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EROSION POTENTIAL MODELING OF THE TERRITORY OF MUNICIPALITIES PEHCHEVO AND SIMITLI USING REMOTE SENSING DATA

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Abstract: *This work presents an evaluation of soil erosion in the municipalities Pehchevo and Simitly based on digital data integrated in GIS settings, Digital Elevation Model generated on the basis of satellite data - ASTER Global DEM, a modified version of 2012 with spatial resolution of 30 meters and satellite images from Landsat ETM +. In the generation of the model to assess the potential erosion the following factors was reported: erosion resistance of soils and rocks, the influence of vegetation cover, the slope gradient, average annual rainfall and average air temperature. These factors was considered that have the most significant impact on the development and manifestation of erosion. In assessing the average potential of the erosion in the municipalities Pehchevo and Simitly, the model of Gavrilovic 1972 is used. This model have been successfully applied in different parts of the region of the Balkan Peninsula, where it have been compared with actual performance. Therefore we believe created as a result of applying the model thematic map of erosion potential is sufficiently representative of the cross-border region of the two municipalities.*

МОДЕЛИРАНЕ НА ЕРОЗИОННИЯ ПОТЕНЦИАЛ НА ТЕРИТОРИЯТА НА ОБЩИНИТЕ ПЕХЧЕВО И СИМИТЛИ НА БАЗАТА НА ДАННИ ОТ ДИСТАНЦИОННИ ИЗСЛЕДВАНИЯ

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Резюме: *В настоящата работа е представена оценка на почвената ерозия на територията на общините Пехчево и Симитли въз основа на цифрови данни, интегрирани в среда на ГИС, цифров модел на релефа, генериран на базата на спътникови данни – ASTER Global DEM, модифицирана версия от 2012 г. с пространствена разделителна способност 30 метра и спътникови изображения от Landsat ETM +. При генерирането на модела за оценка на потенциала на ерозията са отчетени следните фактори, които бе прието, че оказват най-съществено влияние върху развитието и проявата на ерозионните процеси: ерозивната устойчивост на почвите и скалите, влиянието на растителната покривка, средният наклон на релефа, средногодишната сума на валежите и средногодишната температура на въздуха. При оценката на средния потенциал на ерозията е използван модела на Гаврилович от 1972 г., който успешно е прилаган в различни части от региона на Балканския полуостров, където е сравняван с реални показатели. Ето защо смятаме, че създадената в резултат на прилагането на модела тематична карта на ерозионния потенциал е достатъчно представителна за трансграничния регион на двете общини.*

Introduction

Soil erosion by water is a widespread problem throughout Europe. Erosion rate is very sensitive to both climate and land use, therefore southern Europe and the Mediterranean region is particularly prone to erosion because it is subject to long dry periods followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils. [1]. Part of this region are both Republic of Bulgaria and Republic of Macedonia.

Republic of Macedonia is highly exposed to erosion. The excess erosion as uncontrolled natural phenomena gradually increases in last decades generally due to climate change, causing significant damages [2], [3], [4]. Thus identification of erosion hazard areas is very significant for better prevention and protection of landscape and population [5], [6], [7], [8], [9]. Studies of The National Forest Management and Executive Environment Agency on the status of soil resources in Bulgaria shows that over 80% of the arable land and 15% of the forest are prone to erosion to varying degrees. Struma River watershed is one of the regions in Bulgaria, where the course and one of the strongest erosion.

For assessing soil erosion risk, various approaches can be adopted. In this study Erosion Potential Model (EPM) [10] was used for soil erosion assessment in the municipalities Pehchevo and Simitly based on digital data integrated in GIS environment. The following parameters were used in this model: erosion resistance of soils and rocks, type of vegetation cover, slope angle, the average annual rainfall and average air temperature. Gavrilovic model (EPM) has been successfully applied to various parts of the region of the Balkan Peninsula, where it was compared with actual performance. This model was also already applied to the municipality of Pehchevo. And the results for GIS-produced erosion risk coefficient (Z) according to EPM empirical model, show significant area with moderate, high and very high risk (Z>0.6) with 58.8 km^2 or almost 28% of the total area [11]. The purpose of this study is to apply the model of Gavrilovic (EPM) also for the territory on the other side of the state border - Simitli Municipality, which is part of the territory of Bulgaria and to compare the results.

Study area

The total area of the researched region is 768.3 km^2, of which 27% is accounted for the municipality of Pechevo and 73% for municipality of Simitli. In the 24 settlements in them lives a population of about 20 1000 inhabitants. Simitli municipality is located in the southwestern part of Bulgaria at the border with the Republic of Macedonia. It is in the middle reaches of the Struma River at a distance of 120 km south of Sofia. Its length is about 40 km to the southwest-northeast, and width amounts to 12-15 km. Westernmost point in the municipality is situated at the elevation of 1390 m in Vlahina Mountain (coordinates 22 ° 56'20 "E 41 ° 50'50" N), while the most eastern point is situated at the elevation of 2352 m in the Rila Mountain (coordinates 23 ° 22'16 "E 41 ° 58'30" N). In the quoted limits Simitli municipality occupies an area of 559.8 km^2 (0,5% of the area of Bulgaria) and counts 15 185 inhabitants (0.2% of the population of Bulgaria). Lowest point in the municipality (200 m) is detected at the Struma River Valley and the highest point is Grabenets Peak (2597 m) in the Pirin Mountain. The Municipality of Pehchevo is one of the smallest in the Republic of Macedonia covering an area of 208.5 km2. It is located in the easternmost part of the country, up to the border with Bulgaria. On the west it is surrounded by mountain Bejaz Tepe (1348 m) and on the east by Vlaina Mountain (Kadiica, 1932 m) which is the second highest mountain in the eastern part of Macedonia (behind Osogovo Mountains, 2252 m). On the southeast it is surrounded by the highest part of the Maleshevo Mountains (Dzami Tepe, 1803 m). The Municipality of Pehchevo consists of a total of 7 settlements in which live just over 5000 inhabitants (of which 3,200 residents of the City of Pehchevo). As regards of natural features both municipalities are interesting and varied. This is expressed in terms of the geological composition, topography, climate, hydrography, vegetation cover and soils.

Methodology

Performance of the model was done using the tools of GIS. The modeling is based on the numerical evaluation of the factors that influence erosion using classification and quantitative methods. Database of lithostratigraphic units in the study area was used like a basis for the assessment of erosion resistance of soils and rocks. The model CORINE LAND COVER of 2006 (CLC 2006) was used for the assessment of vegetation cover. The slope gradient were derived from digital elevation model, based on satellite data from the ASTER Global DEM, a modified version in 2012 with a spatial resolution of 30 m by using the tools of GIS. Visible erosion were derived from the red channel (band 3) of satellite images from Landsat ETM + in 2005, which reflects waves in the red range of 0.63 to 0.69 μm. Digital models for average rainfall and average air temperature were generated based on the digital elevation model and data from 12 weather stations at different altitudes, located close to the study area.

Erosion Potential Model (EPM) of Gavrilovic [10] is in form (eq. 1):

(1) $$Wy = T * H * 3.14 * \sqrt{Z^3} * f$$

Where ***Wy*** is average annual soil erosion in m^3; ***H*** is mean annual precipitation sum in mm; ***Z*** is erosion coefficient ranging from 0.1 to 1.5 and over; ***f*** is study area in km^2 and ***T*** is temperature coefficient in form (eq. 2):

(2) $$T = (0.1 * t + 0.1)^{0.5}$$

Where ***t*** is mean annual air temperature.

Among these factors, ***Z*** coefficient has highest importance. It combines soil erodibility (***Y***), land cover index (***Xa***), index of visible erosion processes (***φ***), and mean catchment slope (***J***) in relation (eq. 3):

(3) $$Z = Y * Xa * \left(\varphi + \sqrt{J^{0.5}}\right)$$

Values of ***Z*** usually ranged between 0 (no erosion) and 1.5 or above (excess erosion). In the original form of the model which is catchment oriented, ***Xa*** coefficient, and especially ***φ*** are very subjective in nature, estimated by researches on the field. Because of that, starting from 2001, GIS approach of the model is introduced [11]. Unlike the traditional cartographic tools, in GIS-modified approach of EPM, most of the model parameters are derived from digital elevation model and satellite imagery [12], [13], [14], [15], [16]. Thus, for the ***Y*** coefficient, previously prepared digitalized geologic and soil map are used with corresponding values for the rock and soil erodibility according to that proposed by Gavrilovic [10]. In general, values are in range from 0.1 (very resistant rocks) to 2.0 (very soft rocks and soils). However, because it is very difficult to exactly determinate erodibility, value averaging is made with square rooting in form [11] (eq. 4):

(4) $$Y = \sqrt{Y_1}$$

Thus, the values of ***Y*** is changed in a range between 0.3 to 1.4.

Land cover index (***Xa)*** is prepared from CORINE Land cover model (CLC2006) with added values ranging from 0.1 (dense forests) to 1.0 (bare soils) which is according the original model. Landsat ETM+ band 3 (b3-red) was used for the value of ***φ*** coefficient of visible erosion processes, instead the subjective estimation in the traditional model [11]. The values of 8-bit satellite image (0-255) were divided of 255. The vegetation cover absorbs electromagnetic energy with wavelengths in the red range of the visible spectrum and the bare rocks and the bare soils where the erosion processes are active reflect it. In this way the lower values correspond to areas without visible erosion processes and higher values correspond to areas with excess erosion. However, high values also may represent bright anthropogenic objects. For that reason, correction with slope gradient was made in form [11] (eq. 5):

(5) $$\varphi = \frac{b3}{255} * \log(a + 1)$$

The result is much more accurate values for ***φ*** coefficient. Slope factor ***J*** is calculated from available 30 m DEM as a raster layer for slope angle in radians. The following equation is used (eq. 6):

(6) $$J = \frac{a}{a_{\max}}$$

Where ***a*** is the slope angle.

Finally, GIS-calibrated ***Z*** coefficient is calculated according to the equation 7:

(7) $$Z = \sqrt{\sqrt{Y}} * Xa * (\varphi + 2J)$$

Mean annual temperature (***t***) and mean annual precipitation sum (***H***) were obtained in GIS procedure using vertical interpolation (regression), based on meteorological data and elevation (***h***) from DEM [11] (eq. 8).

(8) $$t = 13.6 - 0.65 * \frac{h}{100} + \frac{h^2}{10^6}$$

For mean annual precipitation sum in the municipalites Pehchevo and Simitli, the regression is in form (eq. 9):

(9) $$H = 500 + \frac{2h}{10} + \frac{h^2}{3 * 10^4}$$

In such way final ***Wy*** values can be calculated as average annual values. However, in this form, soil loss during only one rain event can't be estimated. Because of that, instead of average annual precipitations (***H***), form of daily rain value is introduced as [11] (eq. 10):

(10) $$H = H_y * \left(\frac{H_d}{H_y * 0.1} \right)^2$$

Where ***Hd*** is daily value of rain and ***Hy*** is average yearly sum of precipitations in the area. In that way, daily amount of soil erosion which is precipitation-related can be produced.

Results

Results from the modeling in the form of erosion coefficient (Z) show significant presence of areas with high and very high erosion risk (values greater than 0.6) with 12.8% of the whole territory (Fig. 1). As this percentage is higher for the Municipality of Pehchevo (28%) than for the Municipality of Simitli (13.9%). On these areas, even modest rainfall causes high production, transport and accumulation of eroded material. This is especially evident during heavy rains – more than 0.5 mm/min [11].

The mean value of the Z coefficient for the whole cross-border area is about 0.4. And the same mean value of the Z coefficient has only the territory of Municipality of Simitli. But it is higher in the Municipality of Pehchevo – 0.44.

From the model follows that the average annual production of sediment yields is rather high – 564 m^3/km^2. There is a very large spatial differences within the territory, but also between the two municipalities (Fig. 2). The average annual production of sediment yields in Simitli Municipality is 574 m^3/km^2, while in Pehchevo Municipality is 773 m^3/km^2. The dense forest areas in the source part of Bregalnica River have only 50-100 m^3/km^2, while some areas in the bottoms of the valleys have over 2000 m^3/km^2. Highest erosion rate have areas in the Valley of Zhelevica River and its right tributaries, then the southern slopes of Bejaz Tepe and the area east of Pehchevo. In some places, the erosion intensity exceeds 3000 $m^3/km^2/y$ (soil layer of 3 mm per year), which is a huge value. There actually appears severe or excessive erosion causing numerous destructive landforms, losing valuable fertile land and filling of river beds with a large amount of sediment material [11]. High average annual production of sediment yields (around or over 2000 m^3/km^2) in Simitli Municipality is observed on the southern slopes of the Rila Mountain (right valley slopes of Gradevska River and its right tributaries) and also on the southern slopes of mountains of Pirin, Vlanina and Maleshevska.

On the other hand the well forested areas in the southeastern part of the municipality of Pehchevo and the northeastern part of the municipality of Simitli have normal or "natural" erosion intensity, with values below 400 $m^3/km^2/y$.

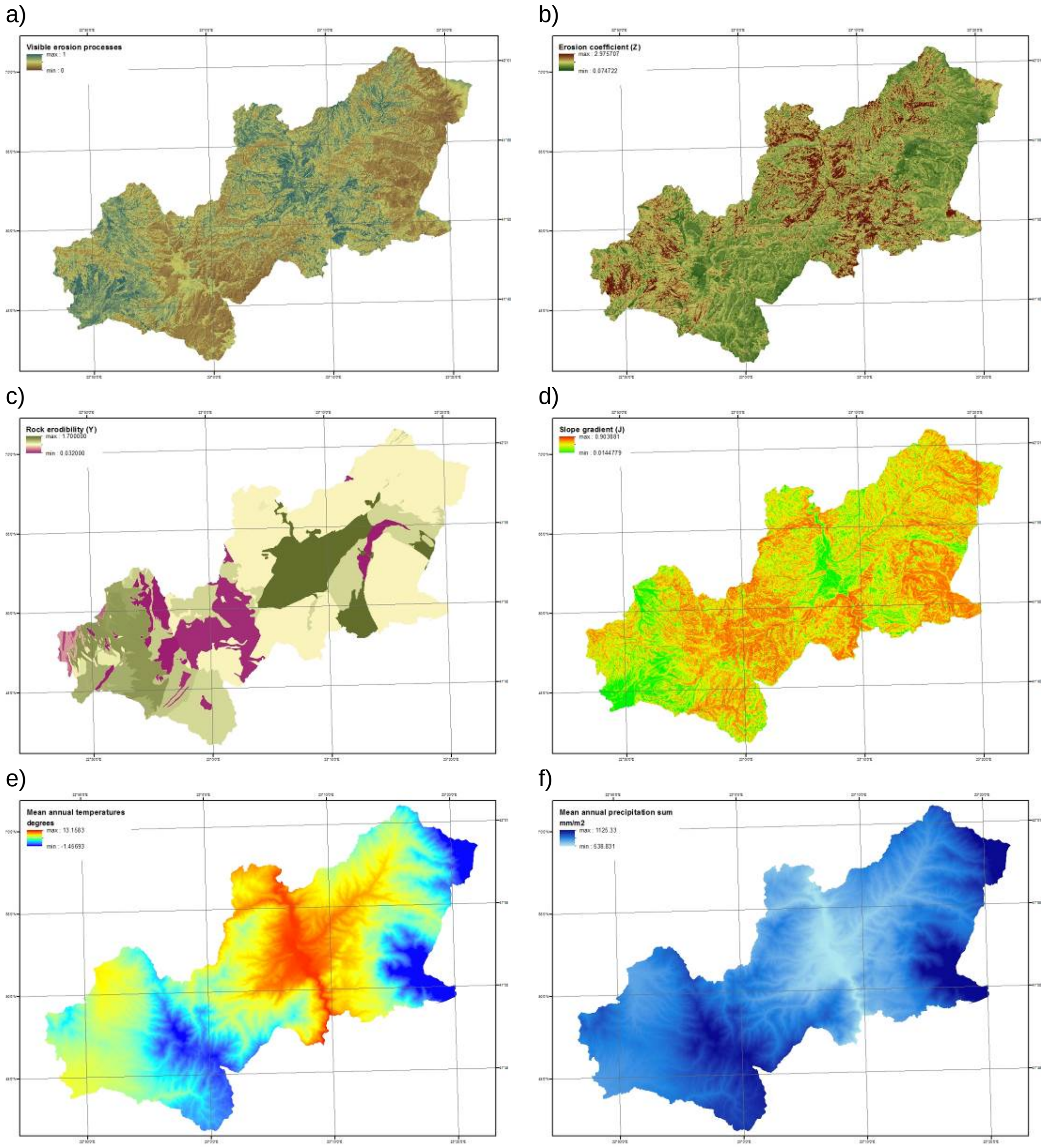

Figure 1. Erosion potential factors: a) Coefficient of visible erosion processes (φ); b) Erosion coefficient (Z); c) Rock erodibility (Y); d) Slope gradient (J); e) Average annual air temperature; f) Average annual precipitation sum

The eroded material is deposed on arable land, roads and buildings, sometime causing considerable damage. Interestingly, erosion risk is greatest at about 900-1100 m above sea level in the municipality Pehchevo [11] and about 200-700 m above sea level in municipality of Simitli, where most of the population lived. This spatial distribution indicates that the significant for the erosion intensity is the anthropogenic factor. At about 1300-1500 m, erosion risk sharply decline, due to the dense forests in that areas. On highest altitudes erosion risk increase again because mountain peaks usually are bare or under rare grassland vegetation and unprotected from erosive action of rain [11].

Quantitative thematic map for the erosion potential within the cross-border region of both municipalities Pehchevo and Simitly was created (Fig. 2a). This quantitative indicator is expressed as the average annual soil erosion in m^3 per m^2.

Classification of this quantitative indicator was carried out using the tools of GIS. The result is a thematic map of erosion hazard within the territory of the both municipalities (Fig. 2b). The presented hazard map simulates the spatial quality evaluation of the menace of erosion occurrence. Established classification contains 5 classes as follows (Tab. 1):

Table 1. Erosion hazard classes

№	Hazard class	Average annual erosion (m^3/m^2)
1	Много ниска	54,7 – 400
2	Ниска	400 – 700
3	Средна	700 – 1 000
4	Висока	1 000 – 1 600
5	Много висока	1 600 – 7 288,6

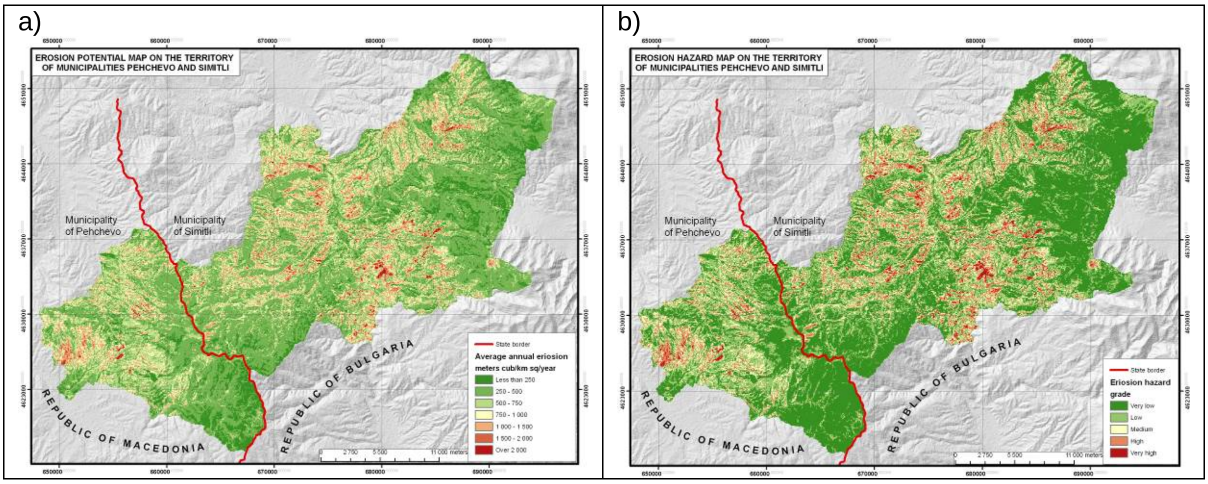

Figure 2. Erosion potential mapping on the cross-border region of municipalities Pehchevo and Simitly: a) Average annual erosion map; b) Erosion hazard map

Conclusion

Qualitative and quantitative evaluation of natural resources of the municipalities Pehchevo and Simitly was made on the basis of collected and integrated into the GIS settings database. Pre-defined risk areas were analyzed. Model that is most appropriate for the available database was selected and implemented after careful analysis of the approbated models – Erosion Potential Model of Gavrilović [10]. The modeling is based on the assessment of the factors that have the strongest influence on erosion processes. Performance of the models was done using the tools of GIS. Erosion potential map and Erosion hazard map for the researched territory was generated by using the methods of classification and quantitative methods that provide numerical assessment of the factors and classes in them.

Municipalities of Pehchevo and Simitli possess valuable natural resources which are quite limited and susceptible to human degradation. Their degradation is closely related to natural hazards which are usually directly or indirectly caused by humans. Excessive erosion is one of the worst natural hazards in that area. As a consequence, there is a deterioration of the quality of the soil or their complete "loss" [11]. The results for GIS-produced erosion risk coefficient (Z) according to EPM empirical model, show significant area with moderate, high and very high risk (Z>0.6) with around 12.8% of the total area. The mean value of the erosion coefficient (Z) for the entire area is 0.4, but there are areas with more than 1.5 of Z-value. On these areas, even during moderate rainfall, severe production, transport and accumulation of alluvial material occur. This is especially evident during intense heavy (over 0.5 mm/min) or prolonged rains [11].

The models show that a large part of the territory would be under some erosion risk in the next period. Therefore, it is necessary to take appropriate preventive measures to reduce the risk or limit their impact. In case of excessive erosion, biotechnical measures must be in first line, as well as construction of small and micro reservoirs, retentions and various other objects, changing the way of land use etc. The areas where the intensity of erosion exceeds 1000 $m^3/km^2/y$ should take appropriate preventive anti-erosive measures and activities that will reduce the loss and degradation of natural resources, especially soil and water conservation.

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