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Geospatial Analysis of Suitable Locations for Exploatation of Small Hydropower and Solar Energy Potentials: A Case Study of Prespa Lake Region in Macedonia

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Abstract
The renewable energy is very important segment of human life in modern world, which provides energy for electricity generation, that is collected from renewable resources which are naturally replenished on a human timescale such as sunlight, wind, rain and others. The renewable energy potentials, that are easily accessible in rural areas are mostly unused. Renewable energy has less negative impacts on environment than fossil fuels. Site selection is a crucially important step for utilizing large investments like small hydropower plants, solar farms and others. Multi-criteria evaluation methods are commonly used for site selection.
There is a huge water potentials of the small river watercourses in Macedoniaonia. The harnessing of the sun as an inexhaustible source of energy mostly depends of the duration of the intensity of the solar radiation, which in Republic of Macedonia is around 3,8 kWh/m^2 and it is about 30% greater than the average value in many European countries.
The goal of this paper is, to describe some GIS-based contemporary methodological approaches of geospatial analysis of some key topographic surface parameters for assessment and evaluation of optimal locations for construction of small hydro power plants and solar power plants. The focus of analysis is set to some of the most important topographic land surface parameters such as: slope (gradient of surface), aspect of slope, as well as the other land surface parameters that have impact and are most important for optimal decision making concerning the site suitability for renewable energy expoatation .
Main accent at the analysis is set at the rural areas. The methodology approach is developed on a few case study areas in the south-west part of Republic of Macedonia (in the north part of the Prespa like region). As input digital data have been used few digitized maps in scale 1:25000 with many vector data layers(grid pint map, map with contour lines and others).
The methodology and analysis is performed on a study area which encompasses a part of the Prespa lake region for small hydropower and solar farms. Throughout the researches it is showed, that the DEM (Digital Elevation Model) is one of primary driving force for analyzing of physical processes of surface resources. In the paper is proposed a methodology for assessment of hydropower potential of small streams as one of the oldest renewable energy resources as well as the energy potential of solar power plants.
The obtained results of performed analyses show, that the analyzed areas have considerable potential for use of renewable energy resources of small streams and solar potentials. The proposed GIS based spatial analysis of suitable sites can be modifyed and efficiently applied to any other spatial location.

Keywords: GIS spatial analyses, GeoProcessing , hydropower, solar power.

INTRODUCTION

Renewable Energy Systems use resources that are constantly replaced in nature and are usually less polluting. These resources can be divided into two categories as renewable and nonrenewable. It can be said, that the renewable energy sources have almost endless power and they don't pose any danger to the environment [1].

These renewable energy sources are: Solar, Wind, Geothermal, Biomass, Hydroelectric power, Wave and Hydrogen. The most popular of these resources are: hydropower of small streams, solar power and wind power. According to the report from Renewable Energy Policy Network for the 21st Century, 19 percent of global energy consumption and 22 percent of electricity generation are contributed from renewable sources in 2012 and 2013, respectively [2].

In order to tap the potential of Renewable Energy sources, there is a need to assess the availability of resources spatially. There are more technological approaches for exploatation of renewable energy resources. The analysis of topographical land surface parameters using conventional methods often is a very tedious work task and demands lot of time for performing of needed analyses. The researches in this paper mainly are focused on applying of some contemporary GIS tools for determination of some basic topographical parameters of land surface which are most importand for the possibility of exploatation of the renewable energy potentials. Main focus of researches is set on developing a GIS-based methodology approach for site selection of renewable energy resources of Small hydropower plants and solar farms.

The research in the paper focuses on the implementation of GIS-based methodology approach for above mentioned renewable resources. So, for determination of surface water potential and especially stream flow, the amount of achievable hydropower at any given site is a function of hydraulic head(elevation drop) and flow rate. The geospatial analysis of hydropower potential of small streams in GIS platform is an efficient way toward the preliminary screening of suitable sites for development of small hydropower project.

The solar energy potential at a given location in a large extent depends on values for altitude gradient on the land surfaces as well as on values for compas aspect direction of slopes. Having on disposal the necessary data about the quantity of the solar radiation at any given location wether at annual or daily level, the other factors that mostly have a great influence on the assessment of suitable locations for exploatation of the solar energy depend on some other topological parameters of land surface.

A GIS-based multi-criteria analysis involves two types of evaluation methods: Boolean overlay operations and WLC-Weighted linear combinations [3]. Solving the complex phenomena in GIS environment with use of s.c. Multicriteria analysis of problems can be a very useful tool [4]. After all the proposed geospatial analysis of renewable energy potentials in general is an efficient tool for preliminary screening of suitable locations for constructing of SHP-Small hydropower plants and solar photovoltaic farms. After all, the GIS-based multicriteria analysis of site suitability for exploatation of renewable energy resources together with an economic and eco-environmental analysis, certainly will also enhance the feasibility&reliability of the decision making process for the site-analysis for renewable energy resources.

For assessment of the small hydropower potentials of the small river streams during the analysis has been taken the Brajcinska river in the east part of the Prespa lake watershed Fig.1. The watershed area is mainly covered with miscelaneous forest, pastures, agricultural land, rocky surfaces and rural built up areas. The total watershed area of the Brajchinska river is about 64,5 km^2. The Brajchinska river rises under the mountain Baba and discharges into the Prespa lake with total length of 14.720 m. The river has many tributaries that flow into it from left and right side of its downflow direction. The elevation differences in the study area varies from 850 to 2560 m.a.s.l. The river is perennial with quite stabil flow without abnormal variations during the year seasons. The extent of the area is 21^0- 21^0 15'(west-east) and 40^0 52' 30" – 41^0 (south-north). The river has many tributaries that flow into it from left and right side of its downflow direction.

Concerning the analysis of the solar power potentials , the study area encompases the north part of the Prespa lake (Fig.1). More exactly the area comprise of the town of Resen, Resen field area and some villages located in the south and south-west part of the town as well as part of the massif of the mountain Baba. In the lower flat area the surfaces are planted with apple orchards , there are also meadow areas and some smaller low shrubby areas .

The mountain part of the study area is mostly covered with deciduous forests and some parts are covered with conifer forests. The geographic extent of the study area encompasses the area between 20^0 45'- 21^0 in east-west direction and 41^0 - 41^0 07' 30" in south-nord direction. The elevation differences in this study area are in interval from 851 m.a.s.l. to 1776 m.a.s.l.

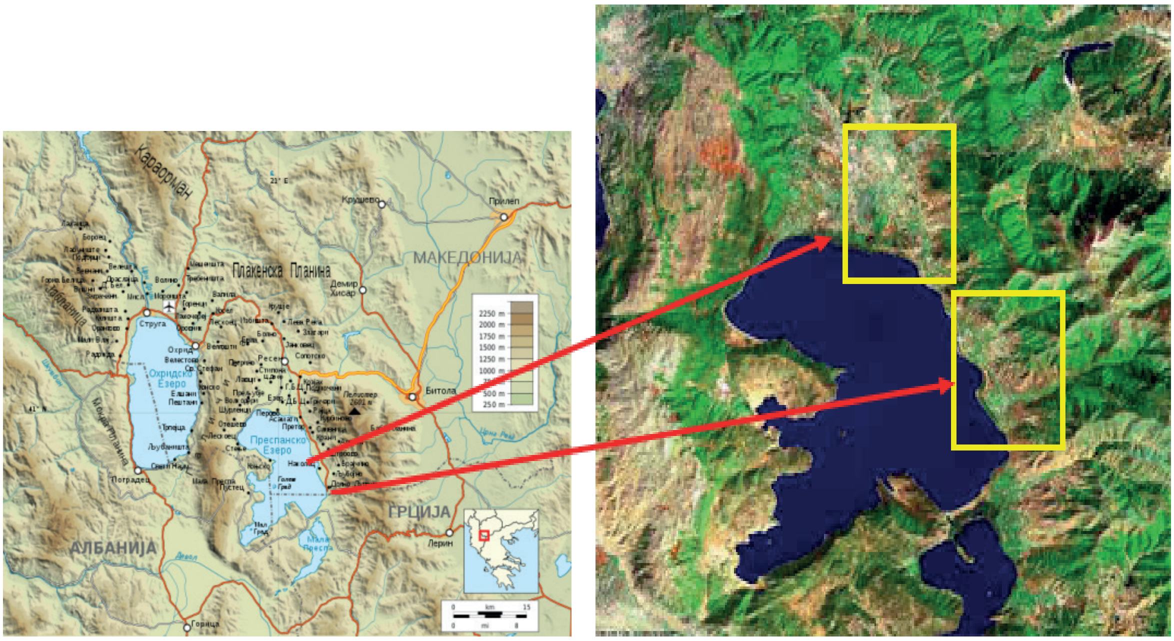


Fig.1. Cartographic and satelite display of the location of study area for SHP and Solar power plants (Wikipedia)

The developed data structure of Macedonian 25000SDI comprises the fundamentals of information infrastructure in Macedonia [5]. Therefore , as initial input spatial dataset for analysis of SHP potentials is used a topographic map as single dataset with different layers of data in vector format in scale 1:25000. Each map covers an area of about 140 km^2. For the purpose of study were used the data layers of point grid, contours and digitized stream network. Beside the mentioned spatial dataset , have been also used numerical data in Excell tabular format of historic hydrologic measurements at one gauging station for precipitation and runoff for the period 1961-2000.

Concerning the solar power potential analysis , as initial input data are used same topographic maps as describer above with different layers of data in vector format . In accordance with the purpose of this study were used the data layers of point grid, contours, digitized road network , digitized stream network map, digitized map with polygons of all populated places(villages and towns) land cover and land use vector dataset. Beside the maps with spatial data are also used some numerical data which are related to the solar irradiation in the study area at annual, monthly and dayly level.

During the research study was used a GIS software QGIS. All data processing and modeling have been performed with this software package which is used for geospatial and data management as well as for combined and complex spatial analyses.

MATERIALS AND METHODS

Methodology approach for selection of suitable locations for Small hydropower plants

The general methodology for GIS-based analysis of small hydropower energy resources is sumarized in Fig.2.

As can be seen from the Fig.2., the availability of digital elevation models (DEMs) is essential for creating of a hydrological model . DEM models are generally produced by photogrametric techniques from stereo photo pairs, stereo satellite images or with interpolation of digitized data. In this way, from the input graphical and numerical data of the digitized map has been developped a GIS topography dataset (DEM, slope, hilshade map). Employing the interpolation tool, and using the grid points and contours as input layers firstly has been created a DEM with cell resolution of 20m. The DEM was hydrologically corrected with filling sinks and correcting s.c. padding terraces in order to be suitable for further hydrology analysis.

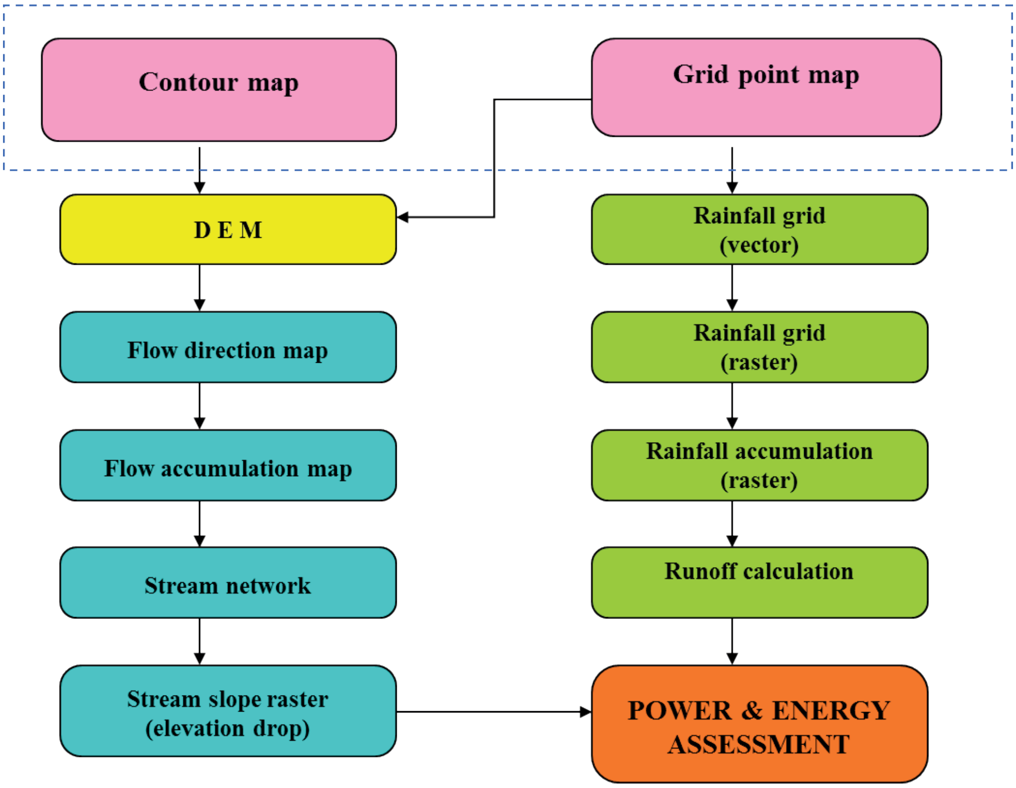


Fig.2. Flowchart diagram for determining of hydropower potentials in GIS

A hidrologically corrected DEM was used as a main spatial input dataset to determine the needed hydrologic parameters such as: slope, flow direction, flow accumulation, stream network delineation, watershed delineation, pour points and others. The flow direction raster map was obtained from the hydrologicaly corrected DEM as input raster.

Water in a given cell can flow to one or more of its neighbouring cells according to to the slopes of drainage paths [6]. This concept is based on the 8-direction pour point model.

The resulting flow direction grid is encoded with numbers 1,2,4,8,16,32,64 and 128 for each direction of flow at a given cell. The Flow accumulation grid was determined using the flow direction grid as input raster dataset. The flow accumulation grid from the physical point of view is the drainage area at each cell in unit of cells and means, how many upstream cells contribute with flow to a given cell in the raster map [7]. With the product of the number of upstream cells and area of a single cell was determined the flow accumulation or watershed area of each cell in the map. Here, the area of one cell is 20x20 = 400 m^2. The cell with highest flow accumulation determines the outlet point of the watershed. Using flow accumulation raster as input data and seting of a certain treshold value for cells in the raster is automatically made stream network delineation. In the similar way, the cell at a given stream with the highest value of accumulation defines the catchment area of the stream. The outled point of the Brajchinska river has value of 161.351 cells, so the product of the number of these cells with the area of the single cell gives the total area of watershed of 64,54 km^2 (Fig.3).

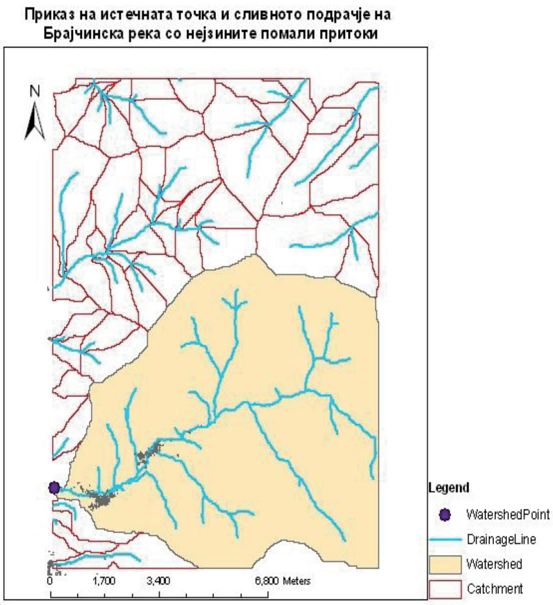


Fig.3. *Catchment area of Brajcinska river with its outlet point.*

The cell with highest value is outlet point at which water flows out of the catchment area. It can be also manually created a pour point shapefile with location of many outlet points along a given stream. Each outlet point then represent a subwatershed for each stream segment or tributary of the main river. In the same way as described above it can be calculated the watershed area for each manually determined outlet point along the Brajchinska river and its left and right tributaries. Using variety of tools for spatial analyses in GIS can be also determined some other useful hydrological parameters.

From the engineering point of view, two main criteria are crucial for good evaluation of the hydropower potential of streams. First criteria is elevation drop along a given stream segment or along the total length of the stream , and the second one is amount of stream flow or discharge. This arises directly from the equation 1.

$$P = \rho g \eta_t Q_i H_n (kW) \qquad (1)$$

where P is the power in kW, η_t is the efficiency coefficient , g is the gravity acceleration, H_n is the net elevation drop and Q_i the installed discharge at the certain location.

Considering the hydrology analysis, the initial step is the determination of rainfall values at each raster cell. Here an empirical quadratic equation (Eq.2) for relationship between the annual rainfall values and elevations was employed, where: R is annual rainfall and H is the elevation in hecto meters. This equation is valid for the south-west part of the country and hence also for the study area [8]. Using the equation 2 with the *raster calculator* tool are calculated annual rainfall values for each grid point.

$$R = 166{,}93 + 100{,}42H - 2{,}80H^2 \qquad (2)$$

Regarding the elevation drop , there are a few approaches for its determination along a stream. The stream network in the study area is already digitized in vector format and with different lengths of stream segments.

With overlaying procedure of the DEM and the stream network map in vector format can be determined the elevation drop between the starting and ending point of each stream segment.

Using the output results of analyzed elevation drops and hydrologic data, is made a final evaluation and estimation of hydropower potentials along the main river stream as well as its tributaries, and it is also calculated the power and energy output at different potential point locations along the river streams.

Methodology approach for suitable locations of Solar farms

For analyzing of solar power potential location the availability of DEM is also essential. Using DEM raster map, with further geospatial analyses in GIS platform are determined additional land surface parameters which are important for site suitability analysis such as: Slope map, Aspect map, Hillshade map and others.

The general methodology for GIS-based analysis of small hydropower energy resources is sumarized in Fig.4.

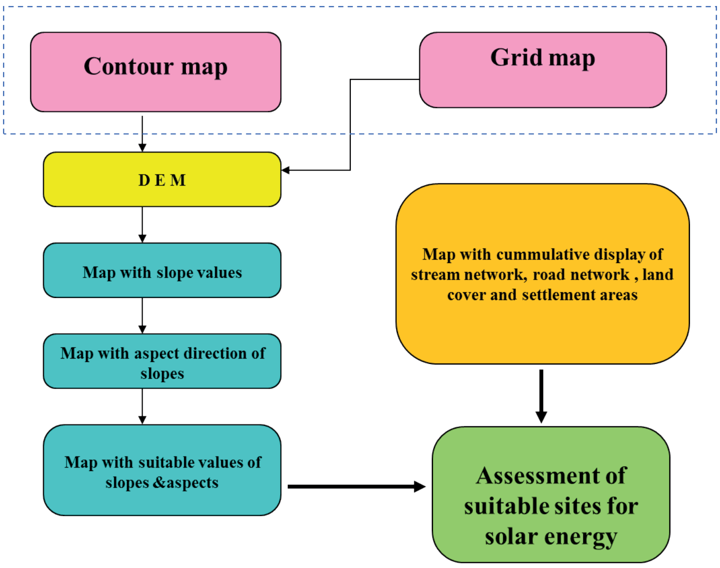


Fig.4. *Flowchart diagram for determining ofsolar power potentials in GIS*

In raster analyses in GIS platform very often is used so called Multictriteria analysis-MCA. The main goal of this type of analysis is to simplify the more complex issues using multiplicatice criteria in order to be found some optimal solutions concerning the screening of suitable locations at some part of the surface area which is of our interess.

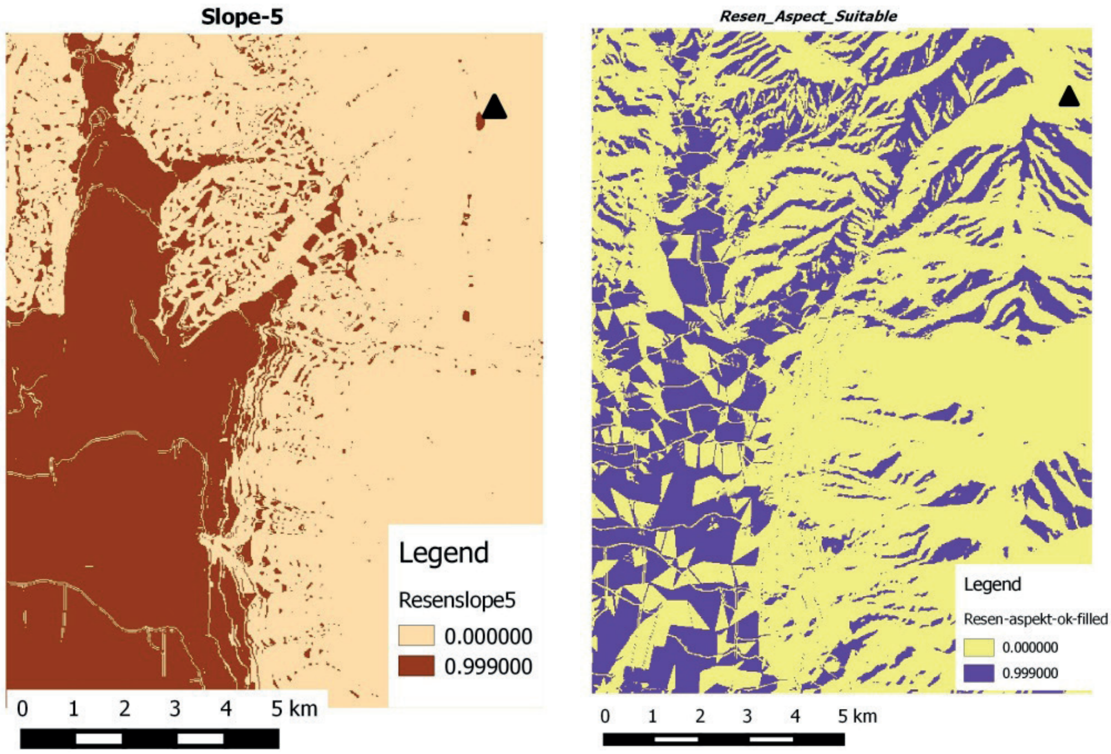
Principally GIS based multicriteria analysis involves two types of evaluation methods: 1. Method with boulean operators of overlaping and 2. Linear combinations with use of factors of influence for particular datasets.

Two criteria concerning the topological parameters of land surface are of main influence in the preliminary screening of suitable locations for solar power exploatation:

1. Locations with small slope values
2. Locations whose aspect direction of the slope is in interval from south-east to south-west

In this context, as appropriate locations regarding the slope values are taken these parts of the surface which have small slope values (mainly flat surfaces). Using as input dataset the slope raster map it is set a treshold value of slope of 5%. In this way is obtained a boulean raster map with filtered slope values at pixel level with resolution of 20m shown in Fig 5 - left.

In similar way, using the input raster map with values of aspect compas directions of slopes can be derived and filtered the values of aspect directions which are most appropriate for exploatation of solar energy. Because the study area is located in the north hemisphere, as appropriate aspect directions of slope are taken into consideration the directions: south-east, south and south-west. The coded values for these directions are in range from 135(south-east) 180(south direction) to 225 (south-west) direction, shown in Fig 5 – right.



a.) b)

b.)

Fig.5. *Raster map with slope values smaller than* 5 % a) *and raster map with aspect values in the interval between 135 and 225(south-east and south-west) b.)*

Now with combination of both raster maps with filtered suitable values of slope and aspect direction, using the Raster calculator tool in QGIS in an efficient way ccan be determined a digital raster map with appropriate values for both, the slope and aspect directions.

Regarding the other factors of ecological nature which have highest influence at the choice of suitable locations, in this paper were made analysis of several factors with greater influence, such as: road network infrastructure, stream network, watershed surface areas, land cover, land use as well as locations of settlement areas (towns, vilages etc) in the study area. For this purpose were used several already prepared digital maps in vector format.

RESULTS AND DISCUSSION

On the basis of the available elevation drops, mean annual and monthly discharges and flow duration curvec(F-DCs), the power and energy outputs were calculated either at annual as well at monthly level. In the calculation of the power at each particular site, always is taken the discharge value at the intake location or upper vertice of a stream segment. As elevation drop or hydraulic head is taken the total elevation difference between the intake and SHP location.

From the results of the GIS analysis as explained in the section 3 the potential sites for SHP development are located. In the stydy area have been found more than 10 suitable sites for SHP exploatation, and 2 to 3 of them seems to be most appropriate regarding the power output values. The graphical layout of suitable sites for SHP construction is shown in Fig.6.

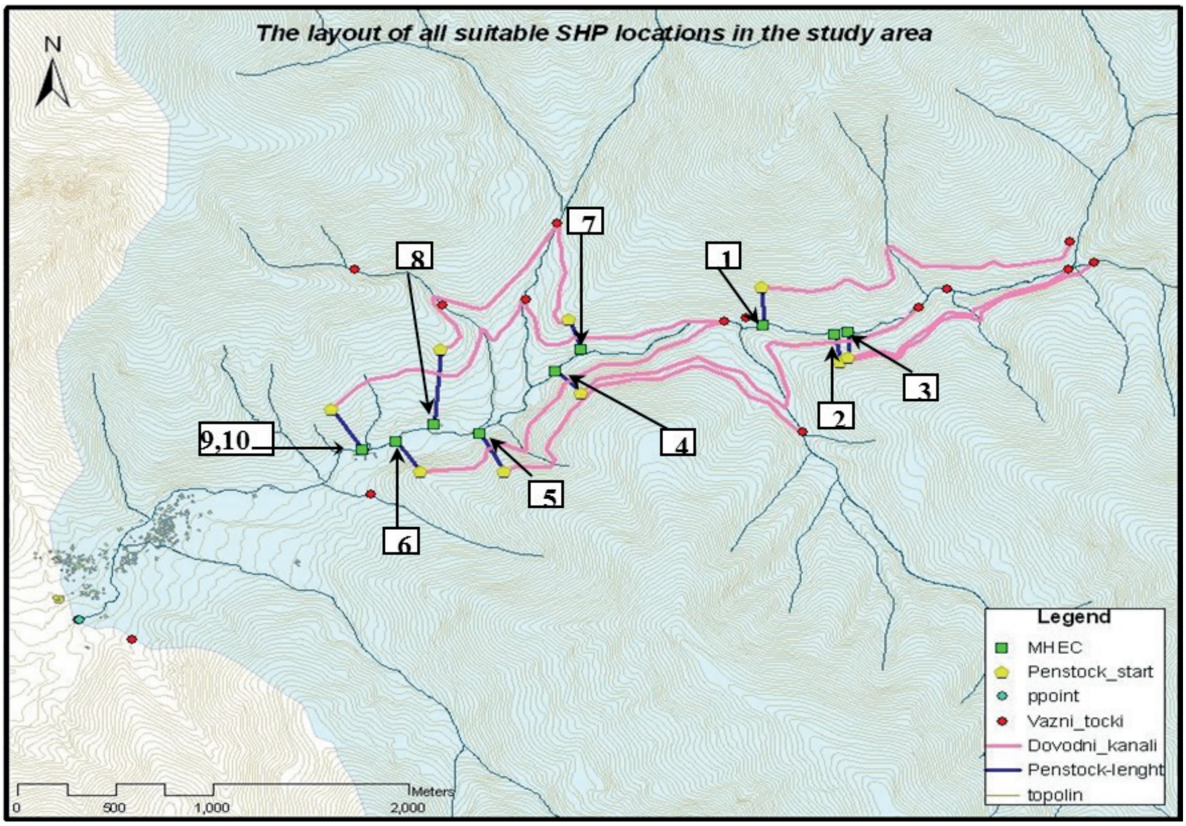


Figure 6. *Graphical layout of sutable sites for SHP construction.*

On the basis of the calculations of monthly rainfall and discharges of the Brajcinska river and its main tributaries we can realize, that the river with its main tributaries is reach with water resources during the all year and can provide uninteruptedly operating of small hydro power facilities all year round.

Concerning the disposable numerical data, in the study area we have only one gauging station for measuring of flow rates and one gauging station for precipitation, so the interpolation methods for determining of precipitation and discharges were excluded, and hence for the final decision making should be made also some classical hydrology measurements and analyses at a particular site, in order to be calibrated with the results of discharges with the geospatial analysis in GIS.

In the final digital map, the optimal locations for construction of solar photovoltaic farms are shown with green colour . The final map with suitable areas is in vector format and is overlaed on the raster hillshade map , with wich is ensured a bether visualisation of the land surface area.

The small suitable polygons(in green) are excluded from selection due to their very small area for construction of farm for exploatation of solar power. This is done with settin of an empirical treshold values for the area of suitable polygons.

As a final result of the performed research and analysis on Fig. 7 can be seen , that almost all suitable location surfaces are located in the flat area in the south-west part of the study area arround 10 km in the south direction of the town of Resen and several kilometers in the south direction of the village Carev Dvor.

As was mentioned above, it should be emhasized that only these surface area should be taken into consideration wich are sufficiently large , where it can be foreseen a construction of farm for exploatation of solar power potentials with sufficient solar power capacity.

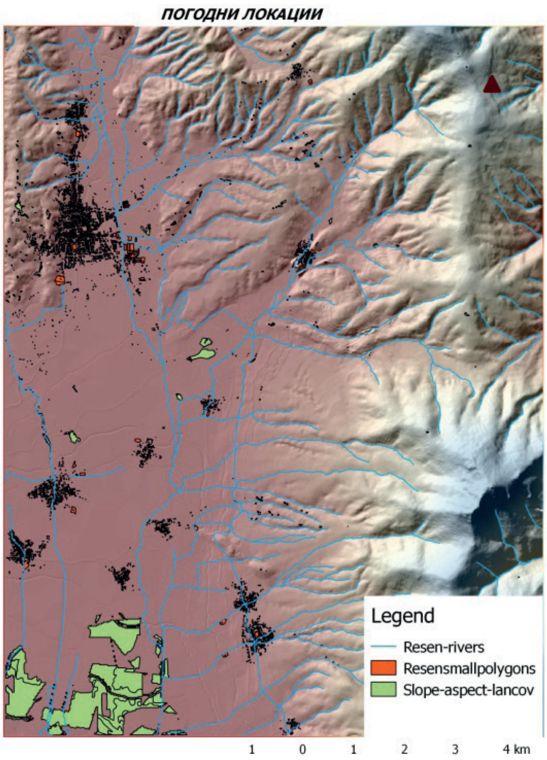


***Fig.7**. Map with final display of the optimal locations for exploatation of solar power potentials*

It should be also pointed out, that the exploatation of the solar energy potentials at the selected optimal surfaces in a great extent can also depends on the season of the year. For example, the setting of solar pannels during the summer season at lower slope values in degrees allows greater exploatation of solar radiation. On the other side, during the winter season the pathway of movement of the sun from east side toward the west side is much lower toward the south horizont. In this case greater values of the slopes of panels allow greater exploatation capacity of the solar radiation.

In the process of making final decisions for construction of solar photovoltaic farms certainly should be performed also some additional analyses for every potential location separatelly, in order the obtained results to be compared to those which were obtained with geospatial analysis in GIS platform.

It must be pointed out that the identified locations are provisional and require further and more detailed investigations before the final decision can be brought!

The GIS based method in this paper provided a quantitative evaluation and assessment of factors and constraints that should be taken into consideration at determining of the land suitability for locations of wind farm. The final suitability map can be used as guidance toward to narrow search of new wind farm locations. Of course, additionally field visits and measurements should be done before making of the final decision for wind power farm development. Besides that, the final results of the final map should be additionally validated with measurements of wind speeds as well as with observation of other important ecological variables in each particular area for potential placement of wind farms.

CONCLUSIONS

Concerning the small hydropower potentials, in the paper was presented a contemporary methodological approach for application of SDI in hydrology modeling of surface water resources and particularly in assessment of hydropower potentials and identifying of suitable sites for SHP projects developing. The analysis is mainly based on engineering criteria using geospatial analysis in GIS. The proposed methodology offers an efficient way to examine also any other similar or larger watershed mountainous areas rich with water resources.

The analysis of solar power potentials showed, that the combination of GIS with the MCA(multi criteria analysis) evaluation is very useful software tool for right decision making concerning the location and modeling of potential locations for building of photovoltaic solar power plants.

It should be pointed out that the proposed methodology for preliminary screening of suitable locations can be easilly applied at any other geographical area. In this paper has been done analysis of the suitability of locations taking into consideration the most important technological, engineering and environmental criteria of impact factors.

Certainly, the proposed methodology is very useful tool for preliminary screening of optimal locations for wind farms development, although the further analysis and measurements on situ is obligatory before the final decision can be brought. Also the methodology illustrated in this study can be used to other regions in the world using the similar digital input data.

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