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CIVIL ENGINEERING - SCIENCE & PRACTICE

GNP 2022 PROCEEDINGS

Kolašin, March 2022

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GIS / 3D SOLUTIONS IN THE FUNCTION OF MANAGEMENT IMPROVEMENT IN AGRICULTURE

Abstract

This paper presents GIS/3D solutions and their application in agriculture. Further, the possibilities of obtaining information important for planning the development of viticulture, fruit growing and farming are analysed and presented. Until now, maps have been most commonly used as models for terrain analysis. The main weaknesses of the maps are content freezing and difficult 3D analysis. With the advent of geoinformation technologies, the way of processing is changing and the concept of GIS/3D data modelling is being emphasized. The aim of this paper are new solutions that provide an efficient opportunity in field analysis and resource management in agriculture. An algorithm has been designed where, based on the given criteria (terrain slope, aspect, vegetation index, altitude), representations of potential areas for growing certain crops are obtained. The results show numerous possibilities of GIS methodology for agricultural crop management, in this specific case of viticulture, arable farming and fruit growing. Also, the results in the form of geostatistical maps provide a more precise insight and serve as a basis for better decision-making in agriculture. The area of interest includes the Srem district, which is located in the northern part of the Republic of Serbia. This district is a resource of great importance for the further development of agriculture, of which viticulture and fruit growing are of special importance. For planning the development of agriculture in an area, it is necessary to have information related to both the assessment of land suitability and land valuation for certain agricultural species in order to be able to assign the optimal purpose.

Keywords

GIS, agriculture, 3D model, slope, aspect, NDVI

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1. INTRODUCTION

Today, however, primarily thanks to GIS technology, it is possible to create more efficient tools, so it is then possible in a relatively simple and fast way to obtain the necessary information to make the right decisions in planning, use and land management [1]. In the last few years, a new approach to agriculture has been developed, called precision agriculture [2]. In relation to classical agriculture, where arable land is treated evenly, applying an equal amount of funds over the entire territory under crops, in precision agriculture, land is treated variably in terms of cultivation, irrigation, pesticide application, all in accordance with the geographical characteristics of the land [3]. Also, precision agriculture involves the application of geographic information systems (GIS), remote detection of various sensors, analysis of terrain using global positioning systems [4]. Digital terrain modeling is especially interesting and significant. Geomorphological parameters such as slope and terrain exposure, altitude, relief are of great importance when analyzing and assessing the suitability of land for raising a plant culture [5, 6, 7].

The advent of 3D modelling and the application of computers has led to the use of a continuous approach in the representation of land surfaces. This has a special advantage in describing and perceiving the topography of the terrain [8]. Namely, a 3D terrain model is created that has a quality resolution and accuracy of displaying altitude variability within the field. From this it is possible to derive various topographic attributes [8]. The primary topographic parameters are quantities that can characterize any two-dimensional surface area and represent the morphometric characteristics of the relief over which the evaluation is performed [9]. In order to improve the functions of the selected soil, before sowing or planting any plant species, it is necessary to analyse the topographic characteristics of the terrain. The main goal of precision agriculture is to establish a decision support system for the entire property, where investment is optimized in order to achieve maximum profit in accordance with the availability of natural and technological resources [10,11]. The main goal of this paper is to determine the suitability of 3D models and research of agricultural areas suitable for growing selected crops in the field of farming, fruit growing and viticulture

2. MATERIALS AND METHODS

2.1. STUDY AREA AND DATASET

The area of interest includes the Srem district, which is located in the northern part of the Republic of Serbia, that is within the Autonomous Province of Vojvodina. The Srem district is a resource of great importance for the further development of agriculture, of which viticulture and fruit growing are of special importance. It encompasses various geomorphological characteristics and features of the terrain. It is mostly a lowland plain with an average altitude of 70 to 80 m, which grows from the Sava River in the south to the Danube River in the north (Figure 1). The highest peak is located on Fruška gora. It is called Crveni Chot and its height is 539 m. Apart from the mountain Fruška gora, low alluvial plains stretch along the Sava river. Above them are lower terrace plateaus, and southeast of the Danube is the Srem light plateau [12,13].

Figure 5. Area of interest – Srem district

The inputs for the selected work area are: satellite imagery, the global digital elevation model (DEM) of the Earth, and a defined polygon boundary encompassing the area of interest. The global DEM has a spatial resolution of about 30 m covering most of the world with absolute vertical height accuracy of less than 16 m [13]. Now, the 30 m (1 arc-second) resolution SRTM (Shuttle Radar Topography Mission) is publicly available on the USGS Earth Explorer for most of the globe. This enhanced version presents the full resolution of the original measurements [14]. Satellite images were collected using the *Sentinel-2* platform, that is processing level 2A [15]. Based on satellite images, the *NDVI* vegetation index *(Normalized Difference Vegetation Index)* was analyzed, and based on the global DEM, the slope, exposure and hillshade were analyzed.

2.2   METHODS AND TECHNOLOGY OF THE STUDY

Within this chapter, GIS tools for surface treatment, display and analysis of 3D model and its application for the needs of precision agriculture are considered [16]. Further processing and definition of the concept of the algorithm was performed in the *QGIS* software package (Figure 2). The creation of the algorithm itself was done using the *Graphical modeler option*, which is located in the *QGIS* software header, that is within the *Processing / Graphical Modeler* tab.

Input data	Data processing	Output data
• Global 3D model; • Polygon boundary; • Satellite images.	• Cutting 3D model and satellite images toward the polygon boundary; • Calculation of slope, exposure and terrain illuminance based on 3D model; • NDVI index calculation; • Reclassification of the obtained slope, exposure and NDVI index; • Setting conditions for obtaining suitable zones for growing different crops.	• Raster that meets the requirements for growing vines; • Raster that meets the requirements for growing corn, soybeans and wheat; • Raster that meets the requirements for growing apples, pears and peaches.

Figure 6. The conceptual scheme of the algorithm

The main function of the conceptual model is to consider and describe the process of collecting, processing and displaying data, that is obtaining suitable zones for growing different crops in the field of fruit growing, viticulture and farming. The criteria for obtaining suitable zones are: terrain slope, aspect and *NDVI* index.

The slope of the terrain is an inevitable topographic parameter that is of great importance in agriculture, in the construction of road infrastructure, the movement of slopes and soil in surface mines, etc. The speed of surface water runoff, soil saturation with moisture, terrain illumination, etc., depend on the slope of the terrain, among other things [17]. The slope of the terrain (S) is determined by the gradient, that is the vector that shows the direction of the largest growth of the scalar function z = f (x, y). The intensity of the change in height in the direction of the greatest slope is expressed by the equation:

$$S = \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} = \sqrt{z_x^2 + z_y^2} \tag{1}$$

A lower value of the calculated slope, whether it is a TIN or a GRID, indicates a flatter terrain, and a higher value of the slope indicates a steeper terrain. Graphically, it can be expressed in degrees or in percentages of slope (Figure 3).
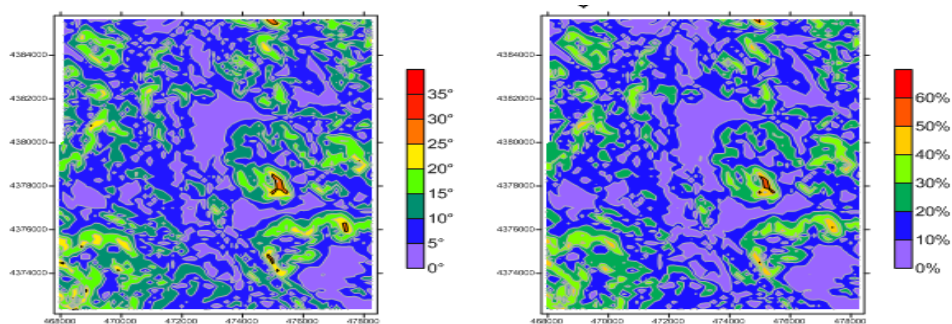

Figure 7. Terrain slope expressed in degrees and percentages

The aspect or exposure of the terrain in relation to the sides of the world, affects the light, temperature and humidity, and each exposure has its favourable and unfavourable characteristics (Figure 4). It is defined as the orientation angle (azimuth) of the direction of the greatest fall of the terrain. It is determined from the north direction to the direction of the greatest fall of the terrain, measured in a clockwise direction.
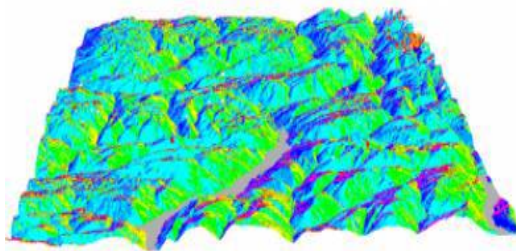

Figure 8. Terrain exposure

Measurement of reflection in the near-infrared and red visible part of the spectrum is a very precise mechanism for determining the health of vegetation. The parameter that defines it is the vegetation index *NDVI*. This index can be used to monitor seasonal and perennial vegetation changes [18]. The expression by which *NDVI* is calculated from the reflection of light in the visible and near-infrared spectrum is:

NDVI = (NIR-RED) / (NIR+RED) (2)

where RED and NIR represent measurements of spectral reflection in the red and near-infrared bands, respectively [9].

3. PROCESSING OF DATA AND RESULTS

The first step in the algorithm is to enter the global DEM by dragging *the Raster layer* from *the Input* part into the working area of the interface. For further data processing and processing, satellite images collected using the *Sentinel-2* platform and DEM with a spatial resolution of 30 m were used. The area of interest is covered with several satellite images. After that, *shape* data is inserted by dragging the *Vector layer* from *the Input* part, based on the fit limit of satellite images and 3D models is defined. The following tools were used to process 3D models and satellite images: *Clip raster with polygon, Slope, Aspect, Hillshade, R.reclass, Raster calculator.*

The Clip raster with polygon option is used to crop satellite imagery and DEM. The creation of an output raster containing terrain slope information in the algorithm is shown using the Slope option, using a pre-cut DEM resolution of 30 m to create (Figure 5).
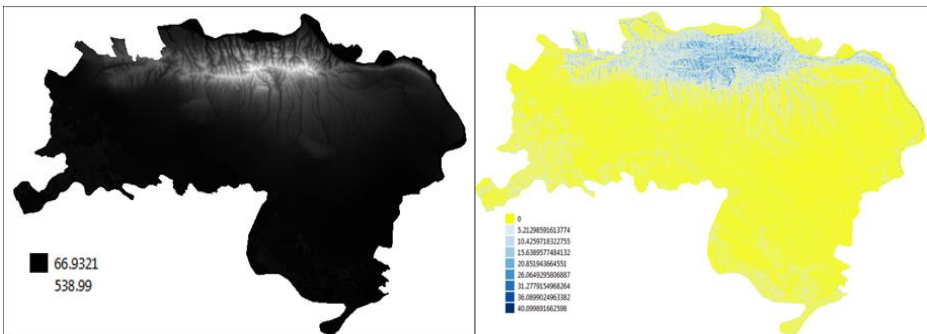

Figure 5. Polygon boundaries and global DEM and result of the Slope option

This is followed by the creation of a raster that contains information about the sunshine *(Aspect)* and brightness *(Hillshade)* of the terrain. The truncated 3D model represents the input parameter for both of these options, while the other settings for *the Aspect* option are the same as the previously explained option. The settings of the parameters *Z factor, azimuth and vertical angle* represent the values based on which the 3D model can be shaded and displayed for further analysis (Figure 6).
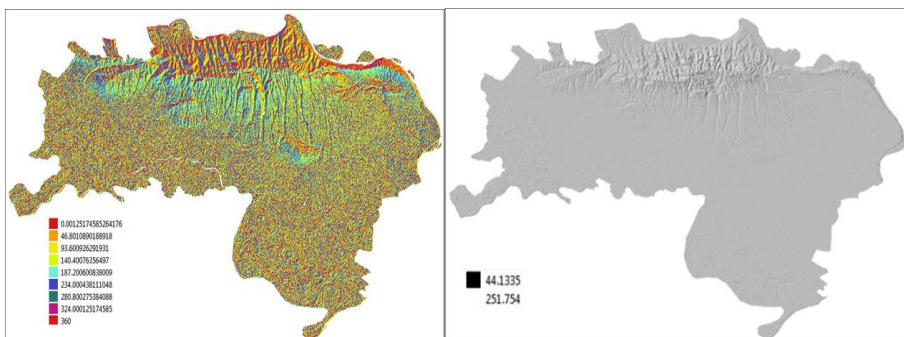

Figure 6. The result of the *Aspect* and *Hillshade* option

To obtain the vegetation index, two bands from satellite images *(NIR and RED)* were taken, so before inserting them into the algorithm, it is necessary to extract the necessary bands from satellite images, and merge them using the Merge option located in *the Processing Toolbox* tab. This step is followed by inserting satellite images using *the Raster layer* option from the *Input* tab. When all input parameters are set, further data processing is started. Vegetation index calculation is performed using the *Raster calculator* option (Figure 7).
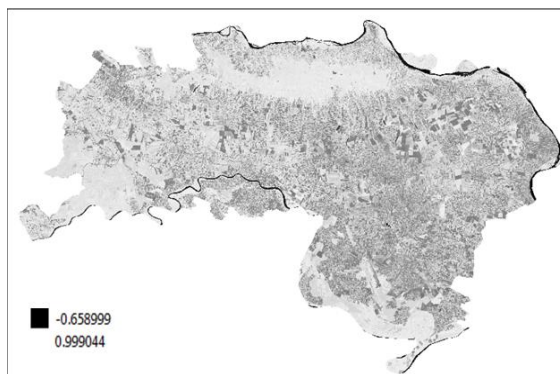

Figure 7. The result of vegetation index NDVI

In *the Layers* field, previously cut satellite images are selected, by double-clicking on the selected raster, after which the required operator is selected from *the Operators* field according to expression (2) for calculating the vegetation index. The selected rasters and the operations applied to them are displayed in the *Expression* field.

3.1.   RECLASSIFICATION OF SLOPE, ASPECT AND VEGETATION INDEX

Reclassification operations consist of a complete or partial modification of the raster value. This operation can be useful in the analysis of different types of satellite images. *The r.reclass* option was used to reclassify the terrain slope and exposure. The input raster layer loads a previously created raster that contains information from the slope. The raster is classified into 8 classes, where the first range is in class 10 and refers to the flat type of terrain, the second in class 20 which refers to the terrain with a slight slope, etc. The result of the reclassified terrain slope for the area of interest is shown in Figure 8.
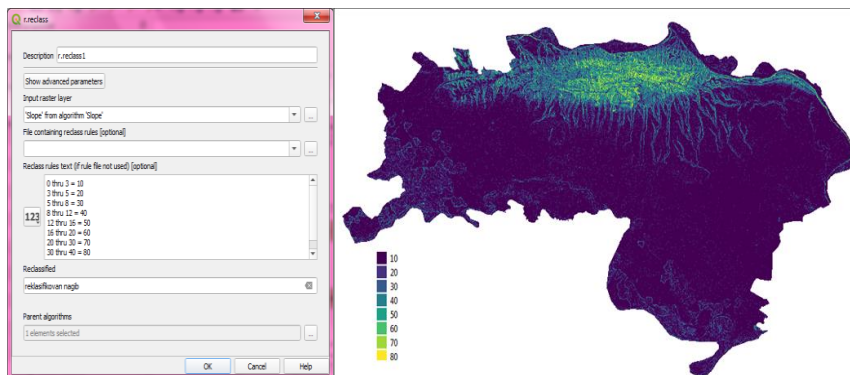

Figure 8. Reclassified terrain slope with classes shown

A similar procedure is applied in the reclassification of terrain exposure, where the reclassification of exposure is performed according to the appropriate division [12]. The results of the reclassified terrain exposure are shown in Figure 9.
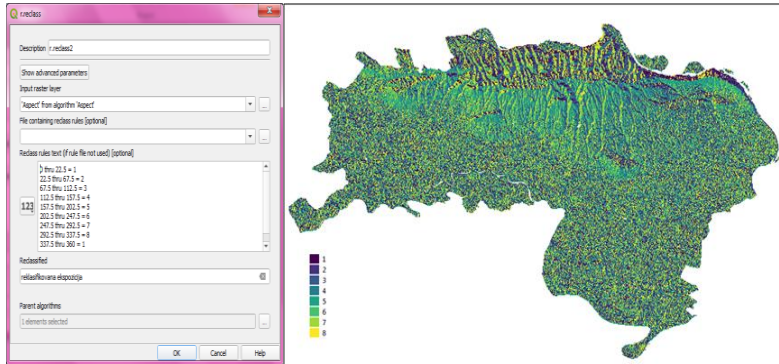

Figure 9. Reclassified terrain exposure with shown classes

The *NDVI* index was reclassified using the *raster calculator* option. The operations used for reclassification are listed in *the expression* section. Values less than 0 represent water, snow, desert and are located in class 1. Class 2 covers the range from 0 to 0.33 and it represents bare land, that is land without vegetation. Low vegetation is located in class 3 (range from 0.33 to 0.66). The healthy area of forest and high vegetation is located in class 4 and covers the range from 0.66 to 1. By defining the desired number of classes for the previously mentioned rasters, it enables more precise and easier setting of conditions that meet certain criteria. The result of the reclassification of the NDVI index is shown in Figure 10.
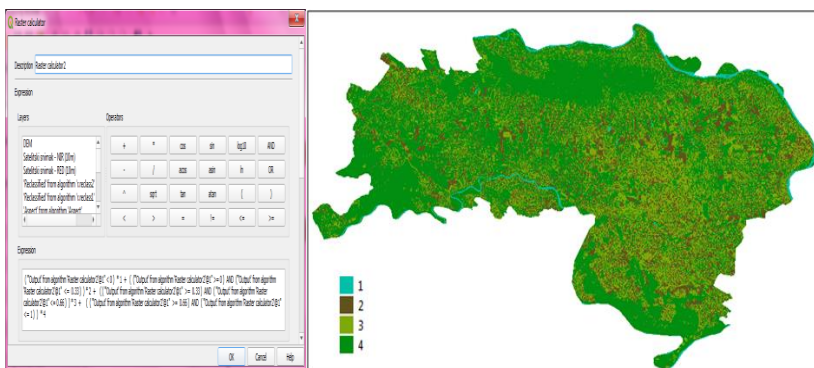

Figure 10. Reclassified *NDVI* index with shown classes

4. ANALYSIS AND DISCUSSION

After processing the data and reclassifying the raster, it is necessary to define the conditions for growing certain agricultural crops in the field of farming, fruit growing and viticulture. Namely, multivariate analysis methods were applied in order to obtain optimal results [19]. Conditions for obtaining suitable zones are created based on certain experiences of producers and defined criteria (slope of the terrain, exposure, *NDVI* index).

4.1   CONDITIONS FOR GROWING VINES

The first part of the conditions refers to the altitude of grapevine cultivation, where the range Z between 160 m and 300 m above sea level is considered. In the second part of the conditions, the slope of the terrain is defined, and for that, values greater than or equal to the value of 30 are considered, which refers to terrain with a slope greater than or equal to 8°. The last part of the conditions refers to an area that is not water and high vegetation. The results are shown in Figure 11, where the yellow pixels refer to *"false"* values that do not meet the condition, while the black pixels refer to *"true"* values that meet the specified condition.
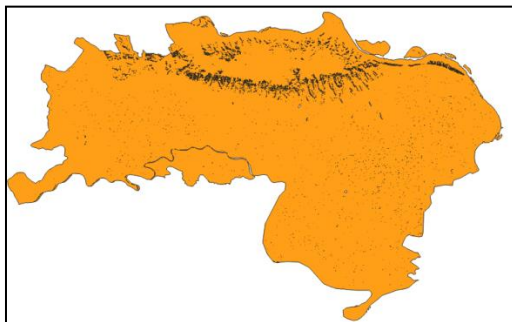

Figure 11. Result of the raster calculator option (viticulture)

4.2   CONDITIONS FOR GROWING APPLES, PEACHES AND PEARS

One of the results of the research is a thematic presentation of the terrain suitable for fruit growing. Namely, since all previously explained fruit species require approximately similar growing conditions, the raster calculator option defines the condition that unites them. To define the altitude Z, values between 120 - 160 m were considered. All these fruit species can thrive at higher altitudes, depending on the location where they are grown [20]. The next part of the condition is to define the slope of the terrain, and for that a value less than or equal to 20 is taken, which refers to a slightly sloping and flat type of terrain. As the southern and southwestern exposures are the least suitable for these fruit species, all other exposures, except the southern and southwestern ones, were considered to define this part of the conditions. The last part of the conditions is the same as in the previous case. The results are shown in Figure 12.
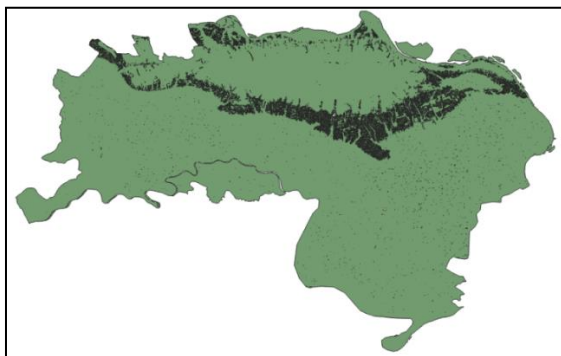

Figure 12. Result of the raster calculator option (fruit growing)

4.3 CONDITIONS FOR GROWING MAIZE, SOYBEANS, WHEAT AND SUGAR BEET

Corn, soybeans, wheat and sugar beet thrive on flat and slightly undulating terrain. For that reason, a value of up to 120 m was taken for the altitude, while a value less than or equal to 20 was taken for the slope of the terrain, and that refers to flat and slightly undulating terrain.

Figure 13. Result of the raster calculator option

As for the illumination of the terrain, all exposures come into consideration, which is confirmed by the condition. High vegetation and water were eliminated from the conditions, as in the previous cases. The results are shown in Figure 13.

5. CONCLUSIONS

For planning the development of agriculture in an area, it is necessary to have information related to both the assessment of land suitability and land valuation for certain agricultural species in order to be able to assign the optimal purpose. The paper analyses GIS / 3D solutions as opportunities for efficient and sustainable management in precision agriculture. Based on the given criteria (slope, exposure, altitude and NDVI index), suitable zones for growing crops in the field of arable farming, fruit growing and viticulture have been identified and calculated. For the input data, the global DEM, the boundary of the polygon representing the zone of interest and the satellite images with the necessary bands for creating the NDVI vegetation index were taken.

The application of GIS / 3D solutions contributes to a better view and use of land. The path to such information, without making a 3D model, would certainly be much more complex and time-consuming. Namely, the accuracy of the display of terrain altitude variability and analysis of geomorphological parameters significantly contributes to decision making in precision agriculture. Based on the analysed and presented results, it is concluded that the algorithm used, in combination with a certain filtering of the final results, can be applied to create a plan for growing crops depending on the geographical location.

LITERATURE

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