

Wind speed and wind power changes with height in the Absheron peninsula coastal zone

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Abstract. The article analyzes in detail the change in wind speed with height in four main points located in the coastal zone of the Absheron Peninsula, which are quite promising in terms of wind energy production in Azerbaijan - Pirallahi, Mardakan, Sumgayit and Sangachal for 2001–2024. Within the framework of the study, the statistical characteristics of wind speed and wind power change dynamics at heights of 10 and 50 meters were investigated for each point. Graphs reflecting the change in wind speed and power by years, months and seasons were constructed, and long-term trends were assessed. In addition, special attention was paid to the changes in wind speed during the day at the selected points. As a result of the analysis, it was found that the wind regime in coastal zones differs in both seasonal and daily rhythms, and these characteristics directly affect the possibilities of using wind as a renewable energy source. At the end of the study, two important theoretical models - the power law and the logarithmic law - were applied to take into account the height-dependent variation of wind speed, and their advantages and suitability were comparatively evaluated.

Keywords: wind speed; wind energy; wind power; Log law; Power law.

Citation: Rasulzadeh, V. (2026). Wind speed and wind power changes with height in the Absheron peninsula coastal zone. *Bulletin of the L.N. Gumilyov ENU. Chemistry. Geography Series*, 154(1), 154-170.

<https://doi.org/10.32523/3107-278X-2026-154-1-154-170>

Academic Editor:
N.E. Ramzanova

Received: 26.02.2026

Revised: 28.02.2026

Accepted: 11.03.2026

Published: 31.03.2026



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1. Introduction

The acceleration of climate change and the challenges of energy security are driving countries around the world towards clean and renewable energy sources. In this context, wind energy is considered one of the most attractive alternatives with its long-term environmental and economic efficiency. (International Energy Agency, 2023; Pryor et al., 2010). Wind parameters are determined by altitude and synoptic conditions. At the same time, differences in their values are observed in different months and seasons of the year, as well as at different times of the day (Kubik et al., 2011). For the correct assessment of wind energy potential, it is of particular importance to study the variation of wind speed depending on altitude (Tar et al., 2009). The research study analyzed the characteristics of wind speed variations at heights of 10 and 50 meters at four selected points located on the Absheron Peninsula. The analyses conducted contribute to determining the optimal heights and locations for technical applications of wind energy.

Brief information about the climate and wind regime of the area

The Absheron Peninsula is the largest peninsula located on the western coast of the Caspian Sea. The semi-desert dry-steppe climate prevails on the peninsula. The average wind speed on the Absheron Peninsula is 5.8-7 m/s. The number of days with strong winds (over 15 m/s) in different points of the peninsula is up to 64-145 days. Winds over 30 m/s are often observed. North winds (strong winds), winds blowing from the northeast and south directions prevail. In general, the influence of meridional atmospheric processes is characteristic of the Absheron-Gobustan region. This is explained by the influence of the Kara, Scandinavian, Azores maxima, and high-pressure areas formed in the south of the European part of Russia. As a result of the influence of these processes, the weather changes sharply, strong northerly winds blow, the air temperature drops, and precipitation is often observed. During the cold period of the year, the influence of Central Asian and subtropical anticyclones increases (Mammadov, 2014).

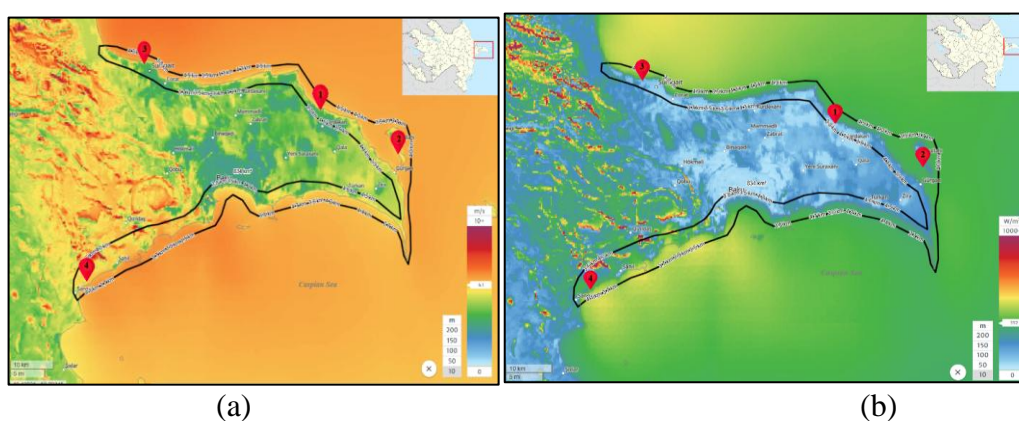


Figure 1. Wind speed and power distribution at height of 10 m

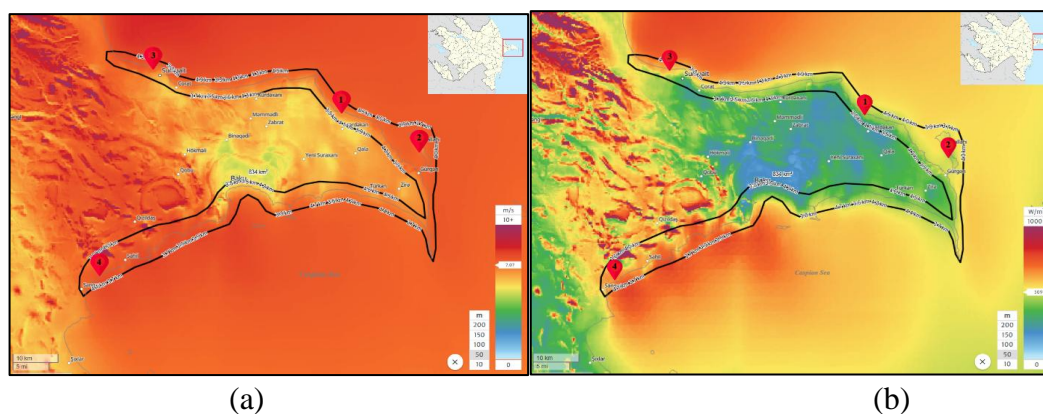


Figure 2. Wind speed and power distribution at the height 50 m

Figure 1 shows the distribution of wind speed (a) and wind power (b) at a height of 10 m and Figure 2 at a height of 50 m on the Absheron Peninsula. At a height of 10 m, wind speed is mainly high in the western and southwestern areas of the peninsula, and relatively weak inland. Accordingly, wind power is also more limited and local in nature; large-scale potential areas are limited (Figure 1). At a height of 50 m, a general increase in wind speed is observed, and this increase is especially noticeable in areas in the coastal zone. Wind power has also increased significantly, and areas with 500–600 W/m² and higher have expanded (Figure 2). As the height increases, both wind speed and power increase significantly. This also indicates that wind turbines installed at heights of 50 m and above enable a more efficient assessment of the region's wind energy potential across different altitudes.

2. Materials and methods

The study analyzed the variation of wind speed and wind power depending on altitude on the Absheron Peninsula, located in the coastal zone of the Azerbaijani sector of the Caspian Sea. For this purpose, hourly wind data at heights of 10 m and 50 m with a resolution of $0.5^{\circ} \times 0.625^{\circ}$ were obtained from the NASA (NASA, 2025) space database. These satellite data, collected and archived for four stations included in the study area, cover the years 2001–2024. Based on the obtained data, statistical indicators of wind speed and power at different time intervals (annual, seasonal, and monthly) for both altitudes were calculated, and the results were visualized in the form of graphs. In addition, wind speed and power maps of the study area were prepared using the ArcGIS software based on the data obtained from the Global Wind Atlas (GWA, 2025), and wind rose graphs were drawn up for each station in the Grapher program. Based on the obtained results, comparative analyses were conducted at different altitudes.

3. Results and discussion

3.1. Variation of wind speed and direction depending on height

Wind speed and direction are key parameters of the movement of air masses in the atmosphere and play an important role in assessing wind energy potential. Wind speed is usually measured in meters per second (m/s) and can vary at different altitudes, while wind direction is determined based on geographical directions. According to the International Energy Agency (IEA, 2013), the consistency of wind direction and statistical distribution of speed are considered key indicators in optimizing wind energy projects (Archer et al., 2005).

Observations show that the wind increases in strength with increasing height above the ground. This is called the Velocity or Height Effect. Near the ground surface, the flow encounters surface roughness that impedes the flow to reduce the wind speed and present a variety of wind patterns with random vertical and horizontal velocity components at right angles to the main direction of the flow. The slowing or retarding effect occurs in the air layers near the ground and gradually decreases with increasing height until it becomes negligible. Also, there are no obstacles at high altitudes. Thus, the wind speed increases with increasing height above the ground (Aiyer, 2021).

Table 1. Average multi-year wind speed, force, and standard deviation at selected points at 10 and 50 meters altitude

№	Coordinate (Lat/Lon) N / E	Average wind speed, V (m/s)		Standard deviation, σ_v (m/s)		Wind Power, P W/m ²		Wind Power Classifications	
		10m	50m	10m	50m	10m	50m	10m	50m
1	40.52 / 50.13 - Mardakan	5.5	6.65	2.94	3.93	196	347	Poor	Moderate
2	40.43 / 50.37 - Pirallahi	5.75	6.58	2.95	3.67	224	336	Marginal	Moderate
3	40.64 / 49.54 - Sumgayit	4.52	5.84	2.6	3.13	109	235	Poor	Marginal
4	40.24 / 49.51 - Sangachal	4.55	5.76	2.41	2.86	111	226	Poor	Marginal

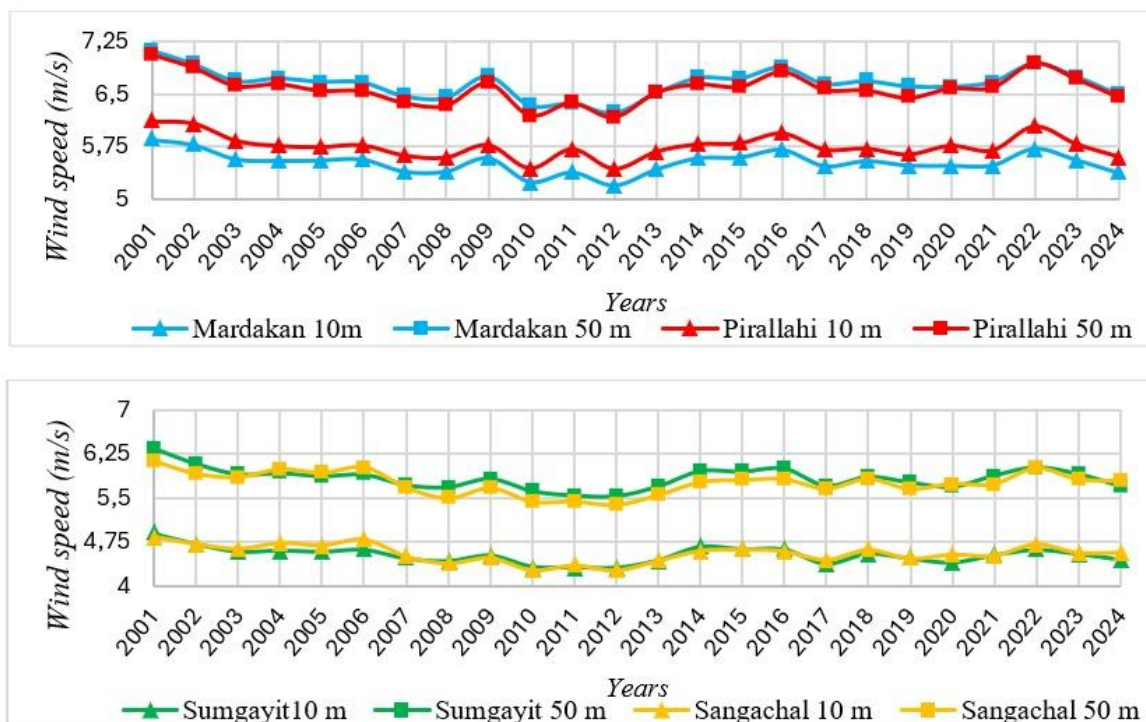


Figure 3. Time-varying average annual wind speed at 10 and 50 meters height at the study points during 2001-2024

Figure 3 shows the change in wind speed at 10 and 50 meters altitudes over a multi-year period at the survey points. Thus, the maximum values were observed at 50 meters altitude in Mardakan and Pirallahi, respectively, as 7.12 and 7.06 m/sec. At 10 meters altitude, these values were recorded as 6.12 and 5.86 m/sec. At Sumgayit and Sangachal stations, the maximum wind speed at 50 meters altitude was 6.34 and 6.13 m/sec, respectively. At 10 meters altitude, the indicators decreased to 4.89 and 4.83 m/sec. Although a certain downward trend in wind speeds was observed over time, local increases were recorded in some years. In general, an increase in wind speed was observed at higher altitudes, highlighting the wind energy potential of these areas.

Table 2. Variation of average monthly wind speed with height at selected points

№	Coordinate (Lat/Lon) N / E	Height (m)	Months											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
			Multi-year average monthly wind speed (m/s)											
1	40.52/50.13 Mardakan	10	6	5.9	5.8	5.1	4.4	5.1	5.5	5.0	5.6	5.8	6.1	6.2
		50	7.2	7.2	7.2	6.8	5.7	6.2	6.5	5.8	6.5	6.7	7.2	7.3
2	40.43/50.37 Pirallahi	10	6.5	6.3	6	5.1	4.4	5.1	5.5	5.1	5.8	6	6.5	6.7
		50	7.4	7.3	7.2	6.4	5.5	5.9	6.1	5.6	6.3	6.6	7.3	7.5
3	40.64/49.54 Sumgayit	10	4.6	4.7	4.7	4.2	3.9	4.5	5	4.6	4.5	4.4	4.5	4.5
		50	6.1	6.2	6.2	5.5	5.1	5.7	6.2	5.7	5.7	5.7	6	6.1
4		10	4.4	4.5	4.6	4.2	4	4.6	5.2	4.9	4.9	4.6	4.5	4.3

40.24/49.51 Sangachal	50	5.7	5.9	5.9	5.3	5	5.7	6.3	6	6.1	5.8	5.8	5.6
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Figure 4, prepared based on Table 2, shows the monthly average wind speeds at 10 m and 50 m altitudes for 4 locations (Mardakan, Pirallahi, Sumgayit, Sangachal) based on multi-year averages. As can be seen, at 10 m altitude in Mardakan and Pirallahi, the highest values are reached in I, II, III, XI, and XII months. In June, July and August, the wind speed decreases to a minimum. In Sangachal and Sumgayit, the highest wind speed is in July, and the lowest speed is in May.

At 50 m altitude, the wind speed for all months is higher than at 10 m. The highest speeds are observed in the winter months, especially in December and January - rising to 7.5 m/s (in Mardakan and Pirallahi). In Sumgayit and Sangachal, the maximum wind speed at 50 m is observed in July, with 6.2 and 6.3 m/s.

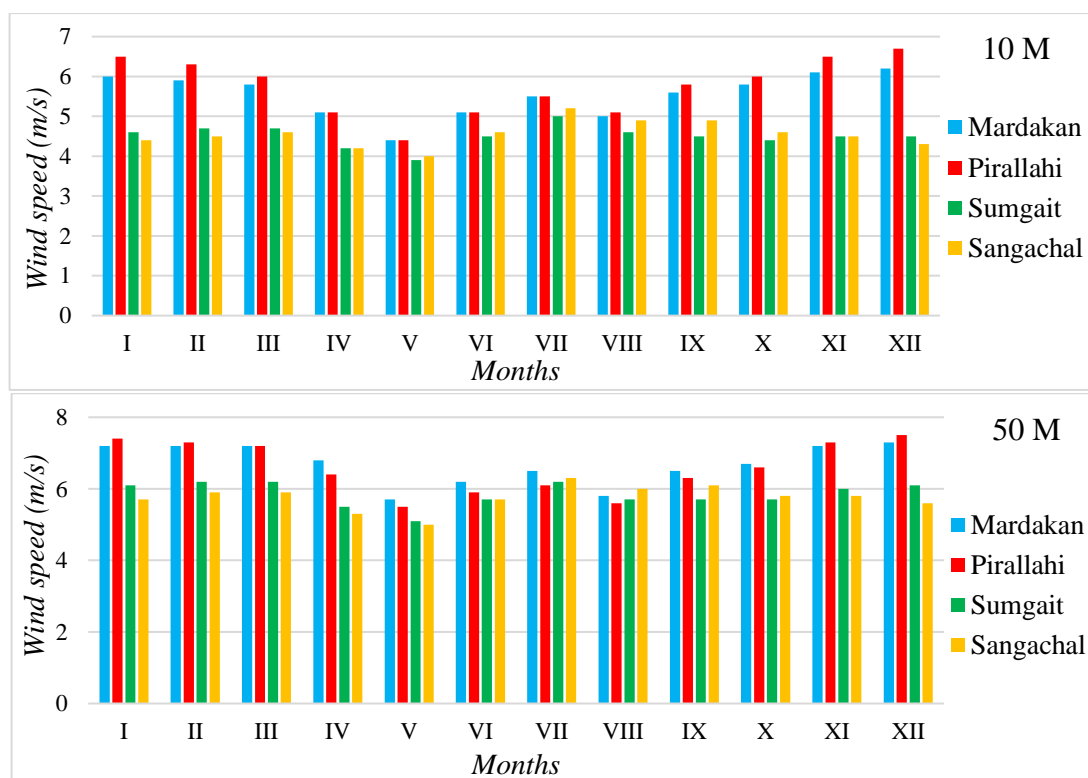


Figure 4. Multi-year average monthly wind speed at 10 and 50 meters height

Table 3 shows that at a height of 10 meters, winds with a speed of 0-6 m/s dominate at all locations. However, at a height of 50 meters, the opposite process occurs, and wind speeds above 6 m/s are observed more often than at a height of 10 meters. This trend confirms that wind speed increases with increasing height. Thus, at a height of 50 m, more favorable conditions are formed in terms of wind energy production.

Table 3. Percentages of the total number of windy days by year

Wind speed gradations (m/s)	Percentage of windy days (%)								
	Mardakan		Pirallahi		Sumgayit		Sangachal		
	10m	50m	10m	50m	10m	50m	10m	50m	

0-3	13	5	12	8	22	6	18	5
3-6	50	41	46	38	59	54	63	57
6-9	20	35	32	34	16	28	16	29
9-12	7	15	9	16	3	10	3	8
12-15	0.98	3	1	3	0.3	2	0.2	1
>15	0.13	0.7	0.02	0.38	0	0	0	0.1

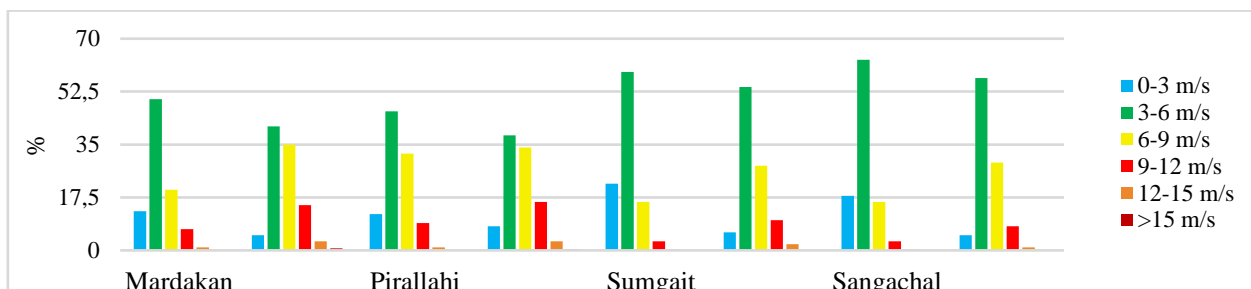


Figure 5. Distribution of wind speed recurrence frequency at the survey points at 10 and 50 meters height

According to the frequency of windy days in the studied areas, the speed interval of 3–6 m/s prevails at all altitudes. In Mardakan and Pirallahi, especially at an altitude of 50 m, the share of winds in the range of 6–12 m/s is significantly higher, which is significant in terms of wind energy. Speeds above 12 m/s were observed mainly at 50 m in Mardakan. In Sumgayit and Sangachal, more low-speed winds were recorded, and the energy potential in these regions can be assessed relatively poorly (Figure 5).

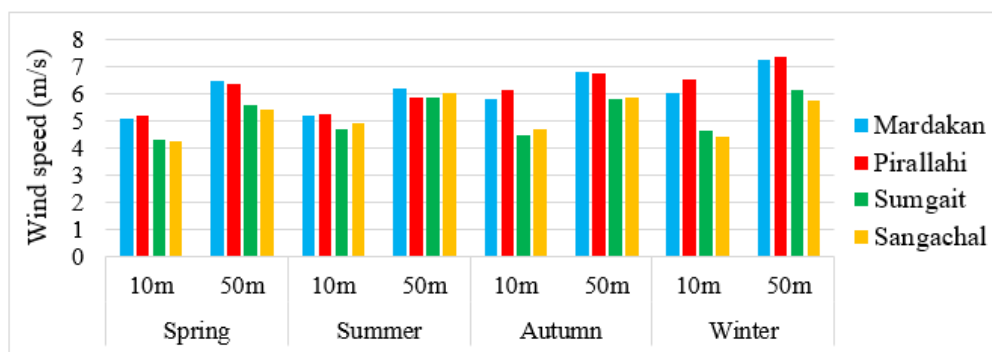


Figure 6. Seasonal variation of wind speed at 10 and 50 m height at the study points

The maximum values of wind speed at a height of 50 meters in Mardakan, Pirallahi and Sumgayit are observed in winter and in Sangachal in summer. At a height of 10 meters, these values are observed in Mardakan and Pirallahi in winter and in Sangachal and Sumgayit in summer (Figure 6).

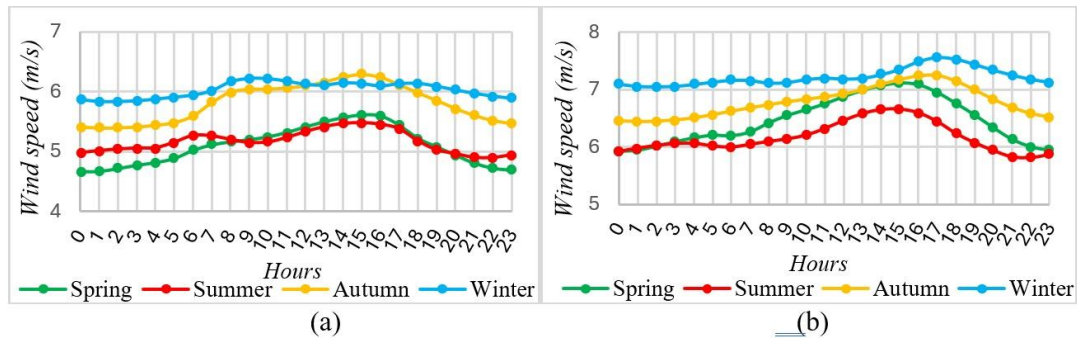


Figure 7 . Diurnal seasonal variation of wind speed at 10 (a) and 50 meters (b) altitude in Mardakan

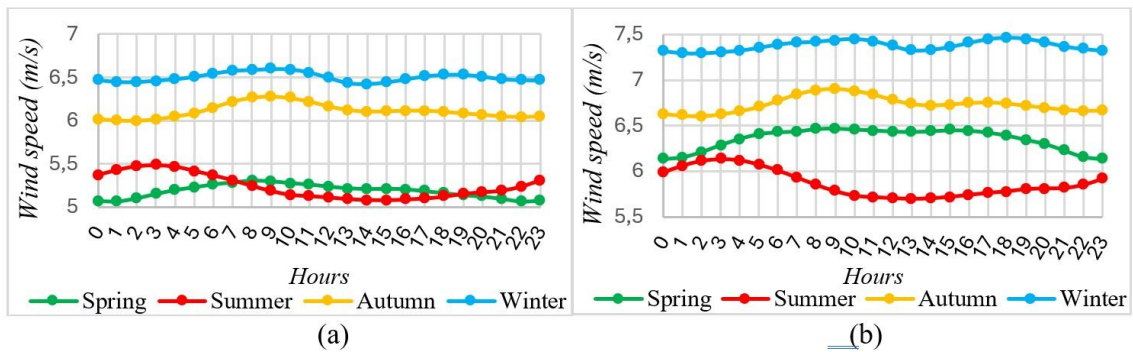


Figure 8. Diurnal seasonal variation of wind speed at 10 (a) and 50 meters (b) altitude in Pirallahi

At a height of 10 meters, although the wind speed in Mardakan remains stable throughout the day in winter and autumn, a certain increase is observed in the afternoon hours (12:00–16:00) in spring and summer. At a height of 50 meters, the wind speed increases during the daytime hours (10:00–15:00) in other seasons, except for winter (Figure 7a, 7b).

Analysis of data obtained at Pirallahi at altitudes of 10 and 50 meters shows that, unlike other locations, the diurnal variation is very weak here, there is stability. Pirallahi peninsula is located on the coastline extending directly into the Caspian Sea and is in full contact with the sea. In areas close to the sea, the diurnal temperature variation is weak, which prevents the formation of thermal convective flows during the day. While the temperature difference between the surface and the atmosphere (thermal contrast) varies strongly during the day over the land, this variation is minimal over the sea. As a result, local wind systems originating from the surface of the earth (for example, daytime breeze flows) develop poorly in coastal and island-type areas. For this reason, diurnal variability is not observed (Figure 8a, 8b).

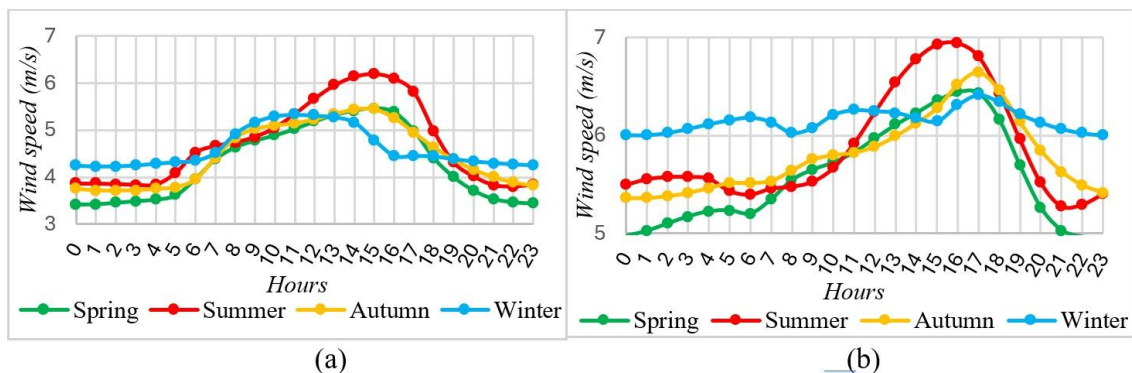


Figure 9. Diurnal seasonal variation of wind speed at heights of 10 (a) and 50 meters (b) in Sumgayit

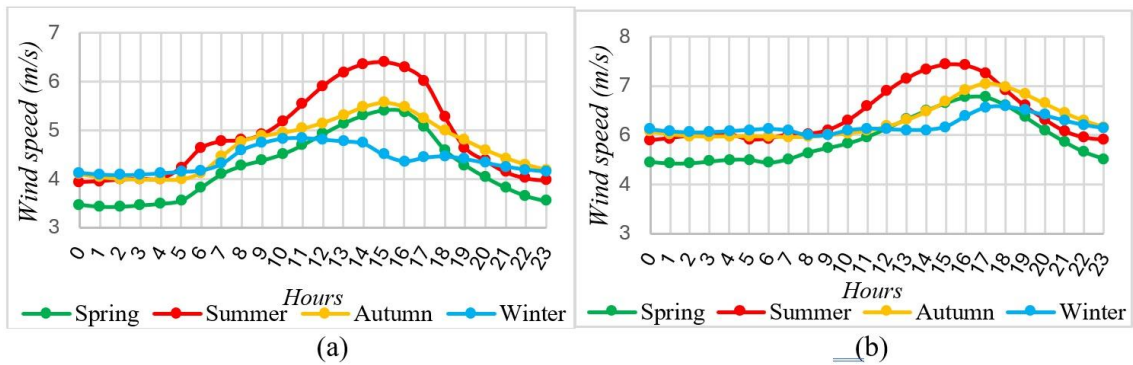


Figure 10. Diurnal seasonal variation of wind speed at 10 (a) and 50 (b) meters in Sangachal

In Sumgayit, in the summer (especially between 12:00 and 17:00), the wind speed increases significantly (6-7 m/s), while in other seasons it varies between 3.5–5 m/s. Although the wind is strong at night in winter, it decreases in the afternoon. In summer, on the contrary, it is weak in the morning and reaches its peak in the afternoon (Figure 9a, 9b).

In Sangachal, at both altitudes, in spring, summer and autumn, the wind is weak in the morning and reaches its maximum in the afternoon. This process is observed until 17:00 in the evening. Then the wind speed begins to decrease. In winter, the wind speed is almost constant throughout the day and is higher in the evening (Figure 10a, 10b).

As the altitude increases, the effect of the earth's surface (friction) decreases, as a result of which air currents move faster. This is especially noticeable in dry and open areas (Sumgayit, Sangachal). On the coasts (Mardakan, Pirallahi), the increase in altitude is not as effective because the wind is stable even in the lower layers.

Proper knowledge of wind direction is also essential to harness the maximum possible wind energy. This can also help to install the wind turbine in the best position (Hulio, 2021).

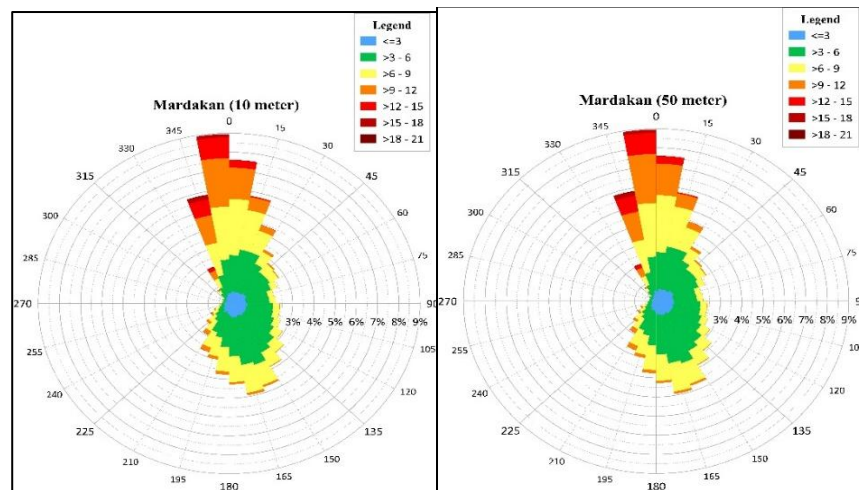


Figure 11. Wind rose graph at heights of 10 and 50 meters in Mardakan

Wind rose diagrams constructed at heights of 10 m and 50 m in the Mardakan area show that the main wind direction is dominant in the northern and northwestern sectors. The increase in wind speed at a height of 50 m and the increased probability of recurrence of winds with a speed of ≥ 15 m/s indicate that there is a favorable potential for wind energy exploitation in this area. The relatively stable wind direction can ensure the continuity of energy production (Figure 11).

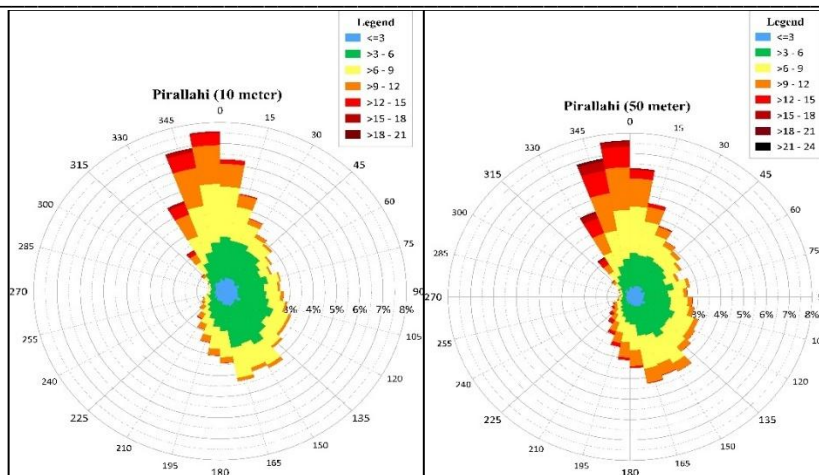


Figure 12. Wind rose graph at heights of 10 and 50 meters in Pirallahi

The wind rose graphs at Pirallahi similarly show a predominance of wind in the north and northwest directions. The fact that high-speed winds (>15 m/s) cover a wider sector, especially at an altitude of 50 m, confirms the high wind energy potential here. The high repetition frequency and stable direction compared to lower altitudes are important indicators for planning wind power plants (Figure 12).

At 10 meters above sea level, winds in Sangachal are predominantly northeasterly, with the main share of speeds varying between 3–9 m/s. Strong winds (above 12 m/s) are relatively rare. As the altitude increases to 50 meters, the dominant wind direction remains constant, but the share of speeds above 12 m/s increases significantly (Figure 13).

In Sumgayit, the main wind direction is northeasterly, with the wind mainly varying between 3–9 m/s, and high speeds are rare. At 50 meters above sea level, the wind intensifies, and the share of high speeds increases (Figure 14).

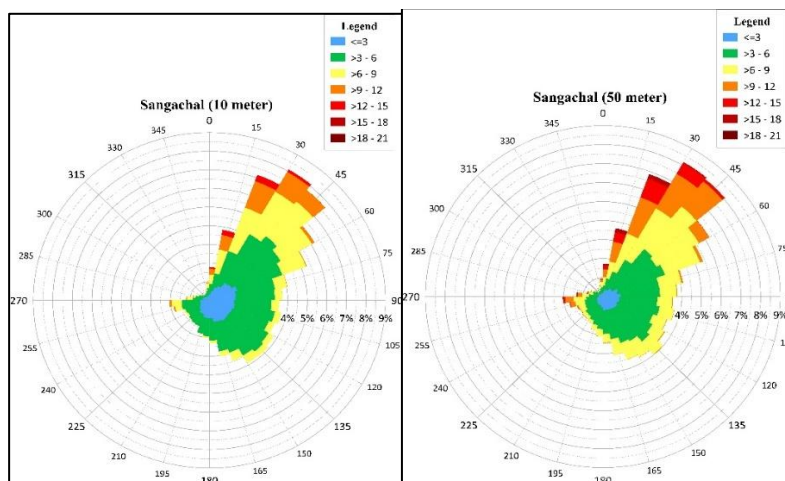


Figure 13. Wind rose graph at heights of 10 and 50 meters in Sangachal

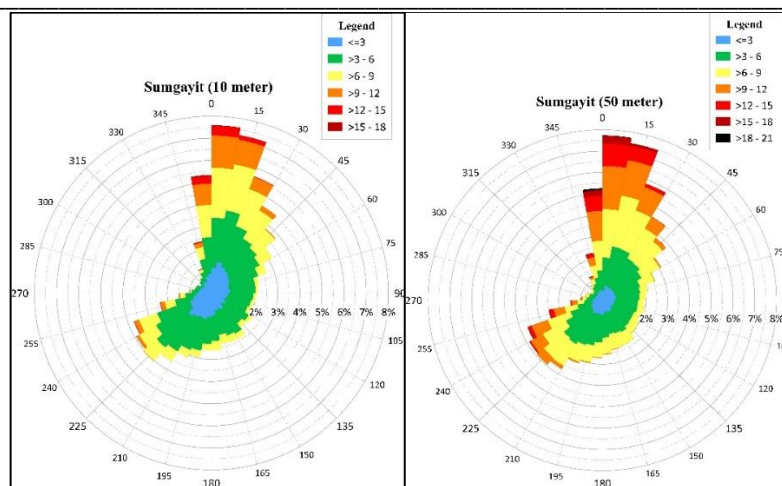


Figure 14. Wind rose graph at heights of 10 and 50 meters in Sumgayit

3.2. Variation of wind power depending on height

One of the most important factors for assessing the wind energy potential in an area is calculating the wind power (W/m^2) (Fagiano L et al., 2021). Wind power P is the energy obtained from the kinetic energy of air currents. It is proportional to the cube of the wind speed v and is calculated by the formula (Manwell et al., 2009):

$$P = \frac{\rho}{2} \bar{v}^3 \tag{1}$$

Here, $\rho = 1.225 \text{ kg/m}^3$ is the air density (Gardashov et al., 2024; Rasulzadeh, 2025).

Wind power is one of the main indicators of wind energy potential and is considered a key parameter in the initial assessment of the available opportunities for electricity generation in a given area (Sathyajith, 2007).

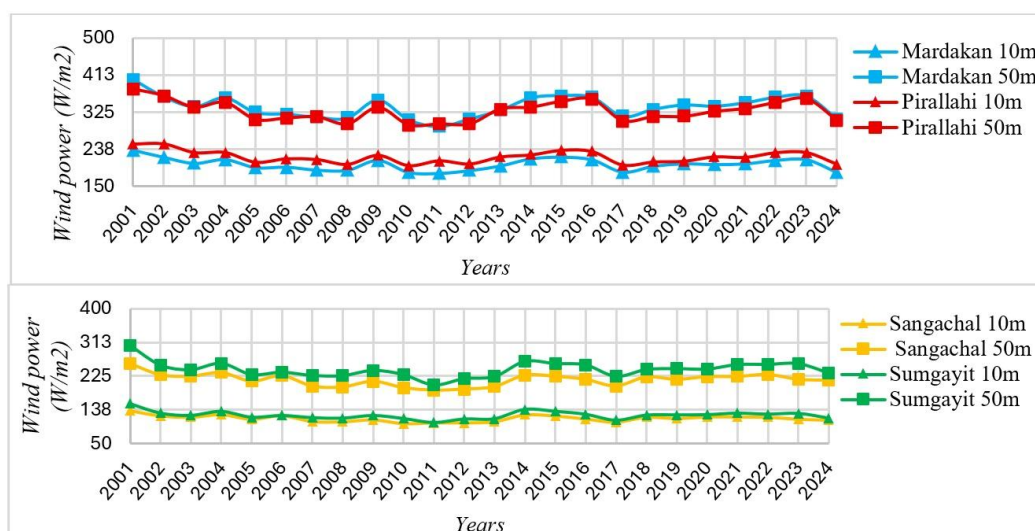


Figure 15. Time-varying average annual wind power at 10 and 50 meters height at the study points during 2001-2024

Figure 15 shows the change in wind power at selected points over the years. As can be seen, the maximum values were observed at Mardakan and Pirallahi at a height of 50 meters,

respectively, at 402 and 380 W/m². At a height of 10 meters in these points, these values were recorded as 235 and 250 W/m². At the Sumgayit and Sangachal points, the maximum wind power at a height of 50 meters was 304 and 2.58 W/m², respectively. At a height of 10 m, the indicators decreased to 152 and 135 W/m².

Figure 16 shows the average monthly wind speed at 10 m and 50 m altitudes based on multi-year averages. As can be seen, at 10 m altitude, the indicators in Mardakan and Pirallahi are higher than at other stations, and the values in I, II, III, XI, and XII months are higher. In May and August, the wind speed decreases to a minimum. In Sangachal and Sumgayit, the maximum wind speed is low throughout the year. At 50 m altitude, the highest wind speed values are observed in November-March. In Sangachal, however, this is an exception and the predominance is recorded in July.

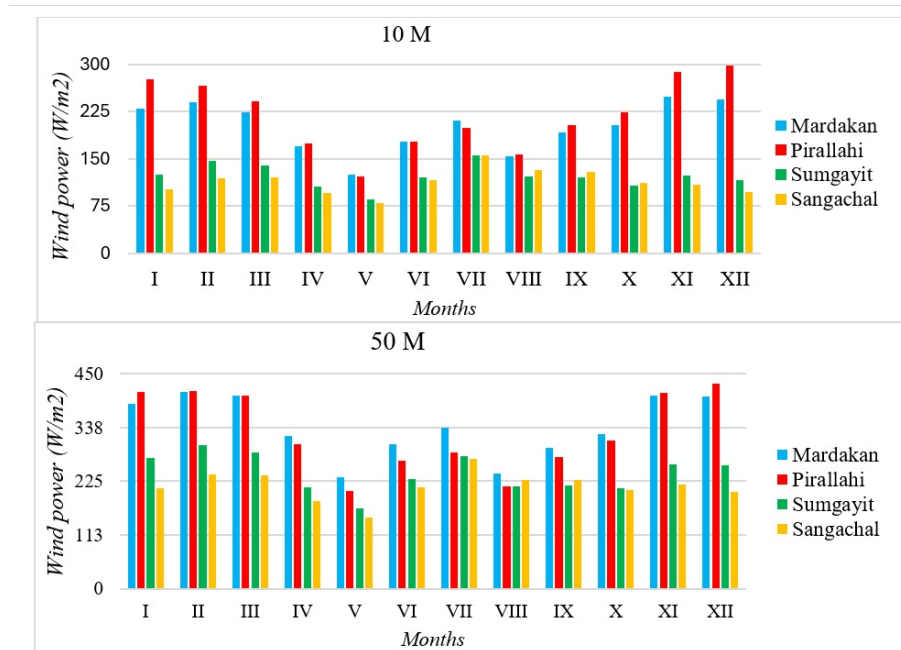


Figure 16. Multi-year average monthly wind power at 10 and 50 meters height

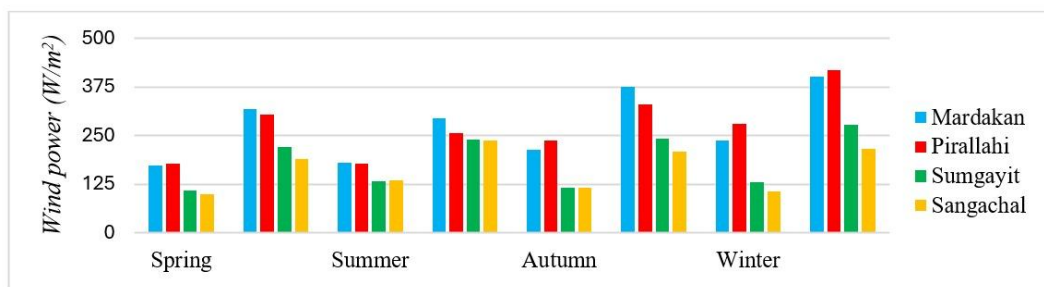


Figure 17. Seasonal variation of wind power at 10 and 50 m height at the study points

Analysis of wind speed indicators by season shows that at a height of 50 meters, the maximum wind speed is observed in the winter season in all 3 locations except Sangachal. The minimum indicators coincide with the spring-summer season. This situation is also evident at a height of 10 meters (Figure 17).

Table 4. Percentage distribution of wind strength gradations at heights of 10 and 50 meters (%)

Wind power gradations (W/m ²)	Mardakan		Pirallahi		Sumgait		Sangachal	
	10M	50M	10M	50M	10M	50M	10M	50M
0-300	79.4	64.2	76.1	63.8	89.6	75.6	90.8	79.2
300-600	13.5	19.5	16.1	19.9	7.8	14.5	7.1	12.7
600-900	4.4	8.2	5.0	8.4	1.8	5.6	1.6	4.8
900-1200	1.6	3.6	1.7	3.9	0.5	2.2	0.4	1.8
1200-1500	0.6	2.1	0.7	2.0	0.1	1.0	0.1	0.9
1500-1800	0.3	0.9	0.3	0.8	0.1	0.4	0	0.3
1800-2100	0.2	0.5	0.1	0.5	0	0.3	0	0.1
2100-2400	0	0.4	0	0.2	0	0.1	0	0.1
2400-2700	0.1	0.2	0	0.2	0	0.1	0	0
2700-3000	0	0.1	0	0.1	0	0.1	0	0
>3000	0	0.2	0	0.1	0	0	0	0

Table 4 presents percentage indicators for wind power gradations. As can be seen, in all stations, only in the interval of 0-300 W/m², the advantage falls on the height of 10 meters. In other cases, the advantage is at a height of 50 meters. This power range is observed at a height of 10 meters, in Sangachal. Based on the wind power gradations, it is clear that in all stations, a higher energy density is observed at a height of 50 meters than at 10 meters. This indicates that as the height increases, the potential for using wind energy increases and the optimal height for wind power plants may be 50 m or more.

3.3. Laws of wind change with height.

As we have seen, wind speed depends on altitude and varies with surface roughness; as altitude increases, wind speed also increases (Khaligh et al., 2010). In wind energy studies, two mathematical models or ‘laws’ have generally been used to model the vertical profile of wind speed over regions of homogenous, flat terrain (e.g., fields, deserts, and prairies). The first approach, the log law, has its origins in boundary layer flow in fluid mechanics and in atmospheric research. It is based on a combination of theoretical and empirical research. The second approach, used by many wind energy researchers, is the power law. Both approaches are subject to uncertainty caused by the variable, complex nature of turbulent flows (Hiester et al., 1981). Wind energy engineers typically model wind shear using one of two mathematical models, a logarithmic profile or a power law profile (Manwell et al., 2009).

3.4. Logarithmic law

The logarithmic profile law states that wind speed is proportional to the logarithm of height above ground (Hsu, 1982). Thus, the following equation expresses the ratio of wind speed at the center height to wind speed at the anemometer height:

$$\frac{U_{hub}}{U_{anem}} = \frac{\ln(Z_{hub}/Z_0)}{\ln(Z_{anem}/Z_0)} \tag{2}$$

Here, U_{hub} – is the wind speed at the central height of the wind turbine (m/s), U_{anem} – is the wind speed at the anemometer height (m/s), Z_{hub} is the central height of the wind turbine (m), Z_{anem} is the height of the anemometer (m), Z_0 – is the length of the surface roughness (m) (Tieo et al., 2020).

Surface roughness length is a parameter that characterizes the roughness of the surrounding terrain. Ground-level obstacles such as vegetation, buildings, and topographic features slow down the wind speed near the surface (Garrett, 2015). Since the effect of these obstacles decreases with height above the ground, wind speed tends to increase with height above the ground. This change in wind speed with height is called wind shear. Table 5 provides approximate surface roughness lengths for various terrain types (Ongaki et al., 2019).

(Irwin, 1979) reported that during unstable conditions, α is only a weak function of stability and instead is strongly dependent on surface roughness. This is in accordance with the findings from this study, where it was discussed that open water likely coincide with unstable atmospheric conditions, and hence the surface roughness is the main factor determining the vertical structure of the profiles.

Table 5. Values (approximate) of surface roughness length for various types of terrain

Terrain Description	Z_0	Terrain Description	Z_0
Very smooth, ice or mud	0.00001 m	Crops	0.05 m
Calm open sea	0.0002 m	Few trees	0.10 m
Blown sea	0.0005 m	Many trees, few buildings	0.25 m
Snow surface	0.003 m	Forest and woodlands	0.5 m
Lawn grass	0.008 m	Suburbs	1.5 m
Rough pasture	0.010 m	City center, tall buildings	3.0 m
Fallow field	0.03 m		

3.5. Power Law

The power law represents a simple model for the vertical wind speed profile. Its basic form is:

$$\frac{U_{hub}}{U_{anem}} = \left(\frac{Z_{hub}}{Z_{anem}} \right)^\alpha \tag{3}$$

here, U_{hub} – wind speed at the central height of the wind turbine (m/s), U_{anem} – wind speed at the anemometer height (m/s), Z_{hub} – central height of the wind turbine (m), Z_{anem} – height of the anemometer (m), α – power law quantity.

The power law is most often applied to extrapolate near-surface wind speed to the wind turbine hub height. Due to variations of the meteorological conditions, the power law exponent varies over time (Jung et al., 2021). The power law exponent is a dimensionless parameter. Fundamental studies in fluid mechanics have shown that its value is equal to 1/7 for turbulent flow over a flat plate. Wind speed researchers have found that in practice, the power law exponent depends on the roughness of the terrain, atmospheric stability, and a number of other factors (HOMER Energy, 2025).

Figure 18 shows the variation of wind speed (m/s) with altitude (m) for the Pirallahi area. The graph compares three different theoretical approaches (Power Law and two different Logarithmic Laws) with Global Wind Atlas (GWA) data. Satellite data from GWA (blue dots) show wind speeds at altitudes from 10 m to 200 m. The increase in the number of blue dots as the altitude increases clearly shows the increase in wind speed with altitude.

Power law (red line, $\alpha = 0.112$): This empirical method predicts wind speed with a simple power function. As we can see, the red line is close to the GWA data and represents the increase in speed with increasing altitude well.

Logarithmic law— $z_0 = 0.00397$. This is the roughness coefficient of the surface and is based on local conditions and is more consistent with the GWA data. $z_0 = 0.0005$ (the “Blown sea” surface) – this is the standard logarithmic curve for a smoothed surface over the sea. As can be seen, this line does not coincide with real observations and underestimates the wind speed.

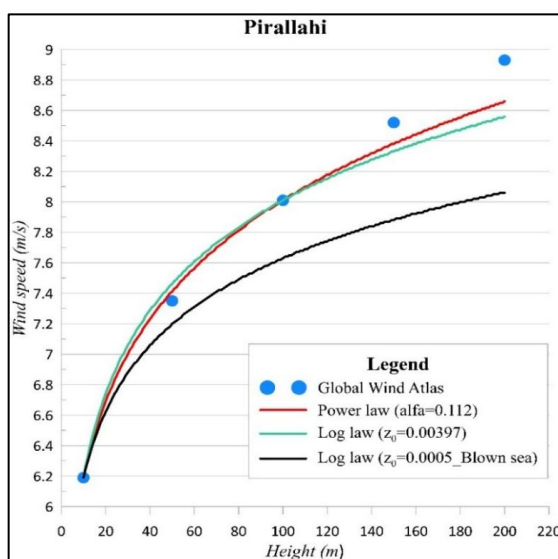


Figure 18. Analysis of the variation of wind speed in Pirallahi with height using Power and Logarithmic Laws (The graph was created by the author using Grapher software)

Both the Power Law and the Logarithmic Law ($z_0 = 0.00397$) fit the GWA data well. These indicators confirm that the area under consideration has a high wind energy potential and that it is more favorable to place turbines at heights above 50 m. Also, these results show how important the correct choice of model is in the assessment of wind energy.

4. Conclusion

The conducted analyses showed that the wind speed in the coastal zone of the Absheron Peninsula tends to increase with altitude, and this increase is more noticeable in some areas. In particular, the speeds recorded at a height of 50 meters are higher than at a level of 10 meters, indicating the potential opportunities in terms of wind energy. These results provide important scientific foundations for planning renewable energy projects in selected points of Absheron. At the same time, such analyses create conditions for making technologically and spatially correct decisions for the transition to sustainable energy systems.

5. Supplementary Materials: no supplementary materials.

6. Author Contributions

The author carried out all work related to obtaining data and preparing the article himself.

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8. Funding: none.

9. Acknowledgements: none.

10. Conflicts of Interest: the author declares no conflicts of interest.

11. References

1. Aiyer, P. (2021). Wind speed change with height in built environment. *International Journal of Engineering Research*, 8 (1).
2. Archer, C. L., & Jacobson, M. Z. (2005). Evaluation of global wind power. *Journal of Geophysical Research: Atmospheres*, 110 (D12). <https://doi.org/10.1029/2004JD005462>
3. Fagiano, L., Milanese, M., Razza, V., & Bonansone, M. (2012). High-altitude wind energy for sustainable marine transportation. *IEEE Transactions on Intelligent Transportation Systems*, 13(2), 781-791. <https://doi.org/10.1109/TITS.2011.2180715>
4. Gardashov, E. R., & Gardashov, R. H. (2024). On the derivation of an analytical expression for wind power probability distribution function and capacity factor of turbine. *International Journal of Sustainable Energy*, 43(1). <https://doi.org/10.1080/14786451.2024.2390447>
5. Garrett, R. (2015). Investigations of surface roughness length modification in Black Rock City, NV [Master Thesis, San Francisco State University].
6. Global Wind Atlas. (2025). Global wind atlas. URL: <https://globalwindatlas.info/en/>
7. Hiester, T., & Pennell, W. (1981). The Meteorological aspects of siting large wind turbines, *Pacific Northwest Laboratory*.
8. HOMER Energy. (2025). Wind resource variation with height. HOMER pro documentation. https://homerenergy.com/products/pro/docs/3.15/wind_resource_variation_with_height.html
9. Hulio, Z. H. (2021). Assessment of wind characteristics and wind power potential of Gharo, Pakistan. *Hindawi Journal of Renewable Energy*, 8960190. <https://doi.org/10.1155/2021/8960190>
10. Hsu, S. (1982). Determination of the power-law wind profile exponent on a tropical coast. *Journal of Applied Meteorology*, 21, 1187-1190. [https://doi.org/10.1175/1520-0450\(1982\)021<1187:DOTPLW>2.0.CO;2](https://doi.org/10.1175/1520-0450(1982)021<1187:DOTPLW>2.0.CO;2)
11. International Energy Agency. (2023). Wind energy technology perspectives 2023. <https://www.iea.org/reports/wind-energy-technology-perspectives-2023>
12. International Energy Agency (2013). Wind energy - technology roadmap. <https://www.iea.org/publications>
13. Irwin, J. S. (1979). A theoretical variation of the wind profile power-law exponent as a function of surface roughness and stability. *Atmospheric Environment*, 13, 191-194.
14. Jung, C., & Schindler, D. (2021). The role of the power law exponent in wind energy assessment: A global analysis. *International Journal of Energy Resources*, 45 (6), 8484-8496. <https://doi.org/10.1002/er.6382>
15. Khaligh, A., & Onar, O.C. (2010). Energy harvesting. Boca Raton.
16. Kubik, M, Coker, P., & Hunt, C. (2011). Using meteorological wind data to estimate turbine generation output: a sensitivity analysis. *World Renewable Energy Congress*, 4074-4081. <http://dx.doi.org/10.3384/ecp110574074>
17. Manwell, J., MCGowan, J., & Rogers, A. (2009). Wind energy explained.

18. Mammadov, R. M. (2014). Geography of the Republic of Azerbaijan: physical geography (Volume 1). Avrupa. [in Azerbaijani]
19. NASA Prediction of worldwide energy resources. (2025). <https://power.larc.nasa.gov/data-access-viewer/>
20. Ongaki, L., Maghanga, C., & Joash, K. (2019). Determination of the surface roughness parameter and wind shear exponent of Kisii Region from the on-site measurement of wind profiles. *Journal of Energy*, 8264061. <https://doi.org/10.1155/2019/8264061>
21. Pryor, S., & Bartelmie, C. (2010). Climate change impacts on wind energy: A review. *Renewable and Sustainable Energy Reviews*, 14, 430–437.
22. Rasulzadeh, V. M. (2025). Assessment of the wind and wave energy potential in the water area of the Caspian Sea. *Вісник Харківського Національного Університету Імені В.Н. Каразіна Серія Геологія. Географія. Екологія*, 62, 315-323. <https://doi.org/10.26565/2410-7360-2025-62-23>
23. Sathyajith, M. (2007). Wind energy: fundamentals, resource analysis and economics. Springer, 24 p. <https://doi.org/10.1007/3-540-30906-3>
24. Tar, K., & Szegedi, S. (2009). Alterations of potential wind energy with height and parts of the day. *Journal of Electrical and Electronics Engineering* 2(1), 206-210
25. Tiew, J., Skote M., & Srikanth N. (2020). Suitability of power-law extrapolation for wind speed estimation on a tropical island. *Journal of Wind Engineering and Industrial Aerodynamics*, 205, 104317. <https://doi.org/10.1016/j.jweia.2020.104317>

Апшерон түбегінің жағалау аймағындағы биіктікке байланысты жел жылдамдығы мен қуатының өзгеруі

Вусала Расулзаде

Аңдатпа. Мақалада 2001–2024 жылдар аралығында Әзірбайжандағы жел энергиясын өндіру тұрғысынан өте перспективалы болып табылатын Апшерон түбегінің жағалау аймағында орналасқан төрт негізгі нүктеде – Пираллахи, Мардакан, Сумгайт және Сангапальда – жел жылдамдығының биіктікке байланысты өзгеруі егжей-тегжейлі талданады. Зерттеу аясында әр нүкте үшін жел жылдамдығының статистикалық сипаттамалары және 10 және 50 метр биіктіктегі жел қуатының өзгеру динамикасы зерттелді. Жел жылдамдығы мен қуатының жылдар, айлар және маусымдар бойынша өзгеруін көрсететін графиктер құрылды және ұзақ мерзімді үрдістер бағаланды. Сонымен қатар, таңдалған нүктелерде күндізгі жел жылдамдығының өзгеруіне ерекше назар аударылды. Талдау нәтижесінде жағалау аймақтарындағы жел режимі маусымдық және тәуліктік ырғақтар бойынша әртүрлі екені және бұл сипаттамалар желді жаңартылатын энергия көзі ретінде пайдалану мүмкіндіктеріне тікелей әсер ететіні анықталды. Зерттеу соңында жел жылдамдығының биіктікке тәуелді өзгеруін ескеру үшін екі маңызды теориялық модель – қуат заңы және логарифмдік заң – қолданылды және олардың артықшылықтары мен жарамдылығы салыстырмалы түрде бағаланды.

Түйін сөздер: жел жылдамдығы; жел энергиясы; жел энергиясы; логарифм заңы; қуат заңы

Изменение скорости и направления ветра с высотой в прибрежной зоне Апшеронского полуострова

Вусала Расулзаде

Аннотация. В статье подробно анализируется изменение скорости ветра с высотой в четырех основных точках прибрежной зоны Апшеронского полуострова, представляющих наибольший потенциал для ветроэнергетики в Азербайджане – Пираллахи, Мардакан, Сумгаит и Сангачал – за период 2001–2024 годов. В рамках исследования были изучены статистические характеристики изменения скорости ветра и мощности ветра на высотах 10 и 50 метров для каждой точки. Построены графики, отражающие изменение скорости ветра и его мощности по годам, месяцам и сезонам, и оценены долгосрочные тенденции. Кроме того, особое внимание уделено изменениям скорости ветра в течение суток в выбранных точках. В результате анализа установлено, что ветровые режимы в прибрежных зонах различаются как по сезонным, так и по суточным ритмам, что напрямую влияет на возможности использования ветра в качестве возобновляемого источника энергии. В конце исследования были применены две важные теоретические модели - степенной закон и логарифмический закон - для учета зависимости скорости ветра от высоты, и проведена сравнительная оценка их преимуществ и пригодности.

Ключевые слова: скорость ветра; энергия ветра; мощность ветра; логарифмический закон; степенной закон