Development of a method for determining the optimal areas for alternative energy facilities based on GIS technologies

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Abstract. Acquisition of alternative energy resources using the modern Global Mapper software on an electronic digital map is an important process. This article analyses the possibility of using maps in the implementation of internationally acknowledged projects, as well as interactive services to the government, and the possibility of mapping alternative energy sources, synthesizing data, and developing management decisions through the development of innovative technologies. The research in this study is about determining optimal locations for the installation of solar panels and wind turbines. For the tests, Tashkent and Samarkand provinces were selected. Initially, the elevation of the provinces was determined by remote sensing and the elevation surface was created by interpolation. According to the data obtained from the regional hydrometeorological stations, the air temperature in the regions was taken and geovisualized as a vector layer. At the same time, the wind speed was mapped using the method of geostatistical analysis, which observed the annual average wind speed. On the basis of the highest parts of the earth's surface and in areas with high temperatures, raster calculations were performed and the method for determining the most optimal place for installing solar panels was improved.

1 Introduction

Today in the world special attention is paid to targeted research aimed at developing effective methods for collecting, storing, digitizing, analyzing, processing, recording, evaluating, and forecasting data, modeling, and visualization based on spatial data using modern geoinformation methods and technologies for mapping alternative energy resources. In this regard, one of the important tasks is the development of modern geoinformation technologies, and cartographic methods, including the creation and updating of maps of alternative energy resources available in Uzbekistan.

It is acknowledged that in the future it is necessary to use energy sources in ensuring environmental, economic, and energy security, and development of the energy sector of

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Uzbekistan [1,2]. Certainly, the development of renewable and alternative energy sources by protecting the environment while conserving natural resources is essential for the lives of future generations.

1.1 Background. Study object.

The object of the study is to automatize the determination of the optimal location for the installation of wind generators and solar panels. This was tested in the Tashkent and Samarkand provinces of Uzbekistan. These regions were selected as the object of study due to the fact that they are on average higher than the level of the Baltic Sea and higher than the average annual wind speed compared to other regions of the country. The average altitude in the Tashkent province is 2,000 meters above sea level, while in the Samarkand region it is 1,800 meters. The average annual wind speed in the Tashkent region is 2.2 m/s and in the Samarkand province 1.6 m/s. The average annual temperature in the Tashkent province is 6 °C and in the Samarkand province, it is 14 °C. Therefore, given the fact that these regions are located in wind corridors and have more access to solar panels in mountainous areas, they were selected as the object of this research.

2. Materials and methods

As part of the case study, large-scale field and laboratory studies were conducted to geovisualize alternative energy resources. Methods for mapping alternative energy resources have been developed. In order to determine the most optimal areas for installing solar panels and wind turbines based on the direction of the wind, wind speed at a height of 10-50 meters above the ground, the air temperature above the ground, and 2 meters above the ground stages were analyzed. Based on the results of the analysis, recommendations were developed for choosing the optimal area for the construction of alternative energy facilities. [1]

In order to analyze the alternative energy resources in the software belonging to the family of geographic information systems, the authors first studied the geographical location of a total of 80 existing hydrometeorological stations in the country (Table 1) [2].

According to table 1, the objects of study are 4 meteorological stations in the Samarkand province and 15 meteorological stations in the Tashkent region, which collect and analyze information on air temperature, humidity, wind direction, and speed. Based on these data, the geographical location of metrological stations is formed in digital form in the ArcGIS program (Figure 1) [3, 15].

The attribute tables of the hydrometeorological stations formed in the ArcGIS program included geovisualized data such as surface temperature, temperature 2 m above ground, wind direction, wind speed at 10 m above ground, and wind speed at 50 m above ground.

In the fieldwork, the use of the GNSS geodetic device to determine the regional coordinate values for digitization of information related to local temperature readings. Moreover, using GNSS geodetic device, the data obtained by hydrometeorological stations in Samarkand and Tashkent provinces were sent to areas with sharp differences in temperature for geovisualization in the form of points, and the coordinate values lying on the x, y, and z axes were determined. In order to increase the accuracy of the obtained coordinates, alignment work was carried out by linking the results of field research to satellite geodetic networks.

Table 1. Nomenclature of existing meteorological stations in the Republic of Uzbekistan.

Number of meteorological stations	Name of meteorological stations	Latitude [degree]	Longitude [degree]
16	Samarkand	66.95	39.65
17	Kushrabad	66.64	40.23
18	Dagbit	66.91	39.75
25	Tashkent	69.30	41.33
26	Yangiyul	69.00	41.08
27	Almalyk	69.60	40.84
28	Kokaral	69.02	40.68
29	Dalverzin	69.28	40.40
30	Bekabad	69.26	40.20
44	Tuyabuguz	69.30	40.99
51	Nurabad	66.29	39.61
54	Angren	70.18	41.00
55	Sukok	69.79	41.24
56	Pskem	70.37	41.94
57	Chimgan	70.01	41.55
58	Dukant	70.10	41.09
59	Bashkyzylsay	69.89	41.10
60	Oygaing	70.88	42.16
69	Kamchik	70.50	41.10

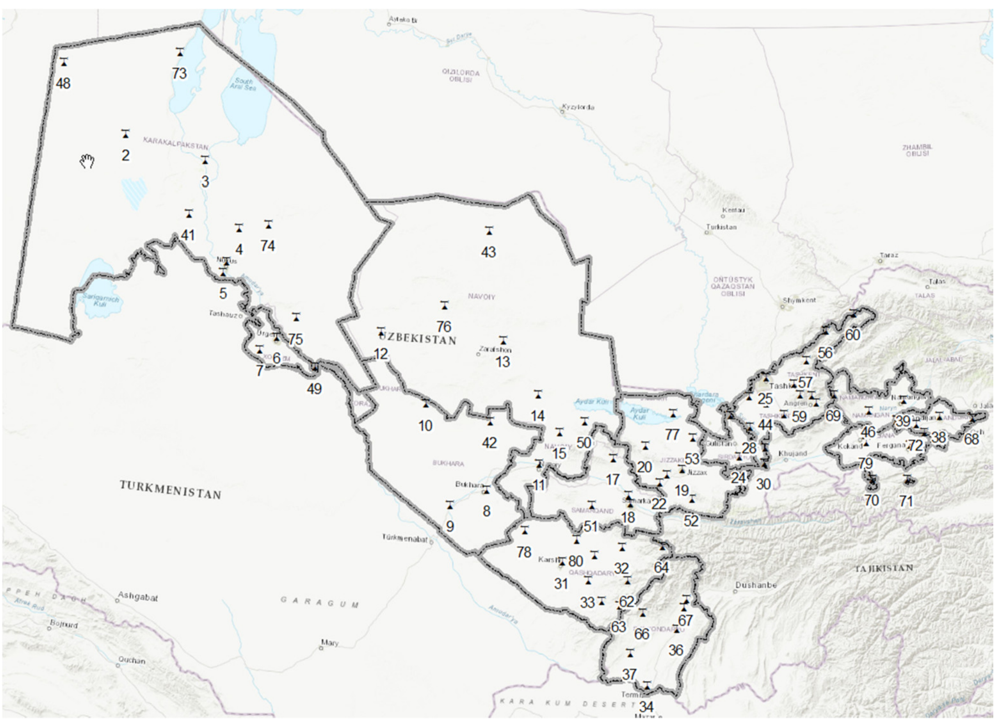

Fig 1. Current location of existing meteorological stations in Uzbekistan.

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3. Results and discussion

Based on the data obtained as a result of research work, the weights of surface temperature indicators were analyzed by inverse distance (IDW-Inverse distance weighting) by interpolation of information using ArcGIS software, and geovisualized temperature maps of Samarkand and Tashkent province (Figures 2 and 3).

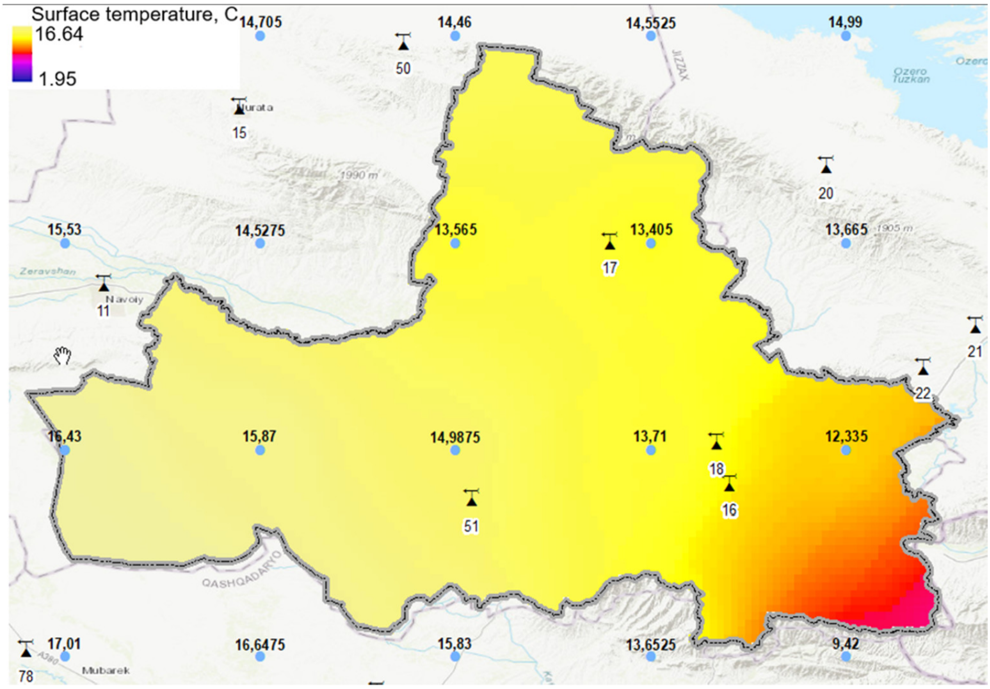

Fig 2. Surface temperature map of Samarkand province

The analysis also analyzed the temperature at a height of 2 meters above the ground and created a cartographic basis for identifying areas where solar panels could be installed by creating an electronic digital air temperature map in the Samarkand and Tashkent provinces. [4]

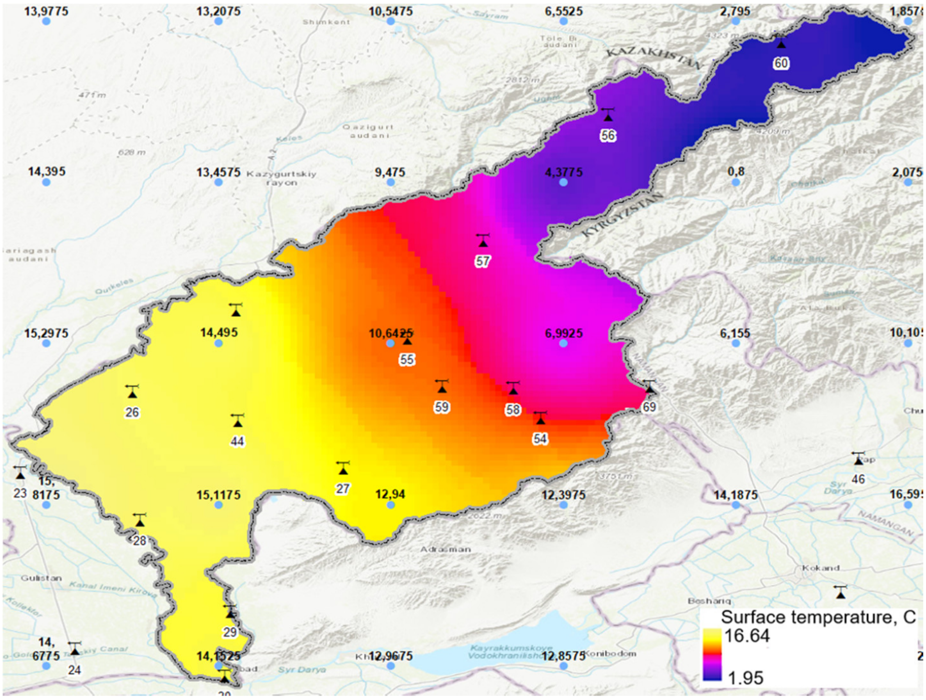

Fig. 3. Surface temperature map of Tashkent province.

Based on the results of the study, it was possible to determine the optimal areas for installing solar panels in any part of the country with increased efficiency using an automated geographic information system. At the same time, the amount of field research was reduced by 50% [6, 14].

In order to improve the system for determining the optimal areas for installing wind turbines using the ArcGIS program, an analysis of the IDW was carried out based on data of wind directions from independent metrological stations that were expressed and plotted on a map (Figures 4 and 5).

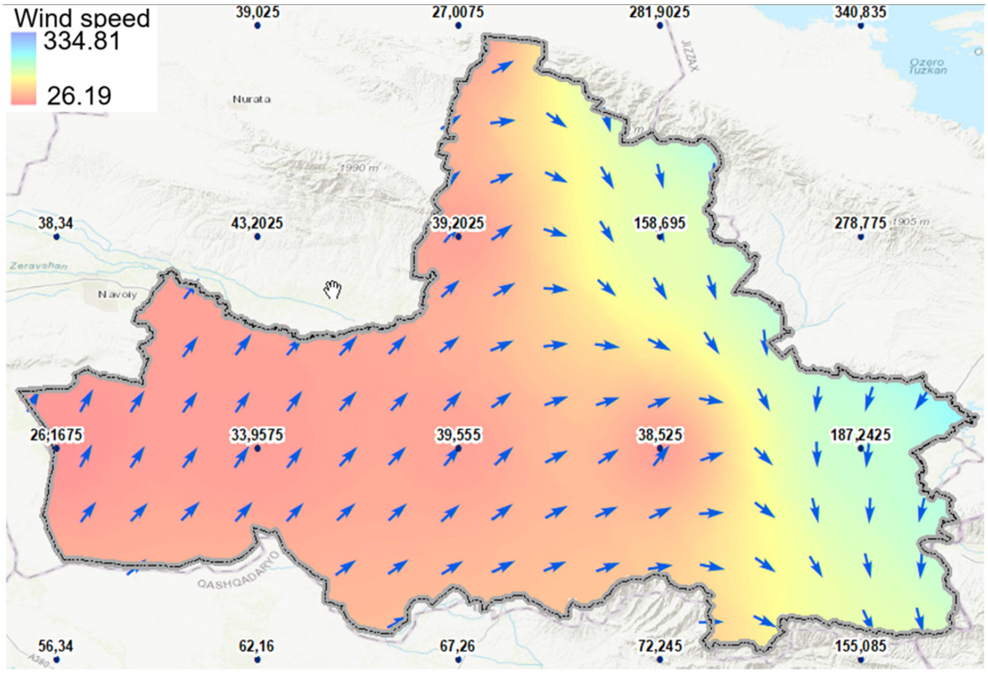

Fig. 4. Map of wind direction in Samarkand region with the help of moving linear signs.

According to the analysis, in Payarik, Bulungur, Dzhambay, Tailak, and Urgut districts of Samarkand province, it is recommended to install wind turbines for Samarkand province in Payarik, Bulungur, Jambay, Taylak and Urgut districts and for the Tashkent province Bostanlyk, Ahangaron, Piskent, Bekabad, Boka, Ortachirchik, Koyichirchik, Chinoz and Yangiyul districts, given that the winds blow mainly from the north in a circle and form a winding path. [7, 20]

In Bostanlyk, Akhangaron, Piskent, Bekabad, Buka, Urtachirchik, Koyichirchik, Chinoz, and Yangiyul districts of the Tashkent province, it is recommended to install wind turbines in the above-mentioned districts in both Samarkand and Tashkent provinces (Figure 5).

In order to improve the quality and efficiency of the research on wind directions based on data from metrological stations, wind speeds in the Samarkand and Tashkent provinces were studied. Wind speed statistics were geovisualized based on vector layers. [8, 13]

An analysis of the Samarkand region shows that it is advisable to install and operate wind turbines in the western part of the Pakhtachi, Narpay, and Nurabad regions since the average wind speed in the western part of the region is above 108.09 m/s per year.

According to the analysis of the Tashkent province, due to the fact that the average wind speed in the southern part of the region is above 282.22 m/s per year, it is advisable to install and operate wind turbines in the southern part of Bekabad, Buka, Piskent and Akhangaran districts.

The study was carried out at a wind speed of 10 meters above the ground. The wind speed at a height of 50 meters above the ground was also formed and analyzed as a vector layer in geodata.

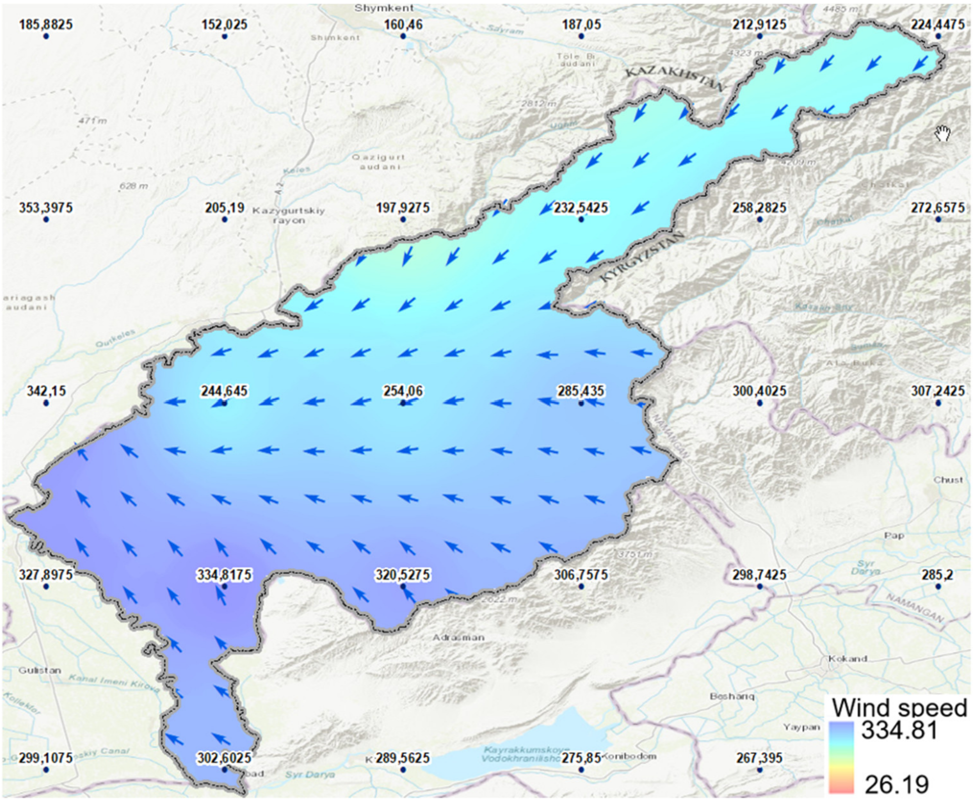

Fig. 5. Wind direction map in Tashkent province using moving linear signs.

In order to further improve the accuracy of the investigations of the use of alternative energy sources, it was analyzed by linking it to the location. Identification of areas above the absolute height relative to the Baltic Sea in the study area has been performed, considering the relief and determining the most optimal areas for the installation of wind turbines and solar panels by the calculation method in the ArcGIS program for areas with high wind speed and air temperature. [9]

During the analysis, the Global Mapper program was used to determine and geovisualize the values of the heights of the earth's surface. Data on the surface of Uzbekistan were downloaded via the Internet in the “DT0” format, boundary lines were drawn from the data received by the territorial unit, and wind direction was set using the create height command.

Point feature layers with height values have been exported to the ArcGIS Shape format module. The exported layers were downloaded to ArcGIS and the points were generalized according to the working scale. Point generalization is considered necessary to create medium-scale maps. The working scale of the study is to create electronic digital maps on a scale from 1:100,000 to 1:450,000.

The altitude attribute assumes that the absolute altitude values of each point relative to the Baltic Sea level are automatically lowered when downloaded from the Global Mapper program. Based on these elevation points, ground elevation was geovisualized as a field layer by interpolation using the IDW analysis command in ArcGIS. [10]

In total, 354 marking points were defined in the Samarkand province, while it was noted that the ground level is located relative to the Baltic Sea in the range from 250 meters to 2298 meters.

In total, 335 marking points have been created in the Tashkent province.

Once the map data is structured in vector form, it is categorized according to elevation. The program included the classification of the altitude range of provinces. For Samarkand province, 5 classes were obtained from 250 meters to 2,500 meters, while for the Tashkent province 5 classes were determined from 200 meters to 4,000 meters. [11, 16]

Based on the results of the classification, an algorithm was developed using the ArcGIS software, as well as suggestions and recommendations were made for choosing or determining the most optimal location for solar panels and wind turbines (table 2).

Table 2. Algorithm for determining the optimal location using the program ArcGIS.

#	Eligibility levels	Surface temperature, °C	Wind speed, m/s	Height above ground level, m
For Samarkand province				
1	Level 1	13<	4,0<	2500<
2	Level 2	10-13	3,5-4,0	1500 -2500
3	Level 3	6-10	2,5-3,5	250 -1500
For Tashkent province				
1	Level 1	10<	3,5<	3000<
2	Level 2	5-10	2,5<3,5	2000 -3000
3	Level 3	1-5	1,5<2,5	200 -2000

Acceptance levels were divided into 4 types, as shown in table 2. According to it, areas with 1 degree are highly accepted, areas with 2 degrees of medium acceptance, and areas with 3 degrees of low acceptance were divided. Level 4 areas cover mountainous areas with steep slopes. [12]

The study used ArcGIS software which meets the requirements for solving the problems. Above, when creating digital maps developed in the second part of the first chapter of the research work, mapping describing alternative energy resources was performed based on the GISAE structured structure.

In particular, considering the level of acceptance of installing alternative energy sources, the results of the above works were linked to the theoretical base developed during the study, i.e. by placing the collected research results in a central database using geolocation. Then, using cartographic methods, a map of territories suitable for the installation of alternative energy sources was built (Figures 6 and 7).

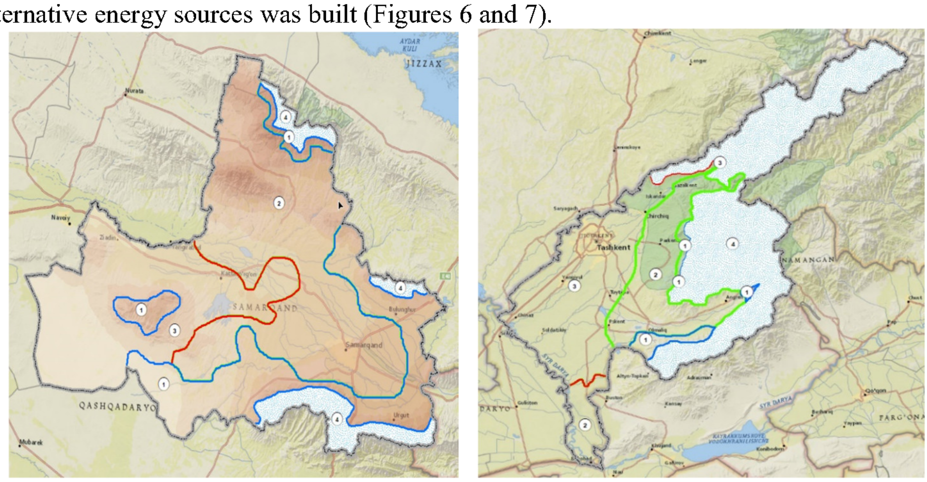

Fig. 6. Most suitable places map for the installation of solar panels in Samarkand and Tashkent provinces.

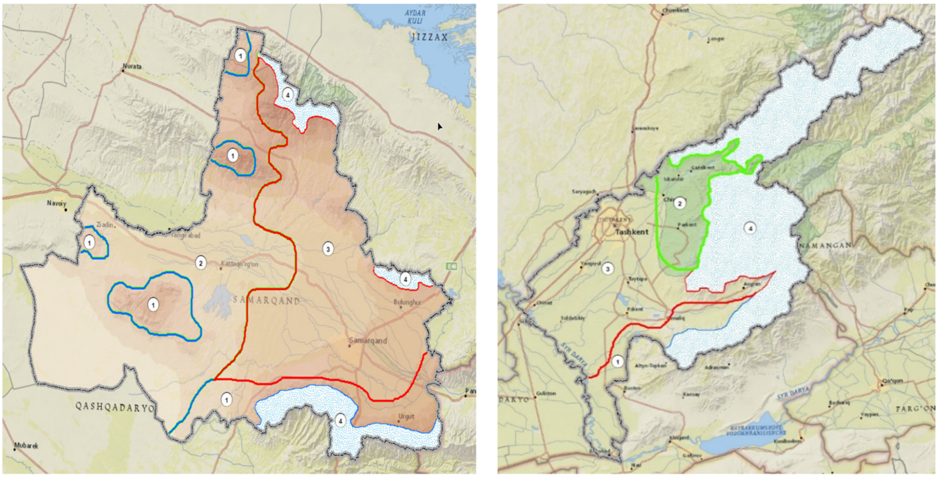

Fig. 7. Most suitable places map for installation of wind turbines in Samarkand and Tashkent provinces.

The algorithm developed in table 2 shows the determination of acceptability levels based on air temperature, wind speed, and absolute altitude of the land and shows the results of the work performed in the Samarkand and Tashkent provinces in Figures 6 and 7. According to the description of the alternative areas in the Figure, Zone 1 indicates areas most suitable for the installation of wind generators and solar panels. Zones 2 have been identified and geovisualized to provide moderate acceptability for the installation of wind generators and solar panels, and Zones 3 to provide low acceptability options for the installation of wind generators and solar panels.

As a result of the study, it was recommended to install solar panels in the regions of the Samarkand province from west to east (Pakhtachi, Narpay, Nurabad, Kattakurgan, Ishtikhan, Kushrabad, Akdarya, and Payarik regions) due to the average annual temperature above 13 °C.

In Tashkent province, in the south-western part of the region (Bekabad, Buka, Akkurgan, Piskent, Quyichirchik, Ortachirchik, Chinoz, Yangiyul, and Zangiota districts) it was recommended to install solar panels in these districts due to the average annual temperature above 12 °C (Figure 3) [5].

4 Conclusions

Today, the existing versions of GIS technologies fully cover the previous versions and are improved further. Existing software has made it possible to effectively use digital maps built-in previous versions.

The creation of alternative energy maps of Samarkand and Tashkent provinces, various topics, including: the creation of alternative energy databases in the provinces, their visualization, etc., was carried out by using modern GIS software.

One of the main objectives of GIS technology in this study was: to create maps and plans based on the research topic, process them, database formation, integration, and visualization.

Alternative energy resources are divided into 2 types, 14 sources depending on the restoration, and 2 parts and 14 types depending on the level of environmental safety of the means of energy production.

In the map developed using the data of the Global Solar Atlas (GSA) project compiled by the World Bank Group, the indicator of daily daytime sunlight falling on the southern regions of our country is from 4.8–5.3 kWh/m2 to the north and higher in the altitude zones. It drops to 4.0 kWh/m2. The annual indicator also decreases from 1830 to 1400 kWh/m2 based on the same geographical pattern. Such variability corresponds not only to zoning, but also to the laws of height zoning.

Based on the algorithmic analysis of the ArcGIS program, the most optimal areas were identified and introduced into the production organizations by placing them in the elevation points of the terrain in relation to wind and temperature indicators of the Samarkand and Tashkent provinces.

The most important factor in the development of alternative energy is the prospective placement of alternative energy resources. GIS technologies were used to locate alternative energy resources in numerical and visual analysis. Based on the methodological and theoretical foundations of the research, a series of maps of alternative energy resources was developed using cartographic, geoinformation, mathematical-cartographic modelling, logical, statistical, comparative analysis, data processing, qualitative and quantitative analysis, and graphical interpolation methods.

Based on the theoretical basis developed for the installation of alternative energy sources, the results of the study collected in the central database by geolocation were interconnected and a series of maps of the areas suitable for the installation of alternative energy sources were created.

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