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GIS SPATIAL ANALYSIS FOR DETERMINATION OF POTENTIAL AREAS FOR INSTALLING WIND POWER STATIONS

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ABSTRACT

Renewable energy is a very important segment of human life in the modern world which provides energy for electricity generation, air and water heating/cooling, transportation, and off-grid energy services and which is collected from renewable resources that are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves, and geothermal heat.

Wind power is the use of air flow through wind turbines to mechanically power generators for electric power, with insignificant effect to the environment. Wind farms are the areas with a group of wind power stations connected to an electric power network. Selecting the most appropriate position and orientation related to natural prerequisites is the main challenge concerning the establishment of wind farms by GIS experts. Based on the **official instructions** in Macedonia, wind energy can be used for producing mechanical or electrical energy, while the installation of wind farm depends on wind speed, the power of the wind turbine, obstacle in the direction of wind movement, people health and safety, the impact to the environment and wildlife, as well as security and protection. In this paper, performed **research analyses** for determination of potential locations for installing wind power stations based on GIS spatial analyses **and the obtained results** are presented. During the analyses, the lack of official databases has been recognized, which directly affected the accuracy of the calculated results. As final outputs, **a raster dataset** has been developed and **a map with best locations** for wind farms within whole research area is compiled.

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1. Introduction

Renewable energy is energy that is collected from renewable resources. 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. The renewable energy sources are: Solar, Wind, Geothermal, Biomass, Hydroelectric, Wave and Hydrogen. One of the most popular of these resources is wind power.

Wind power is the use of air flow through wind turbines to mechanically power generators for electric power.

Depending on the season of the year, there can be a change of pace and direction of wind, because wind energy is directly dependent on the energy of the sun. Wind turbine is a device used to transform wind energy into electricity. A wind farm is a group of wind turbines in the same location used for production of electric power. A large wind farm may consist of several hundred individual wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purposes (https://en.wikipedia.org/wiki/Wind_power). In general, it can be summarized, that even wind farms may cover a large area of land; many land users such as agriculture are compatible with it, because only small areas of wind turbine foundations and infrastructure are made unavailable for use.

The main benefits of wind power can be seen in the fact, that as an alternative to other fossil fuels, wind power is renewable, widely distributed, clean, produces no gas emissions during operation and uses relatively little land (Yang Z., 2013). Wind power is one such form of renewable energy that is expected to encounter a widespread commercial success. This is mainly because wind energy can be economically viable and does not produce any physical pollution. In fact, using wind to replace just 1% of the EU's fossil energy production would avoid an annual emission of 15 million tons of carbon dioxide. Therefore, it is contributing significantly to the much-needed reduction in air pollution (Baban M J Serwan, 2004).

Selecting the most appropriate position and orientation related to natural prerequisites is the main challenge concerning the establishment of wind farms by GIS experts!

Szurek M., Blachowski J., Nowacka A. (2014) have used a Spatial multi-criteria analysis (SMCA), which can be described as a process that combines and transforms geographically referenced data into a resultant decision. The GIS data are usually organized as vector or raster format thematic datasets known as maps or layers. Data representing particular criteria are referred to as single-factor maps. Kasinatha Pandian P. and Iyappan L. (2015) proposed a methodology that consists of data preparation and analyzing in open source Geographical Information System (GIS). The required data include different factors such as physical, economic, technical and environmental. For data analysis, to evaluate the potential locations, different parameters are considered, namely wind velocity, terrain slope, distance to road, railway, settlement, power line, water body and turbulence intensity.

The aim of this paper is to propose a contemporary GIS based approach for identification and mapping the optimum sites for locating wind farms in the Republic of Macedonia. The analysis encompasses a wide range of factors and constraints that are most important for the determination of optimal locations for wind power farms. These can be divided into several groups: topographic, technical, environmental, socio-economic and human factors and constraints. The proposed spatial analysis of the wind power potentials is an efficient tool for preliminary screening of suitable locations and significantly contributes toward decreasing of the costs for installation of wind farms.

2. Current Situation in the Republic of Macedonia

The first step for wind farms development in Macedonia is to determine accurately the wind resources and potential wind energy production of a future wind farms in selected sites. Unfortunately, in Macedonia there is no accurate knowledge of country wind resources and it is a major barrier for any possible development of the utilization of wind power.

The available wind speed information in Macedonia originates from the national network of meteorological stations, which used alone are not sufficient for accurate wind resource assessment.

This situation was inspiration to make a strategic plan for investigation of wind resources and potential and possible development of wind farms in the near future. The plan consists of three main phases: preparation of wind atlas which is numerical modeling based on geophysical and meteorological inputs, conducting measurement campaign on the most promising sites defined from the atlas and preparation of feasibility studies as basis for possible erection of wind farms. http://windmacedonia.feit.ukim.edu.mk/project/phase1/background1.

Since the country still depends on coal power for about 80 percent of its electricity production, and since that process causes serious environmental and health hazards in at least two towns, there are constant appeals for investment in cleaner energy. National statistics from the last 12 months shows that the country's only wind farm has contributed with 1.9% to the overall electricity production, http://balkangreenenergynews.com/elem-to-expand-its-bogdanci-wind-farm-to-be-expanded-for-additional-13-8-mw. According to the study made by satellite images by AWSTruewind37, an Atlas of wind energy potentials in Macedonia has been made and the 15 most suitable potential locations for installing wind power farms have been chosen. Most of these sites are located in the east and south-east part of the country in the region of Vardar River and in the region of Ovce Pole.

Lutovska M., Mijakovski V. and Mitrevski V. (2013) in their researches have stated that Macedonia can theoretically secure 7% of its annual electricity needs by utilizing wind as a source. In the country's eastern parts 130 to 170 days per year are windy, with wind speed averaging 3,5 m/s. The construction of wind plants in near future would have positive implications for the Macedonian electric power sector, as well as for the local economy.

Taking into account the current situation regarding the wind power potential there is a need for further researches and to develop a comprehensive study of wind power potential in all parts of the country. Using available digital data and employing the spatial analyses and GIS tools, one of the main aims of the paper is to develop a methodological approach for land suitability and identification of suitable location for wind power farms. With such an approach an increase in the exploitation of wind power resources in Macedonia in the near future is expected.

3. Methodology Approach

In general, a number of wind turbines generate wind power. Typically, the height of a turbine is from 50 to 100 meters. Connected wind turbines make the wind power stations. Thus, the initial step in the process of developing wind stations is the process of determining suitable locations for them. Many methodological approaches are presented in the literature review with slight differences. JISC & EDINA (2002) proposed a methodology approach in two phases: in Phase I they develop an Initial Criteria approach and in Phase II they re-work the process using Modified Criteria approach. They have used GIS analyses in order to be produced a series of optional outcomes, which can be explored further in order to come up with appropriate locational decisions. Concerning the finding of suitable sites, they considered two separate sets of criteria or factors, Technical and Environmental. The technical criteria concentrate on a number of elements linked to wind speeds, topographic conditions and accessibility. The environmental criteria include landscape considerations, restrictions, proximity, and visibility factors associated with local population.

In the paper of Szurek M., Blachowski J., Nowacka A. (2014) the criteria for determination of location for wind farms can be classified into the following groups: environmental, spatial, social and technical. The environmental criteria include nature protection aspects: location of protection areas, sensitive land such as forests, wetlands, and surface waters. The technical criteria include communication, power grid accessibility, as well as anemometric factors. The social criteria include human safety and the spatial criteria that are related to land use.

According to Bennui A., Rattanamanee P., Puetpaiboon U., Phukpattaranont P., Chetpattananondh K. (2007) the topography factors affect the land use planning and the important factors associated with topography including: elevation, aspect and steep slopes. The sites near the cliffs are not suitable for wind turbine development. Also, high elevation areas should be avoided because the costs of investments are high.

Miller A. and Ruopu Li (2014) proposed a suite of 7 criteria for modelling the suitability of wind farm locations, including wind energy potential, land use, population density, distance to mayor roads, slope, distance to transmission lines and exclusionary areas where cities and towns, wetlands, airports and roads are located.

3.1. Developed Methodology for Selection of Suitable Locations for Wind Power Farms

On the basis of literature review, a methodology approach for the selection of suitable locations for wind power farms is developed, which is adopted according to the specific topography of the area of Republic of Macedonia and also is harmonized with the general law rules in Macedonia.

For analyzing the suitability of potential sites for wind farm developing, a set of factors must be considered, which in this study have been divided into four groups: topographic, technical, environmental and socio-economic factors (Table 1).

Topographic factors: Elevation, Slope, Aspect direction and minimum area.

The elevation affects the technical possibility of setting a wind turbine and significantly increases the costs for installation and maintenance. The sites that have high altitude (above 1500 m.a.s.l) or near cliffs are generally not suitable for wind turbine placing. Beside that the elevation of the site should reflect the complexity of the terrain surface with a minimum level set of labor force. The terrain with steep slopes is generally considered as less suitable for wind farm development, due to significant increase in the costs for construction and maintenance of turbines. The aspect direction of the terrain should be taken into consideration, because the optimum ground position of the wind turbines is dictated by the dominant wind direction. Regarding the placement of wind farms, a minimum area of ground surface should also be taken into account. This mainly depends on the technical specifications of wind turbines as well as on specific relief configuration of the surface.

Table 1. Factors used in the analysis of suitability for wind farm development

No.	Factors	Criteria
	Topographic	
1	Elevation	<1,500 meters a.s.l.
2	Slope of terrain	<15%
3	Aspect direction of slope	315°<value<360° (NW - N) 0°<value<45° (N - NE)
4	Area	> 100,000 m^2 (10 ha)
	Technical	
5	Wind speed	>5 m/sec
6	Proximity to power grid	500 m <value < 1000 m
	Environmental	
7	Proximity to rivers	>300 m
8	Proximity to lakes	>300 m
9	Land cover of ground surface	>300 m of woodland & wetland area
10	Proximity to dams and weirs	>500 m
	Socio-economic	
11	Proximity to urban area (city)	>2000 m
12	Proximity to villages	>1000 m
13	Distance to roads	>250 m
14	Distance to railways	>250 m
15	Distance to airports	>3000 m

Technical factors: Wind speed and Proximity to power grid.

The wind speed is one of the key factors for producing energy of wind farms. Wind speed above certain levels is essential to make wind energy production. Wind farms should be located near the existing transmission power grids in order to help reduce the costs that are associated with wind farm construction and to reduce the costs for transmission of electricity produced in the national energy distribution system. So, one of the crucial technical consideration is the need to link our renewable energy source as much as possible into the existing national energy network.

Environmental factors: Proximity to rivers, proximity to lakes, proximity to dams, proximity to weirs; and land cover of ground surface.

This factor should be taken into account due to the potential risk of flooding of wind farms during the autumn, winter and spring season and because the mechanical parts of wind turbines should be kept away from water as well as from dams and weirs in order to be avoided damages of the turbine components in case of falling and breaking of the wind turbine fins. The land cover of the surface can significantly influence the possibility of wind farms development. Some surface areas like woodlands can have negative impact on wind turbines. Therefore, possible interference with woodland should be eliminated.

Socio-economic factors: Proximity to urban areas (cities), proximity to villages, distance to roads, distance to railways, distance to airports.

Due to the safety and low noise intrusion, the wind farm should be at a proper distance from urban areas (cities) and also at a proper distance to rural areas (villages). The distance to roads has influence on costs for installation and maintenance of wind turbines, but the location of wind turbines should be properly placed at a minimum distance from roads due to safety reasons. The similar criteria should be taken into consideration regarding the proximity to railways. The distance of the wind turbines to airports influences the safety of flights.

4. Source Data and Software

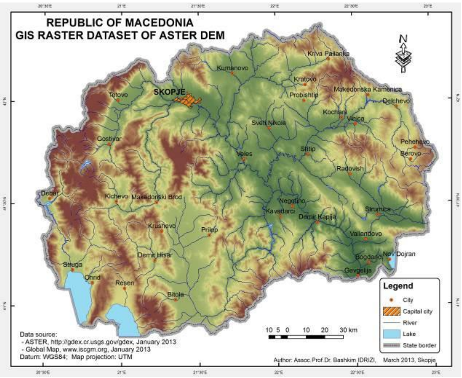
The study area encompasses the whole territory of the Republic of Macedonia. The relief configuration is diverse and covers valleys, fields, mountain regions, lakes and river valleys.

Due to the current conditions in Macedonian market for geodata and copyright rules regarding geospatial data, there are no possibilities to use official data free of charge for scientific researches, except for the Global Map dataset, which is a free and open source for non-commercial use. Therefore our researches have been done by using global open source and free datasets. So, as input DEM the ASTER GDEM has been used with spatial resolution of 30 m. Concerning the land cover raster data Corinne Land Cover European seamless has been used with spatial resolution of 100 m (Version 18.5). For the need of the research climatic wind data only for the Republic of Macedonia has been extracted. Concerning the data for wind speeds a dataset from the WorldClim 2.0 (June 2016) have been used, downloaded from http://worldclim.org, which represents average monthly climate data for 1970 – 2000, where each file contains one month, i.e. in total there are 12 GeoTiff files, one for each month of the year (January is 1; December is 12). For the need of research climatic wind data only for the national area of the Republic of Macedonia has been extracted. All above mentioned data are in raster format.

Also a dataset in vector format has been used, consisting of polygons, lines and points vector layers for the following layers (www.iscgm.org; 2011):

- lakes;
- rivers;
- dams;
- roads;
- railways;
- population centers;
- airports;
- boundaries.

All raster and vector datasets are in projected coordinate system UTM 34N. The extracted input ASTER GDEM and Global Map vector layers for the Macedonian territory are shown in Fig. 1.



Relief of Macedonia, based on ASTER GDEM (Idrizi B, 2013)

Map of Macedonia, based on Global Map vector data (Idrizi B, 2006)

Figure 1. Data sources (ASTER GDEM & Global Map)

During the research study GIS software QGIS was used. All data processing and modelling have been performed with this software package, which is used for geospatial and data management as well as for combined and complex spatial analyses. This software is open source and free for use.

5. Analysis of Suitable Locations for Exploitation of Wind Power Energy

Having on disposal the major necessary raster and vector layer datasets, in the next phase spatial analyses can be performed corresponding to each criterion of the particular factors in Table 1.

For spatial analysis of the main topological parameters of land surface the DEM (Digital Elevation Model) is essentially important and is the main input data for further analyses of the land surface. The input ASTER GDEM for Macedonian territory is with spatial resolution of 30m. Using the obtained DEM by performing spatial analyses in GIS platform, additional land surface parameters which are important for site suitability analysis, such as slope and aspect data, are determined.

With this approach, using the DEM a raster layer with slope values of the surface is determined. The slope tool in QGIS calculates the maximum rate of change from a cell to its eight neighboring cells, which is typically used for representing the steepness 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, where areas in each pixel stored the slope value expressed in percentage (%).

Again, using as input the DEM, the aspect raster map in same pixel resolution with values of the directions of the slopes is also determined. In fact, the Aspect tool in QGIS calculates the direction in which the plane fitted to the slope faces each cell. Aspect tool identifies the down-slope 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 direction that the surface faces at that location, known as azimuth angle. It is measured clockwise in degrees from 0° (north) 90° (east) 180° (south) 270° (west) to 360 = 0° (north) (Fig. 2).

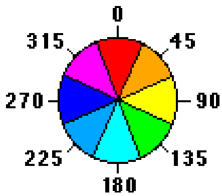


Figure 2. Code numbers for aspect directions of slopes

The flowchart diagram of operations with raster layers is shown in Fig. 3. Raster analyses in GIS often use s.c. Multi-criteria analysis – MCA. Principally GIS based multi-criteria analysis involves two types of evaluation methods: 1. Method with boolean operators, and 2. Linear combinations with use of s.c. factors of influence for particular dataset.

In this research the first method with boulean operators is applied. At the first stage the main criteria for assessment of optimal locations should be determined. It is done with setting a threshold value of raster cells in a given layer. This allows different raster layers or the so-called Boulean layers to be obtained, where raster cells have two values. One value represents the suitable cells in the map whereas the other value represents the unsuitable cells. All suitable cells in the layer have value of 1, and the others have value of 0. Such determined boulean raster maps in the further analysis can be easily combined with the well-known boulean operators, such as AND, OR, NOR, XOR and others.

Setting the correspondent threshold values for elevation, slope and aspect (as shown in Fig. 3) are determined suitable raster boolean layers for elevation, slope and aspect. Similarly with exclusion of unsuitable values of land cover areas it is determined boolean raster layer of land cover areas that are suitable for wind farms development.

Regarding the wind speed as a crucial factor, values with higher wind speeds are taken into consideration and boolean suitable raster wind layer is also determined. Regarding the Corine land cover raster layer, all unsuitable land covers of the area such as urban fabrics, industrial and commercial units, mineral extraction sites, dump sites, construction sites, green urban areas, sport and leisure facilities, forestry areas, bare rocks, marshes and others that are inconvenient for wind farm development are excluded.

Using the Raster calculator tool in QGIS on the five boolean raster layers that are suitable for wind energy exploitation it is determined the final suitability raster layer for wind farm development. For further analysis, this layer then is converted to final vector layer with suitable areas. The flowchart diagram of operations with raster layers is shown in Fig. 3.

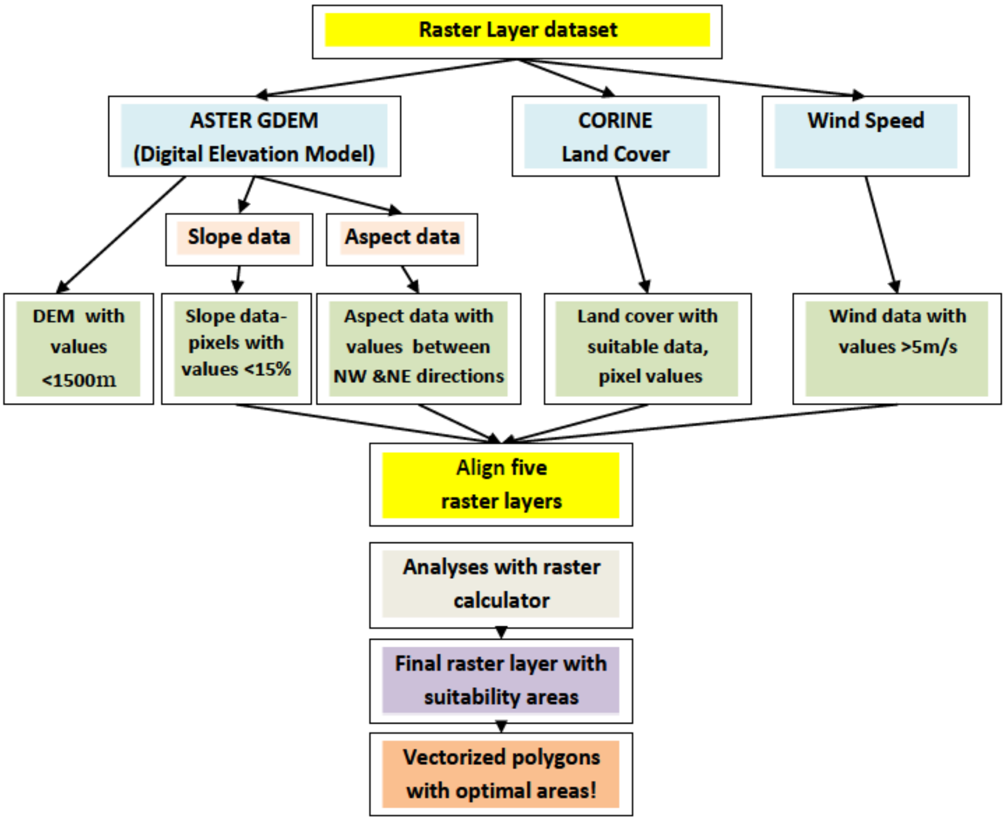


Figure 3. Flowchart diagram of operations on Raster layers

Assuming that all vector layers have equal importance and therefore carry the same weight, a buffer analysis for all point, line and polygon vector layers is made.

This means that the final suitability map of vector layers is based on criteria that are equally important for the analysis. The bend area of each buffering determines the unsuitable area for wind power farm locating.

After obtaining all vector layers with buffer zones, they can be easily combined for further analysis. In this way, using the appropriate vector geoprocessing tool buffering of all vector layers with setting of treshold values for buffer zones is performed, then all vector buffer layers are combined with the geoprocessing tool Union.

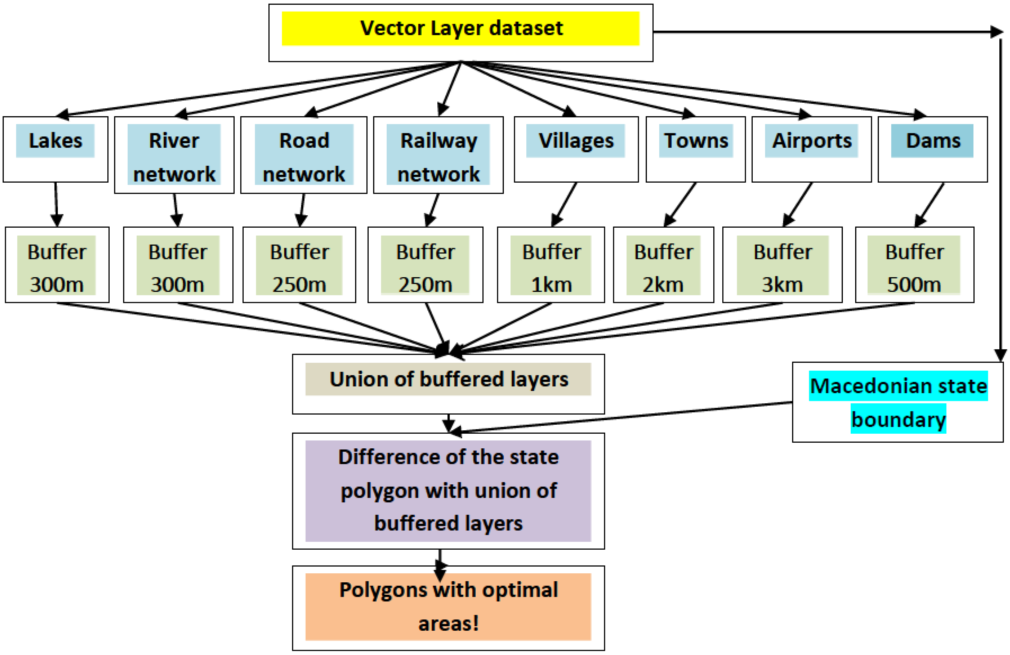


Figure 4. Flowchart diagram of operations on Vector layers

In this way as it is shown in Fig. 4 a cumulative vector layer with the unsuitable area for wind farm development is obtained. Since we need areas that are suitable for location of wind farms, again employing the vector geoprocessing tool Difference, we can extract the suitable areas. The difference tool in QGIS extracts right the opposite areas of these obtained with union tool.

In this way the final suitability layer for wind power farms development is determined, taking into consideration all vector layers with set threshold values for the factor of influence.

In general, the performance of wind turbines can be influenced by every factor that is discussed above. However, each of the above factors presents an entirely different element of importance to the analysis of the overall suitability for wind farms development.

Finally, as can be seen in Fig. 5, with combination of the vectorized polygons with optimal areas in Fig. 3 and the polygons with optimal areas in Fig. 4, employing again the vector geoprocessing tool CLIP, a final layer of suitable locations for wind power farms development can be determined. This layer fulfills all criteria that have been set in Table 1.

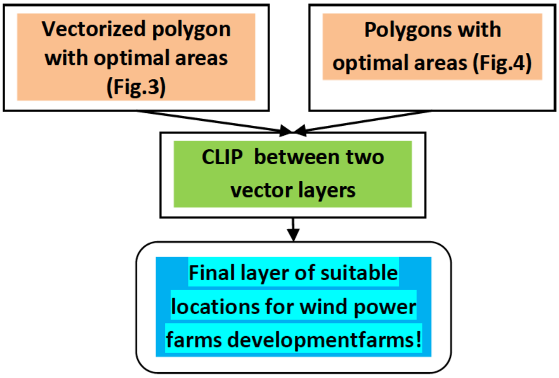


Figure 5. Flowchart diagram of final operations for suitable locations for wind power farms

6. Results and Discussions

The performed spatial analysis of the raster layer dataset (shown in Fig. 3) has determined the suitable areas that satisfy the topographical criteria of DEM, Slope and Aspect of the land surfaces, the technical criteria of wind speed, as well as suitable land cover surfaces.

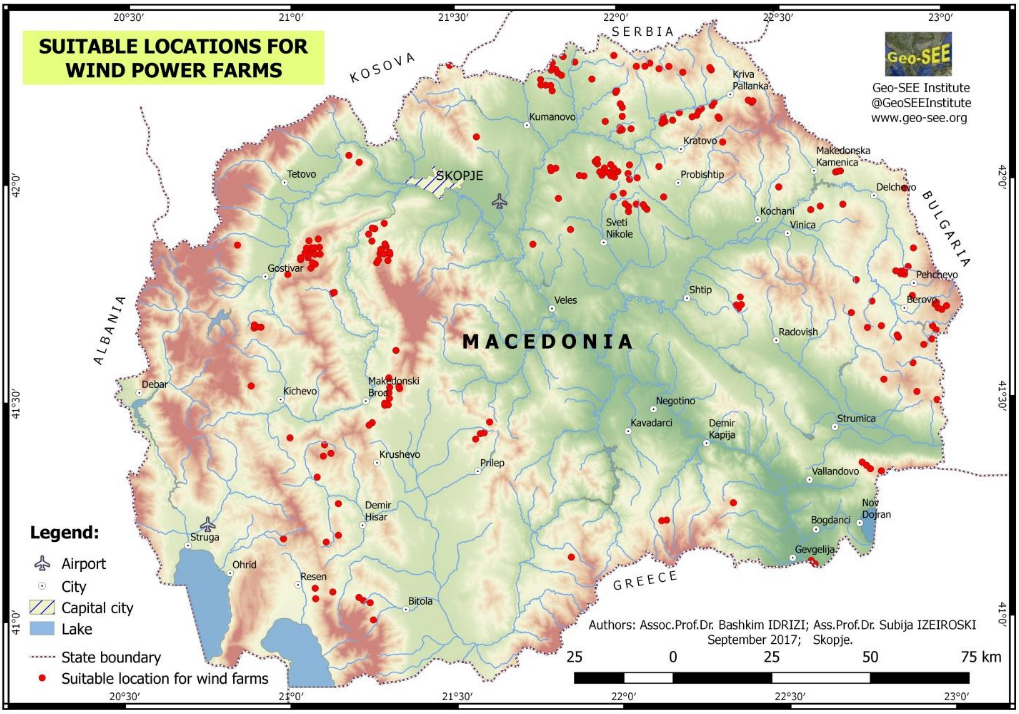


Figure 6. Map of suitable locations for wind power farms development

On the other hand, the performed spatial analysis of the vector layer dataset (shown in Fig. 4) has determined the suitable areas that satisfy the environmental factors and constraints (rivers, lakes, dams and weirs), as well as the socio-economic factors and constraints such as urban areas, cities, villages, roads, railways and airports.

By combining (Fig. 5) obtained results from raster (Fig. 3) and vector (Fig. 4) layers, the 215 potential suitable locations for establishing wind power farms based on criteria defined above (in Table 1) within the entire national area of the Republic of Macedonia have been reached (shown in Fig. 6). As can be seen on the map, most of the suitable locations are in the hilly regions in the central north-west part, the central south-west part, as well as in the eastern and north-east part of the country.

During the performed analysis, from a total of 215 suitable locations located in 37 municipalities, there are identified 11 municipality areas with more than 9 suitable locations for wind power farms, as well as 13 municipalities that have total sum of suitable areas greater than 1 km^2. The results of the most convenient municipality areas with number of suitable locations for wind power farms development, as well as with the total suitable areas for wind farms in each municipality are shown in Table 2.

Table 2. Municipality areas that are most convenient for wind power farms development

No.	***Municipality***	***Number of suitable locations for wind power farms***	***Total area of the suitable locations in m^2***	***Percentage area for wind power farms in relation to the municipality area***
1	Berovo	14	2.168.813	0,36%
2	Bitola	5	3.184.353	0,41%
3	Brvenica	13	2.416.951	1,47%
4	Delchevo	4	1.143.806	0,27%
5	Kratovo	15	2.573.598	0,68%
6	Kriva Palanka	10	1.503.088	0,30%
7	Kumanovo	18	3.403.744	0,66%
8	Makedonski Brod	14	1.905.424	0,21%
9	Pehchevo	12	3.710.518	1,75%
10	Rankovce	15	3.236.728	1,33%
11	Sopishte	12	2.984.830	1,34%
12	Staro Nagorichane	16	2.971.340	0,67%
13	Sveti Nikole	10	2.654384	0,55%

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

The GIS based method in this paper provides a quantitative evaluation and assessment of factors and constraints that should be taken into consideration at determining the land suitability for locations of wind farm. The final suitability map can be used as guidance toward the 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.

7. Conclusions

The proposed GIS based methodology for geospatial analysis for determining suitable sites for wind power farms development has been performed for the whole national area of the Republic of Macedonia taking into consideration the Macedonian conditions.

The main factors and constraints that have been used in the study were divided into several groups: Topographic, Technical, Environmental and Socio-economic. The particular threshold values of factors and constraints have been set based on literature review and taking into account the specific conditions of the terrain surface in the Republic of Macedonia. Due to the lack of data, some factors and constraints have not been considered in the study. So, the proposed methodological framework could be potentially improved by including additional factors and criteria. The factors may include for example: roughness of the terrain which influences the performance of wind turbines, level of noise of wind turbines during the operation, protection of the birds, local ecosystems and animal habitats, protection of the archeological sites, specific demands of investors and environmentalists and others.

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

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