

ASSESSMENT OF VEGETATION COVER DEGRADATION AND SOIL EROSION IN CHUPRENE RESERVE (NORTHWESTERN BULGARIA) USING REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS

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Abstract. Vegetation cover degradation and soil erosion lead to processes connected with alternation of landscape structure and statement of landscape components. Simultaneously, these processes are accompanied by changing of heat – moisture ratio in landscapes and continuously running drought processes. Variations in solar activity can be considered as one of the possible factors causing vegetation cover degradation, drought, and desertification. In the recent study, vegetation cover degradation is assessed using satellite images and the vegetation indices Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Normalized Multi-band Drought Index (NMDI). Vegetation condition is one of the main factors of Universal Soil Loss Equation (USLE) used as basis of soil erosion assessment. Parallel study of both processes in 2000, 2007, and 2014 allows tracing of their dynamics and deriving possible trend in their progress.

Key words: Vegetation degradation, soil erosion, vegetation indices, USLE factors, northwestern Bulgaria

1. INTRODUCTION

Deterioration of vegetation condition and soil cover influences important environmental processes and results into development of negative phenomenon as drought, soil erosion, environmental degradation, and desertification.

Vegetation is the one of most important biophysical indicator to soil erosion. Remote sensing techniques are employed for monitoring and mapping of vegetation condition all over the world. Vegetation cover can be estimated by using vegetation indices derived from satellite images. Vegetation indices allow delineation of vegetation and soil distribution, based on the reflectance characteristics of green vegetation.

Pronounced drying processes of spruce forests are observed in the study area. This drying leads to vegetation cover degradation and increases the risk of erosion. The drying is caused by brown heart-shaped rot and it has taken place since 1965 - '66'. Detailed studies of causes leading to this drying were conducted also in the middle of the 90's [1], in 1994 [18], and in 2002 [17]. The Lubenova et al's study, which is based on Holling model, shows that spruce ecosystem evolution in the reserve entirely follows the Holling model. They have observed three of the phases and predicted the occurrence of the fourth. This fact was confirmed by our team during field work in the summer of 2014.

Soil erosion is recognized as one of the most serious global environmental problems. [13,5]. Soil erosion causes diminution of root layer depth, nutrient depletion, reduction of soil moisture

reserves and soil moisture retention capacity; reduction of soil organic matter; biodiversity loss; soil structure degradation; etc.[21]

The assessment of potential erosion risk in Chuprene reserve is of great importance for the geosystems stability not only in the area of question but also in the lower located territories, which actually are subordinate landscapes.

In order to assess the soil erosion risk in Chuprene reserve, a model-based approach, based on of the well-known and widely recognized USLE [24] has been used .It is one of the least data demanding erosion models and it has been applied widely at different scales.

Traditional methods of investigation of vegetation degradation and soil erosion demand more funds and hardly could be assessed as temporarily comparable. With development of remote sensing methods and techniques, it become possible applied methods of investigation for different periods of time to be unified. This distinction makes remote sensing methods especially valuable.

Aim of this study is assessing vegetation cover degradation and its impact on increase of soil erosion risk in Chuprene reserve. In order to achieve this aim, basic factors causing soil erosion were taken into account. Among them are USLE factors: rainfall erosivity, soil erodibility, slope length, slope steepness, and cover management. Cover management factor is closely related to vegetation type, its distribution within territory, and vegetation condition. In the recent study vegetation condition and areas affected by drying were determined by

applying of NDVI, VCI, and NMDI vegetation indices. They were calculated on the basis of satellite images acquired in 2000, 2007, and 2014. Finally, thematic maps showing different degrees of soil erosion risk were created.

2. STUDY AREA

Biosphere reserve “Chuprene” is selected as a study area. It occupies parts of the eastern and northeastern slopes of the West Balkan Mountain.

The reserve covers 1439 ha and it is located between 1400 and 2004 m a.s.l. (Fig. 1)

Lithological basis of the reserve is represented by various igneous and metamorphic rocks [2,3]. Prevailing landforms are steep slopes descending from the main Balkan Ridge, which form steep vales too. The territory is characterized with moderate continental climate. The coldest month is February and the warmest is August. The average annual air temperature ranges from 5.8 °C for the lowest part of the reserve to 2.3 °C for the ridge areas.

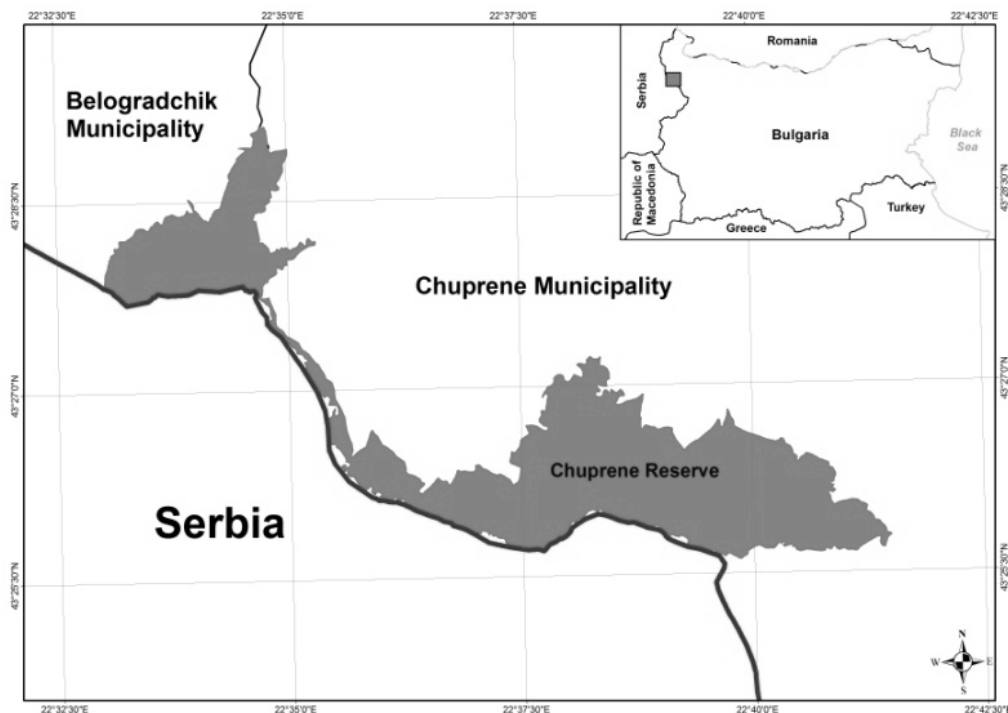


Fig.1. Study area

Precipitations are characterized by a clearly distinguished maximum in May/June and a less expressed in October/ November. Precipitation minimums are respectively in February/March and in August/September. [26]

Dominated soils in the reserve are Cambisols with their main varieties: humic - dark brown forest soils, albic - light brown forest and mollic-dark colored mountain forest soils. There is a small spread of Umbrosols which occupy the highest areas of the reserve. Cambisols, developed in the area are characterized by low-powered humus-eluvial horizon which thickness ranges between 5 cm and 30 cm. These soils distinguish with low soil particle density and crumb structure. Horizon B is low densified, with slight increase in clay, and crumb or thin blocky structure. Lithological basis lies at about 55 -70 cm

under subsoil. Humus content in surface soil ranges from 3.30 to 16.35%. It represents 30-60% of the whole humus soil content. These soils have got low water retention and high permeability. [8, 19]

3. METHODOLOGY

For the purpose of the recent study, a methodology in four steps has been elaborated. It is presented in (Fig.2) and includes: a selection of input data; processing of these data; modeling and discussion of the results.

As input data, terrestrial, GPS, satellite and analogue data have been used. These data has been implemented in the processing mode in order to obtain different output layers for the further modelling.

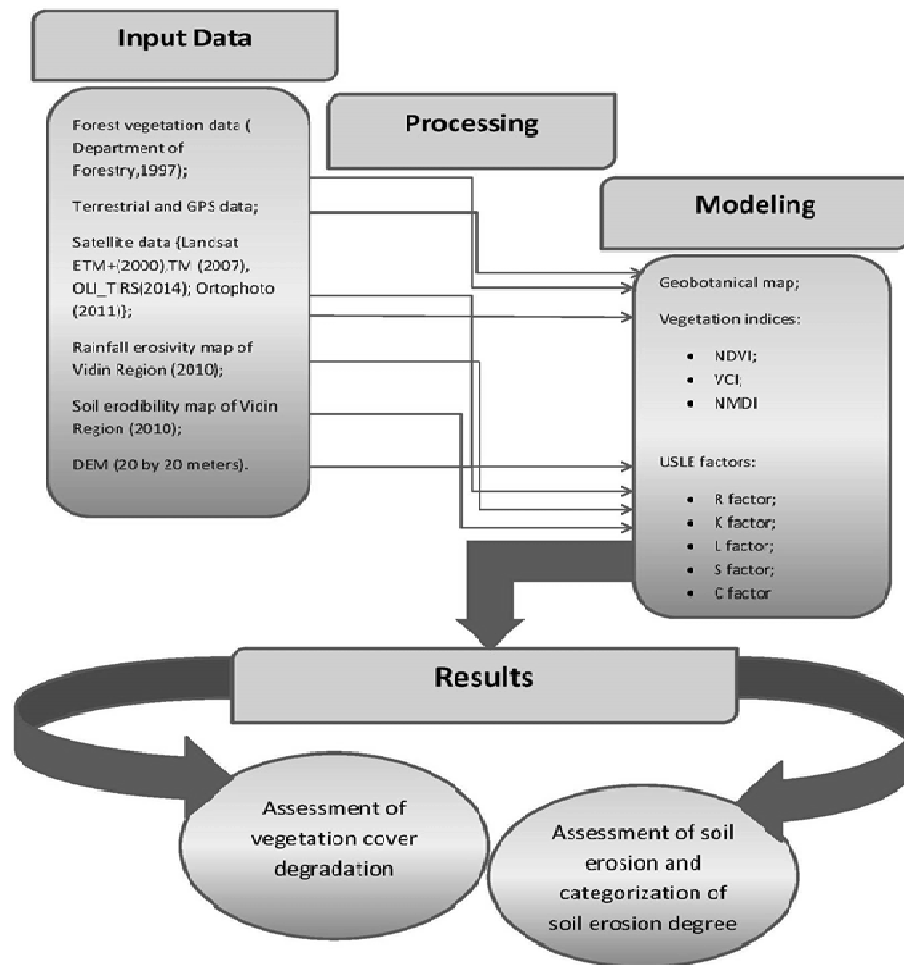


Fig. 2. Principal scheme of methodology

These layers include: raster layers of NDVI, VCI, and NMDI vegetation indices, and raster and vector layers, represent the USLE factors. NDVI provides useful information for detecting and interpreting vegetation land cover. NDVI measures amount of green vegetation. NDVI ratio is calculated by dividing the difference in NIR and red color bands by the sum of the NIR and red colors bands for each pixel in the image. Healthy vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. The formula can be expressed as [10];

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \quad (1)$$

where ρ_{NIR} and ρ_{RED} indicate the reflectance of the near infrared and red bands, respectively.

NDVI varies between -1.0 and +1.0. Negative values of NDVI (values approaching -1) correspond

to deep water. Areas of barren rock, sand, or snow usually show values close to zero (-0.1 to 0.1). Low positive values represent sparse vegetation - such as shrubs and grasslands (approximately 0.2 to 0.4), while high values indicate dense vegetation such as that in the temperate and tropical rainforests, and greater levels of photosynthetic activity (values approaching 1). The typical range of index is between about -0.1 (for a not very green area) to 0.6 (for a very green area). [14,22]

VCI is a vegetation index adjusted to land climate, ecology, and weather conditions survey. This index provides an accurate quantitative estimation of weather impact on vegetation and also measures vegetation conditions. VCI makes available drought studying not only in areas with well-defined, prolonged, widespread, and very strong droughts, but also in such areas, characterized by very localized, short-term, and ill-defined droughts. The advantages of this index compared to conventional ground data are in providing more

comprehensive, timely, and accurate drought information. VCI can be expressed as [12]:

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (2)$$

where $NDVI$ is the current value and $NDVI_{min}$ and $NDVI_{max}$ are the maximal and minimal values of $NDVI$ for the investigated period.

Normalized Multi-band Drought Index (NMDI) is widely used for monitoring of soil and vegetation moisture from space. NMDI is defined as:

$$NMDI_{2014(US8)} = \frac{[(\rho_{0.865\mu m} - (\rho_{1.61\mu m} - \rho_{2.2\mu m}))]}{[(\rho_{0.86\mu m} + (\rho_{1.61\mu m} - \rho_{2.2\mu m}))]} \quad (3)$$

$$\frac{NMDI_{2007}}{2000(US7)} = \frac{[(\rho_{0.84\mu m} - (\rho_{1.65\mu m} - \rho_{2.22\mu m}))]}{[(\rho_{0.84\mu m} + (\rho_{1.65\mu m} - \rho_{2.22\mu m}))]} \quad (4)$$

where: ρ is the apparent reflectance observed by a satellite sensor in the 0.865 or $0.84 \mu m$, 1.61 or $1.65 \mu m$ and 2.2 or $2.22 \mu m$ respectively (depends on the sensor). Similar to NDWI, NMDI uses the channel, which is insensitive to leaf water content changes as the reference; instead of using a single liquid water absorption channel, however, it uses the difference between two liquid water absorption channels as the soil and vegetation moisture sensitive bands. Strong differences between two water absorption bands in response to soil and leaf water content give this combination potential to estimate water content for both soil and vegetation. NMDI is a function of soil and leaf moisture content: an increase of moisture is connected with a reduction of NMDI and decrease of moisture with high NMDI values. Higher values of the NMDI indicate increasing severity of soil and vegetation drought. [16]

For defying of moisture content in the forest canopy, a quantitative assessment on the base of NMDI has been introduced. It can be presented as:

$$(1 - NMDI) \cdot 100 = \text{moisture content (in \%)}$$

A drying process is observed when the forest canopy moisture is below 80%. For grasslands the threshold is 25%.

The next step was soil erosion risk modelling. Models for 2000, 2007, and 2014 were generated. They depict possible trends of progress of soil erosion process. For the purpose of this study, USLE was modified so that each of the factors included in it has been divided into several classes, representing

the differences in the rainfall erosivity, soil erodibility, topographic and vegetation conditions. Each of these classes is given a weight coefficient, which ranges from 0 to 1, and it has been determined according to the influence of the relevant class for the development of soil erosion.

Soil erosion is estimated using the following empirical equation:

$$A = R \cdot K \cdot L \cdot S \cdot C,$$

where:

A: Value of the soil loss (t/ha);

R: Rainfall erosivity factor (MJ mm/ha h);

K: Soil erodibility factor (t ha h/MJ ha mm);

L: Slope length factor (dimensionless);

S: Slope steepness factor (dimensionless);

C: Cover management factor (dimensionless).

Rainfall erosivity (R factor) and soil erodibility (K factor) are the main factors, determining occurrence and development of soil erosion, caused by water. R factor represents rainfall erosivity, or the erosive power of rainfall on the soil regardless of soil type. [11] The assessment of soil erosivity is performed on the base of annual and monthly rates of the number and frequency of intensive rainfalls with duration $T \geq 30$ min and of the amount of a single intensive rainfall with same duration. For the present study, a map of rainfall erosivity of Vidin Region is used. According it, the rainfalls in the reserve are characterized with the highest degree of rainfall erosivity. [21]. So that, to the whole territory of the reserve the maximum weight coefficient was given.

K factor represents the soil erodibility, or to what extent, a specific soil type resists erosive forces. It is estimated using the relevant information, proposed by Wischmeier et al [25], which has been adapted for Bulgarian condition [20] For the present study a map of rainfall erodibility of Vidin Region has been used. The soil erodibility in Couprene reserve is average and average to strong [21]. Thus, in this case, the weight coefficients are two.

The remaining USLE factors (L, S, C, P) may be thought of as adjustment factors. USLE was developed to predict longtime average soil losses in runoff from specific field areas in specified cropping and management systems. The L, S, C, and P factors have been adjust for the real world conditions as compared to the experimental field plot conditions. [11]

Topographic factor (LS factor) combines slope steepness and slope length influence on soil loss, induced by erosion. In order to obtain the relevant data for estimating this factor, DEM (20 by 20 meters) was used. Hypsometry was used in order to

obtain a vector line layer, from which the density of the lines down to each slope and its elevation was defined. Thus, we defined the length between two contours with different elevation. In this way, the length factor was combined that resulted in a raster grid with cell values indicating the LS factor. The delivered grid was incorporated in USLE equation. A weight coefficient was given to each cell value depending on its role for soil erosion occurrence.

One of the most important parameters in USLE is C factor. It represents the effect of vegetation and other land covers types on soil erosion development. Vegetation cover protects soil by dissipating raindrop energy before reaching soil surface. C values depend on vegetation type, stage of growth and cover percentage [9]. Many researchers have used NDVI to estimate C factor for soil loss assessment with USLE [6, 23, 15]

For the purpose of the recent study, NDVI has been divided into several classes representing different

vegetation types and their condition (sparse vegetation, forests in good condition like the beech forests or drying forests like the spruce ones, and grasslands). Weight coefficient was given to each of the classes. This coefficient represents significance of every single class for development of soil erosion. Bare soils are distinguished with the highest weight, and top-quality forests respectively, with lowest weight.

On the basis of assessments conducted, thematic maps showing soil erosion degree within the reserve were generated.

4. RESULTS

4.1. Assessment of vegetation cover condition

For the area in question, NDVI, VCI, and NMDI are estimated on the base of satellite images, acquired on 28.06.2000, 10.07.2007, and 04.07.2014. (Fig.3, 4, 5)

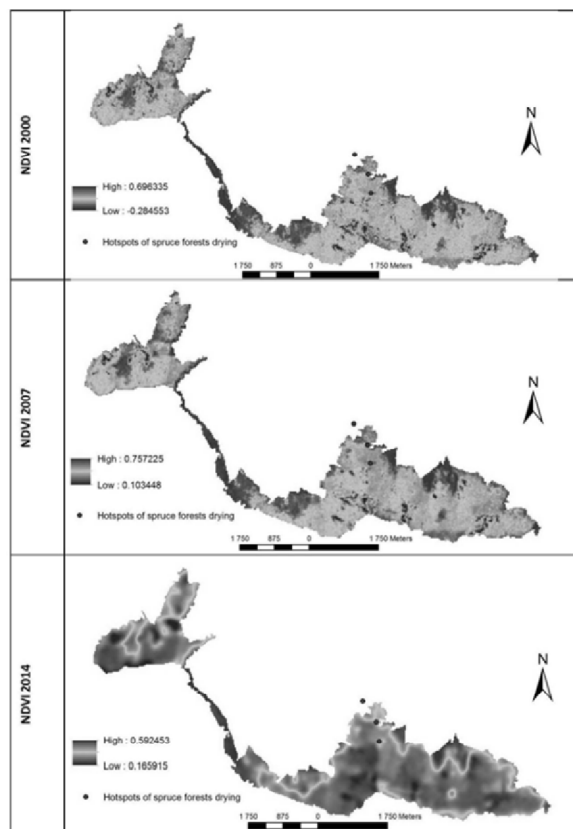


Fig. 3. NDVI values for the investigated years

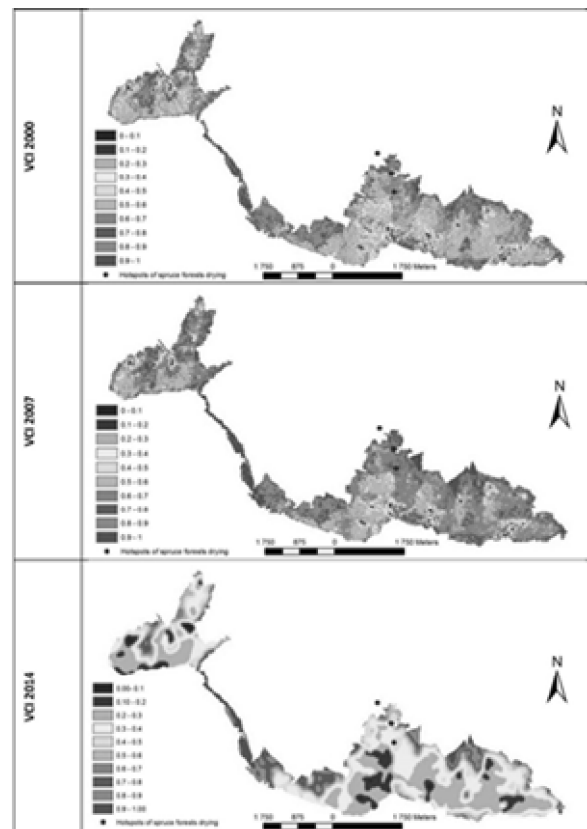


Fig. 4. VCI values for the investigated years

The results show that in 2000 NDVI values range from -0.28 to 0.69. The areas, distinguished with values under 0.1 are 5.58% of the reserve territory. Areas with NDVI values between 0.1 and

0.4 are 68.86%, with NDVI between 0.4 and 0.6 – 21.84%, and with NDVI above 0.6, respectively 3.37%. 2007 is characterized with the highest NDVI values – between 0.10 and 0.75. Areas of barren

rocks and sands are not observed. The areas with NDVI values between 0.1 and 0.4 are 5.86 %, these ones between 0.4 and 0.6 are 70.02%, and very green areas (above 0.6) are 24.12%.

In 2014 is observed decrease in NDVI values. This is an evidence for deterioration of vegetation. Negative values and values above 0.6 are not observed. The values between 0.1 and 0.4, which represent sparse vegetation, are 77.9 % and these between 0.4 and 0.6 are respectively 22.1%.

By applying of an orthophoto and a vector layer of the vegetation formation, it has been established that in 2000 the spruce formations are distinguished with average values of NDVI about 0.25; in 2007 NDVI values increase up to 0.53; while in 2014 they decrease again to about 0.27. NDVI values are more stable for beech formation. In 2000 they are average about 0.58, in 2007 – 0.69, and in 2014 – 0.5.

By applying of VCI, Dillon M. et all [7] suggest vegetation condition classification as follows: (Table 1)

Table 1 Vegetation Condition in % percent for 2000, 2007, 2014

VCI	Vegetation Condition	2000	2007	2014
0.0 - 0.2	very poor	1.29	1.03	7.95
0.2 - 0.4	poor	4.58	3.13	53.99
0.4 - 0.6	fair	44.17	27.13	19.63
0.6 - 0.8	good	34.88	48.75	11.08
0.8 - 1.0	very good	15.08	19.96	7.35

From the data presented in table two, it can be concluded that 2007 is distinguished with best vegetation condition. In that year, the area with good and very good vegetation condition was almost 69 % of the reserves' territory, while in 2000 it was around 50%, and in 2014, respectively – below 20%. In 2014 the area with vegetation, characterized by poor vegetation condition, significantly increased- more than 17 times and that one by very poor vegetation condition- almost 8 times. The worst conditions have barren lands and affected by intensive drying spruce forests.

In 2000, largest area have the forest with canopy moisture 60-50% (47.6% of reserve territory), followed by these with moisture 40-50 % (around 40%). (Fig. ?) In 2007 largest area have the territories with canopy moisture between 50% and 60% (47.4% of reserve territory), followed by these with moisture between 60% and 70% (43.61). The situation has been changed significantly till 2014. In that year 96 % of reserve territory is distinguished with canopy moisture 20-30%. Forests with canopy moisture above 40% are not observed. That fact is an evident that the ecological conditions in the Chuprene reserve have drastically changed in the last years.

On Fig. 5 are presented the NMDI values within the reserve territory.

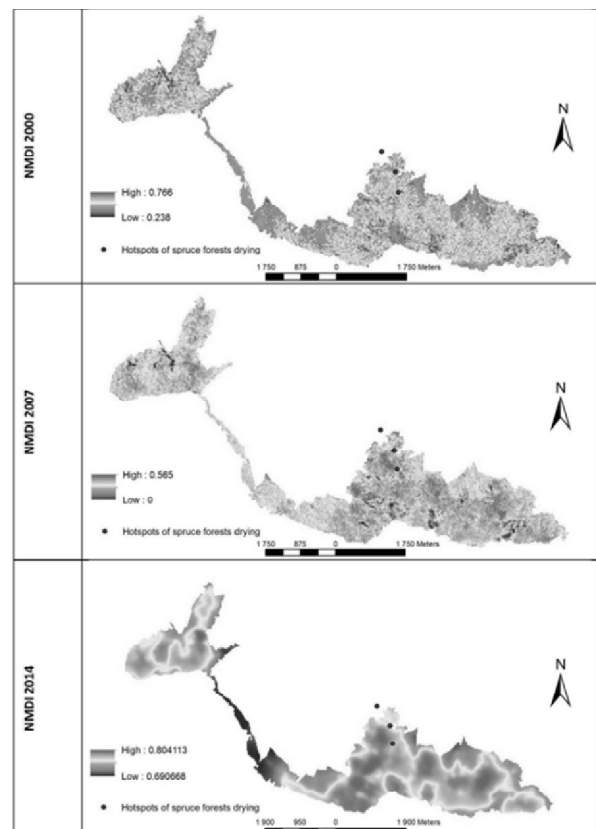


Fig. 5. NMDI values for the investigated years

4.2. Assessment of soil erosion risk

The assessment of soil erosion risk shows that 2000 is distinguished with the highest levels of soil loss, followed by 2014 and 2007. (Fig.6) In order to be achieved more accurate estimation of the soil erosion spatial distribution, the values representing development of soil erosion processes were divided into nine categories. The territories with lowest degree of soil erosion are first category and these with highest, respectively ninth.

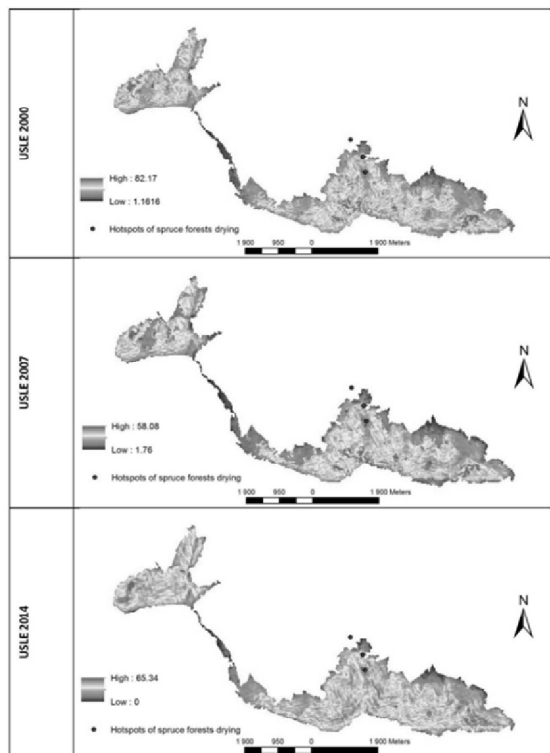


Fig. 6. USLE values for the investigated years

The model shows that in 2000, largest territory had third category lands (38.28 % of the reserve), followed by these of fourth category (25.19 %), and of second category (21.84%). Only in this year could be observed negligible small areas of seventh, eighth, and ninth category. (Fig.7)

5. CONCLUSION

The variations of soil erosion degree in the three investigated years are result of the differences in NDVI values, representing the vegetation condition. The NDVI values are highest for beech formations, followed by grasslands, spruce formations, and bare lands. In 2000, the NDVI values of the spruce formations (around 0.25) were equal with these for bare lands in 2014. In 2014, the NDVI values of bare lands were 0.25 again and these of spruce forests just 0.27. That fact testifies to the poor condition of spruce formations in Chuprene reserve. This condition is due to the great age of these forests and their susceptibility to different diseases.

In 2007 an improvement of spruce formation conditions was observed against these formations of 2000. Probably, this is due to climatic conditions, which most likely were close to the optimal for these forests in the relevant year. On the other hand, climatic conditions are related to solar activity and its variations. Part of a solar activity cycle coincides with the data time-span. The analysis of the factors' leading to vegetation degradation shows some well-marked quazy-periodicities in their variability.

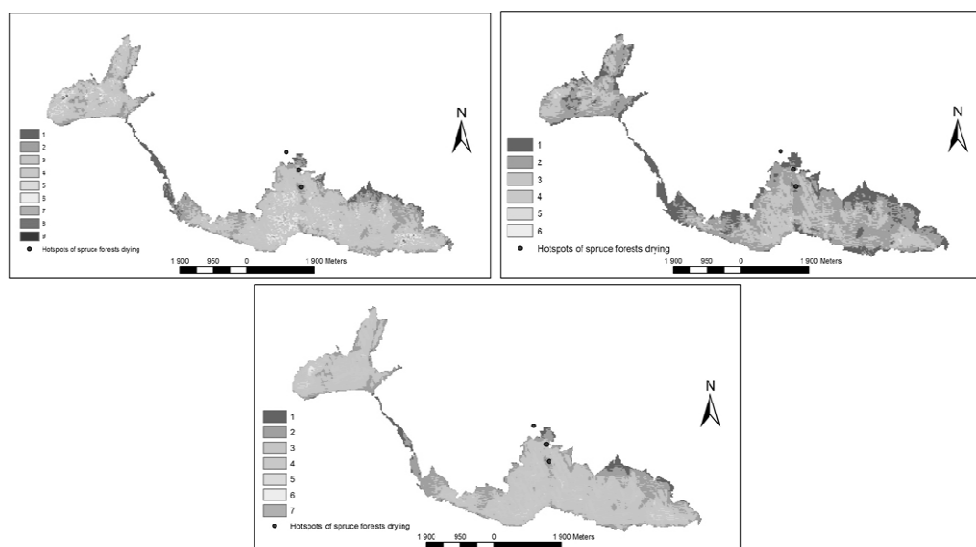


Fig. 7 Territorial distribution of the soil erosion categories in 200, 2007, and 2014

The latter could be interpreted as sub-harmonics representative for changes in the solar dynamo. Besides these possible connections, irregular extremes in the factors' variability probably are generated by hysteresis-type phenomena due to geoeffective elements of the solar spectrum. A possible chain of influence is traced in the aerosols' formation. A more complicated, but realistic scenario includes electro-dynamical connection between solar wind's magnetic field, X-ray bursts and the general atmospheric circulation, the clouds' evolution. A detailed research is going on and the results will be published in short term.

Other factor, which impact on the soil erosion development is the topographic factor. Areas, located on steeper terrain, which in 1997 were grasslands, nowadays are already bare lands. This suggests that territories, exposed to deforestation and characterized by steeper slopes, are very likely to be transformed into bare lands, while these, located on gentle slopes - into grasslands. 85% of the reserve territory is characterized by slopes with steepness above 15°. This is a prerequisite for increase of the portion of areas susceptible to soil erosion development and respectively of these ones, characterized by high erosion degree.

The degradation of the forest vegetation in Chuprene reserve in combination with the topographic features increases the risk of soil erosion occurrence and its development. In the area, the most vulnerable territories and landscapes are these distinguished by lower degree of resistance such as landscapes, developed on the metamorphic rocks in the western part of the reserve. [4]

The Chuprene reserve provides the balance in the lower lying subordinate landscapes. The forest harvesting in these landscapes and deforestation in the reserve territories result in the heat-moisture ratio change, which causes drying of the lands and desertification in the lower located landscapes in the longer term. The slope wash erosion intensification and the rill forming induce irreversible consequences, which by wash of the organic soil horizons and general deterioration of the physicochemical properties of the soil lead to the same negative result. [4]

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ОЦЕНКА НА ДЕГРАДАЦИЯТА НА РАСТИТЕЛНАТА ПОКРИВКА И НА ЕРОЗИОННИТЕ ПРОЦЕСИ В БИОСФЕРЕН РЕЗЕРВАТ ЧУПРЕНЕ (СЕВЕРОЗАПАДНА БЪЛГАРИЯ) ЧРЕЗ ИЗПОЛЗВАНЕ МЕТОДИТЕ НА ДИСТАНЦИОННИТЕ ИЗСЛЕДВАНИЯ И ГИС

Даниела Аветисян

Резюме. Деградацията на растителната покривка и възникването на ерозионни процеси водят до процесир свързани с изменението на ландшафтната структура и състоянието на ландшафтните компоненти. Тези процеси биват съпровождани от промени в съотношението между топлина и влага в ландшафтите и продължително протичащи процеси на засушаване. Като един от възможните факторир водещи до деградация на растителността засушаване и опустиняване могат да се разглеждат измененията в параметрите на слънчевата активност. В настоящето изследване, деградацията на растителната покривка е оценена чрез използване на сателитни изображения и вегетационни индекси: NDVI, VCI и NMDI. Състоянието на растителността е един от

водещите фактори на USLE, използвано като база за оценката на почвената ерозия. Едновременното изследване на двата процеса за 2000, 2007 и 2014 г. позволява проследяването на тяхната динамика и извличането на възможна тенденция за развитието им.

Ключови думи: деградация на растителността, почвена ерозия, фактори на USLE, северозападна България

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