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GIS AND RS-BASED MODELLING OF POTENTIAL NATURAL HAZARD AREAS IN PEHCHEVO MUNICIPALITY, REPUBLIC OF MACEDONIA

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Abstract: In this paper, one approach of Geographic Information System (GIS) and Remote Sensing (RS) assessment of potential natural hazard areas (excess erosion, landslides, flash floods and fires) is presented. For that purpose Pehchevo Municipality in the easternmost part of the Republic of Macedonia is selected as a case study area because of high local impact of natural hazards on the environment, social-demographic situation and local economy. First of all, most relevant static factors for each type of natural hazard are selected (topography, land cover, anthropogenic objects and infrastructure). With GIS and satellite imagery, multi-layer calculation is performed based on available traditional equations, clustering or discreditation procedures. In such way suitable relatively "static" natural hazard maps (models) are produced. Then, dynamic (mostly climate related) factors are included in previous models resulting in appropriate scenarios correlated with different amounts of precipitation, temperature, wind direction etc. Finally, GIS-based scenarios are evaluated and tested with field check or very fine resolution Google Earth imagery showing good accuracy. Further development of such GIS models in connection with automatic remote meteorological stations and dynamic satellite imagery (like MODIS) will provide on-time warning for coming natural hazard avoiding potential damages or even causalities.

Key words: natural hazards, erosion, floods, forest fires

Introduction

Republic of Macedonia (25713 km2) is highly exposed to natural hazards, especially to flash floods, excess erosion, landslides, heat waves, droughts, forest fires and earthquakes. Except the earthquakes as uncontrolled natural phenomena, the number of other hazards gradually increases in last decades generally due to climate change causing significant damages (Lerner, 2007; Mosquera-Machado and Dilley, 2009; Ristić et al., 2012; Jovanovski et al., 2013). Thus, identification of potential natural hazard areas is very significant for better prevention and protection of landscape and population (Tanislav et al.,

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2009; Dragicevic et al., 2011a,b; 2013a,b). One of the regions heavily endangered by natural hazards is Pehchevo municipality (208.5 km2) in the easternmost part of Macedonia. This municipality in upper Bregalnica catchment is selected as a test area for complex based Geographic Information System (GIS) modeling of potential hazard sites. With selected digital vector and raster datasets and its geoprocessing, models of erosion, landslide potential, floods and forest fires are produced. According to the dynamic influencing factors, three scenarios for each treated natural hazard process are produced, compared and corrected by field research and monitoring. Finally, all models are combined showing areas with some degree of potential natural hazard.

Although population and economy were highly affected by natural hayards in the Pechcevo municipality over time, these events were poorly documented. In domestic literature, insufficient attention has been devoted to the research of natural hazards (Blinkov and Mincev, 2010; Dragicevic et al., 2010a,b Milevski, 2010). This research will be integrated in future in a unique multi-user database on natural hazards in Macedonia and in next step it should become a part of the European databases of natural hazards. Although there is growing recognition that similar research can help to mitigate damage and disasters caused by vulnerability to hazards, we still do not have an inventory of natural hazard of this country for spatial and urban planning.

Study area

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 (700 to 1932 m). On the west it is surrounded by mountain Bejaz Tepe (1348 m) and on the east by Vlaina (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 again 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).

Figure 1. Map of location of the Pehcevo municipality in the Republic of Macedonia.

Regarding natural characteristics, apart from the small size, the municipality of Pehchevo is quite interesting and diverse. In geological terms, this area belongs to the Serbian-Macedonian massif (SMM) built by rocks of varying age, from the oldest Proterozoic rocks (gneisses), through younger Paleozoic rocks (schist, granite) toward the youngest Pliocene and other recent sediments (gravel, sands, clay) which cover almost 70% of the area. This means that the prevailing rocks are with high erodibility, which favorably affects erosion, landslides and other natural disasters. Landscape of municipality of Pehchevo on the east and the west side is enclosed by mountains, and in the middle part are open toward the direction north-south. Besides the medium high mountains, important characteristic of the relief of the Municipality of Pehchevo is the river Bregalnica valley, which is deeply carved between the Vlaina and Maleshevska Mountain. Very interesting landforms are deep gullies, badlands called “mel” and earth pyramids. The climate of the municipality of Pehchevo is continental with moderately warm summers and cold winters. Temperatures range from -25°C during winter to above 30°C in July and August, but rarely exceed 35°C. Precipitations varied 600-700 mm per year, mainly falling in the months of May and November. River network that belongs to the basin of Bregalnica is long. The longest watercourses (longer than 10 km) on the area of the Municipality are Bregalnica (540 km) and its right tributaries: Zhelevica, Pehcevska River and Pancharevska River. Large part of Pehchevo Municipality is covered with deciduous, coniferous and mixed forests (54%). At the source of the Bregalnica a dense complexes of natural beech, pine and fir forests are present, which is rarity in the eastern part of Macedonia (Milevski, 2004; 2010).

Methodology

Soil erosion risk

In Macedonia, as well as in other countries in the region, estimation of average soil erosion potential and sediment yield is generally achieved with Erosion Potential Model (EPM) of Gavrilovic (1972). The equation is Wy = T · H · 3.14 · sqrtZ3 · f, where: W is average annual soil erosion in m3; T is temperature coefficient in form: T = (0.1 · t + 0.1)0.5, where t is mean annual air temperature; H is mean annual precipitation in mm; Z is erosion coefficient ranging from 0.1 to 1.5 and over; and f is study area in km2. Among these factors, coefficient Z has highest importance combining: soil erodibility (Y), land cover index (Xa), index of visible erosion processes (φ), and mean catchment slope (J) in relation: Z = Y · Xa · (φ + sqrtJ0.5). Values of Z usually ranged between 0 (no erosion) and 1.5 (excess erosion). Unlike the traditional cartographic tools, in GIS approach of EPM, most of the model parameters are derived from digital elevation model and satellite imagery (Milevski 2001, Globevnik et al., 2003; Petras et al., 2007; Karim, 2009; Tošić et al., 2012). In the original form of the model which is catchment oriented, coefficient φ and X*a are very subjective in nature. Because of that, starting from 2001, GIS approach of the model is introduced where most of the parameters are derived from digital elevation model (DEM), satellite imagery and digital thematic maps (Milevski, 2001; 2008; 2010).

Thus, for the coefficient Y, previously prepared digitalized geologic and soil map are used with corresponding values for the rock and soil erodibility according to that proposed by Gavrilovic (1972). 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 estimate exact erodibility correlation, value fitting is made with double square rooting in form: Y=sqrt(sqrt(Y1)).

Land cover index X*a is prepared from CORINE Land cover model (CLC2006) with values ranging from 0.1 (dense forests) to 1.0 (bare soils). Corresponding values are added to the CLC classes according to values proposed by original model.

For the value of coefficient φ of visible erosion processes, instead of very subjective estimation in traditional model, Landsat ETM+ band 3 (b3-red) is used in such way that grayscale values (0-255) are divided by 255. That is because this channel has 255 tones of gray where low values correspond to areas without visible erosion processes, and values near 255 correspond to areas with excess erosion. However, high values also may represent light anthropogenic objects, uncovered soils and rocks, deposition sites etc. For that reason, correction with slope gradient (a) in form: $\varphi = ((b3/255)*\log(a+1))$ is made, resulting in much more accurate values for coefficient φ.

Slope factor J is calculated from available 20 m DEM as a raster layer for slope angle in radians (a=a/57.3). Finally, GIS-calibrated coefficient Z is calculated according to the equation:

$$Z=\mathrm{sqrt}(\mathrm{sqrt}(Y))*\varphi*((X*a+\varphi)*\log(a+1)+\mathrm{sqrt}(a/57.3))$$

In GIS procedure, with vertical interpolation (regression) based on meteorological data and DEM, mean annual temperature t and precipitation sum H were obtained. For mean annual temperatures in the municipality of Pehchevo, this regression is in form:

$$t=13.6-0.65*(h/100)+((h/1000)*(h/1000))$$

For mean annual precipitation sum in the municipality of Pehchevo, the regression is in form:

$$H=500+2*(h/10)+(h/300)*(h/100)$$

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: H=(Hy*(Hd/(Hy/6))). Here Hd is daily value of rain and Hy is average yearly sum of precipitations in that area. In that way, daily amount of soil erosion which is precipitation-related can be produced.

Landslide susceptibility

The identification of influence factors is the basis of many methods of landslide susceptibility assessment (Dragićević et al, 2012). These causative factors can be separated into three broad categories: relief, geological and environmental. In this research, ten causative factors were considered: lithology, land use, slope, aspect, relative relief, distance from faults, distance from stream, curvature (profile curvature), elevation and seismic zone (Tosic et al., 2014). The data of elevation, slope, aspect, relative relief, and curvature (profile curvature) were derived from digital elevation model (DEM) of the study area using the SAGA GIS v2. Distance from the stream was found using the topographic database, the buffer was calculated at value of 0 – 100 m from the stream, and more than 100 meter from the stream. The lithology map was prepared from a 1:100,000 scale geological map. The distances from the faults were found using geological map, the buffer was calculated at value of 0 – 100 m from the faults, and more than 100 meter from them. The seismic map was prepared by using the map of seismic regionalization of Macedonia. Land use was determined according to CORINE classification hierarchy (CLC2006). After data has been collected, all vector data were converted to a raster grid with 20x20 m cells.

The landslide susceptibility analysis (LSA) is used as a simple and useful bivariate method of analysis that aims to determine the importance of different variables for landslide occurrence. To evaluate the influence of each variable, weighting factors are determined, which compare the calculated density with the overall density in the area (Süzen and Doyuran, 2004) as follows:

$$W_{ij} = 1000(f_{ij} - f) = 1000\left(\frac{A_{ij}^{*}}{A_{ij}} \cdot \frac{A^{*}}{A}\right)$$

where: Wij-the weight given to a certain class i of parameter j; fij-the landslide density within the class i of parameter j; f-the landslide density within the entire map; Aij*-area of landslides in a certain class i of parameter j; Aij-area of a certain class i of parameter j; A*-total area of landslides in the entire map; A-total area of the entire map. In the next step, all weights are summed up as in equation 3 in order to get a resultant LSI map for the study area. The same course of action as in previous method is used for reclassifying the LSI values into different susceptibility zones and the map validation.

Potential flood areas

Potentially floodable area was estimated in SAGA GIS v2 with empirical approach based on the processing of five correlated parameters. First is index of vegetation (Vi), according to CLC 2006 model with values from 0.1 for the forest area with high density to 1.0 for uncovered area. For the value of land cover coefficient (Li), Landsat ETM+ band 3 (red) is used in such way that grayscale values (0-255) are divided by 255, shown in value from 0 (dense vegetation) to 1 (bare soils). The next factor is catchment area (Ca), extracted in hydrology module (Flow Tracing) with square meters units. Topographic Wetness Index (TWI) which show topographic tendency of water retention. The last one is slope height (Sh) which indicated relative altitude above valley bottoms in meters and the potential width of floodplain. In the model, catchment area and TWI are logarithmic because of too high nature of values. Finally, with multiplication of all factors in form: Fa =Vi*Li*log (Ca)*log(TWI)*2/(Sh).

Forest fire risk

For the production of the forest fire risk map, five fire rating classes are used (Ertena et al., 2004). These classes are formed according to slope, aspect, vegetation type, distance from roads and settlements. Slopes and aspects, which play a vital role in spreading of the fire, were generated using the 15m DEM data. Fire travels most rapidly up-slopes and least rapidly down-slope. Southern slopes are more vulnerable to catching fire. For the aspect query, aspect filter was used which calculates the aspect or direction of slope for a DEM. The map of the cultivation environment for the area in which the fire broke out was produced according to the vegetation type map. In accordance with this map, very dry, dry, moist, fresh and fresh-like areas were designated and classified into risk classes in terms of the water they contained. Vegetation, road and settlement maps from the test area were digitized and made available in a GIS data base. Buffer zones were created around the roads and settlements. Distances from the centre of the settlement were created around the centre as a polygon data. Similarly, buffer zones of distance from the roads were created around the roads. The closer are the forest to the roads and settlements, the more probable a fire will break out. According to this, buffer zones were integrated to fire rating classes. The final model is in form:

$$RC = 7*VT + 5*(S+A) + 3*(DR+DS)$$

where, RC is the numerical index of forest fire risk zones where VT indicates vegetation type with 5 classes, S the slope factor with 5 classes, A the aspect variable with 4 classes, DR and DS indicate distance factor from road and settlement (Ertena et al., 2004). Finally, based on these analysis carried out, a fire risk zone map was produced.

Results

Pehchevo Municipality is located on a large active earthquake hot spot that has a very high potential, not only in the Balkans but beyond. Numerous cross faults such as Krupnishki, Kochani, Berovo, cause rare, but sometimes extremely strong earthquakes. Such was the case with the devastating earthquake of 1904, which is considered to be one of the strongest in the Balkans (7.5º by Richter), with Krupnik and Simitli villages in Bulgaria, as well as several villages from the Macedonian side were completely destroyed. Therefore, municipalities

Pehcevo and Simitli lie in a zone with high potential seismic risk (maximum magnitude VII–VIII degrees and around IX–X degrees according to MCS).

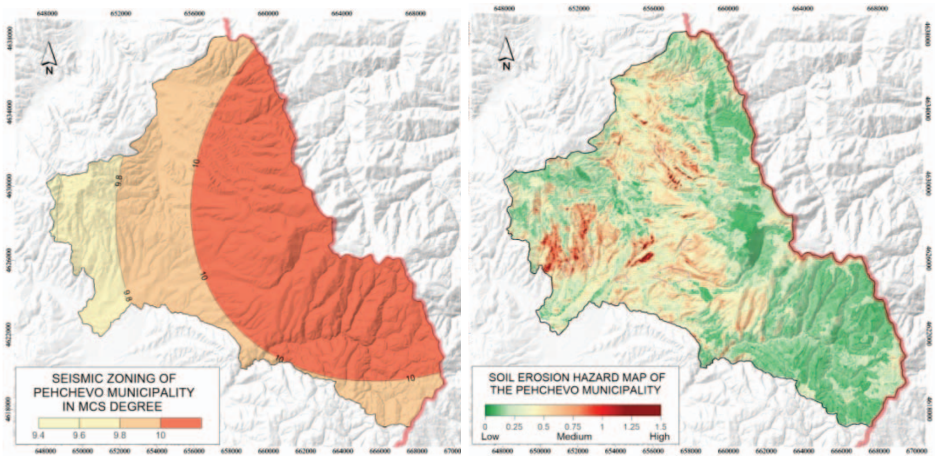

Figure 2. Seismic hazard map (left) and soil erosion hazard map (right) of Pehcevo municipality.

Excessive erosion is one of the worst natural hazards in Pehchevo municipality. As a consequence, there is a deterioration of the quality of the soil or their complete "loss", occurrences of floods, drought, landslides, gullies, rills and numerous other destructive forms which make parts of land to be completely "useless" for any purpose. 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>0.8) with 96.2 km2 or almost 12.5% of the total area. The mean value of the erosion coefficient Z for the entire area is 0.31, but there are even areas with more than 1.2 of Z-value (Figure 2-rigth). 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.

The occurrence of landslides is closely related to areas of high erosion. In municipality of Pehchevo, landslides often occur on the rim of the valleys, on the valley sides, on the sides of deeply incised roads (deep cuts), in settlements on steep slopes, etc. Of the approximately 100 recorded landslides in both municipalities, most are active and together cover an area of about 5%. One of the biggest landslides is that near the village of Crnik (Figure 3-rigth) with 400 m in length, and about 100 m in width, while volume is estimated of about 700.000 m3 (Milevski, 2004; 2010). Some landslides in the area are almost without visible consequences, while others cause damage to the roads and constructions and represent a major threat to human lives. The landslide susceptibility model (Figure 3-left) shows that lowest part (up to 1200 m) of the municipality was especially susceptible to landslides.

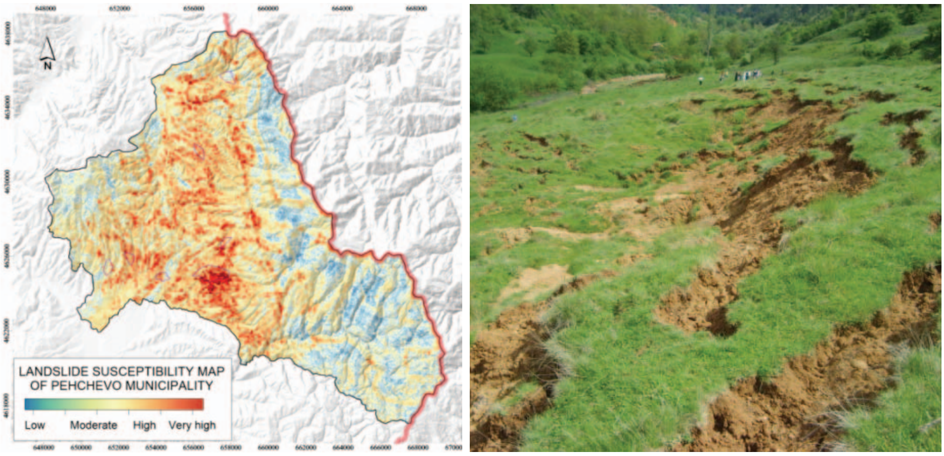

Figure 3. Landslide susceptibility map (left) of Pehchevo municipality and large Crnik landslide (right).

Floods are natural disasters that often occur in the municipality of Pehchevo. The reasons for this are closely related to the high erosion in certain parts, accelerated runoff, setting of various unsuitable anthropogenic constructions along the river banks, interventions in river basins and numerous other factors. According to the findings and taking into account the structure of the landscape, floods do not caused some major consequences in this area. However almost each year some individual properties are damaged, sliding of banks, excess accumulation of sediment etc. The model of potentially floodable area shows that the downstream parts of Zelevica, Pehchevska and Umlenska River valleys are most endangered and prone to flooding (Figure 4-left). Overall area with flood risk is calculated to 30.5 km2 or 14.6% of total.

Forest fires recently more often occur in Pehchevo Municipality which is in relation to the climate change and very hot summers in last decades. According to the forest fire risk model, 53.9 km2 or 25.8% or one quart of the total area is on high risk of forest fires. That is especially in natural and afforested coniferous (especially pine) forest near to frequent roads and settlements (Figure 4-rigth).

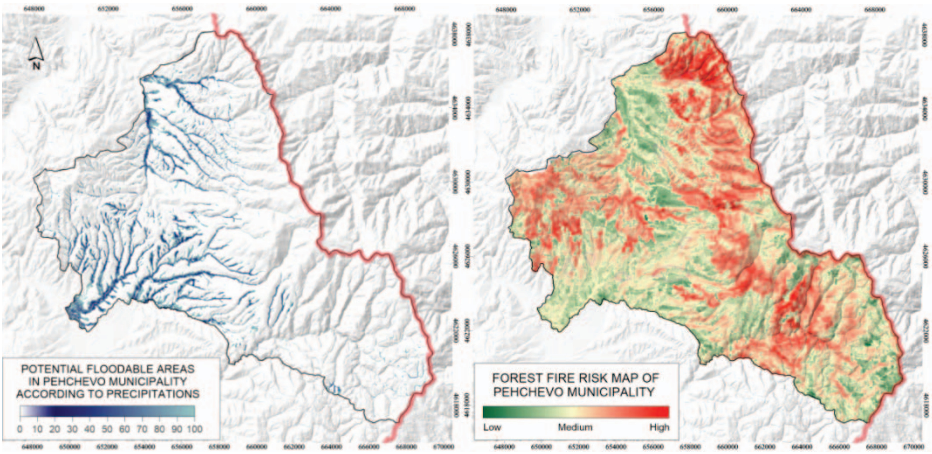

Figure 4. Map of potential floodable areas (left) and forest fire risk map of Pehcevo municipality.

Conclusion

Municipalits of Pehchevo possess valuable natural resources such as ore and mineral deposits (copper, coal, granite, sand), relief, climate, water, forests and soil resources. But they are quite limited and susceptible to human degradation. Their degradation is closely related to natural disasters which were usually directly or indirectly caused by humans, except earthquakes as typical geohazard. Particularly pronounced disasters in the area of both municipalities are excessive erosion, the occurrence of landslides, floods and fires. For this purpose in GIS environment precise models of potential occurrences of such risks are made. They show that a large part of the municipalities would be under some risk in the next period. Therefore, it is necessary to take appropriate preventive measures to reduce the risk of these occurrences 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. In regard to landslides, slope stabilization should be made with drainage of excess underground water, reducing the surface weight, biological measures etc. For the floods basic measure should be regulation of torrential watercourses and all previously mentioned measures related to erosion and landslides. For fire protection, clean shelterbelts are necessary, then setting viewpoints in forests, roads penetration through inaccessible forest terrain, information of population and visitors alike.

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