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APPLICATION OF MULTISPECTRAL SENSOR IN QUANTIFICATION OF SOIL PROTECTION COEFFICIENT (XA) IN EROSION POTENTIAL METHOD

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Abstract: *In this paper, Soil Protection Coefficient (Xa) was quantified through the approach of high resolution multispectral orthomosaic segmentation and classification. The approach was presented in the example of ski lane in ski center Kopaonik. The data collection was performed through application of Unmanned Aerial System equipped with 5-band multispectral sensor and RGB sensor. Data processing was performed with digital photogrammetric and Object Based Image Analyses software. The Soil Protection Coefficient represents the descriptive and very sensitive parameter of Erosion Potential Method. Application of 5 spectral bands, of which 2 bands are very sensitive to the type of land use /land cover allowed precise detection, delineation and classification of different land cover/use types. These types were directly tied to the values of Xa coefficient which were originally proposed by the author of the Erosion Potential Method, professor Slobodan Gavrilović. The final result was a georeferenced digital map classified with both land cover/use and Xa values classes. This approach created the potential to use such maps for further analyses, planning, and modeling of erosion protection measures.*

Key words: Erosion Potential Method, Soil protection coefficient (Xa), Unmanned Aerial Systems, Multispectral sensors, Erosion protection, Object-Based Image Analyses

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PRIMENA MULTISPEKTRALNIH SENZORA U KVANTIFIKOVANJU KOEFICIJENTA UREĐENOSTI SLIVA (XA) U METODI POTENCIJALA EROZIJE

Izvod: *U ovom radu je izvršeno kvantifikovanje Koeficijenta Uređenosti Sliva (Xa) putem segmentacije i klasifikacije multispektralnog ortomozaika visoke rezolucije na primeru ski staze ski centra Kopaonik. Terensko prikupljanje podataka je izvršeno bespilotnom letelicom opremljenom 5-kanalnim multispektralnim senzorom i RGB senzorem. Obrada podataka je izvršena digitalnim fotogrametrijskim softverom i softverom za analizu slika na nivou objekata. Koeficijent Uređensti Sliva predstavlja opisni i veoma osetljiv koeficijent Metode Potencijala Erozije. Primenom 5 spektralnih kanala, od kojih su 2 veoma osetljiva na različite načine korišćenja zemljišta odnosno zemljišnog pokrivača omogućena je precizna detekcija, delineacija i klasifikacija različitih tipova korišćenja i zemljišnog pokrivača. Ovi tipovi su direktno povezani sa vrednostima Xa koeficijenta koje je izvorno predložio tvorac Metode Potencijala Erozije, profesor Slobodan Gavrilović. Krajnji rezultat prikupljanja i obrade podataka predstavlja georeferencirana digitalna karta sa klasifikacijom načina korišćenja/tipa zemljišnog pokrivača, i vrednosti koeficijenta Xa. Ovaj pristup je stvorio mogućnost za potencijalnu upotrebu takvih tematskih karti za dalju analizu, planiranje i modelovanje mera za zaštitu zemljišta od erozije.*

Ključne reči: Metod potencijala erozije, Koeficijent uređenosti sliva (Xa), Bespilotne letelice, Multispektralni senzori, Zaštita od erozije, Analiza slika na osnovu objekata.

1. INTRODUCTION

Soil erosion by water represents the naturally occurring process and geological phenomenon closely tied and an inseparable part of the hydrological cycle. The erosion process gradually increased activity that causes the detachment of the soil particles under the influence of water, which eventually leads to the deterioration of the quality of the soil (Jazouli et al.).

The soil is defined as a surface layer of the hard Earth’s crust, more or less affected and changed under the influence of the hydrosphere, atmosphere, and biosphere. Soil is the main naturally occurring, limited, and non-renewable resource. As a consequence of intense urbanization, industrialization, and exploitation, soil fund is continuously damaged and destroyed at a global level. In the Republic of Serbia, most of the pressure on the soil comes from erosion by water, landslides, and the reduction of organic matter in the most productive layers of the soil. The change in land use has a huge impact on the soil. It was estimated that various degrees of erosion processes affect 80% of the territory of the Republic of Serbia. (Vodič za održivo upravljanje zemljištem na lokalnom nivou u Republici Srbiji, 2018).

The impacts of erosion are multiple. The nature of the impact depends on the positioning of the in-situ and off-site erosion processes – displacement and sedimentation. The erosion processes may have different outcomes in different areas. The erosion in mountain areas may lead to the degradation of the entire ecosystems while the erosion in arable land may lead to loss of soil productivity and reduced crop yield. Even though these are very different outcomes the mechanism of the erosion and the approach to quantify and predict the erosion is the same. (Garcia-Ruiz, J.M, 2010)

For the risk assessment from erosion and assessment of the production of erosion material, there are numerous prediction models in use.

The Erosion Potential Method (EPM) has been widely used in former Yugoslavia and in present Serbia for mapping erosion processes. EPM is a complex methodology designed for usage in the field of Integrated Water Resources Management (Globevnik et al., 2003) This method was based on the Method for Quantitative Classification of Erosion developed in 1954 (Amini et al, 2010). This method allows the assessment of different types of erosion – surface, fluvial, and lateral (Dragičević et al, 2014) It also encompasses erosion mapping, sediment quantity estimation, and torrent classification (Gavrilović et al, 2006).

According to de Vente, the EPM can be considered a semi-quantitative methodology with the inclusion of both descriptive and quantitative factors (de Vente and Poesen, 2005). The descriptive factors are the coefficient of erosion ability of soil, coefficient of protection of soil with vegetation, and coefficient of visible and clearly defined erosion processes in the observed area.

The Erosion Potential Method underwent multiple modifications for various applications. For this purpose, the modification done by Tošić and Dragičević in 2012 (Tošić and Dragićević,2012) is of the most interest. This modification was performed in order to adjust the EPM to the GIS environment. The idea was to apply GPS PDA (handheld positioning device) for the detection and georeferencing of visible erosion processes (**φ**)**.** This modification would especially aim at the geometry of the terrain which would affect the **φ** coefficient of EPM. (Dragičević et al., 2016)

Besides this modification, there were multiple modifications that targeted the values for other descriptive coefficients in EPM (Globevnik et al., 2003), Fanetti and Vezzoli, 2007). In the paper written by Tošić and Dragičević (Tošić and Dragićević,2012), it was presented the idea of application of maps of higher resolution supplemented with digital elevation model (DEM) information. It was proposed that those would allow a more detailed classification of areas of interest. (Tošić and Dragićević,2012) In addition to this premise, high-resolution imagery may prove as a highly beneficial source of information for planning and logistics for field works. (Šurjanac et al. 2019)

The Soil Protection Coefficient (Xa) of the EPM represents the level of vegetative protection of the basin or erosion area. This coefficient is the function of vegetation land cover which covers and protects the land surface from atmospheric effects and erosion forces. This coefficient represents a two-component coefficient. The “X” component represents natural protection while the “a” component represents artificial protection through erosion protection work in a field (construction or bio-technical). The product of these two components is the coefficient that ranges from 0.01 for a well-protected area to 1.0 for bare, unprotected soil. According to (Dragičević et al. 2017 and Ballio et al. 2010) Xa coefficient is one of the most sensitive coefficients in EPM. Dragičević et al tested different sources of land use/cover information (Xa) and noted a very high deviation of the results of the model.

The purpose of this paper is to explore the possibility of airborne multispectral sensors and a set of software solutions to develop an approach for the automatic delineation and classification of various land cover types on high-resolution orthomosaics. This will directly affect the spatial distribution and values of the Xa coefficient of EPM. The idea was to introduce the quantification of otherwise descriptive coefficients and to limit or remove the arbitrary impact of the human factor from the qualification of coefficients. It will also explore the relationship between Xa values and various Vegetation Indices (VI) although the quality of various land cover types and relationship with VI's is out of the scope of this paper.

2. MATERIALS AND METHODS

Study area selected for this purpose is the mountain area in Kopaonik mountain. The area is part of the ski center Kopaonik. Ski lanes are of particular risk for surface erosion. Due to the high slopes and physical exploitation during the winter season ski lanes are very prone to erosion once the vegetation cover is reduced and removed. The development of ski lanes induces soil and vegetation degradation. (Ristić et al, 2012)

The choice of ski lanes as a data source for this paper was due to the fact that ski lanes are prone to erosion processes. They also have various land cover types present which makes them suitable and demanding for high-precision land cover delineation and classification.

The methodology consisted of two main and several sub-processes. The main processes were data collection and data processing.

Instead of relying on satellite and manned aircraft data, this paper required data collected with the unmanned aerial system – UAS, commonly known as a drone. It was equipped with two sensors – RGB and multispectral. The total amount of mapped area was ~28ha. The image acquisition was done between 11 am and 12 pm during the clear weather which resulted in images with high contrast and deep and dark shadows.

RGB refers to Red-Green-Blue channels or colors. It is a 3-channel Bayer pattern[2] sensor that collects the data in the visible part of the light spectrum. This sensor allowed image collection with 256 levels of intensity per channel effectively delivering images with 16 million colors.

Multispectral sensor of choice was MicaSense RedEdge M. This multispectral sensor allowed the simultaneous collection of 5 discrete, narrow-band images, with 65536 levels of intensity per channel. Unlike the RGB sensor, the used multispectral sensor had narrowband channels with a larger total spectral span. Center wavelengths for each of the 5 sensors are – 475, 560, 668, 717, 842. The first three wavelengths correspond with the Blue, Green, and Red parts of the spectrum, while the latest two spectral wavelengths correspond with the Red Edge

[2] Bayer pattern which is a technique whereby instead of requiring each pixel to have its own individual three color planes (requiring 24 bits in total), an array of color filters is placed over the camera sensor requirement for data bits per pixel to a single 8-bit byte (with a known color filter in place)

and Near Infra-Red parts of the spectrum. The last two wavelengths are not visible by the human eye but vegetation, especially alive, dense and healthy vegetation shows a high intensity of reflectance in these areas of the light spectrum. This makes it suitable for differentiation between different types of land cover (Campbell and Randolph 2011).

All collected data was in a form of individual images. All images are georeferenced with geospatial data in WGS 84 geographic coordinate system. The main input for land cover delineation and classification was RGB and 5-channel multispectral orthomosaics shown in image 1.

The first level of processing was digital photogrammetry. The used software was Agisoft Metashape. The products of photogrammetry were colorized point clouds, digital elevation models, and orthomosaics. Multispectral images were co-registered and calibrated through the application of a calibrated spectral panel of which images were taken while collecting the data in the field. Orthomosaics were exported and geospatial information was transformed into a projected coordinate system ETRS89 UTM zone 34N.

The second level of processing was done on produced RGB and multispectral orthomosaics. The Ground Sample Distance (GSD) for RGB orthomosaic was 3.3cm/pixel, while multispectral orthomosaic and Digital Terrain Model- DTM and Digital Surface Model-DSM GSD of 8.4cm/pixel. For the purpose of development of workflow and algorithms for automatic delineation and classification and the drawing of vectors (objects), Object-Based Image Analyses (OBIA) software was used. Trimble eCognition software allowed input of 5-channel orthomosaic and segmentation of the image into small objects. Created objects consisted of groups of pixels with similar contextual values of individual pixels. The segmentation criteria and weight values were set on each of the 5 channels.

The channels with the highest weights were RedEdge and Near Infrared due to their high sensitivity to different land cover types(Šurjanac et al 2015). An example of the resulting segmentation process is shown in image 4.

Initial segmentation resulted in ~1,451,000 objects. The part of orthomosaics with objects after initial segmentation is shown in image 4. All objects have assigned values for 9 initial attributes. These values were reflectance values for 5 spectral channels. Additional information was elevation values in the form of Digital Terrain Model (DTM) and Digital Surface Model (DSM) which are shown in image 2. The next process requested calculations of vegetation indices which used all 5 channel values to assign numerical values to each of the segmented objects. Vegetation indices that were used for differentiation of all present types of land cover were Normalized Difference Vegetation Index(NDVI), Normalized Difference Red Edge (NDRE), and Visible Atmospheric Resistance Index (VARI).

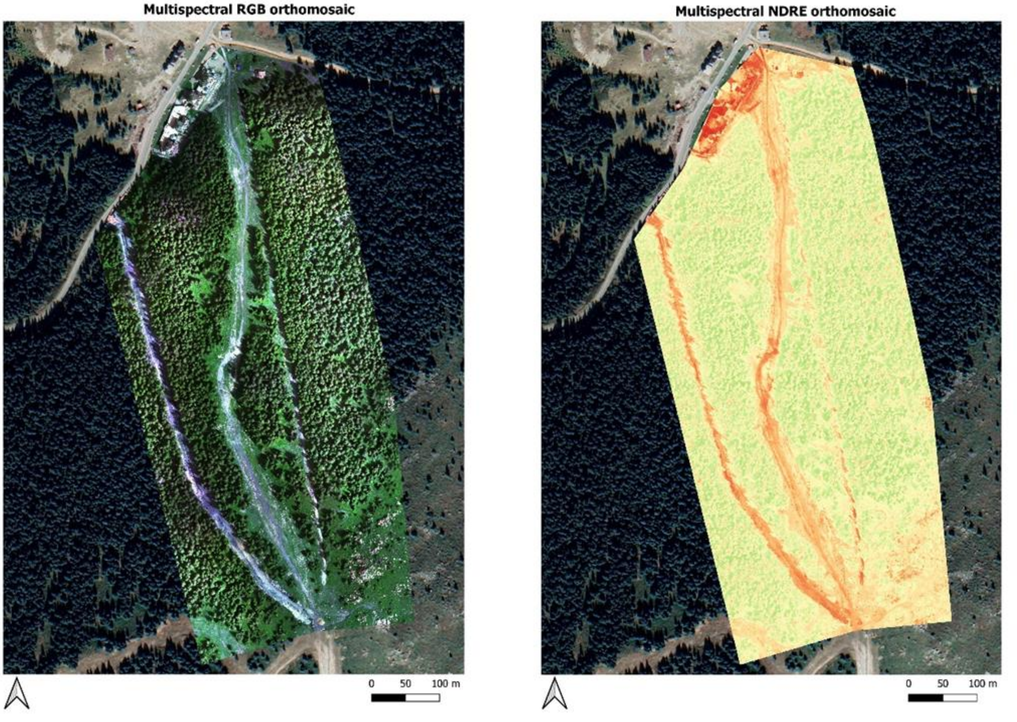

Image 1. *Multispectral orthomosaics RGB and NDRE*

NDVI index required reflectance values in NIR and RED channels, NDRE required NIR and Red Edge values, while VARI required RED, GREEN, and BLUE channels. DTM and DSM elevation models were used to produce a normalized Digital Elevation Model (nDEM) which effectively represented the height of the objects in the field. The raster file with the information on height is shown in image 3. In order to classify Non-Vegetated surfaces and Bare rock surfaces two conditions were supposed to be fulfilled. The height should be less than 0.3m for Non-Vegetated and 2 m for Bare rocks and the VARI index should be lower than -3500 for Bare-Rocks and lower than -300 for Non-Vegetated surfaces.

For vegetation classification NDVI and NDRE values alongside nDEM values were used to classify vegetation as Sparse vegetation (nDEM<0.3m, NDRE<0.3), Low Vegetation (nDEM<0.3m, NDVI>0.5), High Vegetation (nDEM>0.3m, NDVI>0.5).

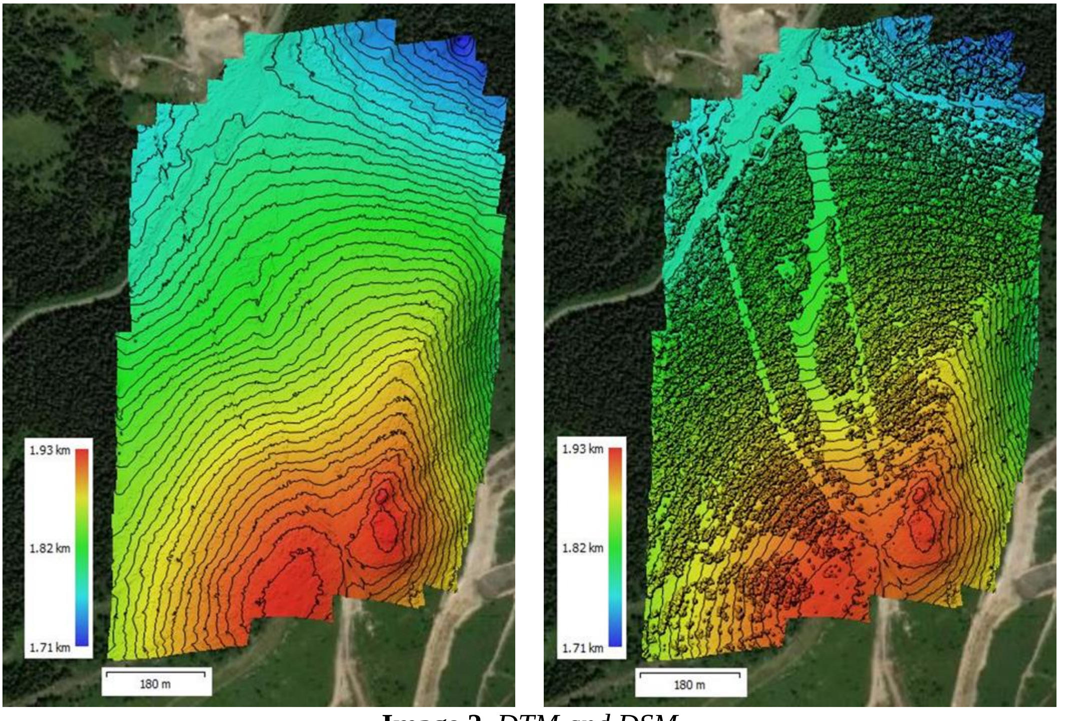

Image 2. *DTM and DSM*

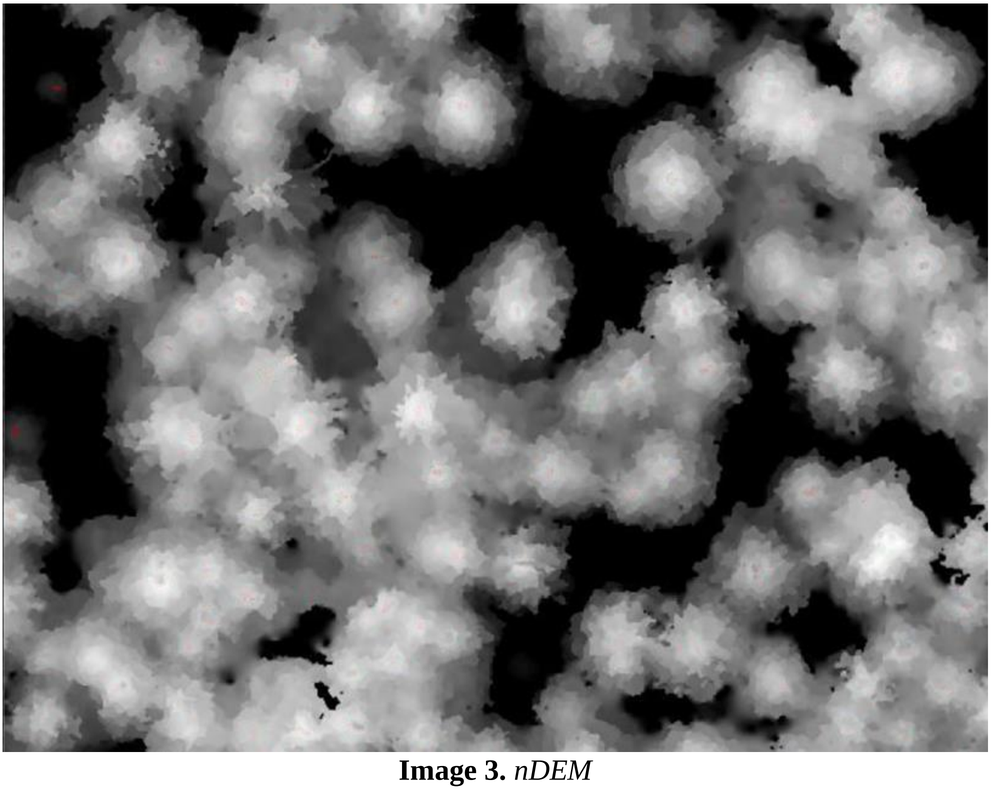

Image 3. *nDEM*

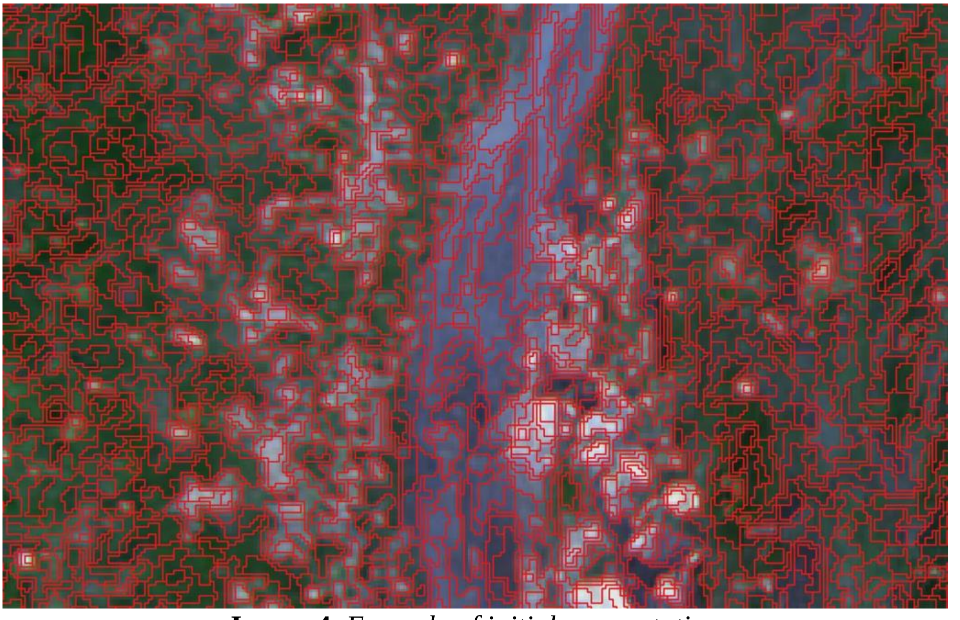

Image 4. *Example of initial segmentation*

3. RESULTS AND DISCUSSION

Initial segmentation resulted in ~1.451 million vectored objects. Classification and merging of adjacent objects of the same classes resulted in ~91 thousand polygons exported in the form of a .shp file. The example of resulting vectors is presented in image 5.

The classification of the objects is shown in image 6. Classification resulted in 5 classes – Bare rocks and disturbed soils, Non-Vegetated areas, Sparse vegetation (low-quality grassland), Low vegetation (good-quality grassland), and High vegetation (trees, forest).

These classes were directly related to the original values defined by Gavrilović (Gavrilović, 1972). The “a” component was 1, since there was no erosion protection work in the area. This meant that classes could be directly transformed into Xa coefficient values. Corresponding Xa values to the aforementioned classes are 1.0 for Bare rocks and disturbed soils, 0.9 for Non-Vegetated areas, 0.6 for Sparse vegetation, 0.4 for Low vegetation, and 0.05 for Trees. This is shown in image 5.

Area which each class occupy is: Trees 172665.332m^2, Sparse vegetation 4332.41 m^2, Non- vegetated 23821.201 m^2, Low vegetation 73303.331 m^2, Bare rock and disturbed soils 7688.704 m^2

The distribution of area classified in each class and Xa values are presented in Chart 1.

The resulting vectors (objects) show high precision of detection and delineation of different land covers/land uses. This is shown in image 6. This image shows multispectral orthomosaic overlaid with automatically generated vectors with 16 attributes.

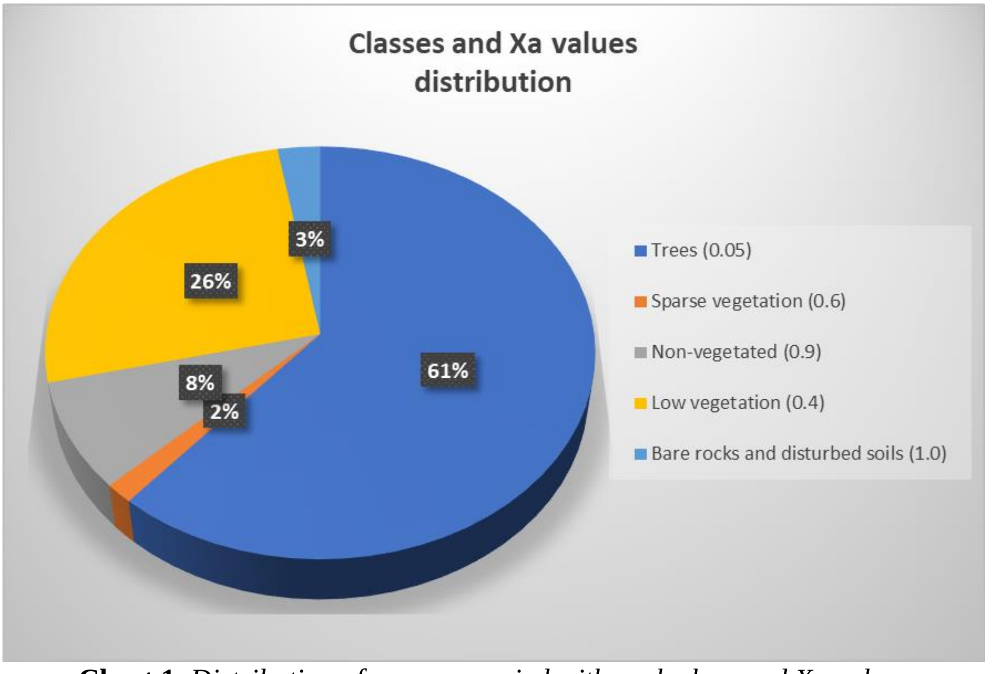

Chart 1. *Distribution of areas occupied with each class and Xa values*

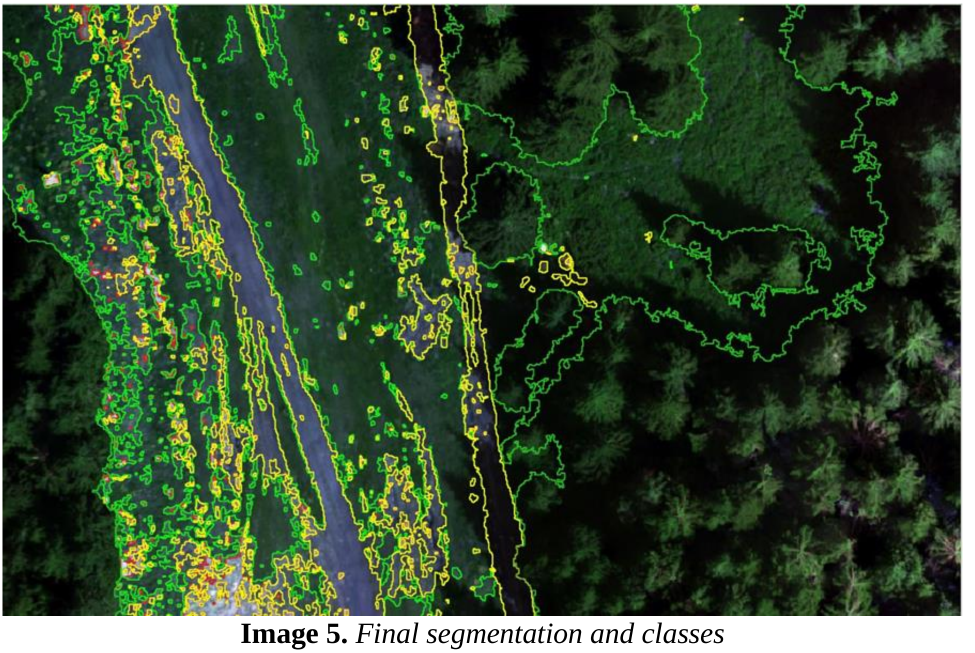
Image 5. *Final segmentation and classes*

The areas of individual objects range from 0.5 meters or below to hundreds and thousands of square meters. The resulting resolution of 8cm/pixel allows the creation of a high variety of sizes of objects and polygons which can be scaled up and/or down to find the most suitable size which is the most usable for calculations of the erosion coefficient Z on a local level. The value of localization and georeferencing of parameters of EPM is in the ability to perform ground truth data collection which can be done with absolute precision. This would also allow planning of erosion protection that can target the areas which are the most critical for sediment production and slope stability which will affect the quality of the ski lane.

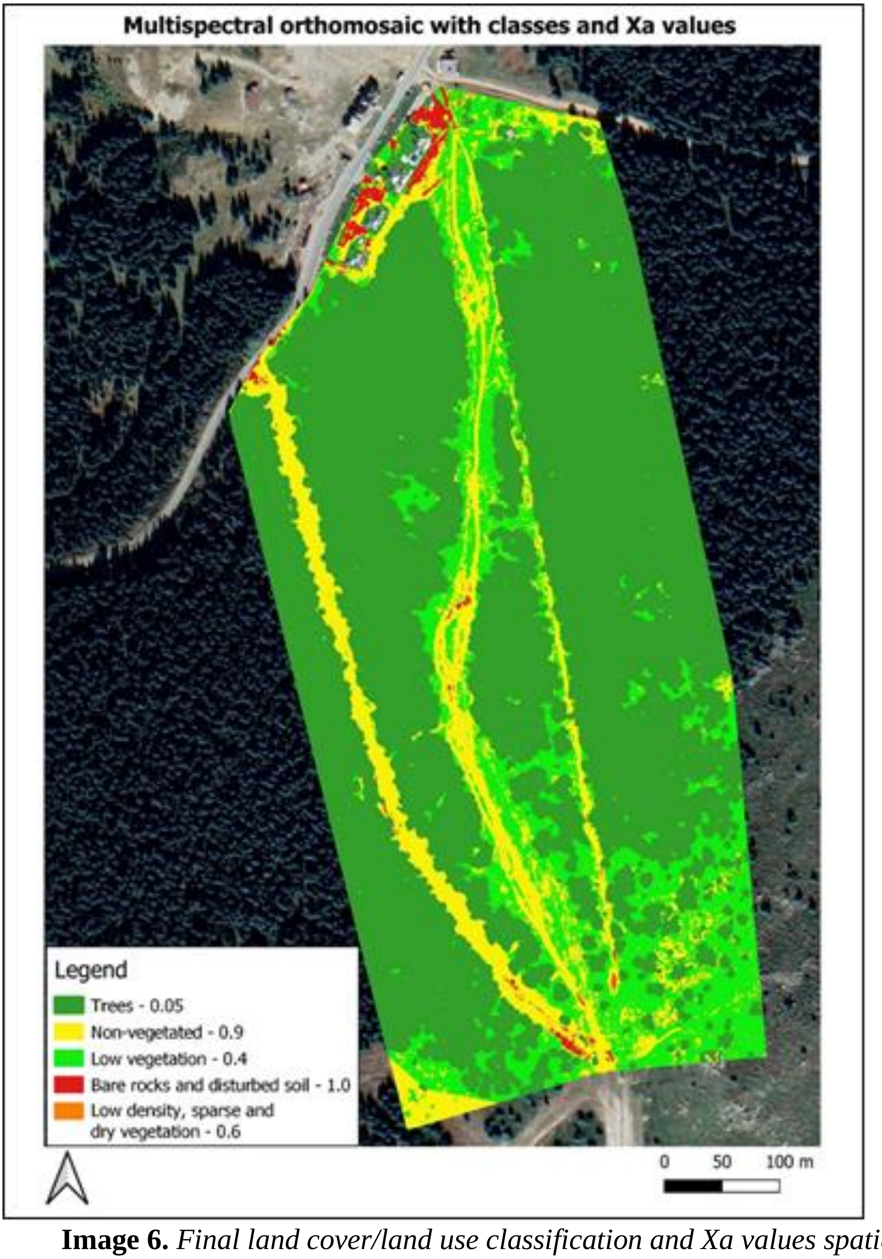

Image 6. *Final land cover/land use classification and Xa values spatial distribution*

4. CONCLUSION

The ability to perform the segmentation of the orthomosaic based on values in an individual channel and classify the created objects on the ground of values which are directly associated with Xa coefficient creates the potential to segment the orthomosaic on the ground of the parameter of digital elevation models and slope which will directly affect other descriptive coefficients of the EPM.

This approach can provide the ability to quantify the descriptive parameters based on spectral values and geometries, rather than on the varying experience of the individual engineers in the field. Combination of RGB and multispectral data provides the ability to verify the multispectral classification of land use/land cover on 2-3cm/pixel RGB orthomosaic. RGB orthomosaic provides ability to detect fine level of detail and delineation of various land cover types. However, for features that affect the results of EPM that might be hidden below the canopy field verification may be required. This kind of field data acquisition, data processing, classification, and analysis allows not only adequate and precise planning of protection measures and modeling, but it allows the inclusion of more environmental parameters for a holistic approach and provides the basis for frequent and regular monitoring of the development of erosion processes and effect of proposed measures and models.

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Summary

Erosion processes pose a danger to ski lanes. Ski lanes in the ski center Kopaonik are heavily exploited during the winter season. During the late spring and summer season, the ski lanes are used for hiking and quad bike enthusiasts. This puts additional pressure on the slopes already prone to water erosion processes. The prevalent methodology for erosion mapping is Erosion Potential Method defined by professor Gavrilović. This is an empirical

semi-quantitative method that relies on 3 descriptive coefficients. One of these is the Soil Protection Coefficient (Xa). This coefficient is represented by numerical values which describe the type of land use/land cover present in the observed area.

This paper presented the approach of automatic quantification of Xa values based on spectral and geometrical characteristics of the groups of pixels in digital orthomosaics. The paper presented the entire pipeline from field data collection over processing to the final classification and digital map production.

Field data was collected with UAS (drone) equipped with RGB and 5-band multispectral sensor. These data were used for automatic object extraction, delineation, and classification of land use/land cover types present in the observed area. This approach resulted in the generation of the digital georeferenced map that presents the high-resolution spatial distribution of Xa coefficient values which is ready for application in the Erosion Potential Method, and planning of erosion protection measures. The approach presented in the paper is also applicable to the automatic extraction, delineation, and classification of other descriptive coefficients in the Erosion Potential Method.

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Rezime

Erozioni procesi predstavljaju opasnost za ski staze. Ski staze u skijaškom centru Kopaonik se veoma aktivno koriste tokom zimske sezone. Tokom prolećne i letnje sezone skistaze se koriste za pešačenje i za vožnju kvadova. Ovo dodatno opterećuje padine koje su već izložene erozionim rizicima. U Republici Srbiji i okolnim zemljama preovlađajuća metoda za kartiranje erozionih procesa je Metoda Potencijala Erozije koja je razvijena od strane profesora Gavrilovića. U pitanju je empirijska polu-kvantitativna metoda koja u se oslanja na 3 opisna keoficijenta. Jedan od njih je Koeficijent uređenja sliva (Xa). Ovaj keoficijent je predstavljen brojčanim vrednostima koje opisuju način na koji se koristi zemljište, odnosno tip zemljišnog pokrivača u posmatranom području.

U ovom radu je predstavljen pristup za automatsku kvantifikaciju Xa vrednosti na osnovu spektralnih i geometrijskih karakteristika grupisanih piksela na multispektralnom ortomozaiku. Rad predstavlja kompletan pristup od terenskog prikupljanja podataka preko obrade podataka do krajnje klasifikacije i izrade digitalne karte.

Terensko prikupljanje podataka je izvršeno bespilotnom letelicom (dronom) sa RGB i multispektralnom kamerom. Ovi podaci su korišćeni za automatsko definisanje poligona i klasifikaciju načina korišćenja zemljišta/tipova zemljišnog pokrivača u posmatranom području. Ovaj pristup je rezultirao u izradi digitalne georeferencirane karte koja predstavlja prostorni raspored Xa vrednosti visoke rezolucije, koja je spremna za dalju primenu u Metodi Potencijala Erozije, i planiranje protiv erozionih radova. Pristup prikazan u radu takođe je pogodan za definisanje poligona i klasifikaciju i drugih opisnih parameter Metode Potencijala Erozije.