CONTEMPORARY GIS-BASED METHODOLOGICAL APPROACH FOR ASSESSMENT OF OPTIMAL LOCATIONS FOR EXPLOATATION OF SOLAR-ENERGY POTENTIALS

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SUMMARY

Generally the country has huge solar potential as a renewable energy source, but they are still exploited in a very small extent. The renewable energy resources, that are easily accessible in rural areas are mostly unused. 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 solar power plants. Main focus of interest in the analyses is set to some most important topographic land surface parameters such as: slope (gradient of the surface), aspect direction of slope, as well as the shading analysys of the land surface. 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). Using various interpolation methods , taking as input data the grid point map and contour map in vector format it is obtained a digital elevation model- DEM od the land surface in raster format with spatial resolution 20x20m. Using different spatial analyses with a set of GIS tools in an efficient way are obtained several raster maps with values of slopes(gradients, inclinations) of the land surfaces , raster maps with aspect-direction values as well as raster maps with shadow analysis of

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the surface and others. Using values of slopes and aspects directions are preliminary determined suitable locations at the surface for exploatation of solar potentials. Results of performed analysis show, that the analyzed areas have considerable potential for use of solar energy. With proper placement and construction of solar photovoltaic power plants can be significantly improved the energy efficiency and supplying of electricity of nearby villages. Beside that, the proposed methodological approach for analysis of suitable locations can be applied to any other spatial location. The proposed GIS-based analysis serves as an efficient tool for identification and quantification of land surface parameters that have a key impact in decision making regarding exploatation of the solar energy potentials. With similar methodological GIS-based approach also can be determined some other land surface parameters necessary for analyzing of suitable locations for other renewable energy sources such as: wind-power potentials, small hydropower potentials and others.

Key words: Geospatial analysis, solar power, GIS , Multicriteria decision making, photovoltaics.

I. INTRODUCTION

Renewable Energy Systems use resources that are constantly replaced in nature and are usually less polluting. The all-time needed energy in our lives has been provided by energy resources. These resources can be divided into two categories as renewable and nonrenewable. It can be said the renewable energy sources have almost endless power and they don't pose any danger to the environment (*Mutlu S., Çabuk A.,Güney Y, 2011)*. These renewable energy sources are: Solar, Wind, Geothermal, Biomass, Hydroelectric, Wave and Hydrogen. The most popular of these resources is solar power, the basis of life. Solar energy is a renewable energy source nearly inexhaustible and pollution free.

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 the solar radiation. At some of them, the solar energy mainly is used for heating and direct illumination, but on the other side some technologies use the solar energy for direct geneating of electricity(Zakšek K., Marsetič A., Kokalj Z., 2007).

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.

Solar Parks would include all required facilities for generation of solar power, which may include evacuation and transmission infrastructure, solar radiation monitoring station, water availability, access roads to the park, interior roads in the park, telecommunication facility, fire station, green belt and security (Sanjeevi Prasad.S, Dineshkumar.K, and Madha Suresh.V,2014)

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 solar energy potentials. The solar energy potential at a given location in a large extent depends on values for altitudinal 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 (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php), 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.

Employing GIS-based methodological approaches, on the basis of digital maps in vector format with grid points and contour lines , it can be easily obtain a Digital Elevation Model-DEM of the land surface which is analysed.

Applying the geospatial analyses and techniques for modeling with GIS tools, now it is possible efficient displaying of land surface with Digital Elevation Models, TIN models , and shading relief models . GIS-based multi-criteria analysis involves two types of evaluation methods: Boolean overlay operations and WLC-Weighted linear combinations (Hott R., Santini R., and Brownson J., 2011). Solving the complex phenomena in GIS environment with use of s.c. Multicriteria analysis of problems can be a very useful tool (Alekhya D. and Karakoti I., 2010). After all the proposed geospatial analysis of the solar energy potentials is an efficient tool for preliminary screening of suitable locations also for constructing of PV-Photovoltaic solar plants.

Innovations in solar radiation mapping are now contributing to the rapid growth of solar energy market in many countries. The developed solar radiation maps benefit everyone from homeowners and solarpanel installers to the developers and financiers of large-scale power projects, industry experts, and governments (Gastli and Charabi,2009).

II. METHODOLOGY APPROACH

II.1. Study area and its properties

The study area encompases the north part of the Prespa lake(fig.1). More exactly the area comrised 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 part is 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 the study area are in interval from 851 m.a.s.l. to 1776 m.a.s.l.

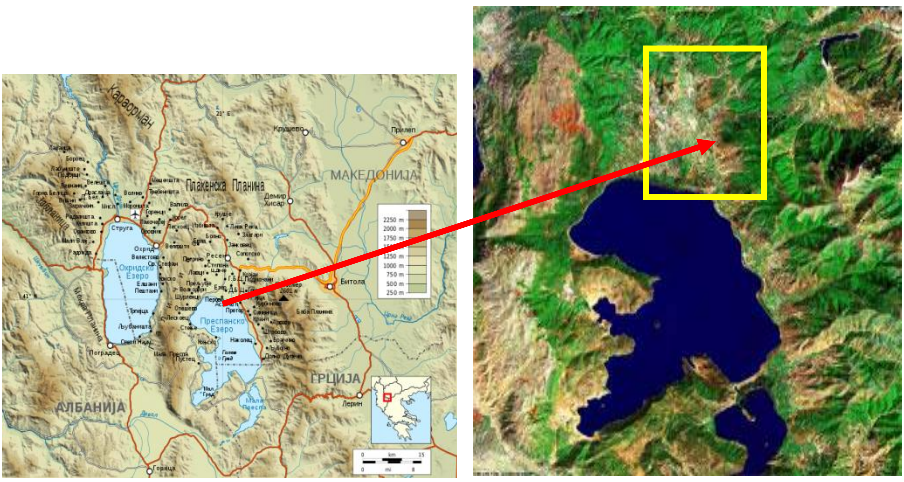


Fig.1. Cartographic and satelite display of the location of study area (Wikipedia)

II.2. Source data

As initial input data are used topographic maps 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, 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 as well as some other layers. All of the data in these maps are projected using the state coordinate system (Bessel) based on the Gauss-Krueger projection.
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 daily level.

II.3. Solar energy and its potentials

Republic of Macedonia extends largely in the solar belt between 40 and 42 degrees north latitude. The annual average solar radiation at optimal slope parameters of the land surface is around 1699 kWh/m2 (Table 1) with a daily solar radiation of 4,6 kWh/m2 .

TABLE 1 Values of global solar radiation for the study area

Annual global solar radiation (kWh/m2)			
	Horizontal surface	Vertical surface	Land surface at the optimal slopes
Minimum	1495	1086	1695
Average value	1500	1089	1699
Maximum	1509	1093	1708

Beside that , the Prespa valley is characterized by prolonged solar radiation, which during the year may be variable from 1400 to a maximum of 2600 hours per year. This amount of solar radiation offers excellent opportunities for the exploitation of solar energy potentials.

II.3. Principle of operation of photovoltaic cells and panels, solar farms

Today more commonly the modern manufactured solar cells are called photovoltaics. They are made of semiconductor material (typically silicon and germanium). When sunlight falls on the surface of these photo-voltaic panels they absorb it through the photons . The absorbed energy from the photons hits the electrons in the silicon allowing them to move. By adding other impurities into silicon (boron, phosphorus, etc.) can be established an electric field (Fig. 2).

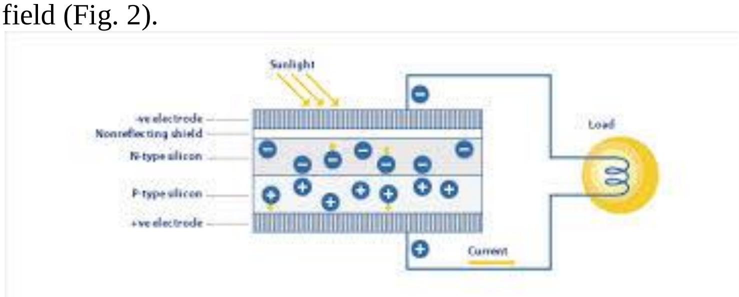


Fig.2. Principle of operation of photovoltaic cells

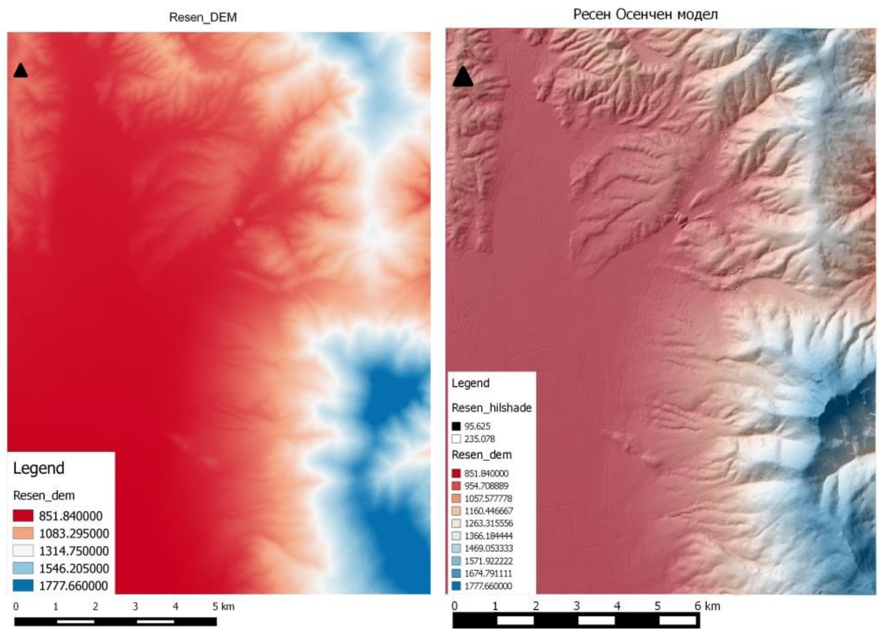
The established electric field acts as a diode because it allows flowing of the electrons only in one direction. As a consequence of that it appears an electric current of electrons or current. In fact the photovoltaic conversion is an direct conversion of the sunlight into electric current or electricity.
In practical meaning the photovoltaic pannels as relativelly simple for design and performance, and beside that they can be maintained with minimal efforts.
Today more and more in the focus of interest are so called photo-voltaic solar farms , whre the solar light is directly converted into electrical energy which is accumulated and used according to the needs (Fig.3).

Fig.3. Display of a photovoltaic solar farm

II.4. Digital Elevation Model-DEM of the lnd surface and analysis of main land surface parameters in GIS platform

For analysis of main topological parameters of land surface the creation of DEM- Digital elevation model is essentialy important and is main input dataset for further analyses of the land surface. In this case study, the DEM for the study area can be obtained with different interpolation methods. Spatial interpolation is the process of using points or contours with known values to estimate values at other points **(Chang K.T. (2012).** In such way can be estimated elevation value at an unknown elevation points using known elevation readings at nearby points or cuntours. Usually in GIS applications spatial interpolation is applied to estimate values for all cells in a raster map. In this way using the interpolation tool Topo-to-raster in ArcgIS is used a combination of two input data in vector format: One is the point grid file and the other is the shape file with contours (Fig.4).

The obtained DEM raster map is with resolution of 20m. Using the obtained 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.



a) b)

Fig.4. DEM model of the study area a.) and Hillshade relief model b.)

For furter analyses is used the DEM raster map of the land surface. Employing different tools for raster and vector analysis of the GIS open source software package QGIS in an efficient way can be obtained also different kinds of vector and raster maps. using these maps can be determined the most important land surface parameters.

With this approach, using the DEM raster map of land surface is determined a raster map with slope values of the surface. The slope tool in QGIS calculates the maximum rate of change from a cell to its eight neighbouring cells, which is typically used for representing of the stepness of the terrain surface. For each cell,Slope tool calculates the maximum rate of change in value from that cell to its neighbors. The maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell. The obtained map is in raster format with pixel resolution od 20m, whrereas in each pixel of the map is stored the slope value which is expressed in percents(%) (Fig.6.).

Again, using as input data the DEM raster map it is determined also the aspect raster map in same pixel resolution with values of the compas directions of the slopes. In fact the Aspect tool in QGIS calculates the direction in which the plane fitted to the slope faces for each raster cell. Aspect tool identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0(north) 90(east) 180(south) 270(west) to 360(north). Each compas side is coded with code number (Fig. 5).

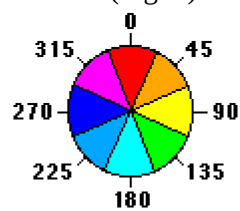
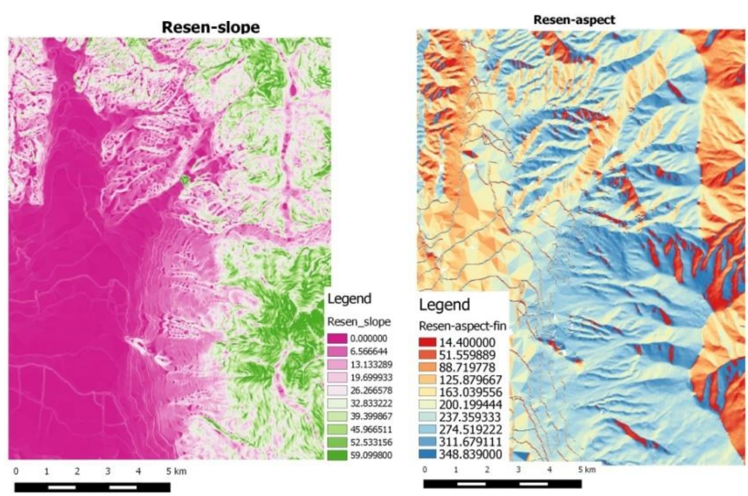


Fig.5. Aspect directions with coded numbers

In this case the north side is marked with 0 or 360^0 (whole circle), the east side has value of 90^0, the south side has value of 180^0 and the west side 270^0 (Fig. 5).The obtained map is in raster format with pixel resolution od 20m, whrereas in each pixel of the map is stored value of the aspect direction of the slope which is expressed in degrees (^{0}) (Fig.6.).



a.) b)

Fig.6. Raster map with slope values in % a) and raster map with values of compas direction of the slopes b.)

III. KEY LAND SURFACE PARAMETERS FOR OPTIMAL EXPLOATATION OF THE SOLAR ENERGY POTENTIALS

III.1. Determining of the suitable slopes and compas directions of the slopes at the land surface

As it was mentioned above, as a basis for determination of suitable locations for exploatation of solar energy potential using GIS tools was used the DEM model of the land surface in study area. Employing the raster DEM map they were obtained raster maps with values of slopes and aspect direction of slopes at pixel level (Fig.6).

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 bi found some optimal alternative solutions concerning the finding and screening of appropriate locations at some part of the land surface area which is of our interest.

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 s.c. factors of influence and importance for particular datasets.

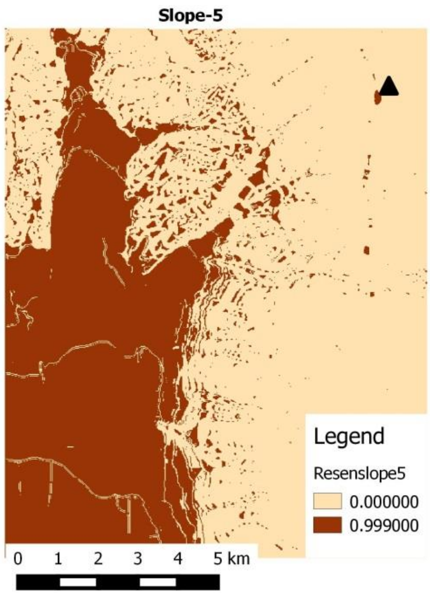
In this research is applied the first method with boulean operators. At the first stage the main criteria for assessment of optimal locations should be determined. It is done with setting of a treshold value of raster cells in a given raster map. Setting the treshold value allows to be obtained different raster maps or so called Boulean digital maps. In boulean maps all raster cells are coloured with two colors. One color represents the suitable raster cells in the map whereas the other colour represents the unsuitable raster cells. All siitable cells in the map have value of 1 and the others have valie of 0.

Such determined boulean raster maps in the further analysis can be easily combined with the well known Boulean operators such AND , OR , NOR, XOR and others.

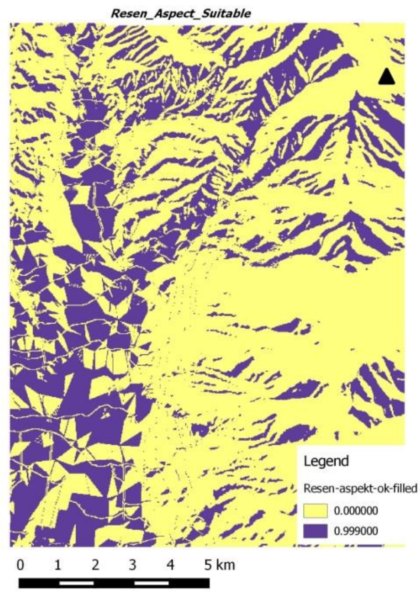
Two criteria concerning the topological parameters of land surface are of main influence in the preliminary screening of suitable locations for solar power exploatation:

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

In context of the above mentioned, as appropriate locations regarding the slope values are taken only these parts of the land surface which have small slope values (mainly flat surfaces). For this purpose, using as input dataset the slope raster map it is set a treshold value of slope of 5% . In such a way is obtained a boulean raster map with filtered values of slopes at pixel level with resolution of 20m (Fig.7). In the figure 7.a. below the suitable raster cells in the map are shown in brown colour, whereas the unsuitable raster cells are shown with light cream colour.



a.)



b)

Fig.7. 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.)

The appropriate values in the raster map of slopes (Fig. 7.a.) have value of 1 whereas the unappropriate values have value of 0.
In similar way, using the input raster map with values of aspect compas directions of slopes (Fig.6.b) can be efficiently derived and filtered the values of aspect directions which are most appropriate for exploatation of solar energy potentials. Because the study area is located in the north hemisphere of the earth, 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.
Following this approach, the most suitable direction of slopes in the study area should be in the interval from 135^0 to 225^0 that is to say along the line which is in direction toward the south-east until the line which is directed toward the south-west direction.

Using the raster map with aspect direction values (Fig.6.b.) with setting of treshold values in the interval from 135^0 to 225^0 can be easily obtained a new raster boulean map with filtered values of optimal compas directions at pixel level. In the figure 7.b. below the suitable raster cells for aspect values in the map are shown in dark blue colour, whereas the unsuitable raster cells of aspect values are shown with yellow colour. Again here, the appropriate values in the raster map of aspect direction of slopes (Fig. 7.b.) have value of 1 whereas the unappropriate values have value of 0.

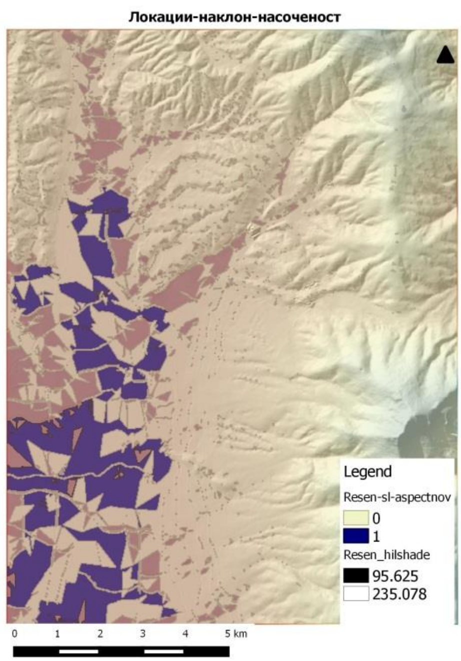


Fig.8. Raster map with suitable values of slopes and direction of slopes

Now with combination of both raster maps(Fig.7. a &b.) 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 (fig.8). As cabn be seen in the above raster map , the suitable location are with blue colour whereas unsuitable locations are with light cream colour. This map satisfyes both mentioned topographic criteria concerning the suitable locations for exploatation of solar power potentials.
The final obtained raster map with filtered cells can be furtermore easyly converted to a digital map in vector format. The overlaying of the final vector map above the hillsahade map gives much bether visualisation of the terrain surface.

IV. EVALUATION OF SUITABLE LOCATIONS FOR EXPLOATATION OF THE SOLAR POTENTIALS. РЕЗУЛТАТИ И ДИСКУСИЈА

In the process of making a quality geospatial analysis of suitable location for construction of solar energy farms should be taken into consideration more factors which have influence at the choice of location. These factors can be divided into several groups: Techno engineering, ecological , economic factors and others. Of course here one of the most important group of impact factors are techno-engineering factors and ecological factors. Therefore a main accent in the research was set right on the analysis of these groups of factors. In the previous chapter was explained, in which way with combination of the raster map with suitable slope values and raster map with suitable values of aspect direction can be obtained a new digital map in raster and vector format with suitable locations for construction of photovoltaic solar farms. In this case were taken into account the slope values and aspoect direction values as two factors that have most powerful impact in the selection of suitable locations from the technological and engineering point of view.

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. In fact here it is going for different vector layers of datasets of the same map in the study area. In this way was used the digital map vit vector layer of road network, hydrography network, polygonal layer of settlements as well as polygonal layers for land cover and land use types of the land surface in the study area. In the map with vector dataset of land cover are taken into consideration only those polygons with land cover that are suitable for construction of solar energy farms, so that at the same time the land cover must satisfy the criteria not to destroy the ecological balance of the environment in the study area.

All digital maps with different vector layers were overlaped, so that with such overlaping of several vector layers in an efficient way is obtained a digital map in vector format on which are presented the road network and stream network with lines as well as polygonal layers of settlements and polygonal surfaces with appropriate land cover of land surface which allow construction of farms for exploatation of solar energy potentials.

All vector layers are cummulative displayed in one vector map (Fig.9). Here as suitable locations for solar farms are taken into consideration those surfaces that are covered mainly with low shrubby areas and meadows which are shown on the map with dark blue and yellow colour of polygons (Fig.9.).
At the vector layers for road network infrastructure and stream network is also performed a buffer proximity analysis. With this analysis are set buffer zones along the streams and roads, so that all areas that are in proximity bends to rivers and roads are excluded from the selection of suitable locations for solar energy farm construction.
In the analysis of suitable poligonal areas of land cover and land use was also set a treshold value for a minimal acceptible area for solar farm construction. It was also set a polygonal buffer zone at settlement polygons, so that the proximity zones of towns and villages were also excluded in the analysis of optimal locations.

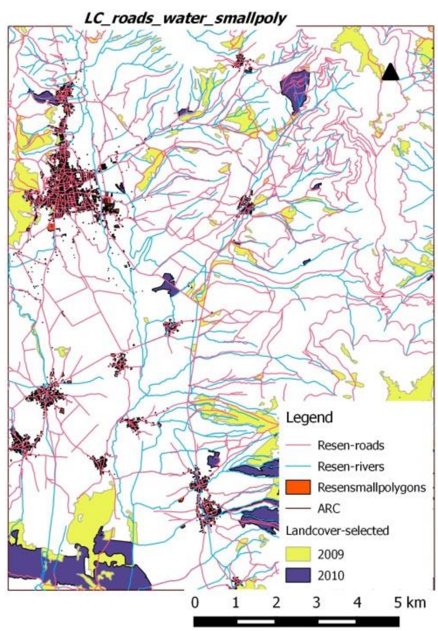


Fig.9. Map with a cumulative display of road network, river streams, settlements and land cover in vector format

Using a combined geospatial analysis of the vectorized digital map of Figure 8. with the digital map of Figure 9. in an efficient way is determined a final digital map in vector format for determined polygonal areas that satisfy the technological engineering and ecological criteria for selection of suitable areas for solar enegy potential development (Fig.10).

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.

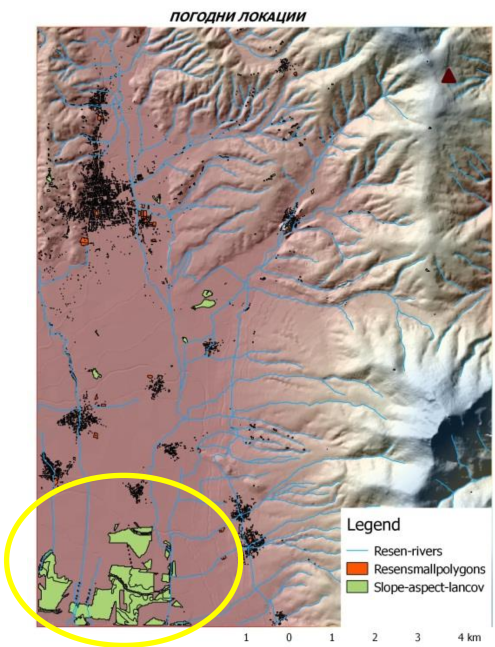


Fig.10. Map with final display of the optimal locations for exploatation of solar power potentials

V. RESULTS AND DISCUSSION

As a final result of the performed research and analysis on Fig. 10 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.
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.
Taking into consideration the above constatations, it should be take into account some possibility for authomatic controlling of movement of solar panels not only from east to west direction but also from lower to greater slope in degrees depends of the season in the year. The optimal slope angles of solar panels are shown in Table 2. below.

TABLE 2 Optimal slope values of photo voltaic panels in the study area

Optimal slope angle of Photovoltaic solar panels (in degrees)	
	ANGLE
Minimal	32^0
Average	33^0
Maximal	33^0

The proposed methodologial approach in GIS platform mainly is used for preliminary screening of optimal location for solar power exploatation. 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. The comparation analysis at the end stage will contribute toward the final right decision making concerning the exploatation of solar power potentials.

VI. CONCLUSIONS

In the paper it is presented a GIS-based methodology with spec ial approach and application of MCA(Multicriteria Analysis) evaluation of suitable sites for expolatation of solar power potentials.

The combination of GIS with the MCA 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. The research is practically proved with obtained results at astudy area of 140km^2 .

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. In order to find suitable sites for exploatation of solar power potentials it has been done slope analysis, aspect analysis, buffer analysis of stream network and road network infrastructure, as well as analysis of the land cover classes of the land surface in the study area.

With GIS-based geospatial analysis of a combination of many digital maps with land surface parameters has been performed a final assessment of suitable locations for optimal use of solar power potentials.

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