.000	-0.098
J	-481.000	0.001	-0.783	-666.000	0.0001	-0.069
J	-20.000	0.861	-0.008	-626.000	0.0001	-0.015
A	165.000	0.271	0.135	-489.000	0.002	-0.004
S	-43.000	0.778	-0.082	-589.000	0.000	-0.008
Y	-331.000	0.027	-7.925	-382.000	0.015	-0.79

Positive values in the table indicate an upward trend and negative values a downward trend.

Table 3. Results of the Mann–Kendall test and Sen's slope for monthly and annual precipitation and streamflow (figures shaded in grey indicate significant trends).

Analysis of changes in monthly precipitation and mean flow provides much greater temporal detail, and can help reveal and explain the cause of changes in annual patterns [50]. **Table 3** provides the calculations for the Mann-Kendall statistics and p-values derived for each month for precipitation and stream flow.

The results show that all of the months reveal a downward trend, with the exception of August rainfall which has a positive trend that is not statistically significant. It is interesting to note that rainfall only exhibited significant negative trends (p - value < 0.05) for the months of March and June, whereas stream flow demonstrated statistically significant decreasing trends between February and September. These negative trends in streamflow affected the late winter period and the whole of the spring and summer seasons.

Following the M-K test, the Sen slope estimator was also used to calculate the change per unit of time for the trends observed in all the precipitation and stream flow time series. The outputs are presented in **Table 3**, where a negative sign represents a downward slope and a positive

sign indicates an upward one. On a monthly basis, only August rainfall confirms an upward slope. During the winter season (January, February and March) downward approximates of 4.4 mm/hydrologic year were recorded. As this concerns the monthly stream, the decreases were more significant between February and April.

4.2. Changes in the pre- and post-1980 period

Noticeable differences in streamflow and precipitation were recorded when comparing the statistics for the pre- and post-1980 period. As **Table 4** shows, the mean annual streamflow for the pre- and post-1980 period was 10.1 m³s⁻¹ and 7.4 m³s⁻¹ respectively, meaning a decrease of 2.7 m³s⁻¹ (-26.7%). The greatest decreases (-50%) in streamflow were recorded in February and March, followed by June (-43.5%), July (-36.8%), May (-34.6%) and April (-33.9%). Conversely, an increase in the daily mean streamflow can be observed in October (+33%) and December (+8.8%). With regard to precipitation, a significant decrease can be observed in February (-49.2%), March (-47.4 %) and June (-40.8%) whilst slight increases were recorded in August (+25.4%), September (17.9%) and October (5.9%).

Streamflow mean (m ³ s ⁻¹)	O	N	D	J	F	M	A	M	J	J	A	S	Year
1950-1980	3.6	10.4	16.0	19.8	24.6	19.0	11.5	7.8	4.6	1.9	0.8	1.1	10.1
1980-2011	4.8	8.6	17.4	18.7	12.3	9.5	7.6	5.1	2.6	1.1	0.6	1.0	7.4
≠ in m ³ s ⁻¹	1.2	-1.8	1.4	-1.1	-12.3	-9.5	-3.9	-2.7	-2.0	-0.7	-0.2	-0.1	-2.7
≠ in %	33.3	-17.3	8.8	-5.6	-50.0	-50.0	-33.9	-34.6	-43.5	-36.8	-25.0	-9.1	-26.7
Rainfall mean (mm)	O	N	D	J	F	M	A	M	J	J	A	S	Year
1950-1980	103.4	146.6	182.9	178.7	178.7	156.3	92.8	81.6	56.4	18.0	18.1	50.5	1264.0
1980-2011	109.5	141.8	161.9	132.1	90.8	82.2	95.0	80.5	33.3	16.1	22.7	59.5	1025.3
≠ in mm	6.1	-4.9	-21.0	-46.6	-87.9	-74.1	2.1	-1.1	-23.0	-1.9	4.6	9.0	-238.7
≠ in %	5.9	-3.3	-11.5	-26.1	-49.2	-47.4	2.3	-1.4	-40.8	-10.8	25.4	17.9	-18.9

Table 4. Daily mean flow for the pre- and post-1980 period.

4.3. Changes in extreme flows

In order to evaluate the differences between low and high-flow regimes during the six decades analysed, trends were also calculated for the quantiles of discharge < 10th and > 90th percentiles (<0.54 and >20.9 m³s⁻¹ respectively). As **Figure 3A** shows, the annual 10th percentile of daily discharge has increased significantly (M-K score: 615.000; P-value: 0,000; Sen's slope: 0.774), particularly in the last decade. Conversely, the number of daily annual classified with maximum discharges of > 90th percentiles is decreasing (**Figure 3B**). This tendency is not statistically significant according to the M-K test and Sen's slope (M-K score: -263.000; p-value: 0.103; Sen's slope: -0.322).

This pattern indicates that baseflows have been decreasing (which suggests that hydrological drought is increasing), whilst extreme hydrological events are tending to decrease in frequency and/or magnitude.

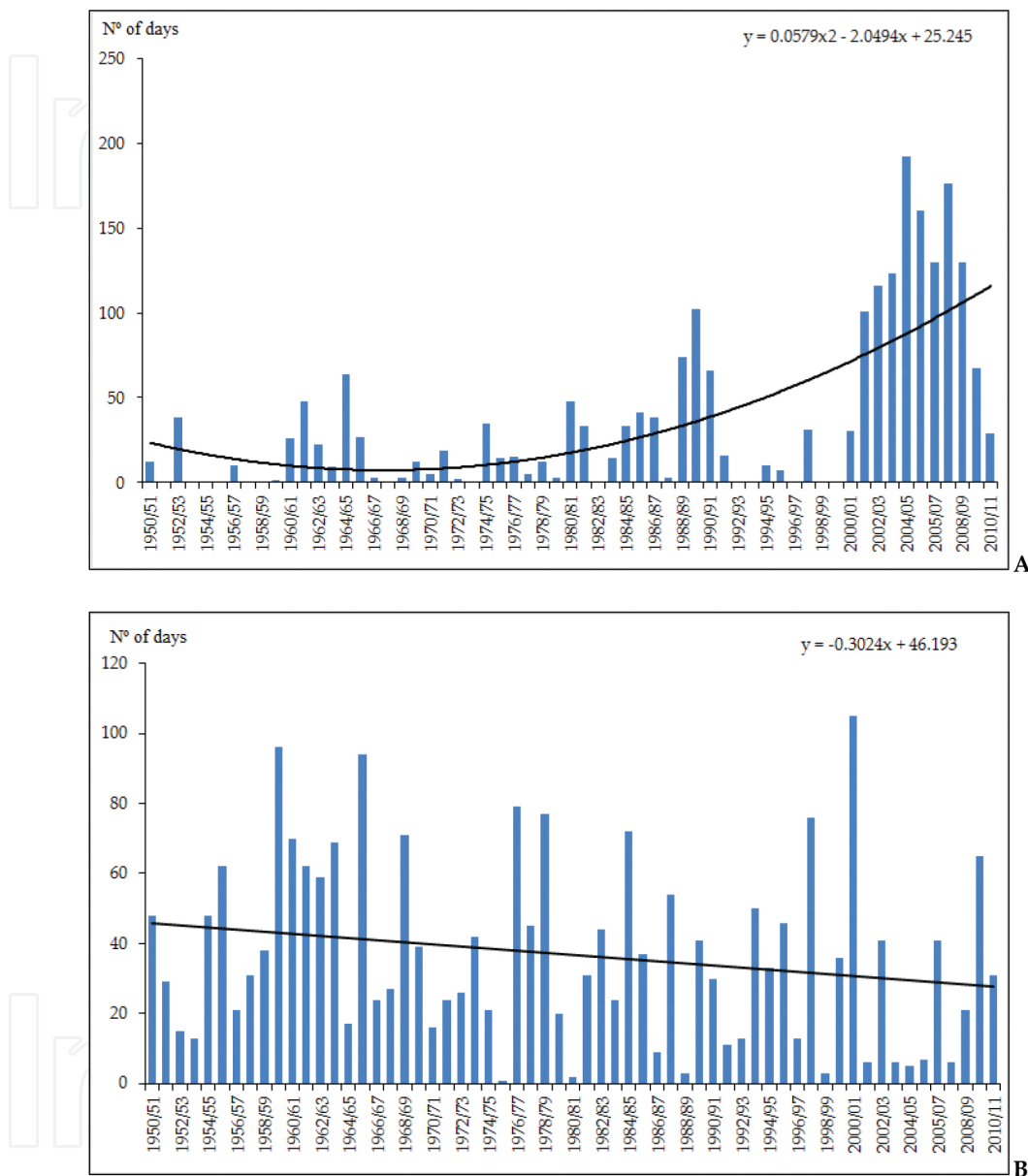


Figure 3. Number of days, per year, included in the <10th (A) and >90th (B) percentiles.

4.4. Analysis of land use/cover change

As indicated by the two land use maps (**Figure 4**), the major changes within the last 30 years are changes from agriculture and agroforestry to semi-natural vegetation (shrubland). In fact, agricultural activities dominated land use in marginal areas of Portugal for many decades. In the 1960s, over half of the agricultural area utilized was divided between non-irrigated cereals

(the dry system) and unseeded fallow rotations. In recent decades, the marked decrease in cropland and agrosystems in the entire catchment area (-17%) is mainly due to poor conditions for agriculture (a Mediterranean climate, undulating relief, and poor, shallow soils), uncompetitive farm structures (with small, scattered plots), the peripheral location of the area, the lack of alternative employment sectors, a reduction in livestock and the large number of elderly farm owners. This process of farmland abandonment was triggered by the migration of significant numbers of the population to certain European countries and the Portuguese urban centres and, more recently, as part of the set-aside strategy of the EU common agricultural policy [51].

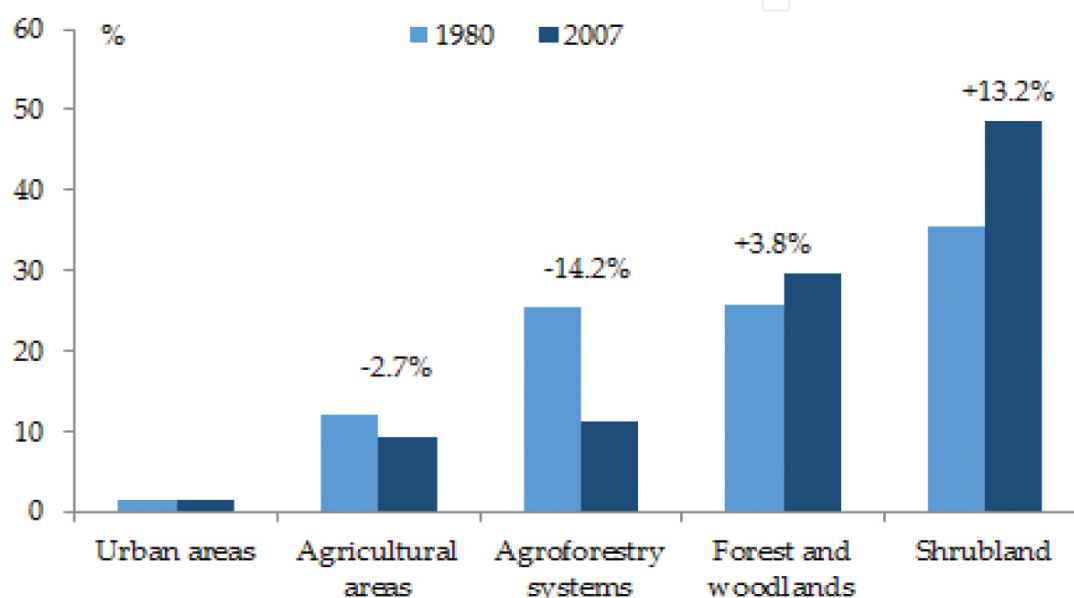


Figure 4. Changes in land use/cover in the River Beça basin, 1980–2007.

The subsequent abandonment of cultivated and pasture land has increased the spread, growth and consolidation of compact wood and shrub masses, which registered an upward trend of 17%. This spread is the result of secondary succession in abandoned pastures and croplands and more frequent disturbances in Mediterranean forests, such as increasing fire recurrence.

4.5. Interactions between hydroclimatic variables and the possible effect of changes in land use/cover

It is clear that the River Beça hydrological regime is largely influenced by the temporal distribution of rainfall (**Figure 5**). Thus, the relationship between annual streamflow and total precipitation shows a significant correlation coefficient of 99% ($R^2 = 0.846$), meaning that the changes in precipitation lead to reductions in streamflow. However, the correlations between regional precipitation and discharge have only changed slightly throughout the study period. A higher correlation was found between precipitation and streamflow in the post-1980 period ($R^2 = 0.895$) in comparison to the pre-1980 period ($R^2 = 0.784$).

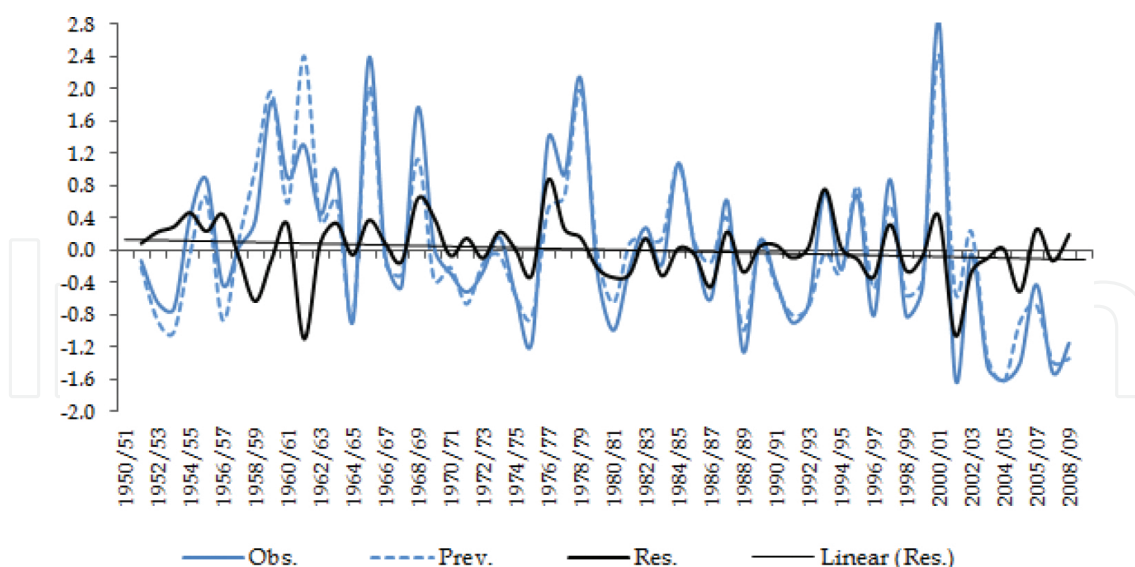


Figure 5. Evolution of observed and predicted streamflow and temporal trend of the residuals.

Given the fact that the relationship between the variables has changed slightly during the period studied, together with the temporal tendency denoted by the residuals, the product of the year-by-year correlation between rainfall and discharge suggests that the changes in land use/cover in the study area might have affected water resources. As the figure shows, although the residuals were randomly distributed over time, a downward trend can be observed which is almost significant at the 5% level ($p\text{-value} = 0.051$), suggesting a gradual decrease in the stream yield for a given precipitation.

5. Discussion

Annual precipitation and streamflow can be described as highly irregular, both in intra and inter annual terms. During the period analysed, namely the last 6 decades, a consistent negative trend was observed, both in the amount of annual precipitation and the mean annual streamflow in the Beça basin. Our results also demonstrate that precipitation greatly influences streamflow dynamics, explaining around 85% of the variability observed in the mean annual streamflow. A significant decrease in precipitation, particularly during the wet period, can have severe consequences for the hydrological cycle and water supply, both for ecosystems and societies. In fact, a change in precipitation quantity results in changes in runoff and affects the groundwater recharge rates which, in turn, have an impact on the water supply to the local population. In terms of agricultural demand, both rainfed crops and irrigated cultures may face a soil-moisture deficit associated with lower precipitation. The post-1980 period was significantly drier in comparison with the pre-1980 period.

Decreasing precipitation and streamflow in southern Europe, particularly in Spain and Portugal, has been linked to an increasingly positive North Atlantic Oscillation Index (NAOI) [52, 53]. As the negative phase of these indices is associated with frontal conditions that trigger

rainfall in the Mediterranean basin, the more frequent occurrence of positive phases after 1970 may explain the drying trends reported for several regions, as well as for Portuguese territory as a whole [54, 55]. Moreover, the analyses of the effects of the NAO on precipitation confirm the major influence of the winter NAO on precipitation in the Mediterranean mountain areas, particularly in the mountains of the Iberian Peninsula [56].

These results concur with the findings of other researchers working on a regional level, who have reported a decline in precipitation and streamflow in the Mediterranean basin. For example, in their study of the behaviour of four direct tributaries of the River Douro (Águeda, Huebra, Uces and the Tormes) in the south-west sector of the Douro basin, Ceballos et al. [17] detected that water discharges have decreased appreciably in three of the basins analysed. This decrease exceeds 50% in some cases and was directly linked to the decrease recorded for rainfall, with a significant correlation coefficient of 99% ($r=0.85$) between both variables, which confirms the notion that a reduction in precipitation plays an important role in the reduction of discharges.

Similar results were found by Morán-Tejeda et al. [19, 20] in analysing the evolution of runoff and fluvial regimes in catchments located in the mountains surrounding the River Douro basin. The results show a general negative trend for annual runoff which is related to a decrease in precipitation and rising temperatures in winter and spring. The effects of land-cover expansion on runoff evolution could be only partially demonstrated, which confirms the difficulty in obtaining a detailed understanding of the interaction between hydrology and land-use at catchment scale in Mediterranean environments. Ceballos et al. [17, 18] also verified that the changes detected in forest land have not affected the water discharges of the rivers and related this to the changes observed in the vegetation cover, which are below the threshold for detecting the effect of the forest on water. In fact, the magnitude of the impact caused by changes in land use/cover varies significantly according to the extent of the vegetation cover and the type of vegetation (shrub or forest type), which have different levels of evapotranspiration [57].

In evaluating water yield evolution across the whole Ebro basin, López-Moreno et al. [22] also found a marked decrease in river discharges in most of the sub-basins. In this case, the changes in water yield are associated with an increase in evapotranspiration rates in natural vegetation, which had expanded as a consequence of land abandonment in areas where agricultural activities and livestock pressure had declined. In fact, the analysis of the time evolution of residuals from empirical models that relate climate and runoff in each sub-basin provided evidence that climate alone does not explain the decrease in river discharge which was observed.

For the Portuguese territory, previous studies on tributaries of the River Douro (the Côa and Sabor rivers) [58, 59] detected significant decreases in streamflow which were also related to changes in annual precipitation and land use/cover. A study of the high Côa river catchment area which aimed to evaluate and compare the hydrological response of soils subject to different land uses and vegetation types (cereal crop, fallow land or short-term abandonment, shrubland, recovering autochthonous vegetation, arable land afforested with *Pinus pinaster* and arable land transformed into pastureland), which represent situations commonly found

throughout central and northern Portugal [37], showed a decrease in runoff, together with an increase in soil cover with vegetation. The results concur with those observed by different authors in a variety of environments [60, 61].

The results obtained for the River Beça basin show that the changes detected in land use/cover may have affected the water discharges of the river, although it is difficult to evaluate the magnitude of the impact.

In fact, two main factors (climate, especially precipitation, and land use/plant cover) govern fluvial discharge variations in streamflow and generally reproduce the variations in precipitation. Quantifying the isolated and integrated impacts of land use/cover change and climate change on streamflow is therefore challenging, as well as crucial to optimum management of river basin water resources [25].

In addition to the downward trend for streamflow, the significant positive trend observed in low flow, particularly in summer, also has some parallels with previous work, which has detected a general drying in Europe in summer [50]. This increasing low flow trend may cause major disasters and severe social and economic losses [62].

6. Conclusion and further research

As in other Mediterranean mountain areas, water resources in the River Beça basin are affected by climate change, lower precipitation and higher temperatures, together with the impacts of changes in land use/land cover associated with major socioeconomic changes that result in land abandonment. It has been widely accepted that climate variability and changes in land cover or land use are two critical drivers which influence watershed hydrological changes. It is therefore important to separate their relative contributions to hydrological change so that their individual effects can be examined. Moreover, other variables should be included, such as evapotranspiration and plant canopy characteristics, in order to understand the watershed hydrological response better. In addition to river flow variations caused by climate variability and changes in land use/cover, the hydrological impact of major wildfires should also be analysed. In fact, several wildfires have occurred in the area since the 1980s. It is generally accepted that wildfires reduce infiltration and increase surface runoff by removing the surface litter and vegetation. Thus, wildfires can significantly change hydrological processes and the landscape's susceptibility to major flooding. Burned catchment areas are therefore at increased hydrological risk and respond faster to rainfall than unburned catchment areas.

However, assessment of the relative effects of land use and cover changes and climatic variability on hydrology is rather limited in Portugal and more case studies are therefore needed, focusing on both small and large watersheds, before general conclusions can be drawn.

The limited hydrometeorological data available at national level, the quality or “fitness use” of this data, inadequacy of spatial and temporal datasets, insufficient temporal data, and data sequences with gaps or incomplete sets are common obstacles in time series analysis which compromise process modelling, since it is essential to have serially complete data. Likewise,

it is difficult to collect data on changes in land use or land cover on large spatial scales over extended time periods.

This should therefore be a priority for future research, since they it is of prime importance both to hydrological modelling and the planning/management of water resources. A greater effort should be made to focus on the reconstruction of serially incomplete data records for basins with short streamflow records or ungauged river basins, as well as climatic data series. In addition, other statistical methods such as the trend analysis method, sensitivity-based approach and elasticity method should be used to quantify the effects of climatic variability first, then estimate the influence of land use/cover change from the total variations in streamflow.

Furthermore, it is imperative for scientists, politicians and managers to coordinate their efforts, since maintaining the water supply in the face of increasing demand presents a challenge, given that climate projections for the end of the twenty-first century suggest a reduced capacity for runoff generation due to rising temperatures and lower precipitation.

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References

- [1] Dunne T, Leopold LB. Water in Environmental Planning. W.H. Freeman and Company, New York; 1978.

- [2] Kondratyev KY, Cracknell AP. *Observing Global Climate Change*. Taylor and Francis Ltd., London; 1998. p. 562.
- [3] Chiew FHS, Whetton PH, McMahon TA, Pittock AB. Simulation of the impacts of climate change on runoff and soil moisture in Australian catchments. *Journal of Hydrology*. 1995; 167 (1–4): 121–147. DOI: 10.1016/0022-1694(94)02649-V
- [4] Chiew FH, McMahon TA. Modelling the impacts of climate change on Australian streamflow. *Hydrological Processes*. 2002; 16: 1235–1245. DOI: 10.1002/hyp.1059
- [5] IPCC. *Climate Change 2014*. In Core Writing Team, Pachauri RK and Meyer LA, editors. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change IPCC, Geneva, Switzerland; 2014. p. 151.
- [6] Miranda P, Valente M, Tomé A, Trigo R, Coelho M, Aguiar A, Azevedo E. The Portuguese climate in the 20 th and 21 st centuries. In Santos FD and Miranda P, editors. *Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures*, ed., Gradiva Publications, Lisbon, Portugal; 2006. pp. 45–113.
- [7] Nunes A, Lourenço L. Precipitation variability in Portugal from 1960 to 2011. *Journal of Geographical Sciences*. 2015; 25 (7): 784–800. DOI: 10.1007/s11442-015-1202-y
- [8] McCabe GJ, Wolock DM. A step increase in streamflow in the conterminous United States. *Geophysical Research Letters*. 2002; 29 (24): 2185. DOI: 10.1029/2002GL015999.
- [9] Mansell MG. The effect of climate change on rainfall trends and flooding risk in the west of Scotland. *Nordic Hydrology*. 1997; 28: 37–50.
- [10] Shorthouse C, Arnell N. The effects of climatic variability on spatial characteristics of European river flows. *Physics and Chemistry of the Earth (B)*. 1999; 24 (1–2): 7–13. DOI: 10.2478/quageo-2013-0006
- [11] Pfister L, Humbert J, Hoffmann L. Recent trends in rainfall-runoff characteristics in the Alzette river basin, Luxembourg. *Climatic Change*. 2000; 45 (2): 323–337. DOI: 10.1007/s10584-006-9195-2
- [12] Hisdal H, Stahl K, Tallaksen LM, Demuth S. Have streamflow droughts in Europe become more severe or frequent? *International Journal of Climatology*. 2001; 21: 317–333. DOI: 10.1002/joc.619
- [13] de Wit MJM. *Effect of Climate Change on the Hydrology of the River Meuse*. Report 104, Wageningen University Environmental Sciences, Netherlands; 2001.
- [14] Burn DH, Elnur M. Detection of hydrological trends and variability. *Journal of Hydrology*. 2002; 255: 107–122. DOI: 10.1016/S0022-1694(01)00514-5
- [15] Christensen NS, Wood AW, Voisin N, Lettenmaier DP, Palmer RN. The effects of climate change on the hydrology and water resources of the Colorado river basin. *Climatic Change*. 2004; 62: 337–363. DOI: 10.1023/B:CLIM.0000013684.13621.1f

- [16] Ceballos A, Morán-Tejeda E. Evolution of water discharges in a mountain basin from the Central System: headwaters of river Tormes (1941-2004). *Cuadernos de Investigación Geográfica*, University of La Rioja, Spain. 2006; 32: 7–28. DOI: 10.1007/s00382-013-1885-7
- [17] Ceballos A, Morán-Tejeda E, Luengo-Ugidos MA, Llorente-Pinto JM. Water resources and environmental change in a Mediterranean environment: the south-west sector of the Duero river basin (Spain). *Journal of Hydrology*. 2008a; 351: 126–138. DOI: 10.1016/j.jhydrol.2007.12.004
- [18] Ceballos A, Morán-Tejeda E, Luengo-Ugidos MA, Llorente-Pinto JM. A Water discharges in River Douro headwaters: relationship with climate variability and changes in vegetation cover. *Territorium*, Portugal. 2008b; 15: 15–28.
- [19] Morán-Tejeda E, Ceballos A. Water resources and environmental changes in mediterranean headwaters. In: Efe R, Cravins G, Ozturk M, Atalay I, editors. *Natural Environment and Culture in the Mediterranean Region*. Cambridge Scholars Publishing, United Kingdom; 2008. pp. 271–288.
- [20] Morán-Tejeda E, Ceballos A, Llorente-Pinto JM. Hydrological response of Mediterranean headwaters to climate oscillations and land-cover changes: the mountains of Duero basin (Central Spain). *Global and Planetary Change*. 2010; 72(1–2): 39–49. DOI: 10.1016/j.gloplacha.2010.03.003
- [21] Morán-Tejeda E, Zabalza J, Rahman K, Gago-Silva A, López-Moreno I, Vicente-Serrano S, Lehmann A, Tague CL, Beniston M. Hydrological impacts of climate and land-use changes in a mountain watershed: uncertainty estimation based on model comparison. *Ecohydrology*. 2015; 8 (8): 1396–1416. DOI: 10.1002/eco.1590
- [22] López-Moreno JI, Vicente-Serrano SM, Morán-Tejeda E, Zabalza J, Lorenzo-Lacruz J, García Ruíz JM. Impact of climate evolution and land-use changes on water yield in the Ebro basin. *Hydrology and Earth System Science*. 2011; 15: 311–322. DOI: 10.5194/hess-15-311-2011
- [23] López-Moreno JI, Zabalza J, Vicente-Serrano SM, Revuelto J, Gilaberte M, Azorin-Molina C, Morán-Tejeda E, García-Ruiz JM, Tague C. Impact of climate and land use change on water availability and reservoir management: Scenarios in the Upper Aragón River, Spanish Pyrenees. *Science of the Total Environment*. 2014; 493: 1222–1231. DOI: 10.1016/j.scitotenv.2013.09.031
- [24] Peña-Arancibia JL, van Dijk AIJM, Guerschman JP, Mulligan M, Bruijnzeel LA, McVicar TR. Detecting changes in stream flow after partial woodland clearing in two large catchments in the seasonal tropics. *Journal of Hydrology*. 2012; 416–417: 60–71. DOI: 10.1016/j.jhydrol.2011.11.036
- [25] Chawla I, Mujumdar PP. Isolating the impacts of land use and climate change on streamflow. *Hydrology and Earth System Sciences*. 2015; 19: 3633–3651. DOI: 10.5194/hess-19-3633-2015

- [26] Bosch JM, Hewlett JD. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology*. 1982; 55: 2–23.
- [27] Stednick JD. Monitoring the effects of timber harvest on annual water yield. *Journal of Hydrology*. 1996; 176 (1/4): 79–95. DOI: 10.1016/0022-1694(95)02780-7
- [28] Sahin V, Hall MJ. The effects of afforestation and deforestation on water yields. *Journal of Hydrology*. 1996; 178 (1/4): 293–309. DOI: 10.1016/0022-1694(95)02825-0
- [29] Vertessy RA. The impacts of forestry on streamflows: a review. In: Croke J, Lane P, editors. *Forest Management for the Protection of Water Quality and Quantity*. Proceedings of the Second Erosion in Forests Meeting. Warburton, 4–6 May, Cooperative Research Centre for Catchment Hydrology, Report 99/6; 1999. pp. 93–109.
- [30] Vertessy RA. Impacts of plantation forestry on catchment runoff. In: Sadanandan Nabia, EK, Brown, AG, editors. *Plantations, Farm Forestry and Water* Proceedings of a National Workshop, 20–21 July, Melbourne; 2000. pp. 9–19.
- [31] Laurance WF. Forests and floods. *Nature*. 2007; 449: 409–410. DOI: 10.1038/449409a
- [32] Bradshaw CJA, Sodhi NS, Peh KS-H, Brook BW. Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biology*. 2007; 13: 1–17. DOI: 10.1111/j1365-2486200701446x
- [33] Clark, C. Deforestation and floods. *Environmental Conservation*. 1987; 14(1): 67–69. DOI: 10.1017/S037689290001112
- [34] Joffre R, Rambal S. How tree cover influences the water balance of Mediterranean rangelands. *Ecology*. 1993; 74: 570–582. DOI: 10.1038/npgels0003196
- [35] Zhang L, Dawes WR, Walker GR. Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research*. 2001; 37(3): 701–708. DOI: 10.1029/2000WR900325
- [36] Brown AE, Zhang L, McMahon TA, Westen AW, Vertessy RA. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology*. 2005; 310: 28–61. DOI: 10.1016/j.jhydrol200412010
- [37] Nunes AN, Almeida AC, Coelho COA. Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. *Applied Geography*. 2011; 31(2): 687–699. DOI: 10.1016/j.apgeog201012006
- [38] Martínez-Fernández J, Sánchez N, Herrero-Jiménez J, Carlos M. Recent trends in rivers with near-natural flow regime: The case of the river headwaters in Spain. *Progress in Physical Geography*. 2013; 37(5): 685–700. DOI: 10.1177/0309133313496834
- [39] Iglesias A, Garrote L, Diz A, Schlickenrieder J, Martin-Carrasco F. Rethinking water policy priorities in the Mediterranean Region in view of climate change. *Environmental Science & Policy*. 2011; 14: 744–757. DOI: 10.1016/j.envsci201102

- [40] Mann, HB. Non-parametric tests against trend. *Econometrica*. 1945; 13: 163–171.
- [41] Kendall, MG. *Rank Correlation Methods*. 4th ed. Charles Griffin, London; 1975.
- [42] Wang W, Chen X, Shi P, van Gelder PHAJM. Detecting changes in extreme precipitation and extreme streamflow in the Dongjiang River Basin in southern China. *Hydrology and Earth System Sciences*. 2008; 12(1): 207–221, DOI: 10.5194/hess-12-207-2008
- [43] Mitchell JM, Dzerdyevskii B, Flohn H, Hofmeyr WL, Lamb HH, Rao KN, Wallen CC. *Climatic Change*. (Report of a working group of the Commission for Climatology). WMO No. 195, Switzerland, 1966. 79 p.
- [44] Zhang Q, Liu C, Xu CY, Xu YP, Jiang T. Observed trends of annual maximum water level and streamflow during past 130 years in the Yangtze River basin, China. *Journal of Hydrology*. 2006; 324(1–4): 255–265. DOI: 10.1016/j.jhydrol.2005.09.023
- [45] Sen PK. Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistical Association*. 1968; 63: 1379–1389. DOI: 10.1080/01621459196810480934
- [46] Gilbert RO. *Statistical Methods for Environmental Pollution Monitoring*. Wiley, NY; 1987.
- [47] De Lima MIO, Marques ACP, De Lima JLMP, Coelho MFES. *Precipitation Trends in Mainland Portugal in the Period 1941–2000: The Fourth Inter-Celtic Colloquium on Hydrology and Management of Water Resources*. Guimarães, Portugal; 2005.
- [48] Beguería S, López-Moreno J, Lorente A, Seeger M, García-Ruiz J. Assessing the effect of climate oscillations and land-use changes on streamflow in the Central Spanish Pyrenees. *Ambio*. 2003; 32(4): 283–286. DOI: 10.1579/0044-7447-324283
- [49] Agroconsultores e Coba. *Soil Charter, land use chart and Land Suitability chart from the Northeast of Portugal*, scale 1:100 000, University of Trás-os-Montes e Alto Douro, Vila Real, Portugal, 1991.
- [50] Stahl K, Hisdal H, Hannaford J, Tallaksen LM, van Lanen HAJ, Sauquet E, Demuth S, Fendekova M, Jódar J. Streamflow trends in Europe: evidence from a dataset of near-natural catchments. *Hydrology and Earth System Sciences*. 2010; 14(12): 2367–2382. DOI: 10.5194/hess-14-2367-2010
- [51] Almeida AC, Nunes A, Figueiredo, A. *Land use and cover change in inland of center and north of Portugal*. University of Coimbra Press, Portugal; 2009. 99 p.
- [52] Trigo RM, Pozo-Vazquez D, Osborn TJ, Castro-Diez Y, Gamiz-Fortis S, Esteban-Parra, MJ. North Atlantic oscillation influence on precipitation, river flow and water resources in the Iberian peninsula. *International Journal of Climatology*. 2004; 24: 925–944. DOI: 10.1002/joc.1048

- [53] López-Moreno J, Vicente-Serrano SM. Positive and negative phases of the wintertime North Atlantic Oscillation and drought occurrence over Europe: A multitemporal-scale approach. *Journal of Climate*. 2008; 21: 1220–1243. DOI: 10.1175/2007JCLI1739.1
- [54] Trigo IF, Davies TD, Bigg GR. Decline in Mediterranean rainfall caused by weakening of Mediterranean cyclones. *Geophysical Research Letters*. 2000; 27: 2913–2916. DOI: 10.1029/2000GL011526
- [55] Trigo RM, da Camara C. Circulation weather types and their impact on the precipitation regime in Portugal. *International Journal of Climatology*. 2000; 20(13): 1559–1581. DOI: 10.1002/1097-0088(20001115)20:13<1559::AID-JOC555>3.0.CO;2-5
- [56] López-Moreno JI, Vicente-Serrano SM, Morán-Tejeda E, Lorenzo-Lacruz J, Kenawy A, Beniston M. Effects of the North Atlantic Oscillation (NAO) on combined temperature and precipitation winter modes in the Mediterranean mountains: observed relationships and projections for the 21st century. *Global Planet Change*. 2011; 77: 62–76. DOI: 10.1016/j.gloplacha.2011.03.003
- [57] Cui X, Liu S, Wei X. Impacts of forest changes on hydrology: a case study of large watersheds in the upper reaches of Minjiang River watershed in China. *Hydrology and Earth System Sciences*. 2012; 16: 4279–4290. DOI: 10.5194/hess-16-4279-2012
- [58] Nunes A. Water resources in the river Côa basin: relationships with climate variability and changes in land use. *Iberografias, Portugal*. 2007; 10: 71–86.
- [59] Nunes A. Water resources in the river Sabor basin: recent evolution and relations with socio-environmental changes. VI Iberian Congress on Water Management and Planning, Vitória-Gasteiz; 2008. 10 p.
- [60] Bochet E, Rubio JL, Poesen J. Relative efficiency of three representative matorral species in reducing water erosion at the microscale in a semi-arid climate (Valencia, Spain). *Geomorphology*. 1998; 23: 139–150. DOI: 10.1016/S0169-555X(97)00109-8
- [61] Durán Zuazo VH, Francia Martínez JR, Rodríguez Pleguezuelo CR, Martínez Raya A, Carcéles Rodríguez B. Soil-erosion and runoff prevention by plant covers in a mountainous area (SE Spain): implications for sustainable agriculture. *Earth and Environmental Science*. 2006; 26 (4): 309–319. DOI: 10.1007/s10669-006-0160-4
- [62] Tian P, Zhao G, Li J, Tian K. Extreme value analysis of streamflow time series in Poyang Lake Basin, China. *Water Science and Engineering*. 2011; 4 (2): 121–132. DOI: 10.3882/j.issn.1674-2370.2011.02.001