Journal of Green Energy Research and Innovation

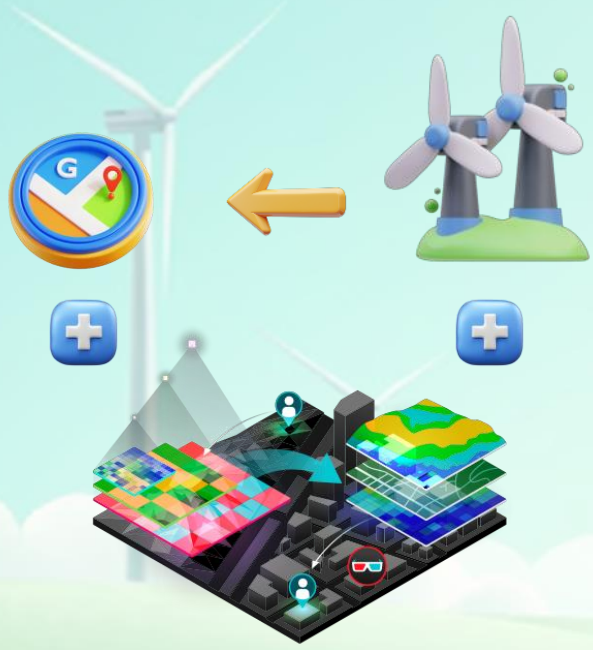
Application of Remote Sensing in Wind Power Plant Location

Mostafa Davodabadi Farahani, Saeed Sharafi, Ali Farahani

Highlights

- **Using remote sensing knowledge to locate the wind power plant.**
- **Using Google Earth Enchain for remote sensing.**
- **Checking the wind condition including wind speed and direction.**
- **Investigating environmental conditions including temperature, pressure and air density.**

Graphical Abstract



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Application of Remote Sensing in Wind Power Plant Location

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A B S T R A C T

Today, the attention to energy security, the increase in the need for electrical energy and the need to create new power plants, especially the power plants that use renewable energy, has increased significantly both in Asia and globally. Wind power is expected to make the largest contribution to global decarburization, ranking first or second in terms of projected capacity by 2050. This type of power plant directly uses natural energy as fuel. And as a result, climate change affects the efficiency of these power plants. Two parameters of the natural phenomenon of wind, which include wind speed and direction, are the main factors of wind power plant efficiency. The science of remote sensing is the process of identifying and monitoring the physical characteristics of a remote area by means of satellites. Google Earth Engine is an artificial intelligence to use this knowledge. Google Earth Engine combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities. Google Earth Engine provides us with these parameters. In this article, by collecting and then analyzing these data, we try to choose suitable candidate locations for the establishment of these two types of power plants, and based on priority, we provide a list for the establishment of solar and wind power plants.

1. Introduction

Fossil fuels are running out, and their extraction is very expensive, which has made humanity look for sustainable energy. Wind energy as a renewable and sustainable energy source and most importantly without pollution is one of the sustainable energies of interest [1]. The energy generated by wind power conversion frameworks (WECS) varies with environmental meteorology and wind speed [2,3], so we need to predict and manage these changes [4]. Wind power plants or wind farms use wind energy to produce electricity. This type of power plant plays an important role in the development of power plants in many countries.

Wind power plants are a group of wind turbines that are used to produce electricity [5]. We also know these power plants as wind farms or wind parks. Wind power plants can consist of one or a thousand wind turbines. Wind farms can be either onshore or offshore. It can be said that the largest onshore wind farms are located in China and the United States. For example, Gansu Wind Farm is the largest wind farm in the world with a capacity of more than 6000 MW located in China. Location is very important for establishing a wind farm. In general, a place to establish a wind power plant should be chosen that has suitable wind conditions, access to the electricity transmission network, and physical access. Electricity production has a direct relationship with wind speed and wind direction [6], which is explained in the section of wind conditions.

Wood Mackenzie analysts expect China to install more than 400 gigawatts of new wind capacity between 2021 and 2030, 73 gigawatts offshore, and the rest of the world to connect nearly 600 gigawatts to the grid. The wind power capacity forecast for the rest of Asia and the Pacific is 126 GW of new capacity between 2021 and 2030, half of which will be provided by India. Meanwhile, analysts expect Europe to connect 248 gigawatts of new wind capacity to the grid over the next decade, 34% of which will be offshore. US wind capacity is projected at 114 GW of new wind power capacity, including 35 GW due to increased PTC development between 2021-2023. In Latin America, there is a forecast of 42 GW of new grid-connected capacity between 2021 and 2030, with the vast majority (90%) of this capacity in Brazil, Chile, Colombia, and Mexico. Analysts also predict that 47 gigawatts of new wind capacity will be added in the Middle East and Africa by 2030Considering the amount of planning and construction that must be done to reach the predicted capacities, the study is necessary to determine the best place to install wind power plants.

One strategy for mitigating the variability of wind power is by aggregating wind farms that cover a large geographical area. The aggregation of wind farms creates a smoothing effect: individual wind farms with different wind utilization rates are grouped into a synthesized system, thereby producing a single output with minimal variability compared to each generation unit or wind farm prior to aggregation [7,8]. Another strategy for mitigating the variability of wind power is by using energy storage systems (ESSs). ESSs can be applied to the power system in a variety of forms (e.g., CAES, electrochemical batteries, and flow batteries) and can provide a variety of services (e.g., renewable power output smoothing, peak shaving, and frequency regulation). Also, ESS can improve the operational reliability of wind power systems and aid in the reduction of electricity production costs [9-12]. reference [6] By incorporating Geographic Information System (GIS) tools and the Analytical Hierarchy Process (AHP) offers a comprehensive solution to balance energy production, cost factors, and environmental impacts.

Remote sensing is the process of identifying and monitoring the physical properties of an area by measuring its reflected and emitted radiation at a distance (usually from a satellite or aircraft) [13]. Today, remote sensing has different uses, including the discovery and mapping of the topography of the unevenness of the earth and oceans and temperature changes without the need for travel [14]. Tracking the growth of a city and changes in agricultural land or forests over several years or decades. Tracking clouds and dust storms and tracking pollution. Google Earth Engine is an artificial intelligence that uses satellite data and is considered a practical tool for remote sensing with the support of Google information. Google Earth Engine (GEE) is a cloud-based platform that facilitates geoprocessing, making it a tool of great interest to the academic and research world. reference [15] proposes a bibliometric analysis of the GEE platform to analyze its scientific production. Reference [16] examines trends and applications of the Google Earth engine in remote sensing and earth science research. and [17] performs planetary-scale geospatial analysis by Google Earth Engine.

Usually, to increase the efficiency of wind power plants, the structure of the turbine, including the structure of the blades and the generator, is examined, and the turbines are installed in the places desired by the operators without a general survey of the area. So that first an area is selected, then with the help of the wind atlas, the amount of wind in the area is checked and if it is suitable, it is installed, but this place is not necessarily the best place to install the power plant, and this is a big bug in the installation of wind turbines. The main goal of this article is to remove this bug by choosing the best place to install wind turbines for establishing a wind power plant.

In this article, we will first examine the effect of wind sources on the performance of wind turbines. Also used GEE as a remote sensing knowledge toolbox. First, the method of using GEE is explained, and then the exact location of a wind power plant is discussed, and all the necessary environmental conditions, including wind speed and direction, and the temperature of the area, are checked, and the best place for the establishment of the power plant is selected.

The rest of the structure of the article is as follows: In section 2, wind power plants are discussed and wind resources are also examined. Also, in section 3, we will discuss remote sensing and how it works, and finally, we will examine a case study in section 4.

2. Wind power plant

Wind turbines work on a simple principle, instead of using electricity to generate wind, they use wind to generate electricity. The wind spins the turbine blades around the rotor, and the blades spin the generator, producing electricity. First, we need to understand wind power, wind is a form of solar energy that is created by a combination of three simultaneous events:

The sun unevenly heats the atmosphere, the irregularity of the earth's surface and the rotation of the earth. The flow and speed of the wind varies greatly across the globe and is modified by flowing water, vegetation and the unevenness of the land. Wind current is a clean and renewable kinetic energy that can be used for many purposes such as sailing, flying kites, and even generating electricity. The terms "wind energy" and "wind power" both describe the process by which the wind It is used to generate mechanical power or electricity. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity. A wind turbine converts wind energy into electricity using the aerodynamic force of rotor blades that act like airplane wings or helicopter rotor blades. As the wind flows across the blade, the air pressure is reduced on one side of the blade. The difference in air pressure on both sides of the blade causes it to rise and stretch. The lift force is stronger than the drag and this causes the rotor to rotate. The rotor is connected to the generator either directly (if it is a direct drive turbine) or through a shaft and a series of gears (gearbox) which speeds up the rotation and allows for a physically smaller generator. This conversion of aerodynamic force into the rotation of the generator creates electricity.

2.1. Wind Resource

Several different factors influence the potential wind resource in an area. The three main factors that influence power output are: wind speed, wind condition, air density, and blade radius. Wind turbines need to be in areas with a lot of wind on a regular basis, which is more important than having occasional high winds.

Wind speed largely determines the amount of electricity generated by a turbine. Higher wind speeds generate more power because stronger winds allow the blades to rotate faster. Faster rotation translates to more mechanical power and more electrical power from the generator. The relationship between wind speed and power for a typical wind turbine is shown in Figure 1. Turbines are designed to operate within a specific range of wind speeds. The limits of the range are known as the cut-in speed and cut-out speed. The cut-in speed is the point at which the wind turbine is able to generate power. Between the cut-in speed and the rated speed, where the maximum output is reached, the power output will increase cubically with wind speed. For example, if wind speed doubles, the power output will increase 8 times. This cubic relationship is what makes wind speed such an important factor for wind power.

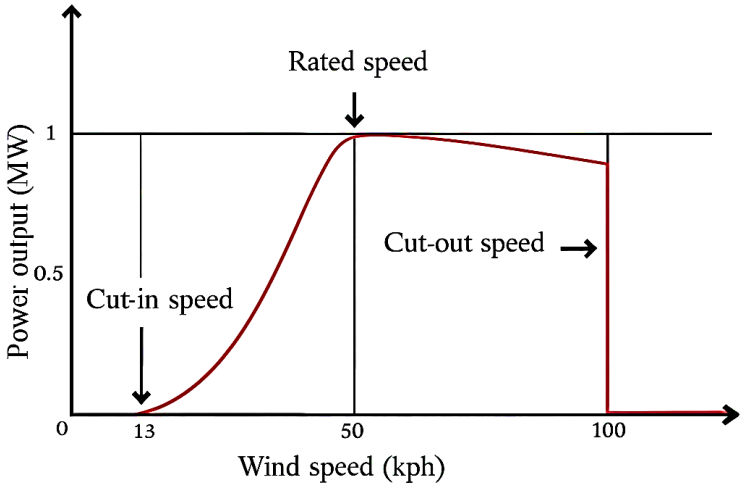

Figure 1. Arbitrary power curve of a 1 MW wind turbine compared to wind speed.

This cubic dependence does cut out at the rated wind speed. This leads to the relatively flat part of the curve in Figure 1, so the cubic dependence is during the speeds below 15 m/s (54 kph). The cut-out speed is the point at which the turbine must be shut down to avoid damage to the equipment. The cut-in and cut-out speeds are related to the turbine design and size and are decided on prior to construction.

The balancing factor is that strong gusts and high turbulence require more powerful and more expensive turbines, otherwise there is a risk of damage. The average power in the wind is not proportional to the average wind speed. The closer the angle of the wind with the blades is to 90 degrees, the more wind power is needed to move the blades. For this reason, ideal wind conditions would be strong but steady winds with little turbulence from one direction. Mountain passes are ideal places for wind power plants in these conditions. Wind turbines are designed to maximize the rotor blade radius to maximize power output. Larger blades allow the turbine to capture more of the kinetic energy of the wind by moving more air through the rotors. However, larger blades require more space and higher wind speeds to operate. As a general rule, turbines are spaced out at four times the rotor diameter. This distance is necessary to avoid interference between turbines, which decreases the power output. It should also be noted that power output of wind power plant is related to the local air density, which is a function of altitude, pressure, and temperature. Dense air exerts more pressure on the rotors, which results in higher power output. Also, high humidity and temperatures below zero and above 40 degrees have a negative effect on turbine performance. So, in general, we need to know the wind speed and wind direction, the density of the environment (temperature, altitude and air pressure) and the humidity of the environment to study the suitable location of the wind power plant.

3. Remote Sensing

Remote sensing provides information about objects at or near the surface of the Earth and atmosphere based on radiation reflected or emitted from those objects. The information is usually captured at a distance from above in the form of image data. Such data allow us to determine the composition and nature of the Earth's surface and atmosphere from local to global scales, and assess changes by analyzing images captured at different points in time. In this sense, remote sensing is useful in providing spatial information that is otherwise difficult or impossible to obtain. In the social sciences remote sensing is useful for visualizing (providing alternative and synoptic views) and classifying human environments. Social science researchers commonly integrate remotely sensed data or its derivatives with other socioeconomic data sets within geographic information systems to conduct spatial analyses. We said that remote sensing is the process of identifying and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (usually from a satellite or aircraft) [13]. And Google Earth Engine is a powerful tool for using remote sensing knowledge. In the following, we will explain the performance of GEE. According to the classification of moisture concepts carried out by UNESCO, Iran's climate is divided into four types: humid, dry, semi-arid and ultra-arid. Based on this, the Tehran with humid climate is considered. In Figure 2 show flowchart of the research process is shown. Using GEE, the desired satellites are selected first, the sentinel-5p satellite is selected to receive and process data. One of the uses of this satellite is weather forecasting and it has the ability to calculate temperature, wind speed, air pressure, etc. Then the desired areas are selected using them that it is shown in Figure 3. Then the desired coding is done to obtain the desired parameters such as the speed and direction of the wind and the density of the environment. Each parameter has its own wavelengths and information, the task of satellites is to identify this information, and the desired parameters are calculated in two medium-term and long-term intervals. Mid-term data of about one year to examine all seasons and examine current environmental conditions. The long-term data of about ten years are analysed to examine the climate changes of the region from the past to the present, so that we can have a general view of the future of the region.

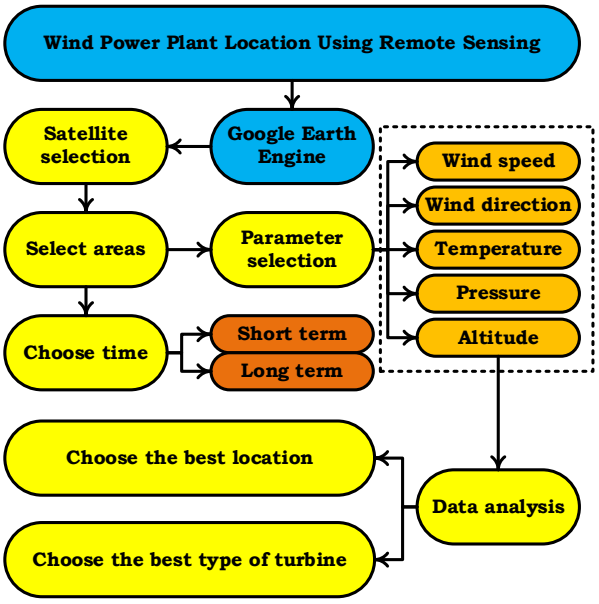

Figure 2. The flowchart methodology of this research.

Figure 3. The Geographical location of desired place.

4. Results

We conduct the desired research on the city of Tehran in two short-term and long-term periods. The short-term period is one year and the year 2020 has been selected. First, we calculate the wind speed. The wind speed is measured in meters per second with the amount of recorded data of 196 data per year, which is one measurement data almost every two days. and this amount of data is reliable. The results of measuring the wind speed in Tehran in year 2020 in terms of meters per second are shown in Figure 4. The wind speed in 2020 fluctuated between 0.31 and 3.247 meters per second. Also, the average wind speed was 1.35 meters per second, which you can see in Table 1.

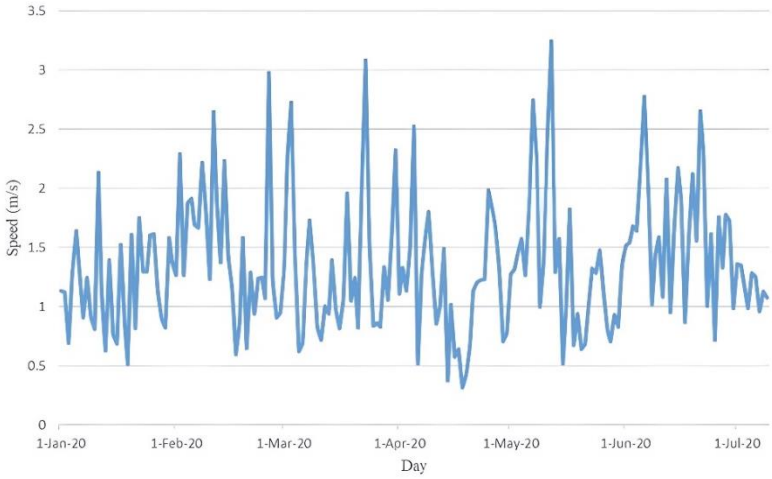

Figure 4. Wind speed chart in (m/s) in 2020 in Tehran city.

Figure 5 is a graphic representation of the amount of wind blowing in different areas of Tehran. Warmer colors show higher wind speeds, and on the contrary cooler colors show lower wind speeds. As you can see, the south, southwest and west of Tehran are the places where the wind speed is higher than other areas. Also, in the north and east of Tehran, the wind speed is lower than in other regions.

In Figure 6, you can see a column chart of wind direction for Tehran city in year 2020. The amount of wind blowing in all directions is expressed separately and as a percentage. The amount of wind blowing in the northeast direction of is 64% as the lowest value. Also, western winds account for 24% of the total wind gusts, which is the highest amount. South, southwest, and northwest winds each account for 14% percent. Southeast winds account for 13% percent, and finally, north and east winds account for 9% and 7% percent are assigned to themselves, respectively. According to the values provided, the best direction to install the turbine blades is in the direction of the west winds so that maximum wind power can be used.

Table 1. Minimum, maximum and average of wind speed in (m/s) in Tehran city in the year 2020.

Average	Maximum	Minimum
1.350	3.247	0.319

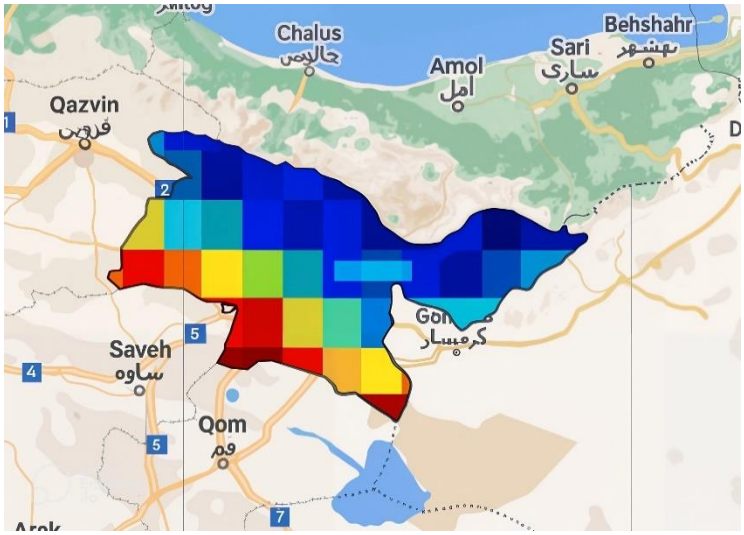

Figure 5. Graphic representation of the amount of wind blowing in different areas of Tehran. Warmer colors show higher wind speeds, and on the contrary cooler colors show lower wind speeds.

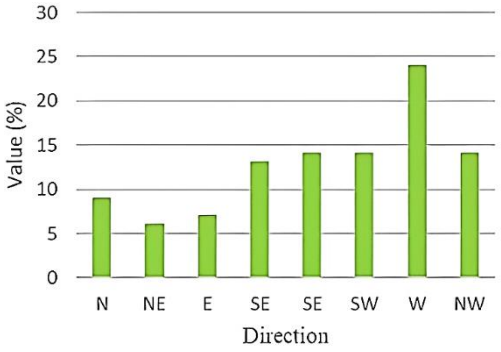

Figure 6. Bar chart of wind direction values in percentage in Tehran city for 2020 (including main and secondary directions**).**

After the short-term surveys (one-year period) of the wind condition, we will move on to the long-term studies (10-year period from 2010 to 2020). As you can see in Figure 7, the wind condition in Tehran is relatively has been stable and the average wind speed in these ten years is about 1.3 (m/s). As you can see in the Figure 8, the average wind speed in 2020 is higher than the annual average, and the 10-year average speed is a more reasonable number for predicting the coming years. As a result, the best value for estimating the wind speed is the ten-year average.

Figure 9 is a graphic representation of the amount of wind blowing in different areas of Tehran for the period of 2010 to 2020. Warmer colors indicate higher wind speed and on the contrary, cooler colors indicate lower wind speed. As you can see, the southwest of Tehran has had the highest amount of wind during these ten years. The 10-year survey was able to show a more accurate location than the 1-year survey.

Figure 10 shows the temperature changes of Tehran city in 2020. The temperature is displayed during the day and night. You can see that in the months of August and July, the daily temperature reaches 50 degrees Celsius. On the other hand, the air temperature at night in December and February reaches below ten degrees Celsius. As a result, the components of the turbine must be selected in such a way that they can work easily in this temperature range and can withstand freezing nights for about 2 months without being damaged. Also, Figure 11 shows the temperature of Tehran in August. You can see that the southern part of Tehran has a higher temperature and the northern part of Tehran has a more moderate temperature.

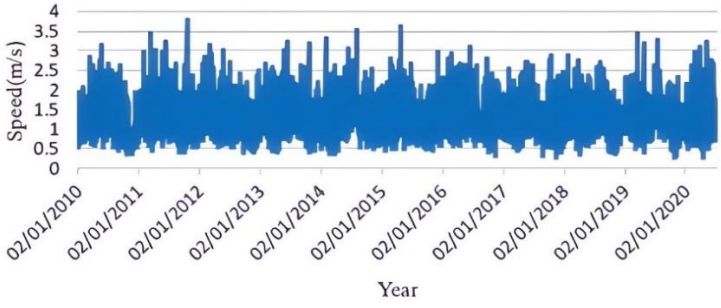

Figure 7. Wind speed chart in (m/s) in years 2010 to 2020 in Tehran city.

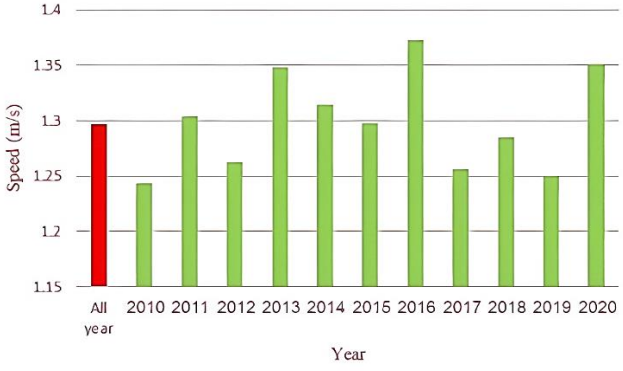

Figure 8. Average wind speed chart in (m/s) in years 2010 to 2020 in Tehran city.

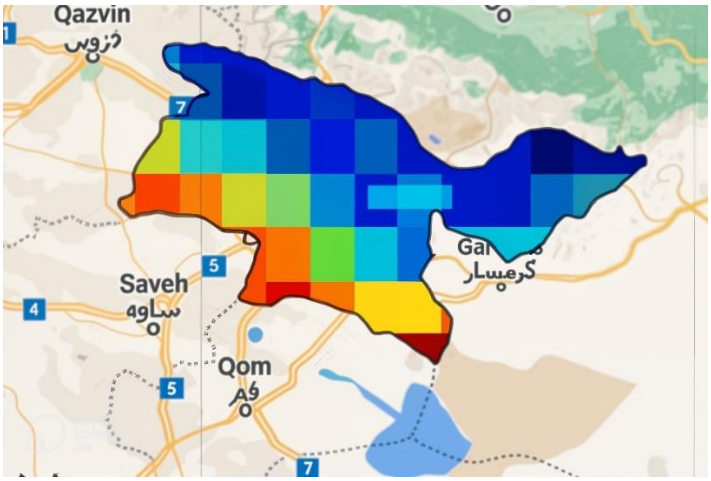

Figure 9. Graphic representation of the amount of wind blowing in different areas of Tehran for year 2010 to 2020. Warmer colors show higher wind speeds, and on the contrary cooler colors show lower wind speeds.

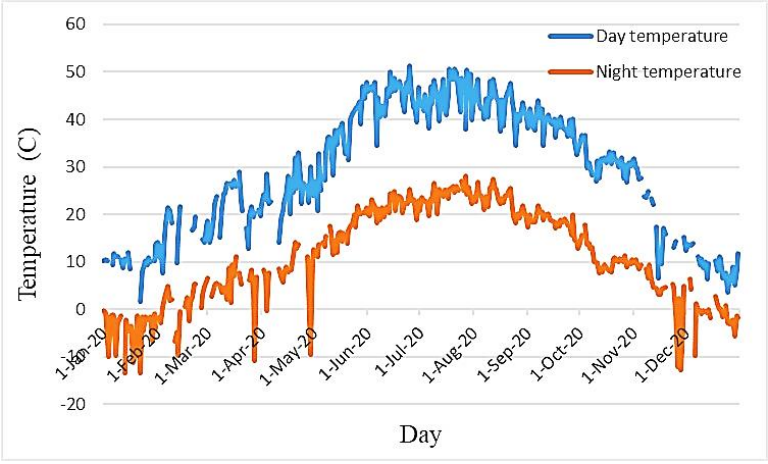

Figure 10. Shows the temperature changes of Tehran in 2020 in Celsius.

One of the advantages of GEE is the remote measurement of parameters, especially the measurement of air pressure. Table 2 shows the average surface air pressure of Tehran city in 2020. It means air surface pressure at heights near the ground (wind turbine installation height). The measurement has been done for 6 months. Also, Figure 12 shows the graphic view of surface air pressure in Tehran in 2020. The south of Tehran has more air pressure and the air pressure decreases as you move to the north of Tehran and increase the height above the sea level.

The purpose of measuring air temperature and pressure is to find air density. Air density is the ratio of mass to volume of air in the earth's atmosphere. Air density decreases with increasing altitude, which is an indication of air pressure. Also, changes in temperature and humidity change the density of the air. The density of air at sea level at 15 degrees Celsius and according to the international standard atmosphere is about 1.225 kg/m3 and 0.075 lb/m3. As a result, in terms of air density, south of Tehran is a more favourable area for establishing a wind power plant.

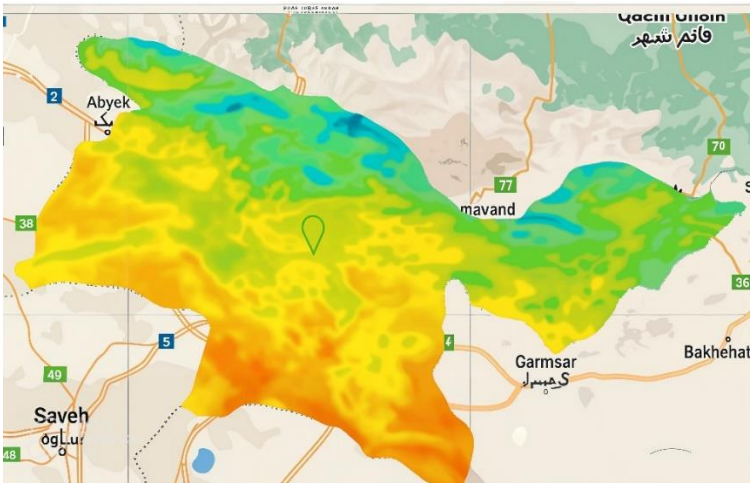

Figure 11. Shows the temperature of Tehran in August graphically for year 2020.

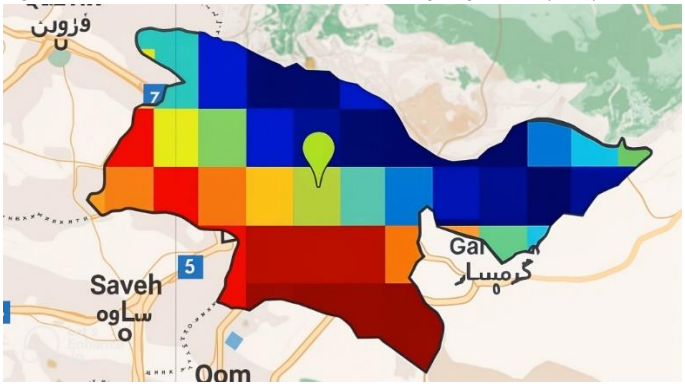

Figure 12. Shows the graphic view of surface air pressure in Tehran in 2020.

Table 2. Shows the average surface air pressure of Tehran city in 2020.

Day	Surface pressure (Pa)
1-Jan-2020	83,466.96
1-Feb-2020	83,445.59
1-Mar-2020	83,362.64
1-Apr-2020	83,393.91
1-May-2020	83,528.11
1-Jun-2020	83,213.36

5. Conclusion

Remote Sensing is a new science that is growing rapidly with the development of satellites and its applications are increasing. We were able to investigate the environmental conditions of the target area by using this knowledge and using GEE. In addition to the mentioned parameters, with GEE, it is easy to look at the geographical situation of the region (lowlands and highlands) and also other parameters, such as the level of air, land and water pollution, to check fossil fuel power plants. In this article, we presented a method for locating the wind power plant according to the environmental conditions to increase the efficiency of the turbines using remote sensing knowledge. One of the advantages of using this method is access to remote area information in all places, including inaccessible places such as the highest mountains to the deepest valleys. Also, high speed and easy access to data and finally large amount of data for long periods of time can be considered as advantages of this method. High accuracy is another advantage of this method. Also, this method can be used to make decisions in the area of choosing the location of other power plants, including solar power plants in the whole country or at the level of a small city.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Contribution Statement: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Software, Writing-review & editing.

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Contribution Statement: Conceptualization.

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Contribution Statement: Conceptualization, Formal analysis, Investigation, Resources, Software, Roles/Writing-original draft, Writing-review & editing.