International Journal of Engineering and Geosciences
https://dergipark.org.tr/en/pub/ijeg
e-ISSN 2548-0960

Topographical features affecting the distribution of wind power plants (WPPs) in Türkiye

Emre Özşahin *[1], **Kerem Girgin** [2], **Tolgahan Köse** [3]

[1] Tekirdağ Namık Kemal University, Faculty of Arts and Sciences, Department of Geography, Tekirdağ, Türkiye, eozsahin@nku.edu.tr
[2] Tekirdağ Namık Kemal University, Institute of Social Sciences, Tekirdağ, Türkiye, keremgirgin1@icloud.com
[3] Tekirdağ Namık Kemal University, Institute of Social Sciences, Tekirdağ, Türkiye, kosetolgahan@hotmail.com

Cite this study: Özşahin, E., Girgin, K., & Köse, T. (Year). Topographical features affecting the distribution of wind power plants (WPPs) in Türkiye. International Journal of Engineering and Geosciences, 10 (3), page 339-351.

https://doi.org/10.26833/ijeg.1602670

Keywords
WPPs
Topographical features
GIS
RS
Türkiye

Research/Review Article

Received:17.12.2024
Revised:12.02.2025
Accepted:24.02.2025
Published:01.10.2025

Abstract

Site selection for Wind Power Plants (WPPs) is crucial in the planning process, considering economic, social, and environmental features, and national legislation. This study aims to examine the topographical features affecting WPPs distribution in Türkiye. Google Earth Pro tools were used and RES inventory for Türkiye was prepared. The data were correlated with factor maps used to describe topographic features such as elevation, slope, aspect, topographic relief, and landforms. This relationship was analyzed using the Random Forest (RF) technique, one of the Machine Learning (ML) models, and the importance percentages of each factor were determined. Factor maps were produced using Geographic Information Systems (GIS) techniques with a 30 m resolution Digital Elevation Model (DEM). The results revealed that in Türkiye, WPPs site selection favors areas with elevations of 250-500 m, slopes of 10-20%, west, and southeast aspects, topographic relief of 0-50 m, and sloped landforms. Elevation was identified as the most significant topographical feature (24.80%). These findings emphasize the importance for decision-makers to consider topographical features in WPPs planning. The study provides valuable insights and recommendations for assessing suitable areas for WPPs installation, contributing to the most economical utilization of Türkiye's wind energy potential.

1. Introduction

Site selection for the installation of wind power plants (WPPs) is essential for planning processes that are based on various economic, social, and environmental features and national legislation [1]. The installation of WPPs in suitable areas not only increases the amount of energy production [2] but also directly affects factors such as efficiency, safety, and accessibility [3]. Therefore, it is essential to choose a suitable location for the installation of WPPs to increase energy, economic, and environmental efficiency [4].

Both the methods used and the features considered have a significant effect on the selection of the location for the installation of WPPs [5]. However, some criteria that support or restrict the potential of WPP installation generally play a guiding role in the results obtained [6]. To minimize environmental risk, reduce opposition from local stakeholders and provide economic benefits, these criteria should be identified as priorities in site selection for WPP installation [7-8]. These criteria, which are selected on the basis of extensive literature research and expert opinions [9-10], are generally divided into three categories: technical, economic, and socioenvironmental [11].

The site selection of a location for installing a WPP is highly dependent on factors such as the wind speed, wind direction, and topography [4]. Wind speed is the most critical factor that directly affects the energy generation potential. Wind direction is an important criterion for WPP siting and efficiency [12]. Topography significantly affects the distribution of wind power by controlling the wind speed and direction [13]. Topographical features are indispensable features affecting both the distribution of WPPs and the installation potential of WPPs [4, 14]. These features directly or indirectly affect the wind speed and capacity [15]. It usually includes elevation, slope, aspect, topographic relief, and landform features of the topography [16]. Therefore, many researchers have analyzed the effects of topographic features on the distribution and location of wind farms under topographic or orographic factors [4].

Türkiye, owing to its favorable geographical location, is a renewable energy source (RES) country in both actual and potential terms [14]. Recently, many geographic information system (GIS)-based WPP siting studies have been conducted in Turkey via various methods. For example, TOPSIS [14], innovative hybrid site selection [16], the ordinal weighted average (OWA) and reference ideal [17], data envelopment analysis and TOPSIS [18], the analytic hierarchy process (AHS) and stochastic multicriteria acceptability analysis (SMAA) [19] have recently been applied in Türkiye. Furthermore, numerous geographic information system (GIS)-based site selection studies have been conducted using methods such as ARIMA and time series analysis [20] and intuitionistic fuzzy TOPSIS [21], fuzzy AHS and fuzzy DEMATEL [22] and AHS [23-25].

In recent scientific studies, either the development potential of wind energy in Türkiye has been evaluated [26], the wind energy potential and utilization of wind energy systems in Türkiye has been examined [27], or the distribution of WPPs in Türkiye has been analyzed from a geographical perspective [28]. However, in none of these studies has the distribution of existing WPPs been considered within the scope of topographic features and has been used only for comparison or control purposes. Therefore, there is still a large gap in the literature on the topographic features affecting the geographical distribution of existing WPPs in Türkiye.

However, to the best of the authors' knowledge, it is still not clear which topographical features are more effective in selecting the location for the installation of WPPs in Türkiye. There are no specific features used in a standardized way in the literature [4, 29]. This situation creates confusion about which features should be taken into account in the selection of the location for the installation of WPPs. Machine learning (ML) models, which are widely used in various fields and are a popular trend today, are preferred for solving similar problems [30]. ML models are used to recognize patterns and make predictions on the basis of data [31]. In this study, the random forest (RF) technique, an ML model, is preferred. RF is a widely used learning algorithm for both classification and regression problems [32-34]. Thus, the effect of the independent variables (topographic features) on the dependent variable (WPPs) was measured.

This study aims to address the topographical characteristics affecting the existing WPP distribution in Türkiye. For this purpose, the features of elevation, slope, aspect, topographic relief, and landforms that affect the geographical distribution of existing WPPs were evaluated both within and among themselves. Therefore, the impact of topographical features on site selection for existing WPP installations in Türkiye has been revealed. The specific purpose of this study is to determine which topographic features are more effective in selecting the location for the installation of WPPs in Türkiye. This is important for the most economical utilization of the WPP potential of Türkiye and the most accurate identification of potential resource areas. In addition, this study reveals the necessity of a planning approach that includes GIS and machine learning analyses in site selection for WPP installation. In this context, our study emphasizes the need for detailed and data-driven methodologies to increase the efficiency and effectiveness of WPP projects and contribute to a more sustainable and resilient energy future.

2. Method

2.1. Study area

The study area is Türkiye, a prominent developing country in the world due to its location between Asia and Europe (Figure 1). In countries where energy demand is high due to economic development and rapid population growth, a significant portion of electricity is generated by nonrenewable energy sources (fossil fuels). However, owing to the inadequacy and limitations of domestic fossil fuels in meeting these needs, Türkiye has experienced energy crises during some periods [35]. Therefore, it is important to explore renewable energy sources to reduce external dependency in the energy market, meet energy needs and prevent energy crises [16].

Türkiye is one of the leading countries in terms of renewable energy potential and renewable energy resource diversity [8]. Owing to the geographical location of the country, wind energy has promising potential among all renewable energy sources [27]. According to the data provided by the Turkish General Directorate of Meteorology (MGM), the annual average wind speed and power density in the study area are sufficient to install WPPs [35]. Indeed, it has been reported that the annual average wind speed in the study area is 2.58 m/s, and the power density is 25.82 W/m² [27]. When the distribution map of WPP density in the study area is examined, this situation can be understood very clearly (Figure 2). In this respect, a significant part of Türkiye, especially the western parts, is highly favorable for the installation of both existing and potential WPPs (Figure 2). Therefore, the distribution and site selection of both existing and potential WPPs are among the priority issues that need to be investigated carefully.

2.2. Method

In the first stage of the study, the coordinates of the WPP facilities whose license status is in force were requested from the Energy Market Regulatory Authority (EMRA) of the Republic of Türkiye in an official letter. Upon this request, the data shared by the relevant institution through the system [36] were first converted into a Microsoft Excel file and organized (Figure 3). These data were then converted into keyhole markup language (KML) files and spatially corrected via remote sensing (RS). For this process, free high-resolution satellite imagery accessed through Google Earth Pro was used [37]. This saves time for data collection, especially in hard-to-reach areas such as mountainous areas [38]. These data were then converted into a shapefile (.shp) file format that can be uploaded to GIS software [39], and an inventory of existing WPPs was created. Thus, 3980 WPPs were identified in Türkiye (Figure 3).

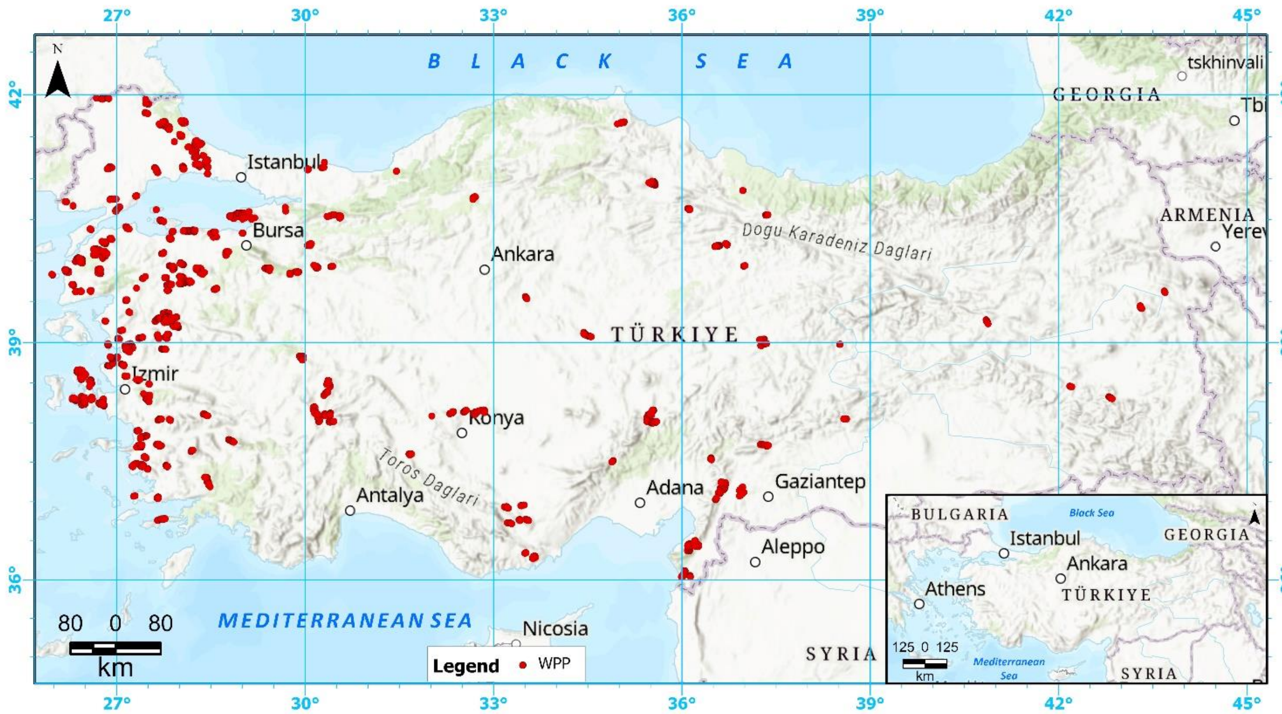

Figure 1. Location map of the study area

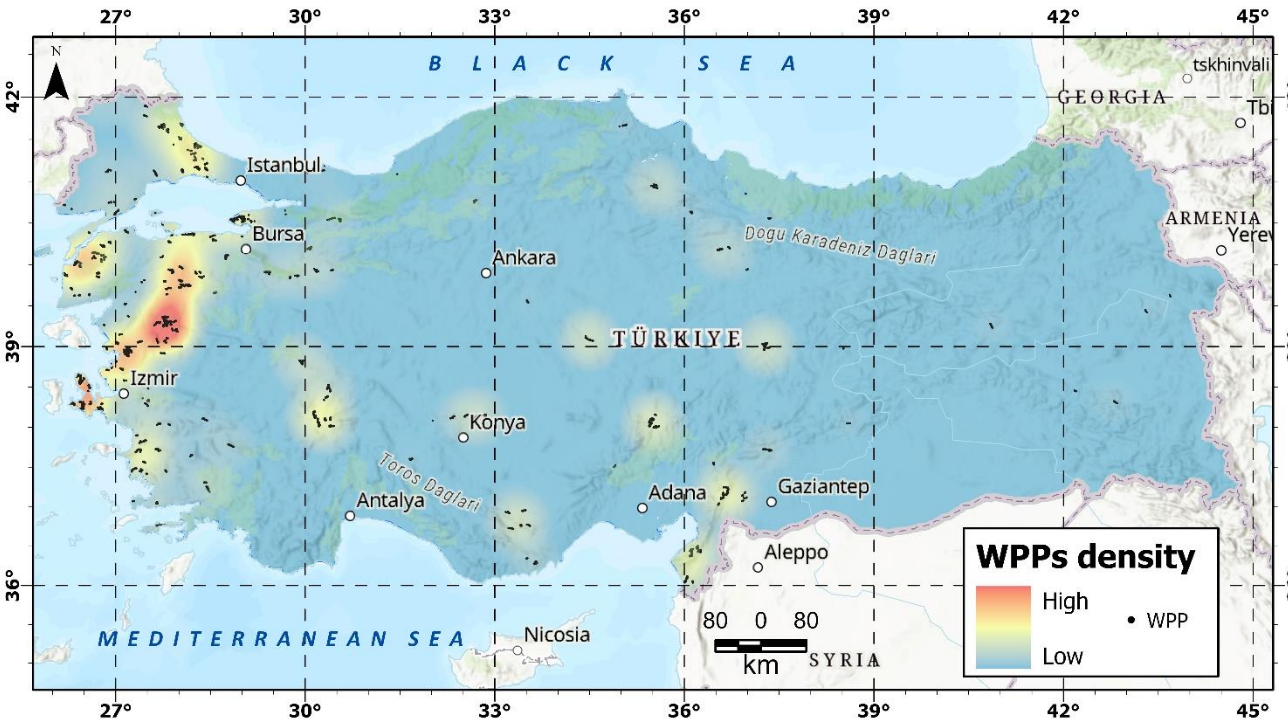

Figure 2. Distribution map of WPPs density in the study area

In the second stage of the study, the inventory data were correlated with different factors used to explain topographic features, including elevation, slope, aspect, topographic relief, and landforms (Figure 3). Maps of elevation, slope, aspect, and topographic relief factors were produced with 30 m resolution FABDEM V1-2 (Forest and Buildings removed Copernicus DEM) [40]. FABDEM data are more advantageous in regional studies on the topographic features of Türkiye and yield results similar to those of high-resolution LiDAR data [41]. Only the landform map was obtained by revising the macro landform map of Türkiye produced by Görüm [42], with some analysis using DEM data.

The association of the inventory data in the study with factor maps and the visualization of these relationships with thematic maps were carried out via GIS techniques [43-46]. Both the rapid and effective evaluation of complex data on the distribution and location selection of both existing and potential WPP areas and the determination of environmentally and economically suitable areas are largely carried out with GIS techniques [47-49].

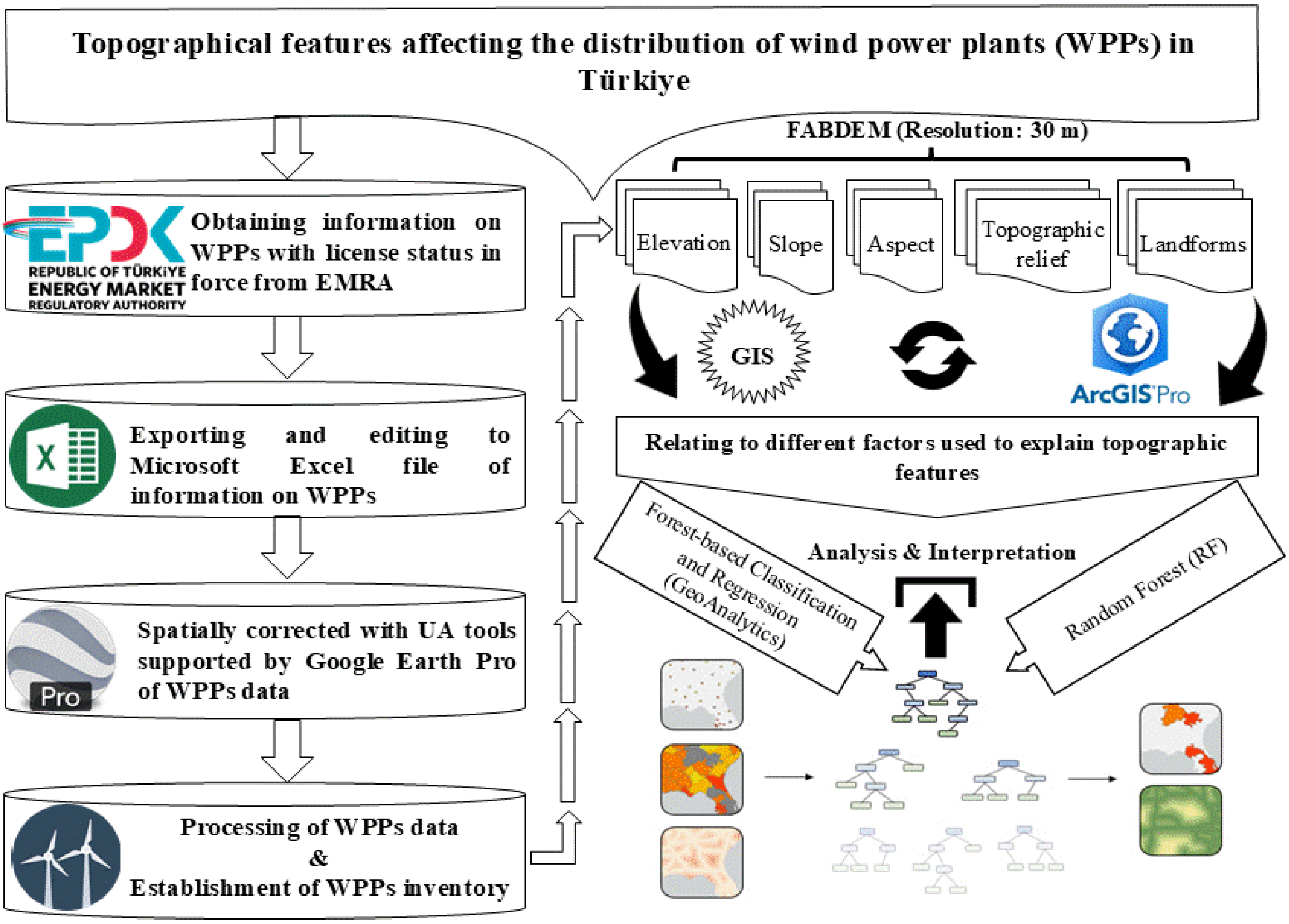

Figure 3. Flowchart showing the main stages of the study

Table 1. Data and data sources used in this study

No	Raw data	Produced data	References
1	WPPs with license status in force	Information of WPPs locations	[36, 37]
2	FABDEM (Resolution: 30 m)	Elevation map Slope map Aspect map Topographic relief map	[40]
3	Macro landforms map of Türkiye	Landforms map	[42]

In the last stage, the impact of topographical features on site selection for WPP installation was investigated via the RF technique, one of the most advanced ML models for analyzing high-dimensional complex data [38]. In this study, RF is used for regression. For this purpose, a series of bootstrap samples were performed from the dataset, and data diversity was ensured. To improve model generalizability, random feature subsets were selected and trained, and multiple decision trees were generated. On the basis of the outputs of the decision trees, the average prediction of the individual trees was extracted. In this way, the importance levels of the independent variables were determined [50]. Consequently, the effects of topographical features on site selection for the installation of WPPs in the study area were analyzed. RF was implemented via forest-based classification and regression tools in the ArcGIS Pro Spatial Analyst extension. Since the range of values of the hyperparameters in the RF algorithm differs for each dataset, they are based on default settings that perform reasonably well across all models in the model library [32]. The analyses and thematic maps in the study were made based on GIS. Because GIS is important for collecting and processing geographical data of objects [51-55]. For this purpose, ArcGIS Pro (Version 3.0.1), a widely used GIS software, was preferred (Figure 2).

3. Results

In addition to favorable wind speed and power density, areas with favorable topographical features are preferable in the selection of locations for the installation of WPPs [28]. This is because topographical features have three important effects on the wind speed and power density: roughness, orographic and screening effects [56]. Therefore, the effects of topographical features, including elevation, slope, aspect, topographic relief, and landforms [57-58], were evaluated in the site selection for the existing WPPs installed in the study area.

3.1. Elevation

Elevation is an important factor in choosing a location for WPP installation. As the altitude increases, the installation of WPPs becomes more problematic. This is because the air density decreases at high altitudes, which leads to a decrease in the efficiency of the turbines [4]. In addition, an increase in elevation leads to increased construction costs, energy transfer and equipment transportation difficulties [60]. In the study area, there are WPPs with a minimum altitude of 6 m and a maximum altitude of 3233 m. However, the highest number of WPPs in terms of quantity is found between the 250–500 m (23.59%) elevation levels (Table 2). This is followed by 0–250 m (16.31%), 500–750 m (15.43%), 750–1000 m (11.93%), 1500–1750 m (10.83%), 1250–1500 m (9.62%), 1000–1250 m (7.14%) and 1750-> m (5.15%) elevation levels (Table 2; Figure 4).

Table 2. Distribution number and ratio of WPPs by elevation in the study area

Elevation (m)	Number	Ratio
0-250	649	16.31
250-500	939	23.59
500-750	614	15.43
750-1000	475	11.93
1000-1250	284	7.14
1250-1500	383	9.62
1500-1750	431	10.83
1750->	205	5.15
TOTAL	3980	100.00

3.2. Slope

Slope is another important factor in selecting a location for the installation of a WPP [61]. This factor, which affects both wind speed and transportation, construction and maintenance costs, can increase wind speed by creating a venturi effect [7, 62]. Therefore, it has been reported that sites with slopes greater than 20% are not suitable for WPP installation [63]. The existing WPPs in the study area are located between 0–46% slope. However, most WPPs are located in the slope class of 10–20% (33.99%) (Table 3). This is followed by the 5-10% (28.89%), 2-5% (16.66%), 20-40% (14.60%), 1-2% (3.79%), 0-1% (1.51%) and 40%-> (0.55%) slope classes (Table 3; Figure 5).

Table 3. Distribution number and ratio of WPPs by slope in the study area

Slope (%)	Number	Ratio
0-1	60	1.51
1-2	151	3.79
2-5	663	16.66
5-10	1150	28.89
10-20	1353	33.99
20-40	581	14.60
40->	22	0.55
TOTAL	3980	100.00

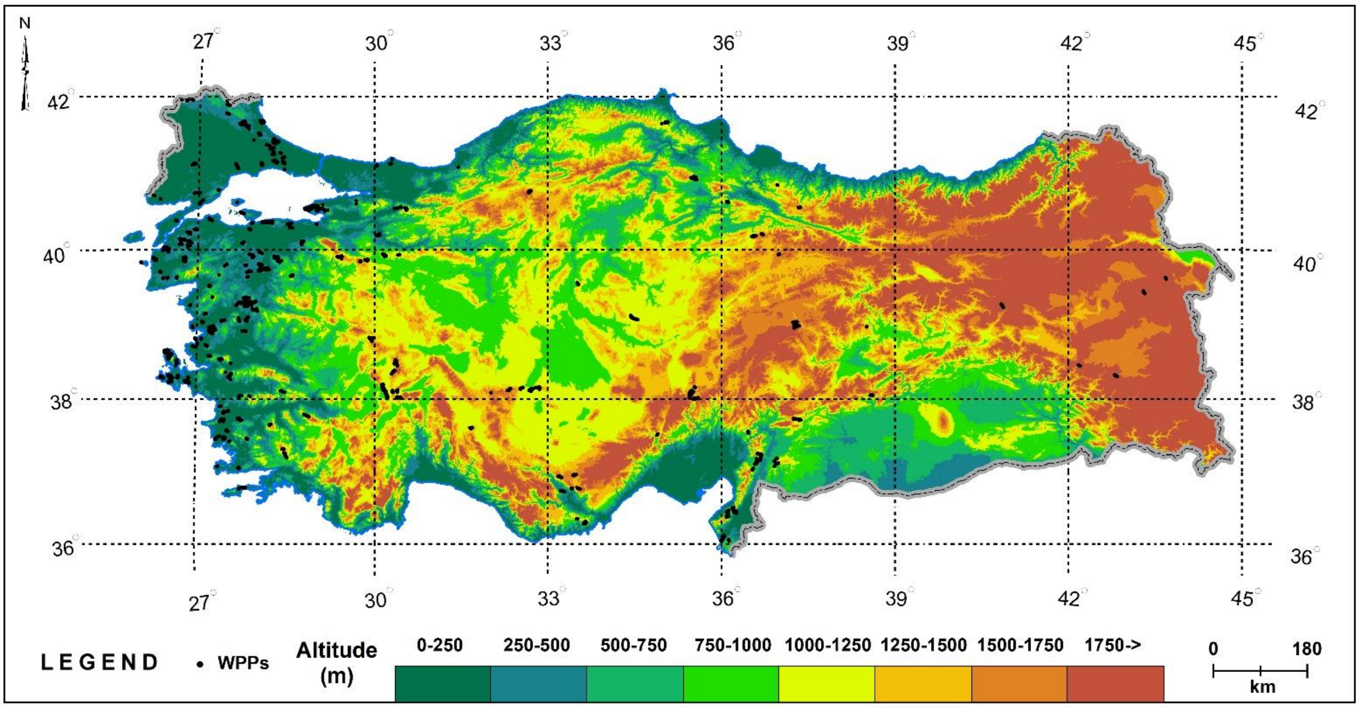

Figure 4. Distribution map of WPPs by elevation in the study area

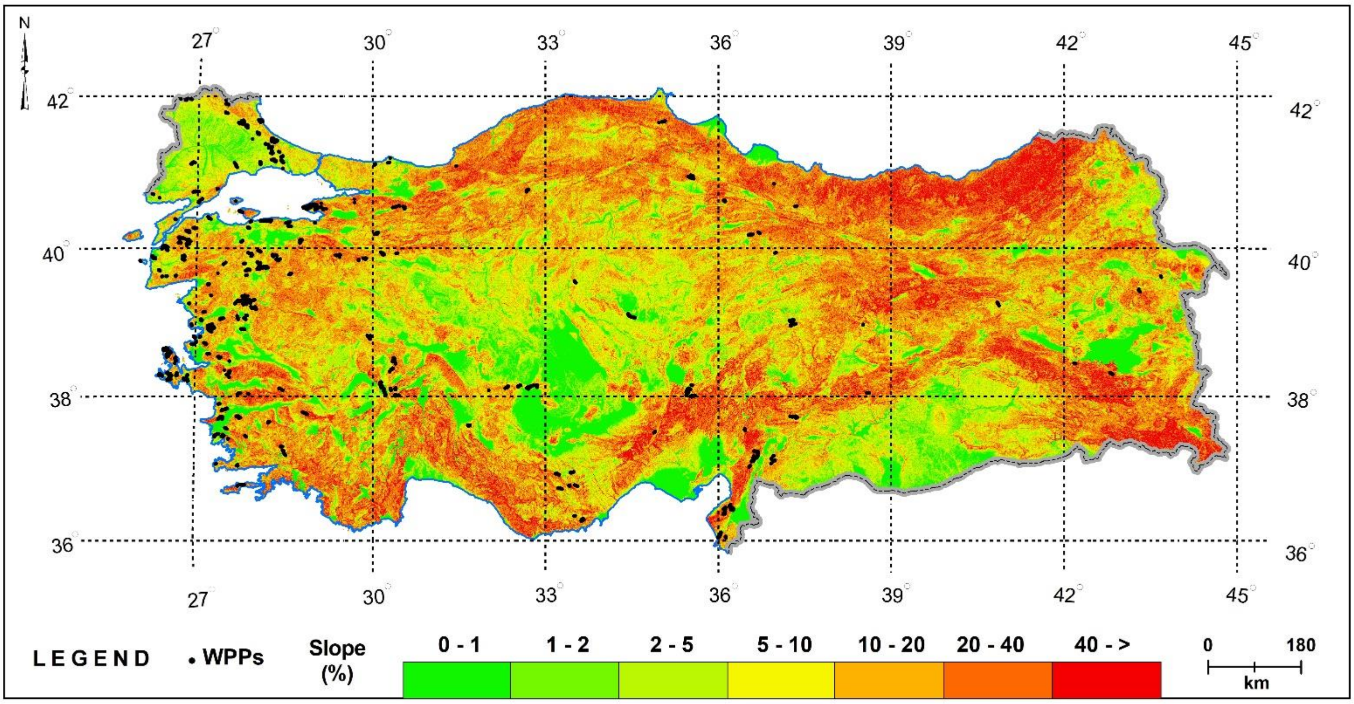

Figure 5. Distribution map of WPPs by slope in the study area

3.3. Aspect

Aspect is another effective factor in site selection for WPP installation [46]. The effect of this factor, which refers to the position of any location concerning the sun and is also defined as geographical direction/orientation or land orientation [4], increases the potential for WPP installation, especially on slopes facing the prevailing wind direction [64]. The existing WPPs in the study area were mostly installed on lands facing east (17.79%) and southeast (17.76%) directions (Table 4). This is followed by the southern (13.32%), western (11.51%), northeastern (11.33%), northwestern (11.01%), southwestern (10.60%), northern (5.65%) and flat (1.03%) aspects in order of proportion (Table 4; Figure 6).

Table 4. Distribution number and ratio of WPPs by aspect in the study area

Aspect	Number	Ratio
Flat	41	1.03
North	225	5.65
Northeast	451	11.33
East	708	17.79
Southeast	707	17.76
South	530	13.32
Southwest	422	10.60
West	458	11.51
Northwest	438	11.01
TOTAL	3980	100.00

3.4. Topographic Relief

Topographic relief, which corresponds to the relative extent of cleavage of the topography, is considered an effective factor in site selection for WPP installation [65]. This factor, which is generally defined as ground roughness or roughness in the relevant literature, increases the roughness and decreases the wind speed [4]. The existing WPPs in the study area were installed on land with a maximum difference of 0–50 m (95.48%) (Table 5). This is followed by the relative splitting class 0--50 (25.18%) (Table 5; Figure 7).

Table 5. Distribution number and ratio of WPPs by topographic relief in the study area

Topographic relief (m)	Number	Ratio
0-50	3800	95.48
50->	180	4.52
TOTAL	3980	100.00

3.5. Landform

Landforms are another effective factor in selecting a location for the installation of WPPs in onshore areas [50]. This is because landforms have a great influence on the intensity and other characteristics of the wind in a region [65]. The installation of WPPs in areas where landforms develop as flat and undulating plains is common and provides a great advantage in terms of positively affecting the wind characteristics and cost [66]. The existing WPPs in the study area are mostly located on plateaus (77.61%), where surfaces have developed as undulating lands (Table 6). This is followed by mountain (16.36%) and plain (6.03%) landforms in order of proportion (Table 6; Figure 8).

Table 6. Distribution number and ratio of WPPs by landform type in the study area

Landforms	Number	Ratio
Plain	240	6.03
Plateau	3089	77.61
Mount	651	16.36
TOTAL	3980	100.00

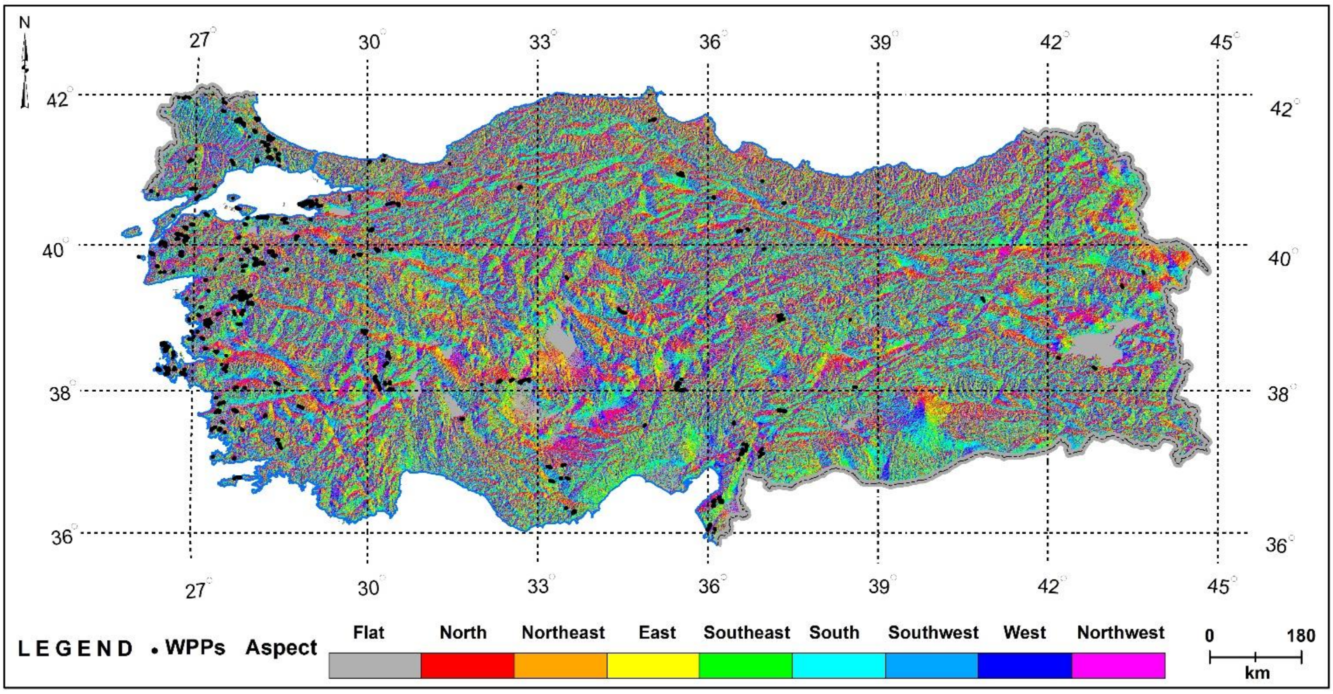

Figure 6. Distribution map of WPPs by aspect in the study area

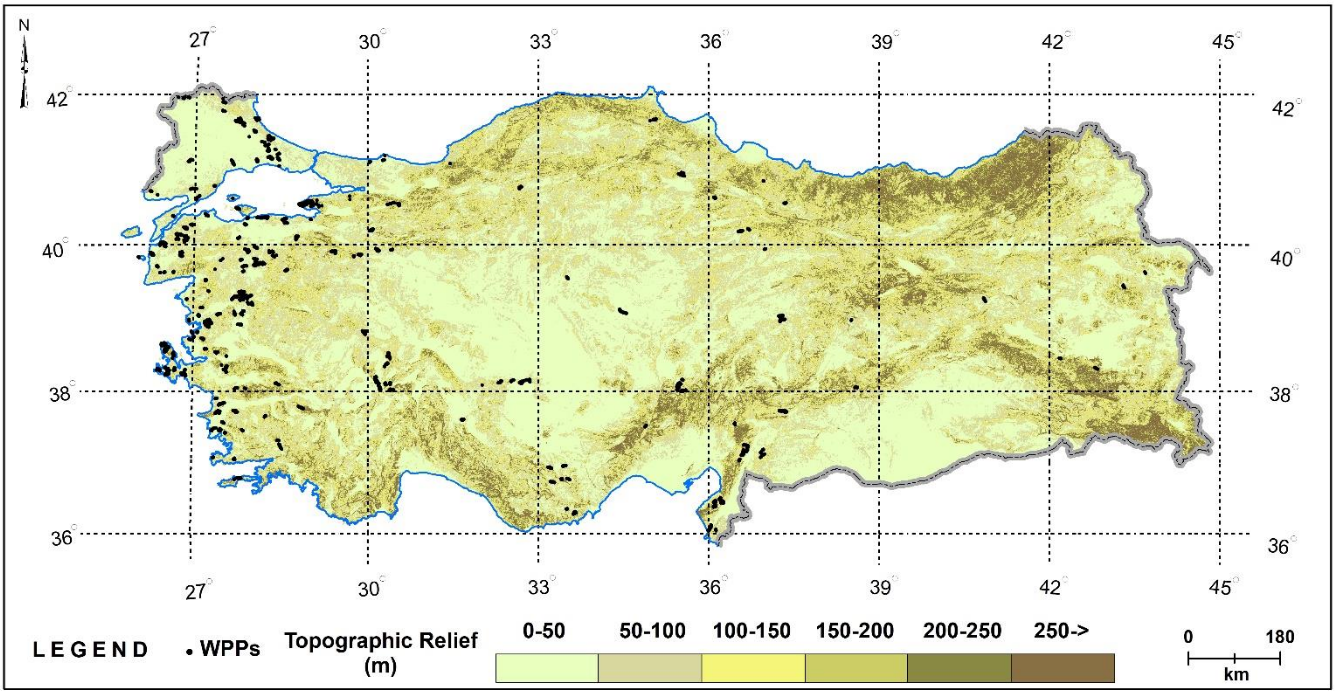

Figure 7. Distribution map of WPPs by topographic relief in the study area

4. Discussion

WPP site selection is important for achieving optimum benefits from electricity generation via wind energy. Healthy management of this process, which requires careful and combined analysis of multiple criteria, is possible by analyzing the factors affecting the current WPP distribution. For this purpose, various types of methods based on GIS techniques are used [7]. Thus, potential areas are more accurately identified and mapped.

The entire land area of Türkiye is not suitable for the installation of WPPs because of its topographic characteristics [67]. In this respect, the most suitable areas are the western (Aegean and Marmara) and southeastern (eastern Mediterranean and southeastern Anatolia) parts of Türkiye [15]. Çam et al. [68] reported that the most attractive locations for WPP installation in Türkiye are the Marmara, Southeast Anatolia and Aegean regions. Ilkılıç [27] noted that the best areas for the installation of WPPs are in the Marmara, Aegean and Southeast Anatolia regions.

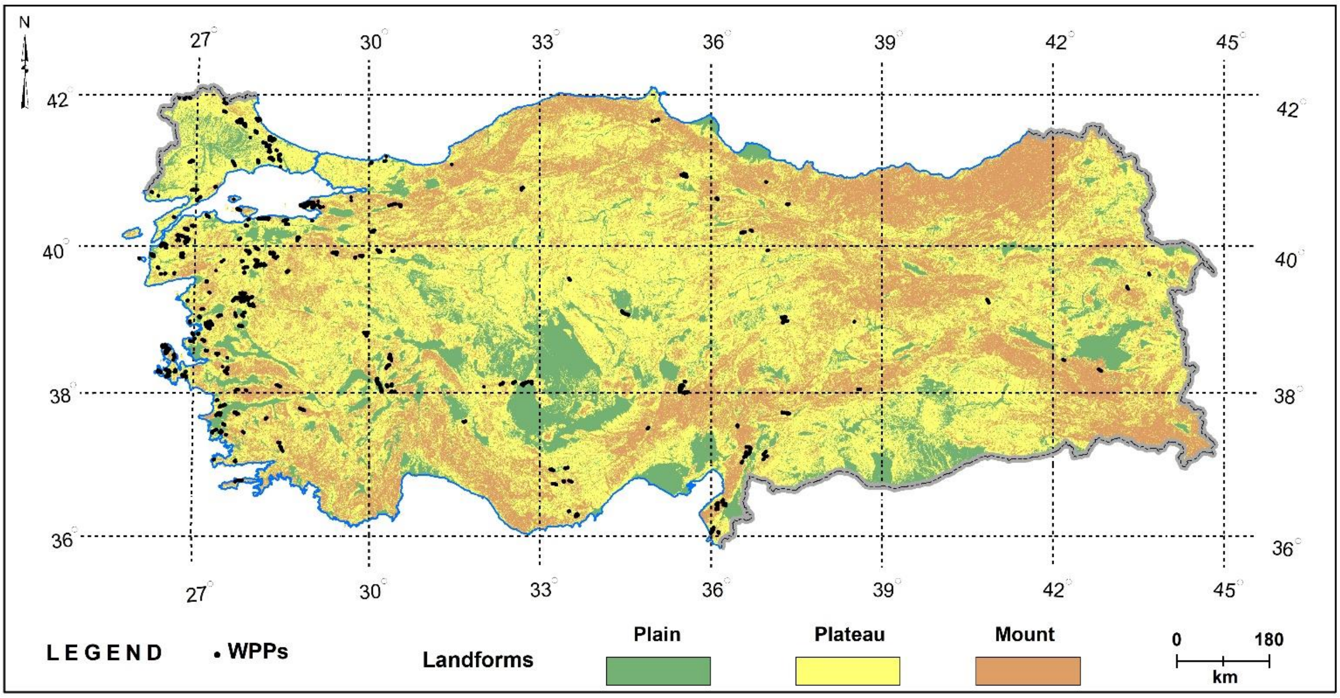

Figure 8. Distribution map of WPPs by landform type in the study area

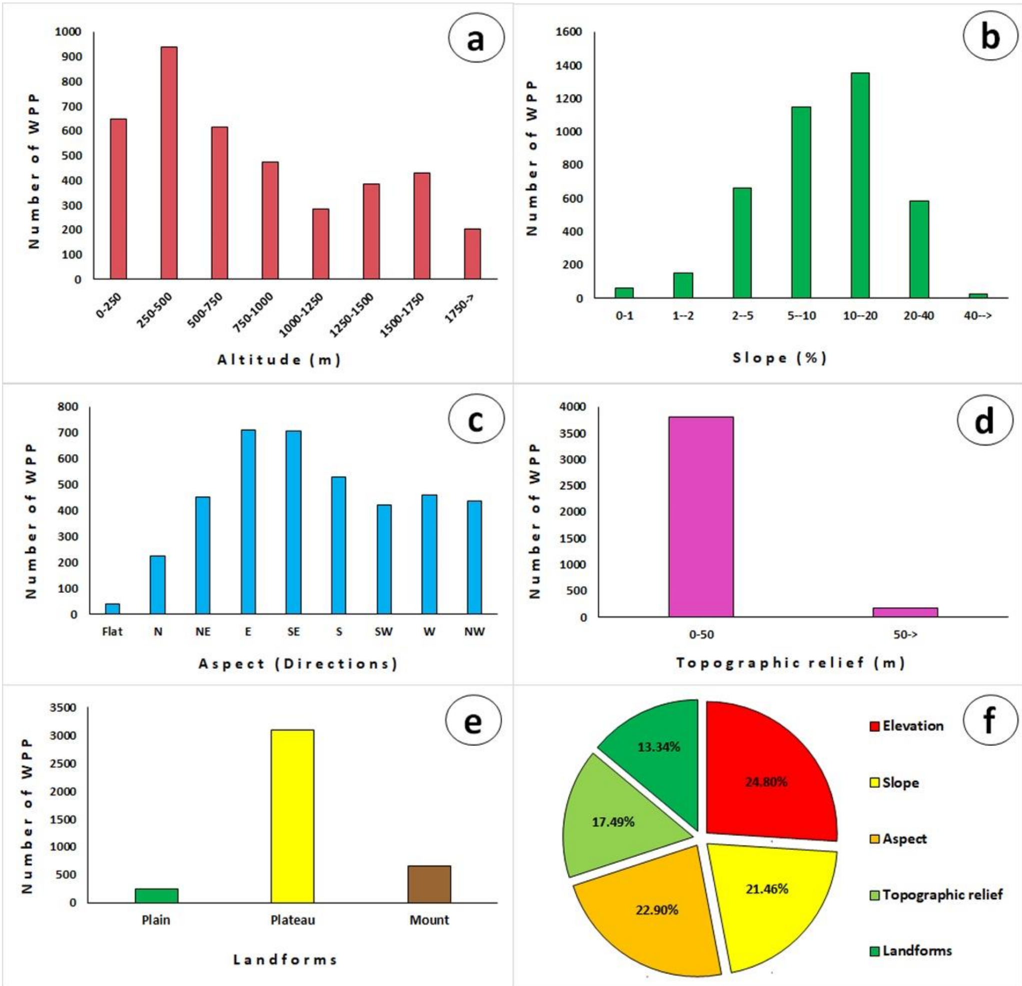

Figure 9. Frequency distributions of bivariate topographic features of WPPs in the study area: a) number of WPPs and elevation relationships, b) number of WPPs and slope relationships, c) number of WPPs and aspect relationships, d) number of WPPs and topographic relief relationships, e) number of WPPs and landform relationships and f) percentage importance graph of topographic features affecting WPP installation

Demir et al. [23] argued that the Marmara, southeastern Anatolia and Aegean regions are attractive for the installation of WPPs because of the dominance of the wind effect over a wider area due to their topographical characteristics. Therefore, it is very important to consider Türkiye's topographical characteristics when selecting a location for the installation of WPPs. However, for this purpose, these characteristics should first be explained according to the current distribution of WPPs.

According to the legislation in Türkiye, areas higher than 1500 m are not suitable for the installation of WPPs [69]. This elevation level is a critical threshold in terms of air density. Since the generation power of WPPs is directly proportional to the air density, this threshold directly affects the performance of WPPs and other atmospheric phenomena [70]. Therefore, it is technically possible but economically extremely difficult to construct WPPs above 1500 m. For this reason, there are very few WPPs above 2000 m in the study area. These are located in inland areas where the relative altitude is low. Pınar et al. [28] emphasized that there are almost no WPPs above 2000 m altitude in Türkiye because of increased installation and maintenance costs and energy loss in the braking systems of turbines due to high wind speeds. They also noted that the height of existing WPPs is high due to the high average elevation in inland regions in general. The highest number of WPPs in the study area are located between the 250–500 m elevation levels (Figure 9). Pınar et al. [28] suggested that the highest concentration of existing WPPs in Türkiye occurs between 250–500 m, which is related to the land use and wind values on the west coast of the country.

In the study area, only a few WPPs have been established on slopes below 1% and above 20% (Figure 9). This is because areas below 1% slope correspond to areas where various types of drainage problems are common, whereas areas above 20% slope correspond to areas where cost problems are common. Ifkirne et al. [71] reported that slopes less than 20% are preferred for WPP installation to facilitate access to the sites by cranes and trucks and to reduce installation and maintenance costs due to turbulence. In this respect, existing WPPs in the study area are generally concentrated on slopes of 10–20% (Figure 9). Pınar et al. [28] reported that the existing WPPs in Türkiye are mostly located on sloping lands (ridges and hilly areas) with slopes of less than 20%, where the wind potential is high.

The most favorable directions for the installation of WPPs are the slopes facing the prevailing wind direction. Therefore, analyzing the parts of the topography facing the prevailing wind direction is an important attempt to increase the efficiency of WPP construction [72]. Memduhoğlu et al. [73] reported that the wind direction is one of the most important decision makers affecting efficiency after the wind speed. The existing WPPs in the study area were mostly installed on lands facing east (17.79%) and southeast (17.76%) directions (Figure 9). Pınar et al. [28] reported that the existing WPPs in Türkiye are located predominantly in the eastern and southern sectors.

For the installation of existing WPPs in the study area, plateaus, then mountains and finally plain landforms were generally preferred (Figure 9). Although the wind potential in the plateaus in the study area is high, the cost for the realization of WPP installation and maintenance activities is low. Pınar et al. [28] emphasized that the main factor in the fact that plateau surfaces in Türkiye are preferable for the installation of WPPs is that these areas are not preferred by other sectors in terms of land use or are less attractive than they are, in addition to the advantages offered by these areas in terms of wind characteristics compared with their surroundings. Plains in the study area are less preferred for WPP installation since they are generally considered within the scope of settlement and agricultural activities (Figure 9). Pınar et al. [28] argued that areas with reduced slopes, which can be defined as plains in Türkiye, are not preferred for WPP installation since they are used mainly by settlements or other economic sectors. Although the mountains in the study area are rugged and prone to extreme weather conditions, they are preferred over plains because they have highly efficient wind resources (Figure 9). However, suitable locations for the installation of WPPs in mountainous regions generally correspond to plains and ridges without steep slopes [46]. Pınar et al. [28] reported that areas with increased slopes and cleavage degrees, which can be defined as mountains in Türkiye, are not preferred for the installation of WPPs because of installation and maintenance costs. Therefore, the effects of landforms on the location selection of WPPs in the study area are directly observed.

The evaluation of the impact of topographical features on WPP site selection in the study area via the RF method revealed that elevation was the most significant topographical variable (24.80%) (Figure 9). The other variables, in order from the most important to the least important, are aspect (22.90%), slope (21.46%), topographic relief (17.49%) and landform (13.34%) (Figure 9).

5. Conclusion

The results of the study revealed that in Türkiye, areas with an elevation of 250–500 m, a slope of 10–20%, an easterly and southeasterly aspect, a topographic relief of 0–50 m, and topographic features dominated by plateau landforms are preferred. The elevation factor was the most important topographic variable (24.80%) in the selection of the location for WPP installation. As a result of this study, it is extremely important for decision-makers to consider topographic features in planning studies to determine suitable areas for the location of WPPs in Türkiye. Moreover, topographic mapping and analysis are effective tools in site selection studies for WPP installation. Therefore, this study provides information and recommendations that will help those who will work on the determination of areas suitable for the installation of WPPs.

Acknowledgment

This study was presented as an oral presentation at the International Geomorphology Symposium 2024

(UJES 2024), which was held between October 17-18, 2024. We would like to thank Mehmet KONURAY, Projects and Events Manager of the Turkish Wind Energy Association (TÜREB) for his contribution to obtaining the Turkish Wind Energy Statistical Reports; the Energy Market Regulatory Authority (EMRA) for sharing the coordinates of the WPP facilities with licenses in force in Türkiye; and Mikayil ÖZTÜRK and Tuğrul Turan SARI for their support in transferring the coordinates of the WPPs to the map. Additionally, we would like to thank the referees and the Editor for their valuable contributions.

Author contributions

Emre Özşahin: Conceptualization, Writing-Original draft preparation, Methodology, Software **Kerem Girgin:** Data curation, Software, Validation, Editing **Tolgahan Köse:** Data curation, Software, Investigation, Editing.

Conflicts of interest

The authors declare that they have no conflicts of interest.

References

1. Tercan, E., Tapkın, S., Latinopoulos, D., Dereli, M.A., Tsiropoulos, A., & Ak, M.F. (2020). A GIS-based multicriteria model for offshore wind energy power plants site selection in both sides of the Aegean Sea. Environmental Monitoring and Assessment, 192, 652. https://doi.org/10.1007/s10661-020-08603-9
2. Çelik, İ., Yıldız, C., & Şekkeli, M. (2018). Rüzgâr Enerji Santrali kurulumunda rüzgâr türbinlerinin mikro yerleşimi için bir optimizasyon modeli. Gazi University Journal of Science Part C: Design and Technology, 6(4), 898-908. https://doi.org/10.29109/gujsc.424155
3. Konurhan, Z., & Başaran, E. (2024). Rüzgâr Enerji Santrali (RES) Yer Seçimi için BWM-CBS Tabanlı Bir Yaklaşım: Tunceli Örneği. Coğrafya Dergisi, 47, 15-28. https://doi.org/10.26650/JGEOG2023-1233104
4. Rediske, G., Burin, H.P., Rigo, P.D., Rosa, C.B., Michels, L., & Siluk, J.C.M. (2021). Wind power plant site selection: A systematic review. Renewable and Sustainable Energy Reviews, 148, 111293. https://doi.org/10.1016/j.rser.2021.111293
5. Alavi, S.M.S., Maleki, A., & Khaleghi, A. (2022). Optimal site selection for wind power plant using multicriteria decision-making methods: A case study in eastern Iran. International Journal of Low-Carbon Technologies, 17, 1319-1337, https://doi.org/10.1093/ijlct/ctac009
6. Arca, D., & Keskin Çıtıroğlu, H. (2020). Rüzgar Enerjisi Santral (RES) Yapım Yerlerinin CBS Dayalı Çok Kriterli Karar Analizi ile Belirlenmesi: Yenice İlçesi (KARABÜK) Örneği. Karaelmas Fen ve Mühendislik Dergisi, 10(2), 168-176. https://doi.org/10.7212/zkufbd.v10i2.1602
7. Tercan, E. (2021). Land suitability assessment for wind farms through best–worst method and GIS in Balıkesir province of Turkey. Sustainable Energy Technologies and Assessments, 47, 101491. https://doi.org/10.1016/j.seta.2021.101491
8. Sekeroglu, A., & Erol, D. (2023). Site selection modeling of hybrid renewable energy facilities using suitability index in spatial planning. Renewable Energy, 219(1), 119458. https://doi.org/10.1016/j.renene.2023.119458
9. Yaman, A. (2024). A GIS-based multicriteria decision-making approach (GIS-MCDM) for determination of the most appropriate site selection of onshore wind farm in Adana, Turkey. Clean Technologies and Environmental Policy, 26, 4231-4254. https://doi.org/10.1007/s10098-024-02866-3
10. Şahin, G., Koç, A., & van Sark, W. (2024). Multicriteria decision making for solar power - Wind power plant site selection using a GIS-intuitionistic fuzzy-based approach with an application in the Netherlands. Energy Strategy Reviews, 51, 101307. https://doi.org/10.1016/j.esr.2024.101307
11. Zhang, J., Cheng, C., & Yu, S. (2024). Recognizing the mapping relationship between wind power output and meteorological information at a province level by coupling GIS and CNN Technologies. Applied Energy, 360, 122791. https://doi.org/10.1016/j.apenergy.2024.122791
12. Ekiz, S., Şirin, A., & Erener, A. (2022). En uygun rüzgâr enerji santrali yerlerinin coğrafi bilgi sistemleri ile belirlenmesi: Kocaeli ili örneği. Jeodezi ve Jeoinformasyon Dergisi, 9(1), 59-79. https://doi.org/10.9733/JGG.2022R0005.T
13. Liu, Z., Guo, H., Zhang, Y., & Zuo, Z. (2025). A Comprehensive Review of Wind Power Prediction Based on Machine Learning: Models, Applications, and Challenges. Energies, 18(2), 350. https://doi.org/10.3390/en18020350
14. Daneshvar Rouyendegh, B., Yildizbasi, A., & Arikan, Ü.Z.B. (2018). Using Intuitionistic Fuzzy TOPSIS in Site Selection of Wind Power Plants in Turkey. Advances in Fuzzy Systems, 6703798. https://doi.org/10.1155/2018/6703798
15. Yıldız, S.S. (2021). Balıkesir İli Rüzgâr Hızı Haritalarının Hazırlanması ve Rüzgâr Enerjisi Potansiyeli Açısından İncelenmesi. Geomatik, 6(3), 198-206. https://doi.org/10.29128/geomatik.737567
16. Emeksiz, C., & Demirci, B. (2019). The determination of offshore wind energy potential of Turkey by using novelty hybrid site selection method. Sustainable Energy Technologies and Assessments, 36, 100562. https://doi.org/10.1016/j.seta.2019.100562
17. Aydin, N.Y., Kentel, E., & Duzgun, S. (2010). GIS-based environmental assessment of wind energy systems for spatial planning: A case study from Western Turkey. Renewable and Sustainable Energy Reviews, 14(1), 364-373. https://doi.org/10.1016/j.rser.2009.07.023
18. Sözen, A., Mirzapour, A., Cakır, M.T., İskender, Ü., & Çipil, F. (2015). Veri Zarflama ve Topsis Yaklaşımları Kullanılarak Türkiye Şehirlerinde Rüzgâr Santralleri için En İyi Yer Seçimi. Gazi Mühendislik Bilimleri Dergisi (GMBD), 1(1), 173-193.

https://dergipark.org.tr/tr/download/article-file/304785
19. Arı, E.S., & Gencer, C. (2020). The use and comparison of a deterministic, a stochastic, and a hybrid multiple-criteria decision-making method for site selection of wind power plants: An application in Turkey. Wind Engineering, 44(1), 60-74. https://doi.org/10.1177/0309524X19849831
20. Derse, O., & Yılmaz, E. (2021). Optimal site selection for wind energy: a case study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 44(3), 6660-6677. https://doi.org/10.1080/15567036.2021.1955048
21. Darende, P., Rouyendegh (B. Erdebilli), B.D., & Khaniyev, T. (2021). Regional Examination of Energy Investments in Turkey Using an Intuitionistic Fuzzy Method. In: Topcu, Y.I., Özaydın, Ö., Kabak, Ö., Önsel Ekici, Ş. (eds) Multiple Criteria Decision Making. MCDM 2019. Contributions to Management Science. Springer. https://doi.org/10.1007/978-3-030-52406-7_7
22. Çolak, Z. (2024). A hybrid MCDM method for enhancing site selection for wind power plants in Turkey. Energy for Sustainable Development, 82, 101536. https://doi.org/10.1016/j.esd.2024.101536
23. Demir, A., Dinçer, A.E., Çiftçi, C., Gülçimen, S., Uzal, N., & Yılmaz, K. (2024). Wind farm site selection using GIS-based multicriteria analysis with Life cycle assessment integration. Earth Science Informatics, 17, 1591-1608. https://doi.org/10.1007/s12145-024-01227-4
24. Urfalı, T., & Eymen, A. (2021). CBS ve AHP Yöntemi Yardımıyla Kayseri İli Örneğinde Rüzgâr Enerji Santrallerinin Yer Seçimi. Geomatik, 6(3), 227-237. https://doi.org/10.29128/geomatik.772453
25. Yılmaz, D., Akkaya, S., & Vaheddoost, B. (2023). Gemlik İlçesi rüzgâr enerji santrali potansiyel yer analizi. Geomatik, 8(3), 264-276. https://doi.org/10.29128/geomatik.1209940
26. Akova, İ. (2011). Development potential of wind energy in Turkey. EchoGéo. https://doi.org/10.4000/echogeo.12457
27. İlkılıç, Z. (2016). Türkiye'de Rüzgar Enerjisi ve Rüzgar Enerji Sistemlerinin Gelişimi. Batman Üniversitesi Yaşam Bilimleri Dergisi, 6(2/2), 1-13. https://dergipark.org.tr/tr/download/article-file/313658
28. Pınar, A., Buldur, A., & Tuncer, T. (2020). Türkiye'deki Rüzgâr Enerji Santralleri Dağılışının Coğrafi Perspektiften Analizi. Doğu Coğrafya Dergisi, 25(43), 167-182. https://doi.org/10.17295/ataunidcd.662785
29. Unal, M., Cilek, A., & Tekin, S. (2024). Maximum Entropy Method for Wind Farm Site Selection: Implications for River Basin Ecosystems Under Climate Change. Water, 16(24), 3679. https://doi.org/10.3390/w16243679
30. Lyu, X., Li, X., Zhang, C., Dang, D., Wang, K., & Lou, A. (2024). Mapping the carbon mitigation potential of photovoltaic development in the Gobi and desert regions of China. Energy, 308, 132936. https://doi.org/10.1016/j.energy.2024.132936
31. Chaibi, M., Ben Ghoulam, E.M., Khallouk, N., Tarik, L., El Yousfi, Y., El Hmaidi, A., Berrada, M., & Mabrouki, J. (2024). A novel fuzzy-multicriteria-GIS-machine learning approach for onshore wind power plant site selection. Euro-Mediterranean Journal for Environmental Integration, https://doi.org/10.1007/s41207-024-00653-6
32. ESRI (2023). Forest-based classification and regression (Spatial Statistics). https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/forestbasedclassificationregression.htm
33. Breiman, L. (2001). Random forest. Machine Learning, 45, 5-32. https://doi.org/10.1023/A:1010933404324
34. Çömert, R., Matcı, D. K., & Avdan, U. (2019). Object based burned area mapping with random forest algorithm. International Journal of Engineering and Geosciences, 4(2), 78-87. https://doi.org/10.26833/ijeg.455595
35. İlkiliç, C., & Türkbay, İ. (2010). Determination and utilization of wind energy potential for Turkey. Renewable and Sustainable Energy Reviews, 14(8), 2202-2207. https://doi.org/10.1016/j.rser.2010.03.033
36. EPDK. (2024). Elektrik Piyasası Üretim Lisansları. T.C. Enerji Piyasası Düzenleme Kurumu. https://lisans.epdk.gov.tr/epvys-web/faces/pages/lisans/elektrikUretim/elektrikUretimOzetSorgula.xhtml
37. Google Earth Pro. (2024). Google Earth Pro programındaki altlık uydu görüntüsü.
38. Frankl, A., Zwertvaegher, A., Poesen, J., & Nyssen, J. (2012). Transferring Google Earth observations to GIS-software: example from gully erosion study. International Journal of Digital Earth, 6(2), 196-201. https://doi.org/10.1080/17538947.2012.744777
39. Tezel, D., Aydemir, S., Taşkın, C., & Gündoğan, Ü. (2022). 3D Modeling and Land Management in Protected Areas: Fethiye-Göcek SEPA. Advanced Geomatics, 2(2), 37–48. https://publish.mersin.edu.tr/index.php/geomatics/article/view/267
40. Neal, J., & Hawker, N. (2023). FABDEM V1-2. https://doi.org/10.5523/bris.s5hqmjcdj8yo2ibzi9b4ew3sn
41. Özdemir, H., & Akbaş, A. (2023). Sayısal yükseklik modelerindeki mekânsal çözünürlük değişkenliğinin taşkın tehlike analizine etkileri. Cografya Dergisi, 46, 137-156. https://doi.org/10.26650/JGEOG2023-1177718
42. Yilmaz, H. M., Yakar, M., Mutluoglu, O., Kavurmaci, M. M., & Yurt, K. (2012). Monitoring of soil erosion in Cappadocia region (Selime-Aksaray-Turkey). Environmental Earth Sciences, 66, 75-81.
43. Cürebal, İ., & Özşahin, E. (2022). Harita Bilgisi (Bilgisayar Uygulamalı Tasarım ve Analiz). Ekin Basın Yayın Dağıtım, Bursa.
44. Hasanzaeh, M., Valizadeh Kamran, K., Feizizadeh, B., & Hassanzadeh Mollabashi, S. (2024). GIS based spatial decision-making approach for solar energy site selection, Ardabil, Iran. International Journal of

Engineering and Geosciences, 9(1), 115-130. https://doi.org/10.26833/ijeg.1341451
45. Çolak, E., Bediroğlu, G., & Memişoğlu Baykal, T. (2024). GIS-based determination of potential snow avalanche areas: A case study of Rize Province of Türkiye. International Journal of Engineering and Geosciences, 9(2), 199-210. https://doi.org/10.26833/ijeg.1367334
46. Jonuzi, E., Alkan, T., Durduran, S.S., & Selvi, H.Z. (2024). Using GIS-supported MCDA method for appropriate site selection of parking lots: The case study of the city of Tetovo, North Macedonia. International Journal of Engineering and Geosciences, 9(1), 86-98. https://doi.org/10.26833/ijeg.1319605
47. Clifton, A., Barber, S., Stökl, A., Frank, H., & Karlsson, T. (2022). Research challenges and needs for the deployment of wind energy in hilly and mountainous regions, Wind Energy Science, 7, 2231-2254. https://doi.org/10.5194/wes-7-2231-2022
48. Doumit, J. (2024). Estimating the efficacy of solar photovoltaic panels in Lebanon using a digital surface model: A geospatial approach. Mersin Photogrammetry Journal, 6(1), 22-31. https://doi.org/10.53093/mephoj.1401603
49. Najatishendi, E., Ergene, E.M., Uzar, M., Balık Şanlı, F. (2022). Production of flood risk maps: Ayancık Stream Example. Mersin Photogrammetry Journal, 4(1), 14-23. https://doi.org/10.53093/mephoj.1123378
50. Yürek, Ö., Birant, D., & Yürek, İ. (2021). Wind Power Generation Prediction Using Machine Learning Algorithms. Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi, 23(67), 107-119. https://doi.org/10.21205/deufmd.2021236709
51. Başara, A.C., Tabar, M.E., Gülsün, S., & Şişman, Y. (2022). Monitoring Urban Sprawl in Atakum District Using CORINE Data. Advanced Geomatics, 2(2), 49–56. https://publish.mersin.edu.tr/index.php/geomatics/article/view/481
52. Unel, F. B., Kusak, L., & Yakar, M. (2023). GeoValueIndex map of public property assets generating via Analytic Hierarchy Process and Geographic Information System for Mass Appraisal: GeoValueIndex. *Aestimum*, *82*, 51-69.
53. Yeniay, E., & Şık, A. (2023). Spatial ecological risk analysis in peach farming in Manisa. Advanced GIS, 3(2), 59–67. https://publish.mersin.edu.tr/index.php/agis/article/view/1044
54. Makhmudov, R., & Teymurov, M. (2024). Importance of using GIS software in the process of application of Analogue terrains and Counter-approach technologies in water resources assessment. Advanced Remote Sensing, 4(1), 36–45. https://publish.mersin.edu.tr/index.php/arsej/article/view/1163
55. Siraj, M., Mahmood, S., & Habib, W. (2023). Geo-spatial assessment of land cover change in District Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. Advanced Remote Sensing, 3(1), 1–9. https://publish.mersin.edu.tr/index.php/arsej/article/view/686
56. Ünel, F. B., Kuşak, L., Yakar, M., & Doğan, H. (2023). Coğrafi bilgi sistemleri ve analitik hiyerarşi prosesi kullanarak Mersin ilinde otomatik meteoroloji gözlem istasyonu yer seçimi. *Geomatik*, *8*(2), 107-123.
57. Aghayeva, F. (2024). Wildfire hazard and risk assessment: The case of Gabala district. Advanced GIS, 4(1), 01–09. https://publish.mersin.edu.tr/index.php/agis/article/view/1089
58. Valizadeh Kamran, K., Nasiri, A., Zandi, R., Shafiei, N., & Farzin, R. (2022). An assessment of physical development prediction in Shiraz (Iran) and its relationship with geomorphological factors. Advanced Remote Sensing, 2(2), 47–57. https://publish.mersin.edu.tr/index.php/arsej/article/view/347
59. Pathak, S., Acharya, S., Bk, S., Karn, G., & Thapa, U. (2024). UAV-based topographical mapping and accuracy assessment of orthophoto using GCP. Mersin Photogrammetry Journal, 6(1), 1-8. https://doi.org/10.53093/mephoj.1350426
60. Shorabeh, S.N., Firozjaei, H.K., Firozjaei, M.K., Jelokhani-Niaraki, M., Homaee, M., & Nematollahi, O. (2022). The site selection of wind energy power plant using GIS-multicriteria evaluation from economic perspectives. Renewable and Sustainable Energy Reviews, 168, 112778. https://doi.org/10.1016/j.rser.2022.112778
61. Özşahin, E., & Kaymaz, Ç.K. (2013). Rüzgâr Enerji Santrallerinin (RES) Kuruluş Yeri Seçiminin CBS İle Analizi: Hatay Örneği. TÜBAV Bilim Dergisi, 6(2), 1-18. https://dergipark.org.tr/tr/download/article-file/200976
62. Gull, A., Liaqut, A., & Mahmood, S. (2023). Landslide Risk Assessment using Geo-spatial Technique: A study of District Abbottabad, Khyber Pakhtunkhwa, Pakistan. Advanced Geomatics, 3(2), 47–55. https://publish.mersin.edu.tr/index.php/geomatics/article/view/983
63. Çalışkan, M. (2011). Türkiye Rüzgâr Enerjisi Potansiyeli ve Mevcut Yatırımlar. Rüzgâr Enerjisi ve Santralleri Semineri (27 Mayıs 2011), Rahmi Koç Müzesi Konferans Salonu, İstanbul.
64. Cunden, T.S.M., Doorga, J., Lollchund, M.R., & Rughooputh, S.D.D.V. (2020). Multilevel constraints wind farms siting for a complex terrain in a tropical region using MCDM approach coupled with GIS. Energy, 211, 118533. https://doi.org/10.1016/j.energy.2020.118533
65. Mostafaeipour, A., Sadeghi, S., Jahangiri, M., Nematollahi, O., & Rezaeian Sabbagh, A. (2020). Investigation of accurate location planning for wind farm establishment: a case study. Journal of Engineering, Design and Technology, 18(4), 821-845. https://doi.org/10.1108/JEDT-08-2019-0208
66. Kim, H.G., Kang, Y.H., & Kim, J.Y. (2017). Evaluation of wind resource potential in mountainous region considering morphometric terrain characteristics. Wind Engineering, 41(2), 114-123. https://doi.org/10.1177/0309524X16689445

67. Hepbasli, A., & Ozgener, O. (2004). A review on the development of wind energy in Turkey. Renewable and Sustainable Energy Reviews, 8(3), 257-276. https://doi.org/10.1016/j.rser.2003.10.006.
68. Çam, E., Arcaklıoğlu, E., Çavuşoğlu, A., & Akbıyık, B. (2005). A classification mechanism for determining average wind speed and power in several regions of Turkey using artificial neural networks. Renewable Energy, 30(2), 227-239. https://doi.org/10.1016/j.renene.2004.05.008
69. Değirmenci, S., Bingöl, F., & Sofuoğlu, S.C. (2017). Türkiye'de Rüzgâr Tarlası Arazilerinin Çok Kriterli Karar Analizi Kullanılarak Belirlenmesi. 4. İzmir Rüzgâr Sempozyumu (28-30 Eylül 2017), İzmir, s.: 27-32
70. Bingöl, F. (2018). Rüzgar Enerji Sistemleri İçin Hava Yoğunluğunun Hesaplanması. Politeknik Dergisi, 21(2), 273-281. https://doi.org/10.2339/politeknik.385523
71. Ifkirne, M., El Bouhi, Hi, Acharki, S., Pham, Q.B., Farah, A., & Linh, N.T.T. (2022). Multi-Criteria GIS-Based Analysis for Mapping Suitable Sites for Onshore Wind Farms in Southeast France. Land, 11(10), 1839. https://doi.org/10.3390/land11101839
72. Yılmaz, D., Akkaya, S., & Vaheddoost, B. (2023). Gemlik İlçesi rüzgâr enerji santrali potansiyel yer analizi. Geomatik, 8(3), 264-276. https://doi.org/10.29128/geomatik.1209940
73. Memduhoğlu, A., Özmen, G., Göyçek, G., & Kılıç, F. (2014). Rüzgar Türbini Kurulacak Alanların CBS–Çok Ölçütlü Karar Analizi Kullanılarak Belirlenmesi: Davutpaşa Kampüsü. V. Uzaktan Algılama ve Coğrafi Bilgi Sistemleri Sempozyumu (UZAL-CBS 2014), 14-17 Ekim 2014, İstanbul.