ESTIMATION OF SOIL EROSION RISK IN THE UPPER PART OF BREGALNICA WATERSHED-REPUBLIC OF MACEDONIA, BASED ON DIGITAL ELEVATION MODEL AND SATELLITE IMAGERY

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ABSTRACT

In this paper is presented a GIS procedure of soil erosion estimation, based on digital elevation model (DEM) and satellite imagery analysis. The research area is upper part of Bregalnica watershed, one of the largest (225 km long, 4307 km² c.a.) tributaries of Vardar in the Republic of Macedonia. As a consequence of suitable natural-geographic factors and significant human impact, this area has severe erosion with high land degradation. For that reason, before any spatial human activity, it is shown essential to precisely identify and quantify soil erosion risk. This task is performed trough the detailed analyses of raster grids for topography, acquired from 3"SRTM DEM, and raster grids for vegetation cover, acquired from Landsat ETM+ satellite imagery. In this way, influence of most relevant topographic indices (hypsometry, slopes, curvatures, aspects) and vegetation index (vegetation cover) is estimated. Then, with clustering module incorporated in SAGA GIS software, and superimposing of several layers, sites (clusters) with excessive erosion processes (gullies, landslides) were identified, showing high erosion risk areas. Average soil erosion potential of the area is estimated with combinations of DEM and satellite image derived raster grids in related equation. These computations resulted in digital map of erosion, which compared with real indicators and measures show satisfactory fitting. Previous procedure may be helpful to relatively fast and accurate predict soil erosion risk in some area.

Key words: Digital Elevation Model, Soil Erosion, Satellite Imagery, Remote Sensing.

1. INTRODUCTION

Because of favourable natural factors and strong human impact over environment during centuries, area of the Republic of Macedonia is characterised with high soil erosion rate. According to "Erosion map of the Republic of Macedonia" (Djordjevic et al., 1993), average soil loss per year is near 700 m³/km², which is among highest values in Europe. In last decades, faster economic growth of the country and lack of soil resources, fresh water, forests etc., reinforce the need for soil protection and soil conservation. That increases the interest for erosion research, especially in the areas highly affected by soil erosion. One of those areas is watershed of river Bregalnica - largest left tributary (225 km long) of Vardar, which is in turn a major river in the Republic of Macedonia. As a result of very suitable characteristics (soft rocks, sandy soils, steep slopes, climate, sparse vegetation, anthropogenic influence) upper part of its watershed has very high soil erosion rate. For that reason, in 1960-ties begins more detailed researches in this area, with primary goal to protect newly constructed Kalimanci accumulation from excess sedimentation. Later were published other studies in which fully or partly was treated soil erosion landforms in the area (Manakovic and Andonovski, 1979; Manakovic, 1980; Andonovski, 1982; Milevski, 2004a, 2004b), soil erosion factors (Blinkov, 1998), and soil erosion intensity (Rakicevic, 1975; Djordjevic et al., 1993). For soil erosion risk assessment in the upper part of Bregalnica watershed, previously mentioned "erosion map of the Republic of Macedonia", has great significance. This map is created according to the "soil erosion potential" method of prof. S. Gavrilovic, widely used and confirmed in former Yugoslavia. However, newly accessible DEM's and remote sensing tools, offer more opportunities for precise soil erosion risk prediction, monitoring and assessment. These tools and corresponding software are used for the purpose of this work.

2. GEOGRAPHIC LOCATION OF STUDY AREA

Bregalnica watershed is located in the east of the Republic of Macedonia, drainaging surface waters from area of 4307 sq. km or 16.7 % of the country. Upper part of the Bregalnica watershed, which is the subject of our interest, extending upstream of Kalimanci Dam (in the easternmost part of the Re-

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public of Macedonia), from 22°27'44" to 23°02'03" East longitude, and from 41°35'09" to 42°09'16" North latitude. The watershed cover Malesh and Pijanec tectonic depressions, and it is bounded by: Vlaina Mountain (1932 m) from the East, Maleshevo Mountain (1745 m) from the South, Plackovica Mountain (1754 m) and Golak with Obozna Mountain (1536 m) from the West and Osogovo Mountain from the North. In that extent, upper part of Bregalnica watershed has area of 1124.7 sq. km which is 26.1% of total area, or 4.4% of country area. It has southeast-northwest direction in length of 55 km, with altitude from 2203 m (Mal Ruen peak on the Osogovo Mountain) to 510 m (Kalimanci Lake) which means altitude difference of 1693 m. There are tree mid-to small size towns in the area: Delcevo, Berovo and Makedonska Kamenica, as well as numerous villages.

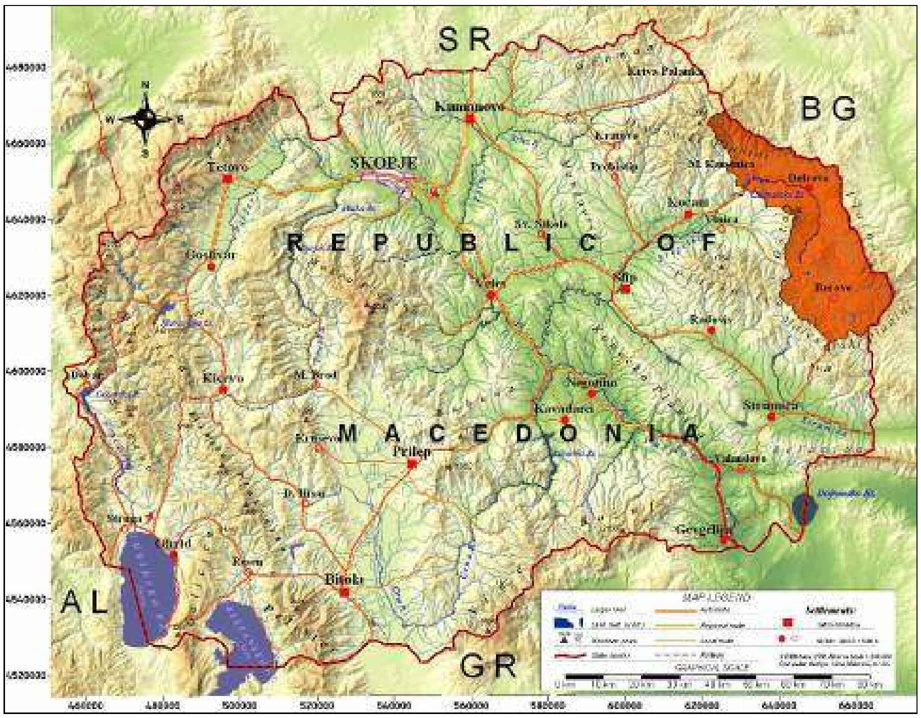

Figure 1: Geographic location of the upper Bregalnica watershed.

2. METHODOLOGY

Instead of classical empiric methods, estimation of soil erosion risk in the study area is done with analysis of digital terrain model and satellite imagery, two tools worldwide largely used for soil erosion research. First of all, from 3"SRTM DEM (version 3 from CGIAR-CSI, Jarvis et al., 2006) detailed analyses of soil erosion related topographic indices were made. 3"SRTM DEM, according to spatial resolution (3" or about 70x90 m in this latitude) and quality is just acceptable for analyzed area (Markoski & Milevski, 2005; Milevski, 2005a). Next step was analysis of vegetation cover in the watershed, as a very important soil erosion factor. Estimation of vegetation cover is obtained from appropriate (NDVI) index derived from Landsat ETM+ satellite imagery (spectral bands 3 and 4). Combining topographic and vegetation indices with relative clustering method incorporated in SAGA GIS software, high erosion risk areas were identified. Ultimately, average soil erosion potential is estimated with GIS-based (adjusted) equation of S. Gavrilovic (1972), using raster grids derived from DEM and satellite imagery (Milevski, 2001). These computations resulted in digital map of erosion, which was compared with real indicators and measures.

3. TOPOGRAPHIC INDICES OF BREGALNICA WATERSHED

From numerous topographic indices which can be extracted from digital elevation model, only several erosion-related were selected for analyzes. They are: hypsometry, slopes, LS factor, curvatures, aspects, terrain relief, stream power index and topographic wetness index. For better calculation of the indices, original 3"SRTM DEM is interpolated to square pixel resolution of 60m.

Hypsometry of upper Bregalnica watershed has generally indirect influence on soil erosion processes, thru the climatic and biogenic (vegetation) zonality, as well as intensity of human impact. The watershed lay between 510 m (Kalimanci Lake), and 2203 m (Mal Ruen peak on Osogovo Mountain), with mean altitude of 1000.5 m. Lower parts of the watershed, from 510 m to 1000 m, cover greatest area (56.6%, from which nearly 40% is between 750-1000 m). Exactly on these lower altitudes, there are low precipitations (600-700 mm/y) but with frequent stormy rain occurrences, with high daily and seasonal temperature amplitudes, sparse (human changed) vegetation, and significant human activity. Thus here it can be expecting elevated erosion potential, which is shown in further analysis. Higher elevations (1000-1500 m cover 38.4%, 1500-2000 m cover 5.3%, and above 2000 m is only 0.05% of the total area), in general are wetter (precipitation 800-1000 mm/y), with denser vegetation cover and better protection from raindrop impact.

Slopes are one of the major factors influencing soil erosion rate (Zing, 1940). Slopes in upper Bregalnica watershed was obtained from preprocessed 3"DEM (60m), and corrected for simple empiric coefficient in form of $\alpha=\alpha*(1+(\alpha/150))$. Analyses show that average slope in the watershed is 12°. Largest areas (31.7%) have slopes of 5-10°, then slopes of 10-15° (28.3%), or both of them have 60%. Those are moderate slopes, here usually characterized with surface sheet to rill erosion. Higher slopes of 15-20° and 20-25° cover 15.9% and 7.2% respectively, typically related with gully erosion, badlands ("mel"), landslides and rock falls. Lower slopes of 0-5° cover 12.4%, and in some cases are related to deposition areas (on the bottom of wider river valleys).

Significant slope-related parameter is length-slope (LS) factor, which combines the effects of a hillslope-length factor, L, and a hillslope-gradient factor, S. Generally, as hillslope length and/or hillslope gradient increase, soil loss increases. In the case of upper Bregalnica watershed, values for LS factor range from 0 to above 100, but mean value is 13. About 47.5% of watershed has LS factor 0-10, other 34.2% of the area has LS factor 10-20, while 17.1% of the area has LS factor 20-50, and above 50 is only 1.2% of all area. It is interesting that LS factor rise with altitude, thus average value below 1000 m is 10.9, and above 1000 m is 15.8. In general, values for LS factor are high and have positive impact on soil erosion potential.

Profile (vertical) and planar (horizontal) curvature shows whatever the shape of terrain (slope) is convex (erosional), concave (probably depositional) or flat (erosional or depositional-depending of slope). Overall, values for planar and profile curvature don't show some rate of erosion, but both can indicate areas of dominant erosion or deposition. About planar curvature of the upper Bregalnica watershed, lowest values (below -0.002) indicate deposition areas (5.7%), as well as values near zero (flat curvature; -0.0005 to 0.0005 with 41.0%), but only for small slope, and highest values (higher than 0.002) indicate dispersion areas (5.4%) 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 28.7%. 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 5.0%, values above 0.002 are highly convex terrain (crest, peaks), and cover 2.8%, while terrains with strong erosion potential (-0.002 to -0.001; 0.001 to 0.002), cover 22.6%. Terrains with flat profile curvature (-0.0005 to 0.0005) has area of 49.0%.

Inclination or terrain aspect is another valuable parameter related to soil erosion potential. In study area (according to latitude), south aspects are dryer, hotter, barer, and more eroded from north aspects. Analyses show that in general, south side terrains has greater fraction (53.7%) than north sided (46.3%). According to 4 main inclinations, west (30.5%) and south (24.8%) aspects prevails, then east (24.0%), and last north aspects (20.7%). It is clear that greater domination of south slopes trigger higher erosion risk, especially evident on south-east Osogovo and Vlaina Mountain slopes.

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 upper Bregalnica watershed is computed from digital elevation model thought MicroDEM software, in m/km^2 square areas. Values range from 12 m (the bottom of Malesh and Pijanec valley) to 580 m (Osogovo and Vlaina mountain areas dissected with deep valleys), whearas mean value is 171 m. Largest areas cover terrains with moderate relief between 100 and 200 m (53.6%), and 200-300 m (20.8%). Low relief representing flats or near flats (0-50 m) occupies only 1.9%, as well as high relief (300-580 m), which cover 1.4%. Previous values mean that upper Bregalnica watershed is characterized with relatively high terrain relief, supposing high erosion potential.

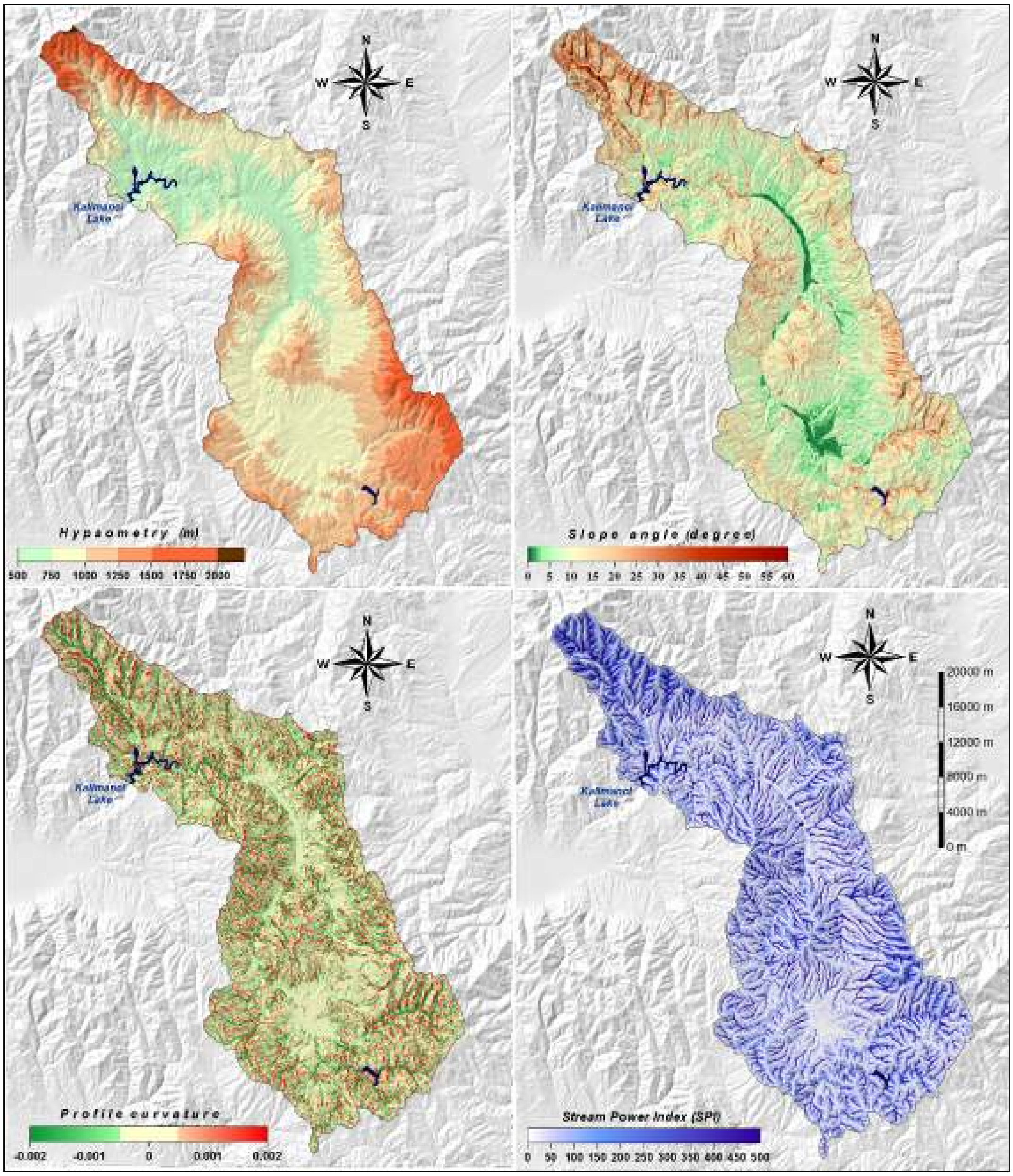

Figure 2: Maps of hypsometry, slope angle, profile curvature and stream power index (SPI) of Bregalnica watershed.

Stream power index (SPI) is very indicative about soil erosion potential, and represent upstream watershed 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 upper Bregalnica watershed is obtained from SAGA hydrology module, like derivative of slope and watersheds area. Values have large range, and mean value is 217.7. However, values up to 100, cover 64.8% (728.8 sq. km) of entire area, from which 15.8% are areas with SPI values below 20. Hipsometrically, highest SPI values has altitude zone of 1000-1500 m (mean SPI=226), which indicate high erosion and transport capabilities of streams in that area.

Topographic wetness index (TWI) is parameter which show tendency of runoff dispersion in the watershed and represent ratio between upstream area and slope. 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 upper Bregalnica watershed range from 9.3 to 19.9, with average of 12.6. Well saturated areas (above value of 15) cover 11.4% of entire area, while moderate saturated (values from 12 to 15) cover 42.6% and poorly saturated (values below 12) cover 46.0%. From TWI map and field analysis outcome that highest erosion is characteristic for areas with moderate values of SAGA TWI (12-15).

All mentioned topographic indices have large impact on soil erosion in the area, especially slopes and their derivatives. Combined together in appropriate cluster classification, the spatial influence of topography on soil erosion is fare more apparent (Milevski, 2007).

4. LAND COVER (VEGETATION) INDICES

Beside of topographic indices, land cover has crucial importance for soil erosion risk estimation. With proper selection of available satellite 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. (Liberti et al, 2006, Milevski et al., 2007).

In our study, Landsat ETM+ imagery (acquired in 2000) was used, precisely the square area containing upper Bregalnica watershed, 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. All of them have 30m resolution. Our field compared analysis shows that spectral band 3 (red) itself can indicate sites with high potential erosion, which are usually between grayscale values of 130 and 210. Forests has values of 0-45 (as well as water bodies), dense pastures and grasslands has values of 45-80, whereas croplands values of 80-130. The procedure of such identification is even more precise if slopes are combined (superimposed) with spectral band 3.

Another possibility of soil erosion risk estimation with Lansdsat ETM+ imagery is analysis of land cover (vegetation cover). In study area vegetation indices are derived from the spectral bands 4 (near infrared) and 3 (red) in widely used NDVI-Normalized Difference Vegetation Index, where: NDVI=(b4-b3)/(b4+b3). NDVI for upper Bregalnica watershed are in range -0.96 to 0.82, and for better calculation (without negative values), these values are transformed according to equation: tNDVI=(NDVI+1)*100.

Table 1: Transformed NDVI and corresponding land cover in Bregalnica watershed.

tNDVI	Above km²	%	Below km²	%	betw. km²	%	description
50	1124.5	100.0	0.1	0.0	1.1	0.1	Water surf.
60	1123.3	99.9	1.3	0.1	2.9	0.3	Water surf.
70	1120.5	99.6	4.1	0.4	6.2	0.6	Bare soils
80	1114.3	99.1	10.3	0.9	66.2	5.9	Bare soils
90	1048.0	93.2	76.6	6.8	146.8	13.0	croplands
100	901.3	80.1	223.3	19.9	168.0	14.9	croplands
110	733.3	65.2	391.3	34.8	163.2	14.5	sparse grass.
120	570.1	50.7	554.5	49.3	155.6	13.8	grasslands
130	414.6	36.9	710.0	63.1	135.5	12.0	grasslands
140	279.1	24.8	845.5	75.2	123.3	11.0	medium forest
150-200	155.8	13.9	968.8	86.1	155.8	13.9	dense forest

Resulting values for tNDVI generally ranged from 60 (water surfaces) to 160 (dense forests). Areas with vegetation index from 70-100, cover significant 34.4% (387.2 sq. km), representing bare soils, sparse grasslands and croplands (lower altitudes of Malesh and Pijanets depression). On the other side, values of tNDVI in range 140-180 represent dense or medium forest, and these areas occupy about 24.9% (higher altitude on mountain areas on: Osogovo, Vlaina, Malesevska). Average vegetation index for the watershed is 121.5, and it significantly rise with altitude. 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 along the rim of depression-mountain areas (altitude of 600-1000 m), frequently sites with severe erosion occur.

5. IDENTIFICATION OF SOIL EROSION RISK AREAS

There are numerous GIS-based methods of soil erosion risk estimation, depending of the purpose of that estimation, available tools and expected results. However, in general these methods can be grouped as relative (qualitative) and absolute (quantitative). One of methods for relative soil erosion risk estimation is cluster classification of erosion-related digitally derived spatial parameters, which is implemented in our study. For that purpose, cluster classification of basic topographic indices and vegetation index is performed, with aim to classify terrain features is small number of as much is possible homogenous erosion-related classes. In that manner 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 raster grid layers. Among previously elaborated parameters were selected: slopes, planar, profile curvature and tNDVI. The result is shown on Table 2. From cluster classification is obvious that classes with ID 7 and 3 as some areas in class 8 along Bregalnica riverbed are deposition areas (valley bottoms and riverbeds). Class with ID 4 represent sites with severe rill, gully erosion, landslides etc., and class 5 are areas with moderate concave slopes, slim vegetation and sheet to rill erosion. Other classes indicate denser land cover, thus smaller extent of (mostly) surface erosion.

Table 2: Erosion related cluster classes of Bregalnica watershed.

Cl.ID	tNDVI	Slopes	Plan curv.	Prof. curv	Description	Erosion risk	Area km^2	%
0	141.4	10.7	0.0009	0.0007	forests, mod. conv.	Low	140.1	12.4
1	145.0	8.8	-0.0004	-0.0004	forests, mod. conc.	Low	159.8	14.2
2	141.6	23.9	0.0008	0.0004	forests-grass, steep sl.	Moderate	89.8	8.0
3	140.7	17.5	-0.0024	-0.0005	forest-grass, valleys	Deposition	75.8	6.7
4	103.7	12.0	0.0015	0.0010	bare soils, convex	Very high	114.4	10.2
5	105.7	8.1	-0.0008	-0.0008	sparse veg., valleys	High	127.3	11.3
6	112.4	15.1	0.0001	-0.0001	grass, steep slope	Moderate	117.9	10.5
7	137.7	17.7	-0.0005	-0.0029	grass, valley bottoms	Deposition	50.4	4.5
8	101.0	5.1	0.0001	0.0001	sparse veget., flat sl.	Low-moder.	248.9	22.2

Instead of relative soil erosion risk estimation, more valuable results can be derived from the methods of quantitative (absolute) estimation, considering that they are more complex. Usually those are empiric equations, frequently adapted to GIS-aided computations. Worldwide there are many such methods: USLE, WEPP, EUROSEM etc., providing better or fever outputs. In the Republic of Macedonia, estimation of average soil erosion potential and soil erosion risk is generally achieved with equation of prof. S. Gavrilovic. The equation is in form: $G=T*H*3.14*sqrtZ^3*f$, where: G is average annual soil erosion in m^3, T is temperature coefficient ((t+0.1)/10), H is annual precipitation in mm, Z is erosion factor and f is watershed area in km^2. Among these factors, Z (with values of 0 to 1.5) has special importance combining: soil erodibility (Y), vegetation (X), antierosive measures (a) and slope angle (J). Because of proven accuracy, there are several recent GIS adaptation of this equation (Milevski, 2001; Milevski, 2005; Petras et al., 2007). However, most of the equation parameters are easily computable from elaborated topographic and vegetation indices, even factors T and H which can be derived from average vertical temperature and precipitation gradients. For that reason, this procedure is fully implemented for soil erosion estimation in the Bregalnica watershed. Final grid-cell oriented map (Fig. 3D) is pretty close with the cluster classification map (Fig. 3B), and traditional Gavrilovic-based, watershed oriented soil erosion map (Fig. 3C) prepared by Djordjevic et al., (1993). Traditional map show average soil erosion potential of the upper Bregalnica watershed of 960 m^3/km^2/y, and our GIS-based show in average 710 m^3/km^2/y, which is better fitting with Kalimanci basin sedimentation measurement (Blinkov, 1998). It is interesting that sites with high erosion risk (specific erosion rate more than 1500 m^3/km^2/y) on classical map cover 128.6 km^2, on GIS-based map cover 99.7 km^2, and on cluster map (class 4) 114.4 km^2.

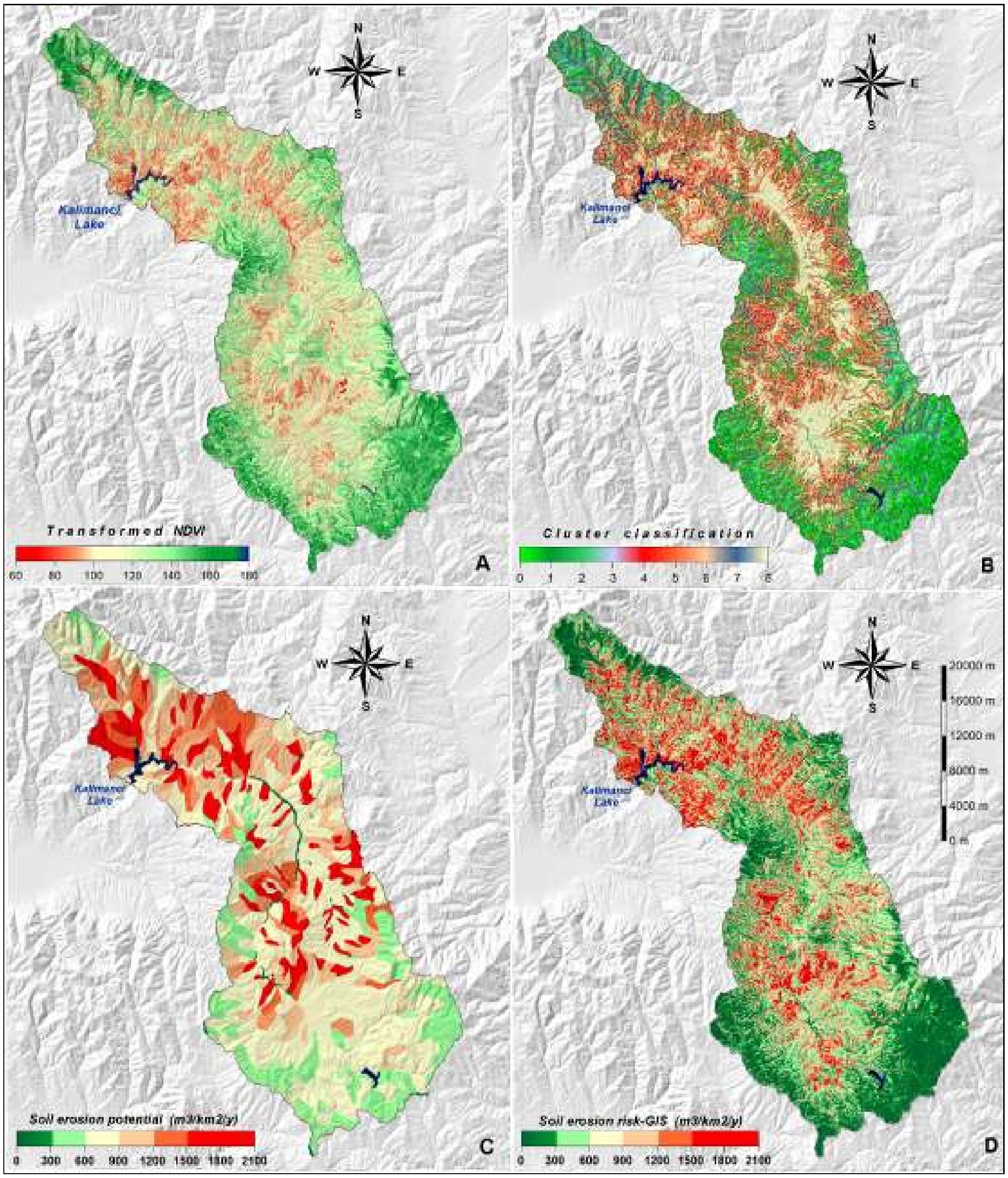

Figure 3: Maps of: A. Transformed NDVI; B. Relative cluster classes; C. Soil erosion potential (according to Djordjevic et al., 1993); GIS-based Gavrilovic model estimation.

6. CONCLUSION

From presented study it is obvious that GIS is valuable tool for soil erosion risk estimation and prediction. With proper selection of digital elevation models, satellite imagery indices and appropriate methodology, very objective results can be achieved. GIS-based soil erosion risk assessment, minimizes subjective errors of the traditional (classical) estimations, and maximizes the possibilities for different uses and spatial computation. As far, final results are good basis for planning of soil erosion protection and conservation measures, which are necessary for sustainable development of the region.

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