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DIGITAL ELEVATION MODEL AND SATELLITE IMAGES AN ASSESSMENT OF SOIL EROSION POTENTIAL IN THE PCINJA CATCHMENT

Abstract: Pcinja is large left tributary of Vardar River (135 km long, 2877,3 km^2 catchment's area), which drainages surface waters from northeastern Macedonia, and small part of southeastern Serbia. Because of suitable physical-geographic factors (geology, terrain morphology, climate, hydrology, vegetation coverage, soil composition, and high human impact), some parts of the catchment's suffer significant erosion process. For this reason, it is necessary to research properly spatial distribution of erosion, then influence of physical and anthropogenic factors for the intensity of soil erosion, related erosion landforms (with morphology, genesis, evolution, soil erosion protection etc.). Earlier researches in the area have been performed generally with combination of cartographic and classic field analysis. But in last decades, there are new possibilities available like satellite images and digital elevation models. In this work has been presented the methodology of utilization of satellite images and DEM for erosion research, with analysis and comparisons of outcome data.

Key words: soil erosion, digital elevation model, satellite images.

Sadržaj: Пчиња је велика лева притока Вардара (135 km дужине и 2877,3 km^2 површине слива) и дренира површинске воде североисточног дела Македоније и малог дела југоисточне Србије. Због разноврсних физичко-географских фактора (геологије, морфологије терена, климе, хидрографије, вегетационог покривача, састава земљишта и изражених антропогених утицаја) поједини делови слива су угрожени значајним ерозивним процесима. Из тог разлога, неопходно је истражити просторни распоред ерозије земљишта, утицај природних и антропогених фактора на њен интензитет, припадајуће ерозивне облике (са морфологијом, генезом, еволуцијом, противерозивним мерама, итд). Претходна истраживања на овом простору представљала су комбинацију картографских и класичних теренских истраживања. У последњој декади, остварене су нове могућности употребе сателитских снимака и DEM-а. У овом раду, приказана је методологија коришћења сателитских снимака и DEM-а у истраживањима ерозије, са анализом и компарацијом добијених резултата.

Ključne reči: ерозија земљишта, DEM, сателитски снимци.

Introduction

Previous research suggests that Pcinja is the most erosive river in this region. This is evident from recorded sediment yield (Rakicevic, T.L. 1975), geomorphologic observations in their catchments (Andonovski, 1982; Andonovski & Kolcakovski, 1989; Milevski, 2002 a, 2002 b, 2005 c), or from map of erosion (Djordjevic et al, 1993). Such high erosion rate is the consequence of several features, like dominance of soft (clastic) sediment and volcanic

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rocks, dissected south-inclined terrains, low precipitations sometimes with severe storms occurrences, sparse (bare) vegetation, sandy or clay soils, high human activities in the past and recent times etc. Actually high soil erosion is strongly amplified with human impact in land-use, with excess deforestation and cultivation. It turn, it is affected by overload soil loss, desertification, rural areas decrease, impoverish and depopulation (Milevski, 2006; Dragicevic & Stepic, 2006; Dragicevic, 2007).

Keeping all above in mind, the aim of this study is an assessment of the distribution of erosion potential, erosion risk and erosion sites in Pcinja catchment, applying sophisticated tools of digital terrain and satellite images analysis. For terrain topography analysis 3”SRTM digital elevation model has been used, and for vegetation and land use, Landsat ETM+ imagery with spectral bands 1 to 5. These two elements, worldwide largely used for soil erosion prediction, in combination can give real idea about relative or even absolute erosion potential of some area.

General characteristics of Pcinja catchment area

Pcinja River is one of the largest left tributaries of Vardar River, which drainages northeastern part of Republic of Macedonia and southeastern endless part of Serbia. According to digitalized topographic maps data, river length is 135 km, divide length is 366 km, and catchment area is 2877,3 sq km. From whole area, 2339,3 sq km (81%) lye in Republic of Macedonia, and 538 sq km (19%) belongs to the Republic of Serbia. Because of large drainage basin in the Republic of Macedonia (9,1% of country area), Pcinja has great significance for many aspects (water supply, irrigation, water balance).

Table 1. The general characteristics of catchment area

drainage basin area, A	2877.3 km^2
drainage basin perimeter, O	366 km
drainage basin length, L	135 km
drainage density, G	1.3 km/km^2
local erosion basis, Be	195 m
mean elevation, Nsr	773 m
mean altitudinal difference, D	578 m
mean slope of drainage basin, Jsr	13°
stream bed slope, Jt	10.8‰

Methodology for analysis of topographical characteristics using 3”SRTM DEM

Topographical characteristics of Pcinja catchment are computed using 3”SRTM model (version 3 from CGIAR-CSI, Jarvis et al, 2006), though SAGA GIS v.2, Micro DEM v.10 and Surfer v.8 software. Used digital model, according his spatial resolution (3” or about 70x90 m in this latitude) and quality is just acceptable for analyzed area (Markoski & Milevski, 2005; Milevski, 2005a). On other side, SAGA GIS and Surfer v.8 software, together gained incredible results. Before analytic procedures, original DEM model for practical purposes is preprocessed and re-interpolated to square pixel resolution of 60 m. From numerous topography indices which can be extracted from DEM, only several erosion-related were selected: hypsometry, slopes, LS factor, curvatures, aspects, relief, topographic wetness index and stream power index. At the end, a cluster classification of principal topography features has been done.

Hypsometry of Pcinja watershed has generally indirect influence on soil erosion processes, thought climatic and biogenic zones (vegetation cover), as well as intensity of human impact. The watershed area lay between 195 m (inflow in Vardar River), and 2.253 m (Ruen peak on Osogovo Mountain), which is altitude difference of 2.058 m, and mean altitude is 773 m. Largest part of area lay from 500-750 m (27,6%), and from 250-500 m (27,4%), when higher elevations are lesser: 750-1000 m (16,9%), 1.000-1.250 m (16,6%), and 1.250-2.253 m (11,2%). Exactly on these lower altitudes (250-750 m) which cover great area, we have mean annual precipitations of 500-600 mm, high temperature amplitudes (Lazarevski, 1993), sparse (human changed) vegetation, and significant human activity (roads, land-use, constructions). So it is obvious that here we can expect elevated erosion potential, which is shown on further analysis. However, except for elevation analysis, DEM model may serve for processing of mean temperature, precipitation and solar radiation grid with means of vertical gradient algorithms. Outputs can represent indexes of climate potential in some equations for soil erosion modeling (for example in Gavrilovic model; Milevski, 2001; Dragicevic, 2007).

Slopes like first hypsometry derivatives, has strong effect on soil erosion processes, especially by slope angle, slope length, and slope curvature, so these parameters must be considered. Moreover, some earlier soil erosion models and equations were based only on slope parameters (Zingg, 1940). Slopes on Pcinja catcment was obtained from preprocessed 60 m DEM, and corrected for simple empiric coefficient in form of $\alpha=\alpha*(1+(\alpha/150)$. Further analysis show that slope values varies from 0° (flat in central part of Kumanovo depression) to 58° (steepest slopes on deep valley sides in Gosinska, Duracka and upper part of Kriva River), with mean slope of 13°. Almost 97% of area cover slopes lower than 30°, while largest areas has slopes of 5-10° (22,4%), and 10-15° (20,6%). Those are moderate slopes in catchment commonly characterized with sheet, rill and gully erosion (on clastic-soft rocks), and smaller landslides. Higher slopes of 15-20° and 20-25° cover 17.1% and 11.3% respectively, usually related with deeper gully erosion, denudation, landslides and rock falls. Lower slopes of 0-5° cover 19.3%, and in some cases are related to deposition areas (on the bottom of Pcinja and Kriva River valleys). Similar like elevations, slopes are applied in soil erosion models, commonly as a main parameter. In our experience, adjusted slope values are incorporated in Gavrilovic model instead of mean catchments slope (index J).

Interesting slope-related parameter is length-slope factor, which show length of terrain with constant slope. Soil erosion usually increase as the slope length increase due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of sediment transport. For that reasons LS factor is included in USLE model for soil erosion prediction. In our case, values for LS factor range from 0 to above 10.000, but mean value for Pcinja catchment is 17,8. About 72% of catchment area has LS factor 0-20, and other 22,3% has values between 20-40, 3,8% has 40-60, and above LS factor 60 is only 1,9% of all area. It is interesting that LS factor rise with altitude, thus mean value below 1.000 m is 16, and above 1000 m are 21. In general, values for LS factor are high and have positive impact on soil erosion potential.

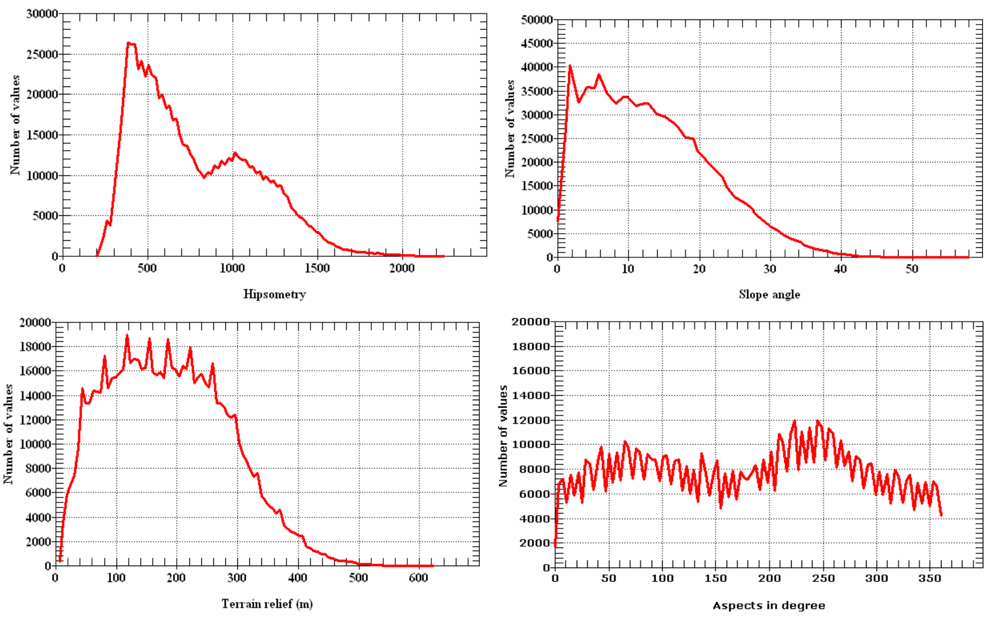

Fig. 1. Graph of Hypsometry, Slopes, Relief and Aspects in Pcinja catchment

Profile (vertical) and planar (horizontal) curvature shows whatever the shape of terrain (slope) is convex (erosive), concave (probably depositional) or flat (erosive or depositional-depending of slope). Profile curvature is in steepest direction, while planar curvature is along contour direction, and correlate with degree of azimuth change. Both parameters for Pcinja catchment are calculated in SAGA software, where convex terrains has positive values, concave terrains negative values, and flat terrains near zero values (with units m/m). Overall, values for planar and profile curvature don't point out some rate of erosion, but in combination can indicate areas of dominant erosion or deposition. About planar curvature, lowest values (below -0,002) indicate deposition areas (6,8%), as well as values near zero (flat curvature; -0,0005 to 0,0005 with 40,8%), but only for small slope, and highest values (higher than 0,002) indicate dispersion areas (7,1%) with slight surface erosion. Usually highest erosion rate is recorded in terrains with planar curvature values from -0,002 to -0,001 and from 0,001 to 0,002, which together cover 23,0%. Other values show terrains with some extent of topographic erosion potential. About profile curvature, values below -0,002 indicate highly concave deposition areas (valley bottoms), and cover 5,7%, values above 0,002 are highly convex terrain (crest, peaks), and cover 3,8%, while terrains with strong erosion potential (-0,002 to -0,001; 0,001 to 0,002), cover 19,.4%. Terrains with flat profile curvature (-0,0005 to 0,0005) has area of 47,1%.

Inclination or terrain aspect is another valuable parameter related to soil erosion potential, where south aspects are dryer, hotter, barer, and more eroded in contrast to north aspects. Terrain aspects of Pcinja watershed are outputted in Surfer software from original 3"SRTM DEM, and values are in azimuth angle. Analysis show that in general, south sided terrains has greater fraction (53%) than north sided (47%). According to 4 main inclinations, east (27,7%) and west (26%) aspects prevails, then south (24,8%), and last north aspects (21,5%). It is clear that greater domination of south slopes, trigger higher erosion risk, especially evident on Kozjak, German, Ruen, and Karadak Mountain.

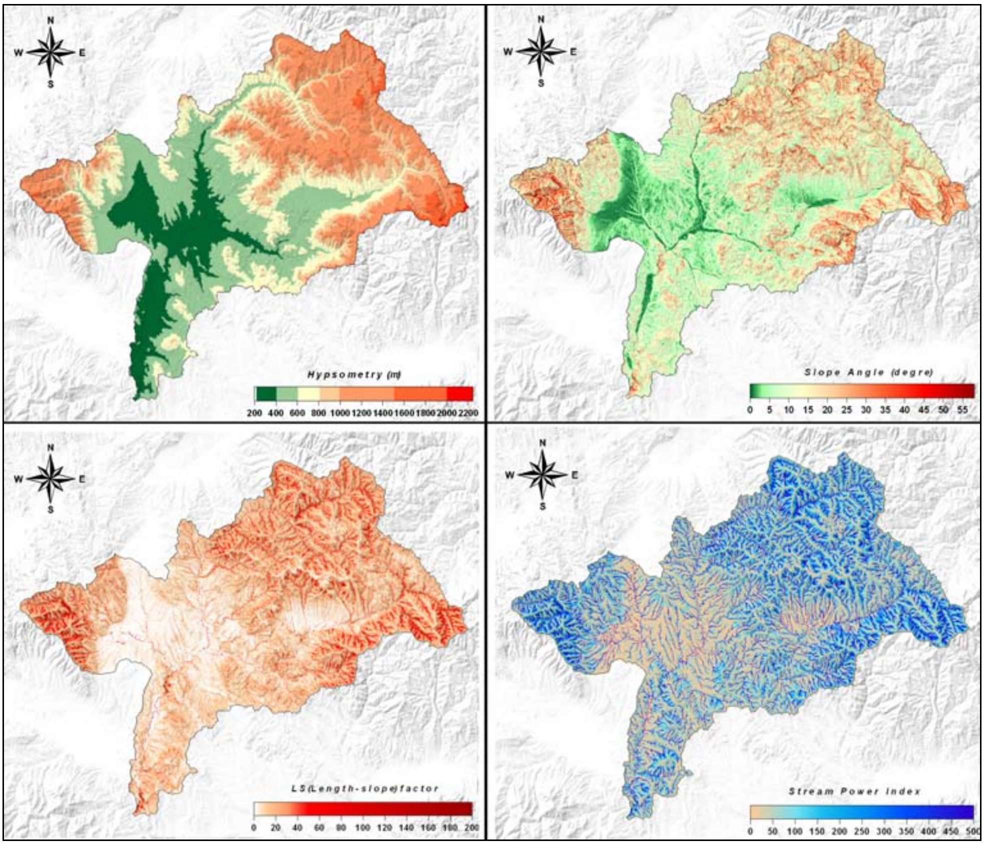

Fig. 1. Maps of hypsometry, slope angle, LS factor and Stream Power Index of the Pcinja catchment.

Terrain (vertical) relief is parameter frequently extracted from DEM's indicating maximal altitude differences in some area, which is typically square with 1km sides. This parameter is closely related with intensity of neotectonic movements and river (valley) incision, where greater values show higher elevation differences, thus higher erosion potential (Markovic, 1983). Terrain relief in the Pcinja catchment is computed from digital elevation model thought MicroDEM software, in m/km^2 square areas. Values range from 6 m (flats and alluvial plains) to 623 m (Osogovo and Skopska Crna Gora mountain areas dissected with deep valleys). Largest areas cover terrains with moderate relief between 100 and 300 m (64%), especially from 100-200 m (33,9%). Low relief representing flats or near flats (0-50 m) occupies only 7%, while high relief (300-623 m) cover 13,7%.

Topographic wetness index (TWI) is parameter which show tendency of runoff dispersion in the catchment and represent ratio between upstream area and slope. Regions of the landscape that drain large upstream areas or that are very flat give rise to high values of the index; thus areas with the highest values are most likely to become saturated during a rain or snowmelt event and thus are most likely to be areas that contribute surface runoff to the stream (Moore et al, 1991). This parameter is computed from DEM model in SAGA hydrology module. The SAGA Wetness Index is similar to the TWI, but it is based on a modified catchment area calculation, which does not think of the flow as very thin film. As result it predicts for cells situated in valley floors with a small vertical distance to a channel a more realistic, higher potential soil moisture compared to the standard TWI calculation (Boehner et al, 2002). Areas with high values for TWI tend to be depositional so TWI (or compound wetness index), usually show that deposition sites, and in combination with slopes and curvature TWI can show erosion areas too. Values for wetness index in Pcinja catchment range from 8,4 to 19,.3, with average of 12,3. Well saturated areas (above value of 15) cover 12% of entire area, while moderate saturated (values from 12 to 15) cover 35.5% and poorly saturated (values below 12) cover 52,5%. From TWI map and field analysis outcome that highest erosion is characteristic for areas with moderate values of SAGA TWI (12-15).

Stream power index (SPI) is also very indicative about soil erosion potential, and represent upstream catchment area multiply with slope. This index is related to erosion processes, constituting an indicator of the capabilities of a flow to generate net erosion (Olaya, 2004). SPI of Pcinja catchment is obtained from SAGA hydrology module, like derivative of slope and catchments area. Values have large range, and mean value is 520640. However, values up to 100, cover 60% (1.740 sq. km) of entire area, from which 16,7% are areas with SPI values below 20. SPI, rise highly with elevation, especially above 1.000 m. Generally, high SPI indicate great erosion (and transport) capabilities of streams.

Methodology for analysis of satellite imagery

Aside from topography analysis, for precise soil erosion prediction and estimation, today satellite imagery has essential importance. With proper selection of available imagery and combinations of provided spectral bands, detailed visual analysis of soil erosion can be accomplish, as well as identification of vegetation cover, sites of excess erosion and sedimentation, appropriate erosion or deposition landforms (gullies, landslides, alluvial fans, alluvial plains) etc. (Milevski, 2005). Lots of studies have been performed about full or partial use of optical satellite imagery for land degradation and soil erosion assessment, while some studies (rarely) used integrated observations from microwave sensors. However, many factors can limit the ability for accurately mapping eroded areas and land cover, from sensors and atmospheric features, to time of image acquiring, procedure and methods of interpretation (Liberti et al, 2006).

In this study, Landsat ETM+ imagery (acquired in 2000) was used, precisely the square area containing Pcinja catchment, within exact limits as previously applied 3”SRTM DEM. From overall 8 ETM+ spectral bands, only 1 (blue), 2 (green), 3 (red) and 4 (near infrared) was used, where 1-2-3 bands are combined for real RGB composite image, and 3-4 bands for vegetation indices. Original resolution of ETM+ images (spectral bands) is 30m (28,5m), which is enough for study purpose. From RGB composite image, with visual analysis was delineated and extracted areas likely to be erosion (gullies, badlands) or excess deposition sites (alluvial fans, sedimentation plains). These sites can be evaluated and quantify by processing of RGB imagery (digital numbers) in appropriate software (SAGA or MicroDEM can do the same), in correspondence with field observations. Similar results can outcome from analysis of band 3 (red), where erosion sites are fine expressed (likely white areas), showing that areas with severe sheet and gully erosion cover 68,7 sq. km, or 2,4%, while areas with moderate to severe water erosion cover 368,5 sq. km, or significant 13% of the catchment.

However, primary task of our Landsat imagery analysis of Pcinja catchment is derivation of some index for vegetation cover, keeping in mind its significance for soil erosion (Dragicevic, Kostadinov, Sandic, 2007). This is done thought SAGA software and vegetation index (slope based) module with band 3 (red) and 4 (near infrared) in NDVI relation (Normalized Difference Vegetation Index; where Vi=(TM4-TM3)/(TM4+TM3)). Then values of vegetation index are transformed in such way that lowest values (near zero) represent dense vegetation cover (forests), and highest values (up to 1) represent bare soils and areas with severe deep erosion and sedimentation. This is in line with values for parameter X*A in Gavrilovic equation for soil erosion potential, or with value C in USLE equation.

Table 2. Vegetation index and corresponding land cover in Pcinja catchment.

veg. ind.	below km^2	%	above km^2	%	betw. km^2	%	description
0	2877.3	100.0	0.0	0.0	0.3	0.0	water surf.
0.1	2877.0	100.0	0.3	0.0	179.3	6.2	dense forest
0.2	2697.7	93.8	179.6	6.2	408.1	14.2	medium forest
0.3	2289.6	79.6	587.7	20.4	422.0	14.7	sparse forest
0.4	1867.6	64.9	1009.7	35.1	460.1	16.0	grasslands
0.5	1407.6	48.9	1469.7	51.1	540.0	18.8	sparse grass.
0.6	867.6	30.2	2009.8	69.8	683.6	23.8	croplands
0.7	184.0	6.4	2693.4	93.6	182.9	6.4	bare soils
0.8	1.0	0.0	2876.3	100.0	1.0	0.0	anthrop. constr.
0.9	0.0	0.0	2877.3	100.0	0.0	0.0	-
1.0	0.0	0.0	2877.3	100.0	0.0	0.0	-

Table show that areas with vegetation index greater than 0,6 cover significant 30,2% (867,6 sq. km), representing sites with strong sheet and gully erosion (lower altitudes of Kumanovo and Slaviste depression), whereas areas with dense, medium or sparse forest cover about 35% (higher altitude on mountain areas on: Osogovo, Skopska Crna Gora, Dukat). These data's tell about weak overall vegetation, with slight protection effect against raindrop impacts. If other elements are appropriate (slopes, aspects, lower precipitation), which is case in the edge of depression-mountain areas (altitude of 400-650 m), frequently sites with severe erosion appear.

Results and discussion

Analysis of topography indicates extracted from DEM or Landsat ETM+ satellite imagery, give us some ideas about spatial distribution of soil erosion. But taken individually, these analyses often produce mistaken conclusion. For accurately results it is necessary to put both indices in combination, with some kind of overlapping. For example, there are some attempts to estimate annual rate of soil erosion with models where only parameters are slopes and vegetation index (Hazarika & Honda, 2001).

However, one of the best ways to combine DEM and satellite imagery for soil erosion research is proper classification of erosion-related spatial parameters in smaller number of classes (units). In this study, cluster classification of basic topographic indices is performed, with aim to classify terrain features is small number of as much is possible homogenous erosion-related classes. In that way will be better identified areas with some degree of erosion or deposition potential. Procedure is made with SAGA discretisation module, where Hill-Climbing algorithm automatically classifies closest homogenous terrain units from several grid layers (topography parameters). Among previously elaborated parameters were selected slopes, planar and profile curvatures and vegetation index. The result is shown on fig. 2. From cluster classification is obvious that classes with ID 7 and 8 as some areas in class 5 along Pcinja riverbed are high deposition areas (valley bottoms and riverbed areas). Class with ID 4 represent sites with severe rill, gully erosion, landslides etc, and class 3 are areas with moderate convex slopes, slim vegetation and sheet to rill erosion. Other classes indicate denser land cover, thus smaller extent of (mostly) surface erosion.

Table 3. Erosion related cluster classes of vegetation index, slopes and curvatures in the Pcinja catchment.

Cluster ID	Area km^2	veget. ind.	Slopes	plan curv.	Prof. curv	Description
0	313.9	0.27676	27.5	-0.00009	-0.00002	forests, steep slopes, slight eros.
1	251.9	0.29082	20.0	0.00272	0.00105	steep crest, grass. forests, slight eros.
2	366.9	0.73564	5.0	-0.00004	-0.00010	crops or sparse grass, surf. erosion
3	264.0	0.40151	10.9	0.00122	0.00193	sparse grass., crests, sheet-rill erosion
4	312.1	0.51904	16.3	0.00024	-0.00024	step slope, rill and gully erosion
5	589.3	0.48291	4.8	-0.00005	-0.00012	flat or slight concave, deposition
6	422.5	0.29030	13.9	-0.00002	-0.00009	grass., forests, slim eros.
7	140.0	0.36392	15.0	-0.00083	-0.00387	valley bottoms, deposition areas
8	217.1	0.35174	14.6	-0.00332	-0.00092	riverbeds, deposition

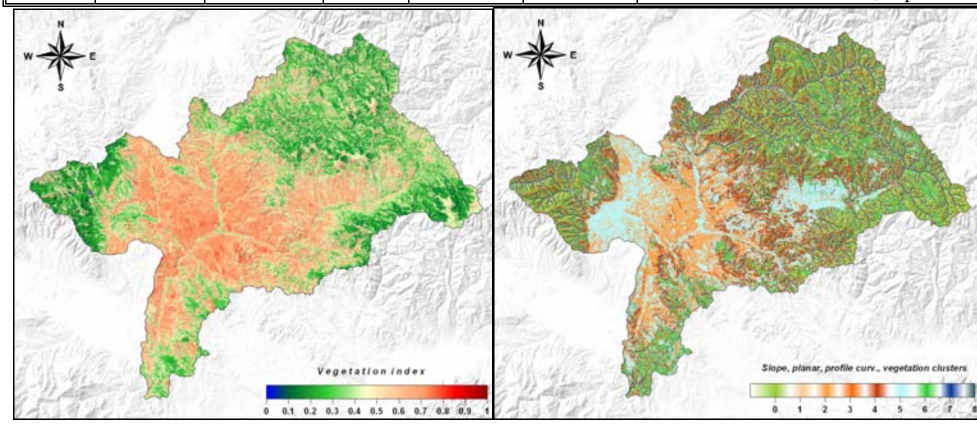

Fig. 3. Vegetation index and slope, curvature and vegetation index cluster classes of Pcinja catchment.

Conclusion

With the development of new techniques it is of great importance to implement them in the existing methodologies. So the main goal of this paper is to implement GIS in the data extraction and analysis. New techniques help us to more precisely detect not only the presence of erosion sites, but in same time to estimate soil erosion potential of the area, to evaluate the influence of natural factors (topography, hydrology, vegetation), as well as large amount of other analysis.

Away from relative assumption of soil erosion potential, DEM derived parameters can be included in standard soil erosion models and equations. Today, it is possible to apply the current achievements of the GIS technology in the process of parameters' evaluation. Hence, already mentioned, LS factor is included in USLE. In our experience, several features obtained from 3"SRTM DEM were included in Gavrilovic model of erosion potential, among these: temperature index (T), mean precipitation (H), both from vertical gradient interpolations, and mean catchments slope (index J) (Milevski, 2001; Kostadinov, Petković, Dragović, Zlatić, Dragićević, 2006; Dragicevic, 2007). Other features (land use and land cover, or parameters X*A), can be obtained from satellite images in above described way.

In such procedure, much accurate results can be outputted than only with classical field research. The method is much more precise than previous investigations in analyzing certain erosive parameters, and its presentation of data offers safer conclusions.

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Резиме

ДИГИТАЛНИ МОДЕЛ ТЕРЕНА И САТЕЛИТСКИ СНИМЦИ ПРИ ПРОУЧАВАЊУ ПОТЕНЦИЈАЛНЕ ЕРОЗИЈЕ ЗЕМЉИШТА У СЛИВУ ПЧИЊЕ

Претходна истраживања интензитета ерозије на овом простору представљала су комбинацију картографских и класичних теренских истраживања. У последње време, са технолошким развојем остварене су нове могућности у геоморфолошким истраживањима потенцијала ерозије неког простора, засноване на употреби сателитских снимака и DEM-а. Дакле, анализа топографских карактеристика терена у функцији утврђивања потенцијала ерозије неког простора, далеко је олакшана применом ДЕМ-а и сателитских снимака. Резултати добијени применом наведених техника омогућавају њихову компарацију са резултатима класичних (досадашњих) истраживања. Савремена истраживања су олакшана чињеницом да сада из комплекса физичко-географских фактора који утичу на интензитет ерозије, можемо издвијити и анализирати само један (нпр. топографске карактеристике) и на основу њега предочити потенцијал ерозије неког простора. Важно је нагласити, да се коначни резултат интензитета ерозије може добити тек након комплексних анализа свих одредишних фактора, а не само анализом једног од њих. Но и поред тога, приказана методологија пружа реалну основу за разматрање потенцијала ерозије неког простора.