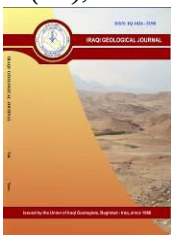
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



GIS and Remote Sensing-Based Assessment of Regional Wind Climate in Maysan Province Using Wind Atlas Analysis and Application Program WAsP

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Received:
16 May 2025
Accepted:
11 July 2025
Published:
31 October 2025

Abstract

This study assesses the wind energy potential in Maysan Province, Iraq, utilizing the Wind Atlas and the WAsP program to investigate the regional wind climate. Despite Iraq's increasing interest in renewable energy, few studies have examined wind resources in this region. The study addresses this deficiency by employing the Global Wind Atlas to acquire wind data and a Generalized Wind Climate file for designated regions. The WAsP software was employed to analyze this data and simulate microscale wind characteristics, including wind speed, power densities, and Weibull parameters across different elevations and roughness categories. The results indicate that Maysan Province possesses favorable wind conditions, especially at heights above 100 m, when wind speed exceeds 8 m/s and power densities reach over 600 W/m². Surface roughness significantly influences wind velocities at lower elevations, however, its effect wanes diminishes with greater altitude, highlights the moderate surface roughness, suggesting a landscape with sparse vegetation or mixed land cover, which affects turbine placement and hub height determination. This research supports Iraq's transition to renewable energy by identifying viable locations for wind power generation, reducing reliance on fossil fuels.

Keywords: Remote sensing; Wind energy; WAsP; GIS; Wind Atlas Analysis

1. Introduction

More power is coming from renewable sources than ever before. One of these competitive clean energy sources is wind energy. It was pollution free, abundant, emission free, inexhaustible and it reduces dependence on fossil fuels (Roga et al., 2022; Sadorsky et al., 2021). The amount of electricity generated from wind increased by 265 terawatt-hours (TWh) in 2022, an increase of 14%, which is the second largest growth among all energy generation technologies (Gajdoš et al., 2019). The regional wind climate denotes the enduring patterns of wind velocity, orientation, and fluctuation in a specific geographic area. It is affected by elements including terrain, land utilization, atmospheric pressure systems, and seasonal meteorological patterns. Comprehending regional wind climate is crucial for evaluating wind energy potential, optimizing turbine placement, and predicting long-term energy production. The Geographic Information Systems (GIS), remote sensing, and numerical models (e.g., Wind Atlas Analysis and Application Program (WAsP), CFD) are routinely employed to assess spatial wind patterns and determine optimal sites for wind energy development (Pryor et al., 2005; Hueging et al., 2013). The regional wind speed is influenced by numerous geological and geomorphological

elements, such as terrain height, landform configuration, and surface roughness. Geomorphology significantly affects wind dynamics, as landforms such as mountains, valleys, plateaus, and coastal plains determine wind velocity, orientation, and turbulence. In wind energy evaluations, comprehending the interplay between wind patterns and geological formations aids in determining appropriate turbine placements that minimize turbulence and maximize energy potential. The application of GIS and remote sensing, in conjunction with WAsP modeling, facilitates comprehensive mapping of wind resources while integrating geological attributes such as sediment transport, erosion patterns, and surface roughness classification, which are crucial for precise site selection and sustainable wind energy planning (Koo et al., 2015; de Jonge-Anderson and Underhill, 2022).

In Iraq, wind energy can play a prominent role in strengthening the national grid and filling the shortage in electricity supply (Darwish et al., 2019). In this context, many studies have been conducted to evaluate several sites that would be suitable for installing wind farms and studying the economic feasibility for these farms (Mohammed et al., 2020; Pires et al., 2022).

Many studies are now looking at how different parts of Iraq might use wind energy. Some studies focus on harnessing renewable energy by calculating wind speed (Al-Assadi, 2024). Others expand their study and discuss the feasibility study, choosing suitable wind turbines for sites in addition to site assessment (Van Haaren and Fthenakis, 2011, Al-Taai et al., 2014). A group of researchers studied the losses that could affect the productivity of wind farms (Santos and González, 2019). Others focused on the design and simulation of some parts of wind turbines and failure detection of wind turbines via power signal processing for stator current of wind turbine (Hussein et al., 2022; Mahmood et al., 2018).

In recent years, the advancement of computer software and simulation has substantially enhanced the systematic examination of the subject matter (Taqi et al., 2025; Tozzi et al., 2017). Modeling and simulation are digital tools that can be used to analyze a system or predict its behavior before it is built or installed on the ground (Salehin et al., 2016). The growing interest in wind energy systems, along with advances in modeling and simulation, has led to the creation and adoption of a variety of software tools that can be used in the design, analysis, simulation, and economic planning of systems. Modeling and simulation have become a global practice followed in various sectors, which has led to the availability of engineering programs at low prices and that are easy to learn. Many engineering programs are extensively utilized in modeling and simulating wind energy systems, including WAsP (Resen and Ahmed, 2019; Yılmaz et al., 2019). Wind Pro (Sharma et al., 2019). WindSim (Song et al., 2020; Düzcan and Kara, 2025). Windographer (AlQahtani et al., 2024). Homer (Zhang et al., 2022). RETScreen (Kassem et al., 2023) applications are routinely employed for the estimation. WAsP is highly effective for wind energy calculations, including site evaluation, terrain analysis, and surface roughness assessment. Sites in every corner of the globe can benefit from WAsP software's models and tools, which cover everything from analyzing wind data to evaluating potential locations for wind farms and calculating their energy yield (Murthy et al., 2017). According to Olsen (2021), the Wind Atlas of Mexico (WAM) includes the procedures that were utilized to generate the mesoscale component, which was derived from the Weather Research and Forecasting (WRF) model, and the microscale component, which was derived from the downscaling of the WRF model through the utilization of the WAsP.

Remote sensing plays a vital role in numerous scientific studies across various disciplines, providing valuable data for environmental monitoring, climate analysis, and resource management (Faris et al., 2021; Al-Rikabi et al., 2024).

The Global Wind Atlas (GWA) relies on remote sensing and numerical modeling to estimate wind resources with high spatial resolution. It integrates satellite-derived data, such as land cover and surface roughness, which influence wind flow patterns. While the GWA is not purely a remote sensing product, it heavily depends on remote sensing data to improve the accuracy of wind resource

assessments worldwide. GIS serve as a fundamental tool in the Global Wind Atlas, enabling efficient data processing, visualization, and decision-making for wind energy development.

The wind energy potential of Maysan Province in Iraq has not been thoroughly examined. The absence of comprehensive regional wind climatic evaluations obstructs the efficient planning and execution of wind energy initiatives. Considering Iraq's increasing demand for renewable energy, comprehending the wind characteristics of Maysan Province is essential for pinpointing suitable sites for wind farm development. This work addresses the research gap by employing GIS and remote sensing technologies, along with the Wind Atlas and Application Program (WAsP), one of the most advanced wind resource modeling tools globally, to thoroughly evaluate the wind climate in this area.

Despite the significance of wind energy potential in southern Iraq, there is a notable gap in the literature regarding the application of WAsP for regional wind climate evaluation in this area. This research also supports Iraq's alternative energy development goal to reduce greenhouse gas emissions by 1% to 2% from 2021 to 2030.

2. Study Area

Maysan Province is located in the southern part of Iraq and is bounded by Wasit Governorate to the north, and Basra Governorate to the south, Dhi Qar Governorate to the west, and the international border with Iran to the east. The total area of Maysan Governorate is 16,381 km², covering 3.7% of the total Iraqi area, and it includes 15 administrative units divided into six districts. The study area is located within latitudes 31º8'15"–32º53'8" N and longitudes 46º17'19"– 47º52'25" E. GIS played a crucial role in defining the study area for wind climate analysis by accurately clipping the region of interest from broader datasets. Using spatial analysis tools, the study area corresponding to Maysan Province was extracted from national and global geographic datasets. This process ensured that only relevant spatial data, such as elevation, land cover, and administrative boundaries, were included in the analysis. The clipped data were then integrated into the WAsP to enhance the precision of wind resource assessment. Fig. 1 shows the location map of the study area.

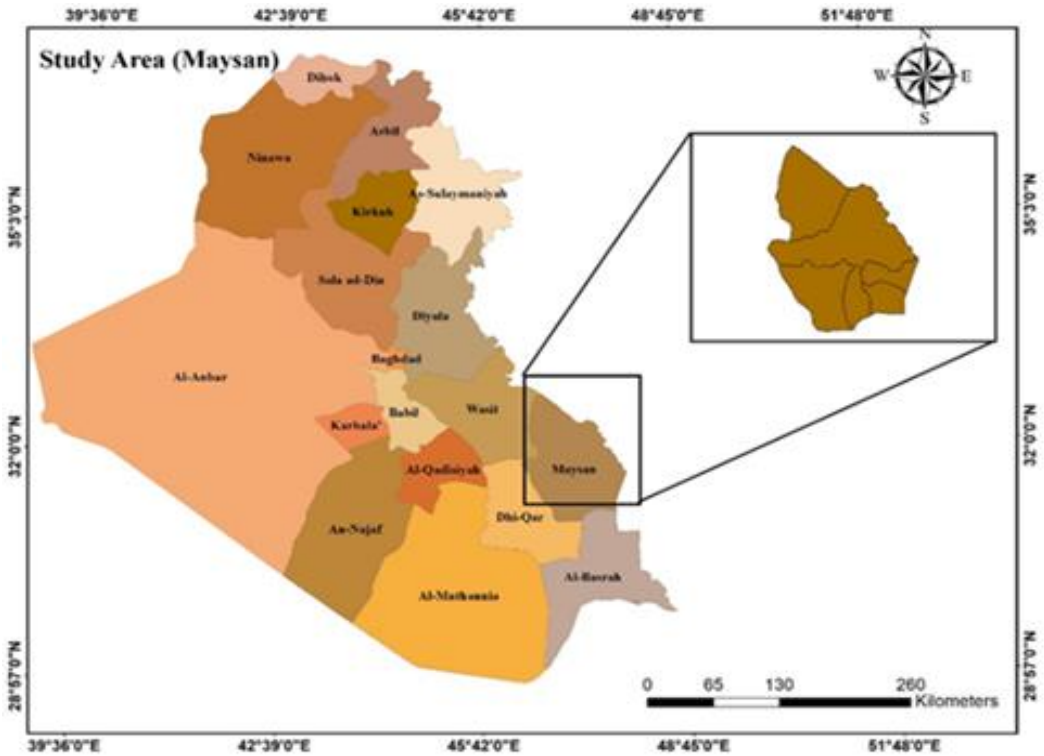

Fig. 1. Location map of the study area

3. Methodology

The WAsP integrates geological and geomorphological factors into wind energy assessments through terrain analysis, surface roughness classification, and obstacle modeling. The methodology of this study is illustrated as follows:

This research employs the Generalized Wind Climate (GWC) as the principal data source for evaluating wind energy potential in the study area as shown in Fig. 2. The study area was segmented into five sections according to topographical and wind resource criteria as illustrated in Table 1 and Fig. 3, and wind data were sourced from a GWA file, acquired from the closest mesoscale grid cell to the center of each region. The GWC data, encompassing sector-specific wind attributes such as wind rose information, Weibull parameters (A and k), and data for various reference roughness classes and altitudes, was analyzed using WAsP. The file, designated as an ASCII text file with the "lib" extension, was imported into WAsP for subsequent analysis.

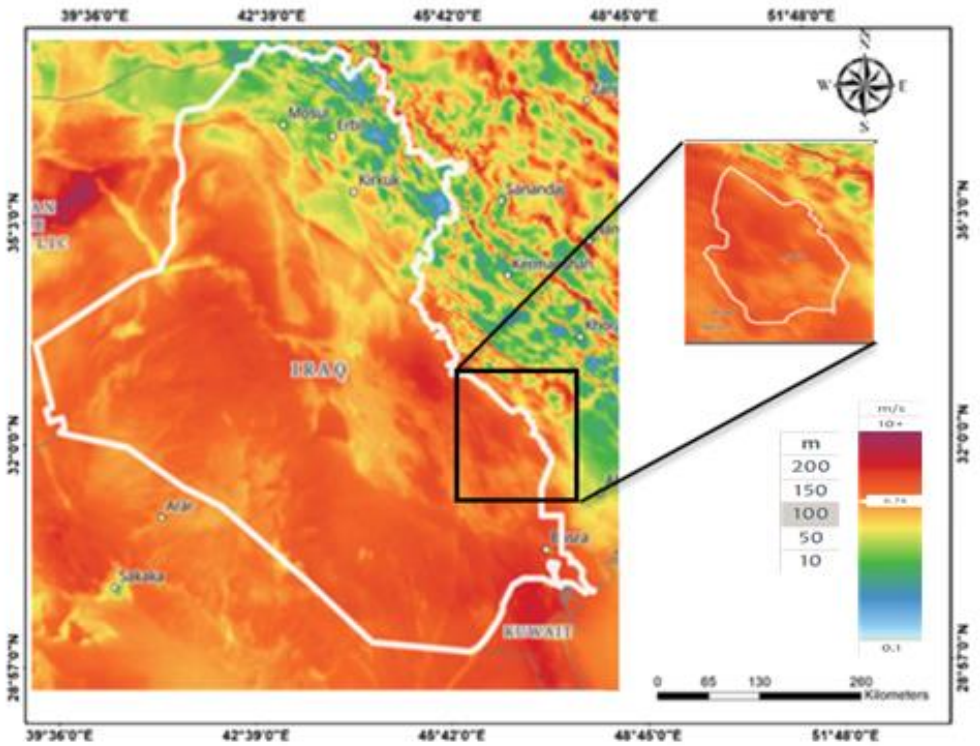

Fig. 2. Global Wind Atlas (GWA)

Table 1. The coordinates of the five sections selected to be studied for wind energy

District Name	Regions	Lat.	Long.	Elevation (m)	Roughness length(m)	Wind Power Density WPD(W/m^2)
Eastern ,Western Ali	Region 1	32.3281	46.9708	29	0.0050	506
District	Region 2	32.2776	46.9551	22	0.0050	538
Al-Musharrah, Al-	Region 3	31.8595	47.5195	12	0.0050	444
Kahla District,	Region 4	31.8474	47.533	10	0.0050	438
Said Ahmed Al-	Region 5	31.5474	46.628	9	0.0050	453

Fig. 3 depicts the geological formations map of Maysan. The map was created utilizing publicly accessible data from the United States Geological Survey (USGS), and then it was reconstructed and

streamlined utilizing GIS tools to distinctly outline the principal geological formations in the area, encompassing Quaternary deposits, Tertiary rocks, and aquatic bodies. The aim was to graphically depict the spatial distribution of these geological units throughout the province for geological and environmental investigations.

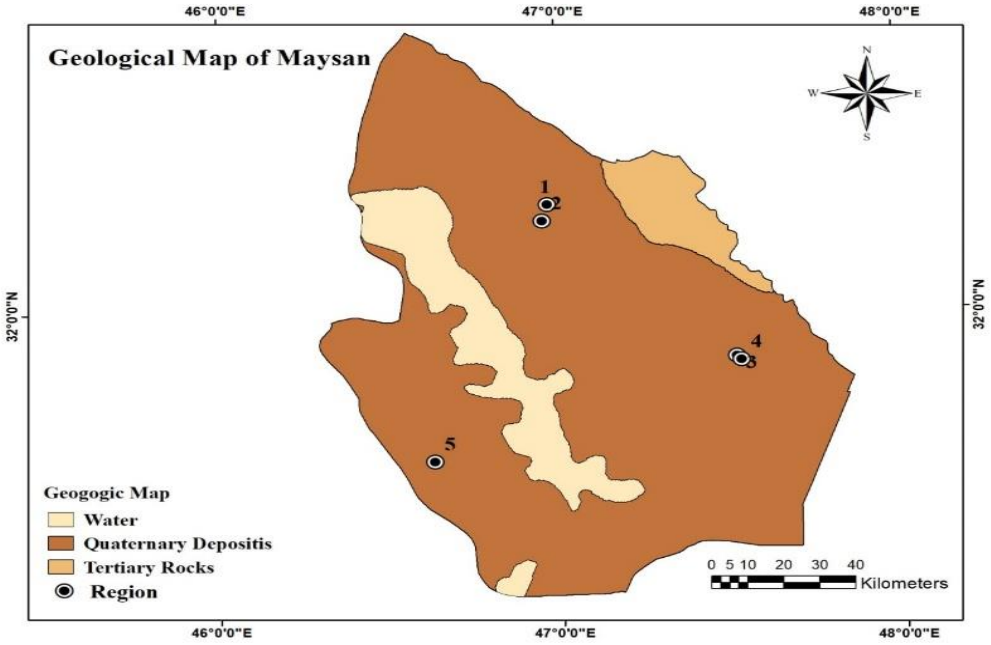

Fig. 3. Geological map of Maysan province shows the selected five sections

Fig. 4 presents the classification of the Digital Elevation Model (DEM) for the study area, categorizing the region into different elevation levels. The elevation is color-coded, with green representing low elevations, yellow indicating moderate elevations, and red highlighting higher elevations. The marked locations correspond to specific regions in Table 1. The data for this DEM classification was sourced from the United States Geological Survey (USGS) and classified in GIS.

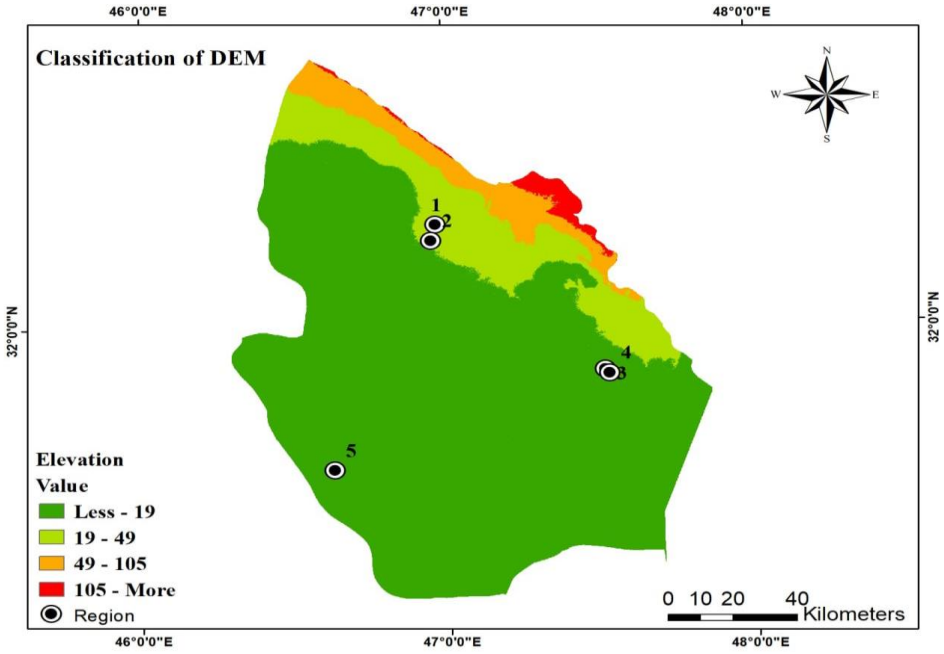

Fig. 4. Classification of DEM of Maysan province

The Weibull Probability Distribution Function (PDF) strongly affects wind turbine output (Ramadan, 2017). The wind speed histogram is often calculated using the two-parameter PDF. WAsP examines wind properties in all sectors using it. Equation (1) defines the Weibull PDF (Teimourian et al., 2022; Mathew, 2006).

$$f(u) = \frac{k}{A}(\frac{u}{A})^{k-1} e^{-(\frac{u}{A})^k}, \mathrm{k} > 0, \mathrm{u} > 0, \mathrm{A} > 1, \quad (1)$$

Weibull PDF was used to simulate the frequency wind speed which is represented by Equation 2:

$$P(u)du = \frac{k}{A}(\frac{u}{A})^{k-1} e^{-(\frac{u}{A})^k} du, \quad (2)$$

In this context, f(u) is the Weibull probability density function for the observation of wind speed u. A is the scale parameter measured in the same unit as wind speed U (m/s), K is a dimensionless shape parameter ranging from 1 to 3, characterising wind behaviour relative to its speed. Then, the corresponding cumulative probability function for the Weibull distribution is expressed in Equation (3):

$$F(u) = 1 - e^{-(\frac{u}{A})^k}, \quad (3)$$

where F(u) is the cumulative distribution function for the observation of wind speed u. The cumulative distribution is the integral of the PDF concerning speed (Teimourian et al., 2022).

Equation (4) is employed in WAsP for the purpose of representing the surface layer wind profile (Topaloğlu and Pehlivan, 2018). This is necessary when changing a wind speed at a certain height to wind speed at another height.

$$u(z) = \frac{u_*}{k} ln \frac{z}{z_0}, \quad (4)$$

Where u (z) is the air velocity at a height of z, u* is the air friction velocity, κ is von Karman's constant which in this case is set equal to 0.40 and z_0 is the roughness length of the surface.

4. Results and Discussion

The Figs. 5 through 9 depict a series of heatmaps, which represent the visual representation of data using color gradients to indicate variations in values across a dataset. They were produced by WAsP for Regions 1 through 5, demonstrating the fluctuation of key wind properties, most notably the Weibull parameters (A and k), mean wind speed, and power density in relation to height and surface roughness. The Weibull scale parameter (A) and mean wind speed exhibit a declining trend as surface roughness increases, confirming the dampening influence of rugged terrain on wind flow. Additionally, both parameters show a considerable increase with altitude, underscoring the stronger and more consistent winds at elevated heights. The shape parameter (k) shows relative stability at elevated altitudes but diminishes near the surface, indicating increased wind speed variability at lower elevations. The power density heatmap exhibits the same trends, with peak values recorded at higher elevations and lower roughness, corroborating that smoother surfaces and higher altitudes enhance wind energy potential.

4.1. Region-1

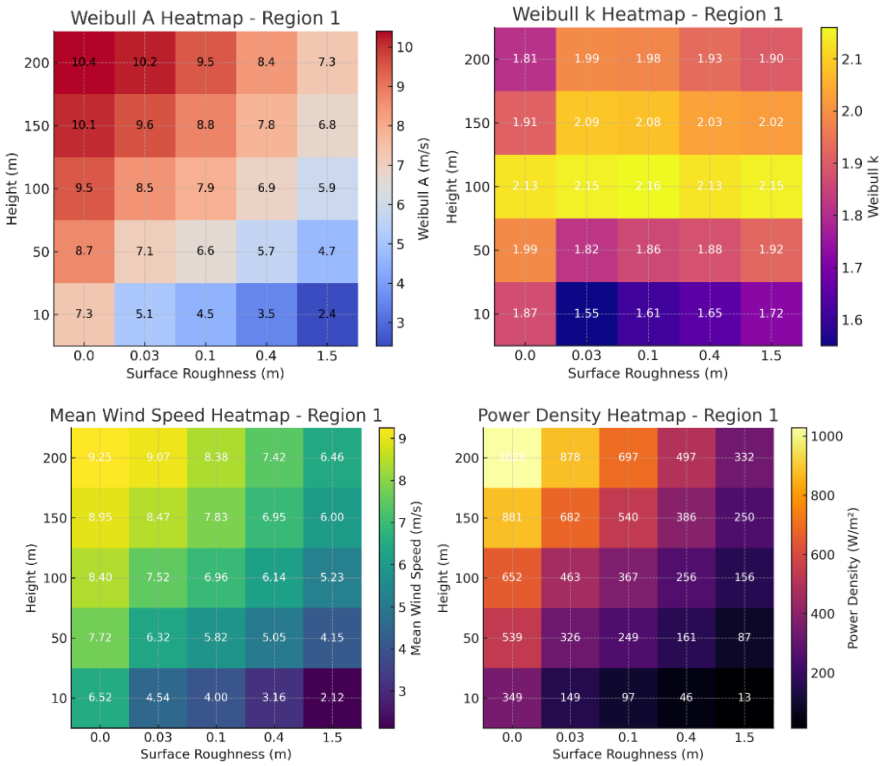

Fig. 5. Regional wind climate summary- Region-1

4.2. Region-2

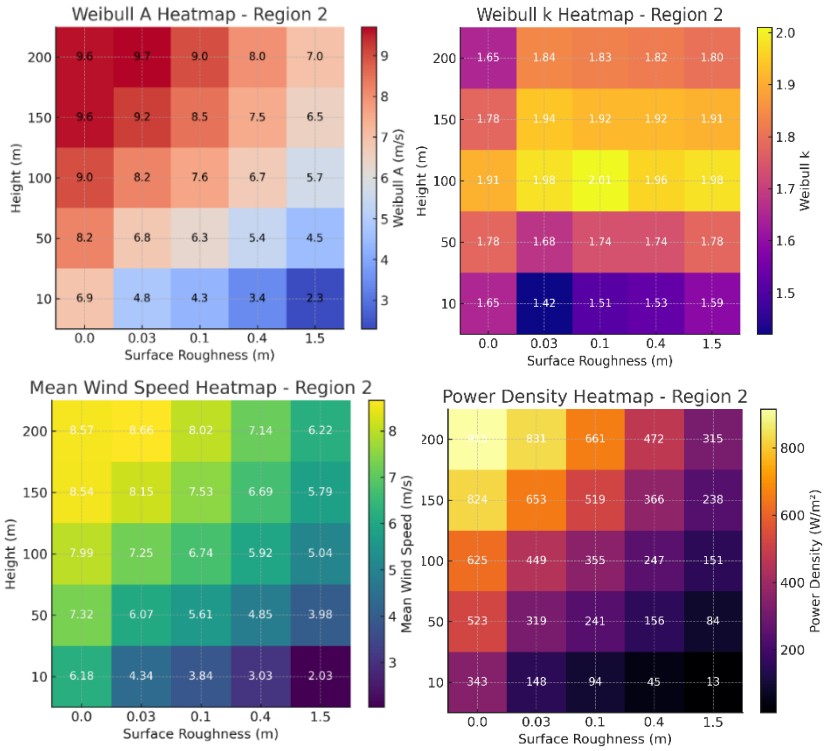

Fig. 6. Regional wind climate summary- Region-2

4.3. Region-3

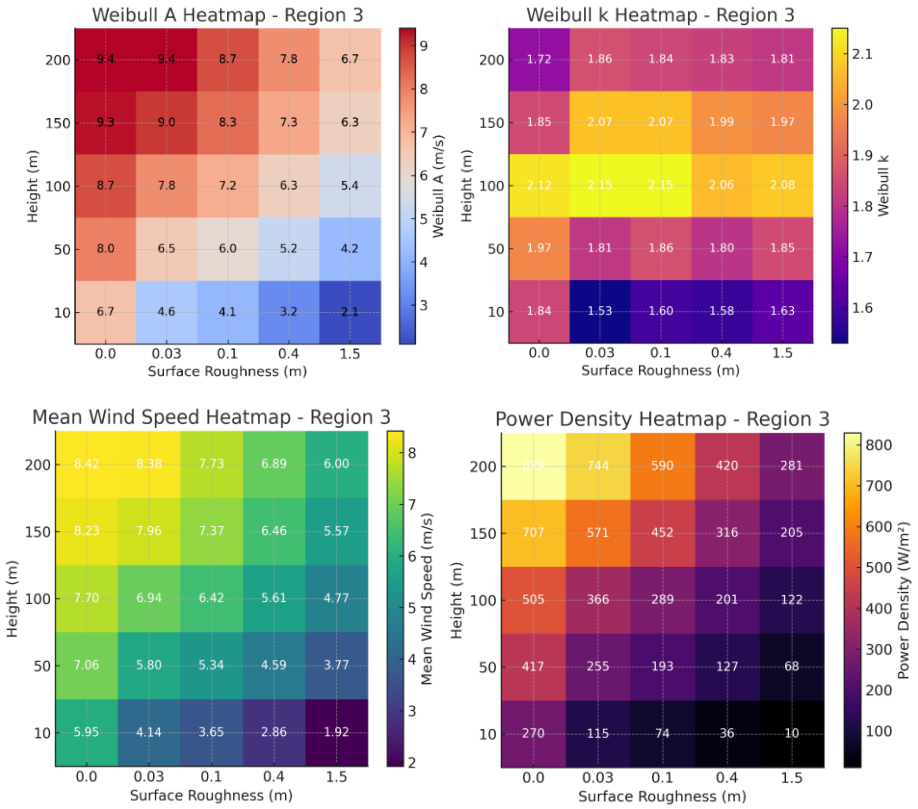

Fig. 7. Regional wind climate summary- Region-3

4.4. Region-4

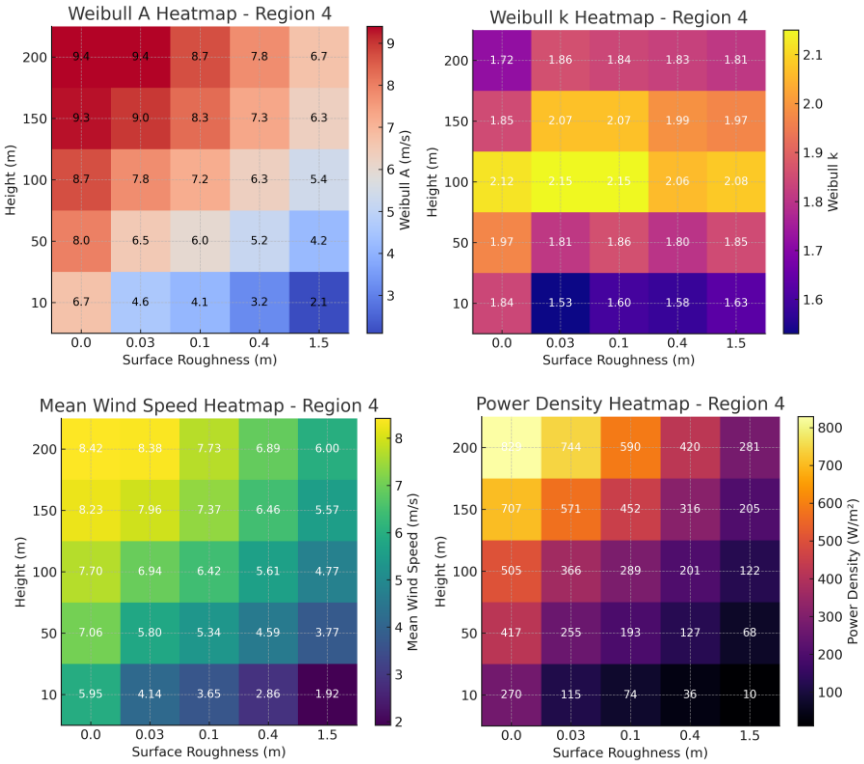

Fig. 8. Regional wind climate summary- Region-4

4.5. Region-5

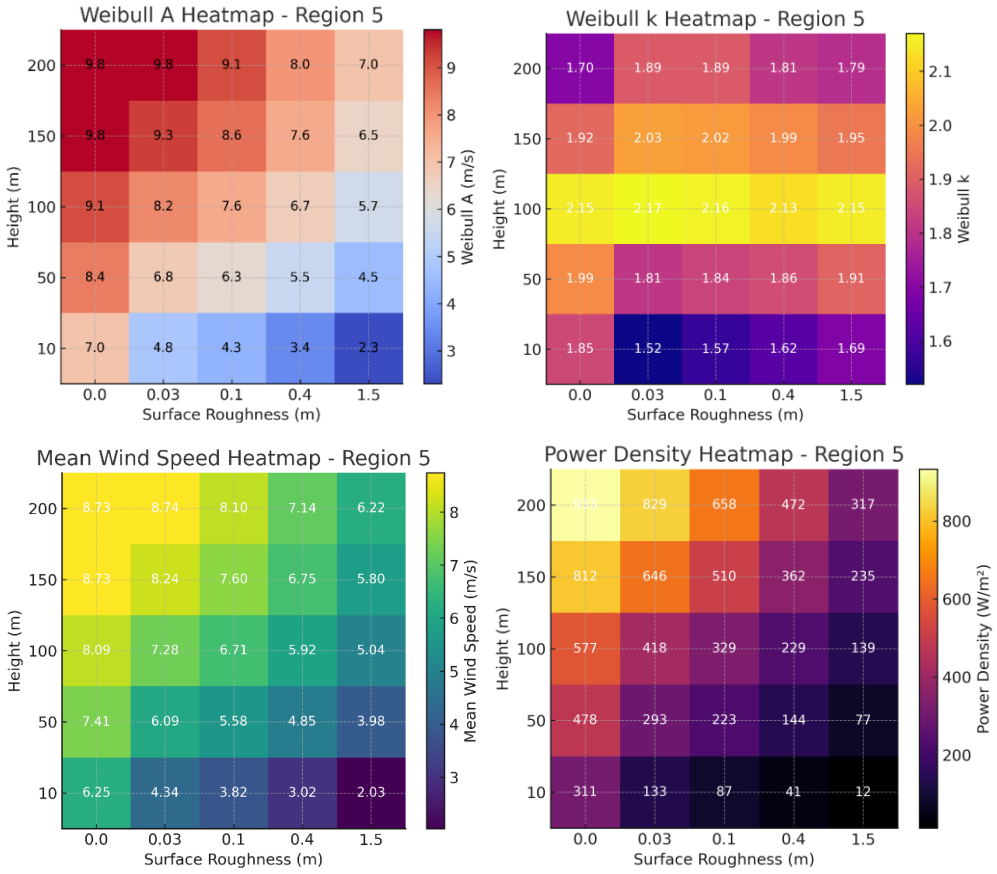

Fig. 9. Regional wind climate summary- Region-5

Fig. 10 presents two essential visualisations for wind resource assessment: a wind rose diagram (left) and a Weibull probability distribution (right), both produced using WAsP.

The wind rose diagram depicts the primary wind directions and their respective frequencies. The largest sector represents the dominant wind direction, indicating the origin of the wind with the highest frequency.

The right plot illustrates the Weibull PDF for the distribution of wind speeds at the site. The two curves presumably compare between empirical and fitted Weibull distributions. The displayed parameters-scale parameter (A) and shape parameter (k) characterise the wind regime, with mean wind speeds (u) recorded as 9.25 m/s, 8.57 m/s, 5.95 m/s, 8.42 m/s, and 8.73 m/s for regions 1 through 5, respectively. The power density (P) reaches a maximum of 1029 W/m² in region 1, signifying substantial wind energy potential, whereas the minimum value recorded is 269 W/m² in region 3.

The results of this study align with prior research conducted in the semi-arid regions of southern Iraq. Mohammed et al. (2024) indicated that the maximum monthly mean wind speeds and energy densities were indecated in May and June, with peak seasonal values in spring and summer, and minimal values in winter and fall. This seasonal pattern corresponds with our observations, indicating that the peak wind energy potential was documented during analogous periods. A further study at the Ali Al-Gharbi site (Khamees et al., 2021) recorded wind speeds of 7.37 m/s in July and minimum values of approximately 3.18 m/s in November, depending on measurement height. The measured mean wind speeds, ranging from 5.95 m/s to 9.25 m/s across the five regions, corroborate these figures. Likewise, the wind power density figures spanning 269 W/m² to 1029 W/m², indicate similar energy potential. These similarities enhance the credibility of our data and underscore the appropriateness of Maysan province for wind energy development in light of regional trends.

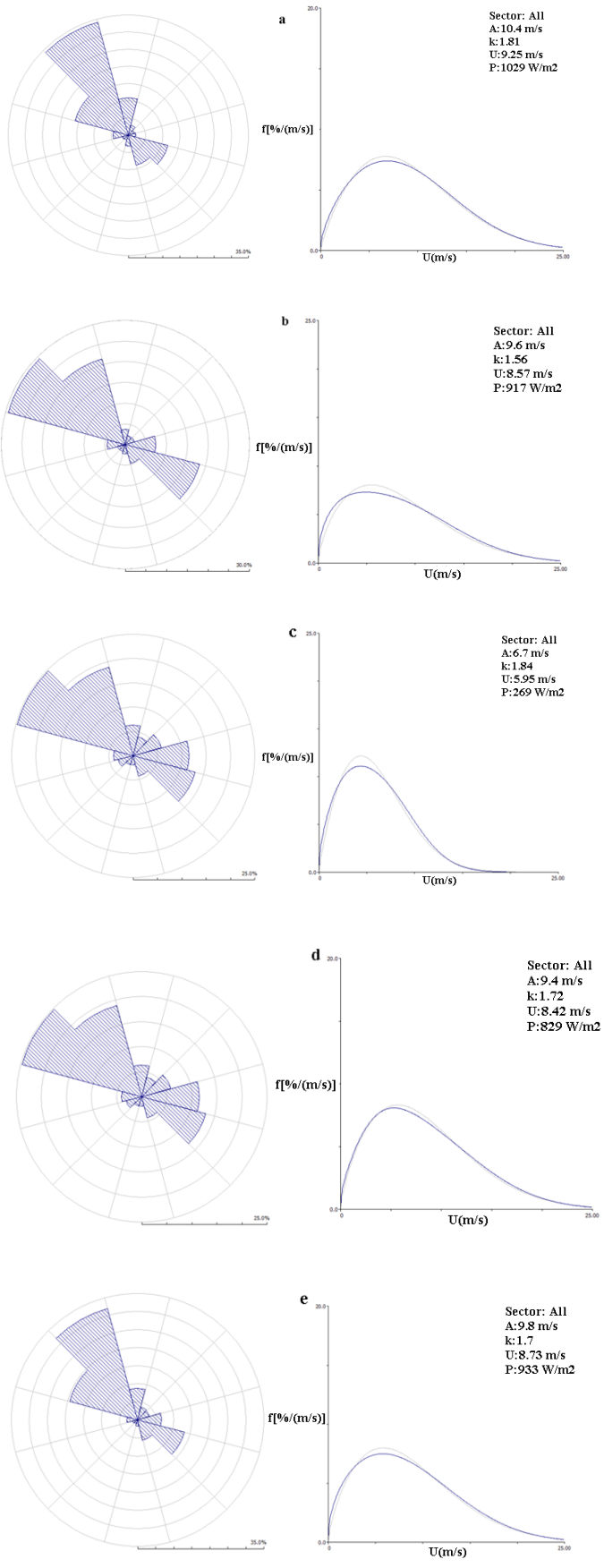

Fig. 10. Wind rose and PDF for a: region 1, b: region 1, c: region 3, d: region 4, e: region 5

The regional wind climate data for all sections indicates a clear increase in wind speed and power density with height, making higher altitudes more favorable for wind energy generation. The Weibull scale parameter (A), which represents characteristic wind speed, increases with altitude, confirming stronger winds at higher elevations. Meanwhile, the Weibull shape parameter (k), which describes wind speed variability, remains relatively stable indicating moderate-to-high wind consistency. These values suggest that wind power generation is viable in this region, particularly above 100 m, where wind speeds exceed 8 m/s and power densities surpass 600 W/m². The tables also implicitly reflect the effect of surface roughness on wind speed variation at different heights. The presence of multiple measurement heights, starting from very low levels (e.g., 0.00m, 0.03 m, 0.10 m, 0.40 m, and 1.50 m) suggests that roughness length (z_0) plays a significant role in shaping the wind profile near the surface. Lower heights exhibit lower wind speeds due to increased friction and obstacles such as vegetation and buildings, while wind speeds increase significantly at higher elevations where frictional effects diminish.

For example, in Region 1, at 10 m, the mean wind speed is 6.52 m/s, while at 50 m, it rises to 7.72 m/s, and at 100 m, it reaches 8.40 m/s. This variation follows the logarithmic wind profile law, which is influenced by roughness length. The steady increase in Weibull A values with height further confirms that surface roughness is impacting wind speeds at lower levels, but the effect decreases as altitude increases. Additionally, the Weibull k parameter, which remains relatively stable (between 1.55 and 2.15), indicates that while wind variability exists, the region generally experiences a consistent wind regime, particularly at higher elevations.

Overall, the data suggest that the surface roughness length in this region is moderate, likely corresponding to a terrain type with low vegetation or mixed land cover. This has important implications for wind farm development, as roughness affects turbine placement and hub height selection. Elevated hub heights (above 100 m) would minimize roughness effects and maximize energy capture, making them preferable for wind power generation in this region.

5. Conclusions

This study emphasizes the considerable potential of wind energy in Maysan Province, Iraq, where wind conditions are significantly affected by surface roughness and elevation. Wind speeds and power densities increase significantly above 100 m, with wind velocities exceeding 8 m/s and power densities exceeding 600 W/m², thereby enhancing the feasibility of wind power generation in these regions. The Weibull shape parameter (k) exhibits stability at elevated altitudes, whereas it demonstrates increased variability at lower elevations, suggesting heightened wind fluctuations near the surface. Surface roughness significantly influences the wind profile, with moderate terrain characterized by low vegetation or mixed land cover, leading to reductions in wind speed at lower elevations. The findings underscore the significance of choosing suitable turbine locations and elevated hub heights, particularly those exceeding 100 m, to mitigate the effects of surface roughness and enhance energy capture. This study offers critical insights for optimizing wind farm design in the region, aiding Iraq's initiatives to diversify its energy portfolio with renewable sources.

Acknowledgments

The author would like to thank the Research and Technology Center of Environment, Water and Renewable Energy at the Scientific Research Commission for their support and for providing the required data and facilities.

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