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RESPONSE OF SOIL EROSION IN A MOUNTAINOUS CATCHMENT TO TEMPERATURE AND PRECIPITATION TRENDS

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Abstract: This study is an attempt to assess the effects of temperature and precipitation variability to soil erosion in mountainous catchments. In order to achieve this goal, long-term meteorological time series (1961-2011) of Pertouli meteorological station was processed and analyzed. The Mann-Kendall non parametric statistical test was applied to detect trends in the mean annual temperature and precipitation. The results of the Mann-Kendall test indicate statistical decreasing trend for precipitation and statistical significant increasing trend for temperature. Moreover, the beginning of the change is associated to 1985 in case of precipitation and 1990 for temperature. Based on the Mann - Kendal test results, the study period was divided to two sub-periods, namely: 1961-1985 and 1986-2011. Finally, the erosion prediction model of Gavrilovic was used to quantify the effect of those trends on soil erosion. The comparison of the results showed that the value of mean annual soil erosion decreased by 2.8 t ha^{-1} yr^{-1} during 1986-2011 when precipitation decreased by 15% and temperature increased by 5%.

Keywords: Gavrilovic, climate change, erosion, Mann-Kendall

1. INDRODUCTION

As soil genesis is an extremely slow process, soil can be considered essentially as a non- renewable resource. The need for its protection is well recognized (EU, 2006) because it has both economic and environmental importance (Zlatić et al., 2010). Soil erosion is considered one of the major threats for forest soils (Vulević et al., 2015). It is a complex process controlled by numerous factors such as topography, climate, soil characteristics, forest cover and human activities. Effective modeling of water erosion can provide crucial information about erosion patterns and trends. Moreover, assessment of soil erosion is needed for rational management of mountainous catchments (Myronidis et al., 2010). The Mediterranean region is particularly prone to soil erosion, due to both the non-uniform rainfall distribution, in space and in time, and the effects of wildland fires (Stefanidis, 1995).

Climate scientists noticed that the earth is warming and as global temperature increase, hydrological cycle became more vigorous. Additionally, the Intergovernmental Panel on Climate Change (IPCC, 2013) indicates decrease of annual precipitation and increase of atmospheric temperature. Variability of climate factors is of great concern due to their economical, social and ecological impacts. Large changes in the wintertime atmospheric circulation along with local factors such as orography and continentality have had a profound effect on the regional distribution of precipitation in the Mediterranean basin (Nastos et al., 2015). So, it is clear that soil erosion and its consequences are influenced by climate change (Nastos et al., 2010, Simonneaux et al., 2015).

The estimation of soil erosion by field work is a time - consuming and costly process that is difficult to cover the total catchment, but limited to experimental plots within the catchment (Stefanidis et al., 2002; Verstraeten & Poesen, 2002; Vanmaercke et al., 2012). That led to the development of empirical methods for soil loss estimation. The most popular soil erosion models are the USLE, WEPP, CREAMS, AMSWER, EPIC, Gavrilovic, Corine and PESERA.

The quantitative erosion prediction model of Gavrilovic was developed using field work and laboratory research to determine the range of values for its parameters. It has been widely used in former Yugoslavia since early 70s along with the

Geographical Information Systems (GIS) for faster and more accurate determination of the model parameters (Globevnik et al., 2003). Also, GIS gives the ability of spatial analysis of the results (Myronidis and Arabatzis, 2009). Regarding the use of model in Greece, comparison with present measurement, showed that gives reliable results (Sapountzis et al., 2009; Xanthakis, 2011). The main purposes of this study are to detect trends to temperatures and precipitations time series and evaluate the associated response of soil erosion to the above mentioned trends by using the Gavrilovic model.

2. MATERIAL AND METHODS

2.1 Study area

The present research was conducted in the University Forest of Pertouli, located in the Trikala Prefecture of Central Greece. The rights for the management of Pertouli forest assigned to the Aristotle University of Thessaloniki at 1934 for educational and research purposes.

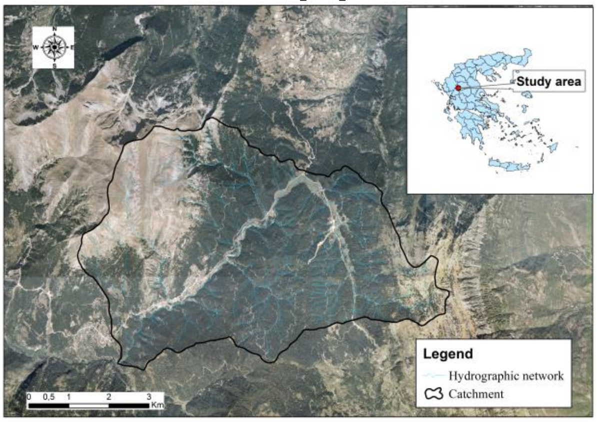

Figure 1. Aspropotamos catchment within University forest of Pertouli.

The forest stretches in the western part of Pindus Mountain and covers 3,290 ha consisting mainly in pure stands of Abies borissi regis. As for the geological substratum, the dominant layers are flysch and limestones which are quite vulnerable to landslides. Hydrologically, the area belongs to the upper part of Acheloos River and the main torrent within University forest of Pertouli is Aspropotamos. Also, it has been included in the Natura 2000 network of nature protected areas with site code GR1440002. Systematic meteorological observations began in November 1960 after the setting up of a weather station at 1180 m.

2.2 Methodology

In order to delineate the catchment boundaries and stream network a GIS toolbox was developed using model builder. The graphical representation of the model is shown in the figure 2.

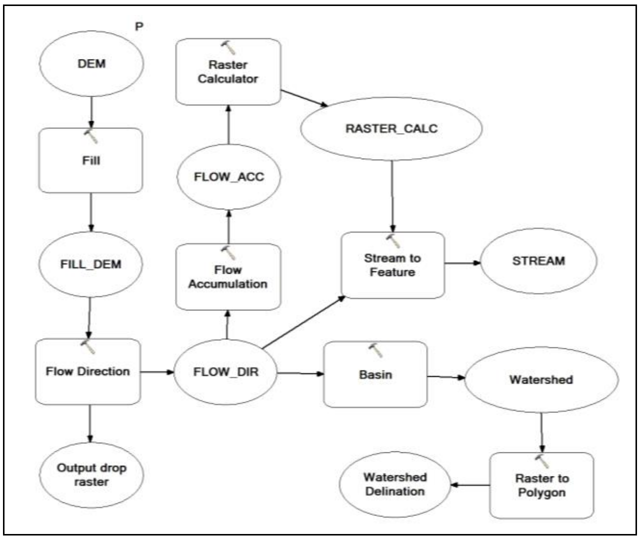

Figure 2. Graphical representation of the model for catchment and stream network delineation.

The only input parameter of the model is the digital elevation model (DEM) and the outputs are the shapefiles of stream network and catchment boundaries. Based on the above mention data the morphometric and hydrographic characteristics of the catchment were assessed (Horton, 1932).

Time series of mean annual precipitation and mean annual temperature were subjected to Mann-Kendall test to detect any trend over the period 1961-2011. There are two advantages of using this test. Firstly, it is a non parametric test and does not require the data to be normally distributed. Secondly, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. This is the most widely used test for the trend analysis in climatological time series (Goossens & Berger, 1986). The Mann-Kendall test was conducted, as it has been proposed by Sneyers (1990). The slopes of the trends were calculated by least-squares linear fitting. For each x_i (i = 1,..., n) of the time series in the Mann-Kendall test, the number n_i of lowest elements x_j ($x_j<x_i$) preceding it (j<i) was calculated and the test statistics t was given by:

$$t = \sum_i n_i \qquad (1)$$

In the absence of any trend (null hypothesis), t is asymptotically normal, independent from the distribution function of the data:

$$u(t) = \frac{(t - \overline{t})}{\sqrt{\mathrm{var}(t)}} \qquad (2)$$

and has a standard normal distribution, with t and var(t) given by:

$$t = \frac{n(n-1)}{4} \quad (3)$$

$$\text{var}(t) = \frac{n(n-1)(2n+5)}{72} \quad (4)$$

The null hypothesis can, therefore, be rejected for high values of $|u(t)|$, this being the probability a1 of rejecting the null hypothesis when it was derived by a standard normal distribution table:

$$a_1 = P(|u| > |u(t)|) \quad (5)$$

The sequential form of the Mann-Kendall test, consisting of the application of the test to all the series starting with the first term and ending with the i_{th} and to those starting with the i_{th} one and ending with the first, was also used for a progressive analysis of the series. In the absence of any trend, the graphical representation of the direct (u_i) and the backward (u_i') series obtained with this method gives curves that overlap several times. However, in the case of a significant trend (5% level $|u_i| > 1.96$), the intersection of the curves enables to detect approximately the occurrence time of one.

Moreover, the Gavrilovic erosion model of was applied after identification of the trends to temperature and precipitation data (Gavrilovic 1972, 1988). Accordingly, the mean annual soil erosion is expressed by the following formula:

$$W = T * h * \pi * \sqrt[3]{Z} * F \quad (6)$$

where W is the mean annual soil erosion ($m^3\ yr^{-1}$), h is the mean annual precipitation (mm), π is a mathematical constant approximately equal to 3.14159, F is the catchment area (km^2), T is a coefficient of temperature given by the equation below:

$$T = \sqrt{\frac{t^0}{10} + 0.1} \quad (7)$$

where t^o is the average annual temperature (^oC) and Z is the coefficient of erosion given by the equation (8)

$$Z = x * y(\varphi + \sqrt{J} \quad (8)$$

In the previous equation (8), the x coefficient quantifies the protective role of forest cover, ranging from 0.05 to 1 and determined from the 2007 aerial orthophoto. Then, y coefficient expresses the soil resistance to erosion, range from 0.25 to 2 and was defined by using geological maps. The φ quantifies the observed erosion process in the catchment within a range of 0.1 to 1 and was evaluated by identifying the sediment sources areas from orthophoto and field surveys. Finally, J coefficient is the mean slope of the catchment (%) and was determined from digital elevation model (DEM) using Spatial Analyst → Zonal Statistics techniques of GIS.

3. RESULTS

After delineation of the catchment and the stream network of Aspropotamos torrent the morphometric and hydrographic characteristics of the catchment were determined (Table 1).

Table 1. Morphometric and hydrographic characteristics of the Aspropotamos torrent.

Characteristics	Units	Values
Area	km^2	36.34
Perimeter	km	28.01
Minimum elevation	m	1,020
Maximum elevation	m	2,074
Mean elevation	m	1,420
Mean catchment slope	%	41.63
Density of hydrographic network	$km\ km^{-2}$	3.13
Main stream length	km	12.42
Main stream slope	%	5.64

The results of the Mann- Kendall statistical test indicate statistical significant (0.05 significance level) decreasing trend for precipitation and statistical significant increasing trend for temperature. The beginning of the change took place in 1985 and 1990 for precipitation and temperature, respectively. The graphical representation of the obtained results is illustrated in the figures no. 3 and no. 4.

Based on the Mann-Kendall test results the time series of the precipitation and temperature data was divided in two sub-periods. During first sub-period, between 1961–1985, the mean annual precipitation was 1,589 mm and average temperature 8.7 ^0C, while over 1986–2011 sub-period the mean annual precipitation was 1,314 mm and average temperature 9.2 ^0C.

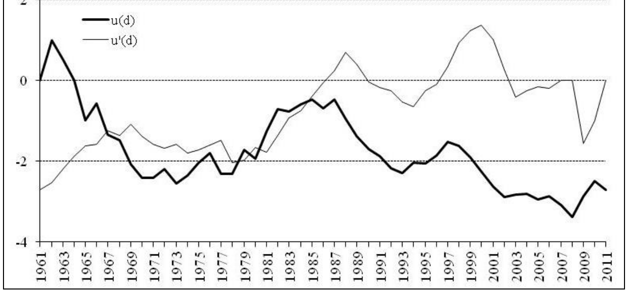

Figure 3. Graphical representation of the precipitation time series of Mann-Kendall rank statistic test.

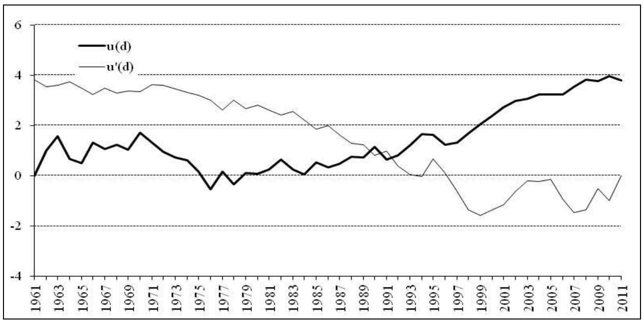

Figure 4. Graphical representation of the temperature time series of Mann-Kendall rank statistic test.

The land cover was determined by using photo interpretation techniques and analyzing aerial orthophoto. The forest cover amounts 70.46% of the total, shrubs and pastures 28.51% and barren land and settlement 1.03%. In order to apply the Gavrilovic method, the land cover data quantified as described to the x coefficient of the model. The forest took the value 0.25, shrubs and pastures equal to 0.35 and barren land and settlement 0.9.

As for the geological substratum, the area consists of limestones (56.24%), flysch (42.44%), alluvial deposits (0.92%) and other sedimentary rocks (0.41%). The value of soil erodibility (coefficient y) was assigned to each geological formation (Table 2).

Table 2. Soil erodibility (coefficient y) values assigned to geological layers

Geological layers	Soil
Limestones	0.8
Flysch	1.15
Alluvial deposits	1
Other Neogene	1.55

The φ coefficient estimated at 0.6 by field observation of erosion phenomena and by identifying sediment sources from aerial orthophoto.

Finally, based on the above mentioned parameter the mean annual soil erosion was estimated for the 1961-1985 and 1986-2011 sub-periods. By using Gavrilovic method the estimated mean soil erosion were 18.73 t ha^{-1} yr^{-1} during 1961-1985 and 15.93 t ha^{-1} yr^{-1} over 1986-2011 in the Aspropotamos catchment within the University Forest of Pertouli.

4. CONCLUSION

The results of the Mann-Kendall non-parametric test indicate statistical decreasing trends for precipitation and statistical significant increasing trend for temperature in the University Forest of Pertouli from Central Greece. By applying the Gavrilovic erosion prediction model for two sub-periods, 1961-1985 and 1986-2011, it was noticed that soil erosion decreased by 2.8 t ha^{-1} yr^{-1} during the second sub-period under 15% decrease of precipitation and 5% increase of temperature.

These findings underline the high conservation value of the forest in the Mediterranean mountainous catchments despite the global warming.

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