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Research Article

Analysis of Maximum Wind Speed in Iraq Using Nakagami Distribution

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Abstract:

The assessment of the frequency of strongest gusts is a vital component in meteorological and climatological investigations with diverse objectives. this research analyzes the frequencies of maximum wind speed using the dataset of three selected cities Baghdad, Arbil, and Basrah in Iraq. Fitting the maximum monthly wind speed data from each city with Weibull, Gumbel, Normal, and Nakagami distributions, the parameters of these distributions are estimated through the method of maximum likelihood. Upon thorough examination of the Akaike information criterion (AIC), the most suitable distribution is selected. After all results done, Nakagami performance stood out amongst other distributions thanks to its thorough analysis and detailed graphic diagrams, making it a viable option for making decisions in different urban areas

1. Introduction

Limited locales sometimes witness drastic weather happenings such as thunderstorms, floods, cyclones, heatwaves, and cold spells embodying the extreme atmospheric situations [1]. Meteorological parameter analysis is crucial in the fields of agriculture, epidemiology, and weather research for their respective advancements. Forecasting weather patterns and their influence on disease transmission necessitates analyzing vital factors like temperature, humidity, wind speed, rainfall, and atmospheric pressure [2].
The exploration of peak wind speeds within city limits is meaningful as it influences city structure, air freshness, and human satisfaction. Urban planning and design rely on crucial information about how wind velocity can be affected by the arrangement and density of buildings in urban areas. The analysis of wind speed variations within cities holds significance as it influences the assessment of air quality, thereby influencing human health and environmental well-being by facilitating the spread of detrimental air pollutants at increased velocities [3]. Furthermore, analyzing the highest wind speeds is crucial when evaluating their impact on urban microenvironments, airflow, and renewable energy technology.
The alterations in the time series stem from either the organic fluctuations within Earth's climate system or influences triggered by human actions. The evolution towards severe weather occurrences is merely one of the multiple ramifications of humanitys impact on the climate. Also Understanding the frequency distribution of annual maximum wind speeds is vital for numerous purposes, particularly in the areas of renewable energy and urban planning. Reviewing the distribution of wind velocities is key to comprehending the common atmospheric conditions at a specified place, vital for creating successful wind power setups like turbines. Various investigations have been carried out in the realm of meteorological data frequency distribution using diverse models, each with a practical utility across various industries. The wind speed frequency distribution might align with either a normal distribution, Weibull distribution, or autoregressive

model, and suggested pertinent adaptive conditions; nevertheless, the deviation from the real distribution proved to be substantial. Asghar and Liu introduced an innovative system that combines intelligent learning techniques with adaptive neuro-fuzzy inference to accurately predict the Weibull wind speed probability density function [4]. Examining data from 1969 to 2016, Devi et al (2021) studied the daily maximum temperatures in Delhi and Bengaluru using two different distributions: Gumbels extreme value type 1 and log Pearson type III [5].
Therefore, this study analyzes different statistical distributions for three important cities in Iraq and evaluates the insight into the distribution of important meteorological parameters, wind speed, in the form of monthly maximum data. By applying the processing, we will present a more comprehensive understanding of the original methodology through the examination of station data on maximum wind speed from three crucial Iraqi cities - Erbil, Baghdad, and Basra - all known for their hot and dry climates. As per our knowledge, this is the inaugural application of a frequency distribution methodology to the collected data from three chosen cities. According to the locations of all three cities, wind speed is effective in deciding on aviation processes, wind turbines, agriculture, and fine dust in the air. The noteworthy point is that so far little study has been done regarding the frequency distribution of the max wind speed with the Nakagami relationship in Iraq.

2. Materials and Methods

2.1. Study area and data required

For this study, an analysis of the frequency of maximum wind speed is conducted specifically for Arbil, Baghdad, and Basrah - three crucial cities in Iraq. The illustration in figure 1 showcases a map featuring the cities and also marks the locations of the three stations.
Arbil is positioned in the north of Iraq, roughly 80 kilometers (50 miles) in the east direction from Mosul. Arbil, accommodating around 1.5 million inhabitants, holds the distinction of being Iraq's fourth most populous city, following Baghdad, Basra, and Mosul. The coordinates of Arbil, are approximately 36.1921° N, 44.0109° E and the area of Erbil is approximately 115 square kilometers. The city of Erbil experiences a semi-arid climate characterized by hot summers and cool winters.
The capital city of Iraq is Baghdad, which can be found in central Iraq along the Tigris River. Positioned within ancient Mesopotamia, the city is approximately 530 km distant from where the Persian Gulf begins. With an estimated population of 7 million individuals, Baghdad stands out as Iraq's largest city and one of the most heavily populated urban agglomerations in the Middle East. The coordinates of Baghdad, Iraq are approximately 33.34058° N, 44.40088° E and has an area of approximately 204.2 square kilometers. The climate in Baghdad is characterized by a hot desert climate with lengthy, scorching summers and brief, mild winters.
Nestled in the southeastern coastal region of Iraq, Basrah stands as a prominent urban hub, with its proximity to the borders of Iraq and Iran on one side and Kuwait on the other. Situated at the mouth of the Shaṭṭ Al-ʿArab, about 110 km from the Persian Gulf, Basrah stands as a pivotal port city. The coordinates of Basrah are approximately 30.508102° N, 47.783489° E and Approximately 181 square kilometers make up the overall area of the Basrah Governorate. Surpassing a total of 1.5 million inhabitants when considering both its urban and metropolitan areas, this city stands as quite large. In this city, the weather boasts of a scorching desert climate with blazing hot summers and pleasant winters.

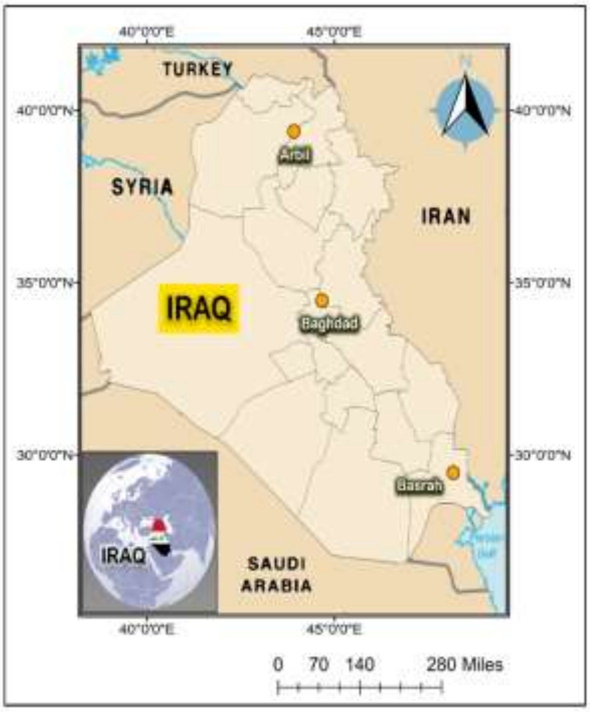

Figure 1. *Study region Arbil, Baghdad, Basrah important cities*

In figure 2, the maximum wind speed values for the three cities are depicted, while their Statistical characteristics are presented in table 1. Table 1 presents the basic characteristics of these stations and their associated data, including maximum, mean, minimum, and standard deviation.

Table 1. *Statistical characteristics of data*

Station	Statistical characteristics	Max Wind Speed (km/h)
Baghdad	Min	25.19
	Median	39.63
	Max	90.01
	Mean	41.14
	Variance	104.54
	Skewness	1.539
Arbil	Min	21.67
	Median	43.15
	Max	97.04
	Mean	48.21
	Variance	230.78
	Skewness	0.666
Basrah	Min	28.71
	Median	51.86
	Max	88.9
	Mean	53.01
	Variance	148.54
	Skewness	0.414

2.2. Data and methods

The climatic three stations of Arbil, Baghdad, and Basrah were included in the study using data from the NOAA and Mathematica software database. The analysis of maximum wind speed involved using data from three synoptic stations covering the years 2000-2023. The data considered for the frequency analysis are the annual maximum monthly wind speed.

The frequency analysis of wind speed at each station was conducted using all four distribution functions and a single parameter estimation technique. These distributions include Weibull, Gumbel, Normal, and Nakagami, and Obtaining the parameters of these distributions involves utilizing maximum likelihood estimation.

2.3. Frequency distribution model

Nakagami distribution

The Nakagami distribution, referred to as the Nakagami-m distribution, is a statistical distribution linked to the gamma distribution. The distribution has two parameters: a shape parameter μ and a second parameter controlling the spread ω.

$$x^{2\times\mu-1}exp(-\frac{\mu x^2}{\omega}) \quad (1)$$

Gumbel distribution

In statistics, the Gumbel distribution is frequently utilized to simulate extreme values by modelling the largest element in a large independent set coming from distributions with quickly declining tails, such as the normal or exponential distribution [6]. This particular distribution is also recognized as the first type of extreme value distribution and serves the purpose of identifying the maximum extreme value. The Gumbel distribution can be described by its defining features: the location parameter alpha and the scale parameter beta.

$$e^{-e^{\frac{x-\alpha}{\beta}}+\frac{x-\alpha}{\beta}} \quad (2)$$

Weibull distribution

The Weibull distribution is commonly utilized in reliability engineering, hydrology, and various other disciplines as a dependable continuous probability distribution. Reliability engineering often relies on the Weibull distribution for examining life data, forecasting failure times, and assessing product dependability [7]. This distribution versatility in handling different types of data distributions, it can mimic distributions like normal and exponential distributions [8]. The Weibull distribution function can be found below. $\alpha > 0$, $\beta > 0$ assumption and $x > 0$ domain.

$$\frac{\alpha x^{\alpha-1}}{\beta\alpha} e^{-(\frac{x}{\beta})^{\alpha}} \quad (3)$$

Normal distribution

The Gaussian distribution, known as the normal distribution, is a key continuous probability model utilized across diverse disciplines such as statistics, physics, finance, and beyond. The mean, median, and mode coincide in a standard normal distribution, leading to a perfectly balanced curve with an even distribution of values around the center point. Two distinct factors, the mean (μ) and the standard deviation (σ), shape the bell-shaped curve of this phenomenon.

$$e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (4)$$

2.5. Parametric estimation

Maximum likelihood estimation

The process of determining the parameters of a probability distribution is commonly done in statistics through maximizing the likelihood function with the MLE method. The MLE process involves taking into account both the probability density function of the distribution and the observed data to derive the likelihood function. The goal is to find the parameter values that maximize this likelihood function, thus indicating the most likely parameter estimates drawn from the data and offering precise and dependable parameter estimates for examining event frequencies, assessing risks, and reaching critical decisions in. Likelihood function, given by Equation (5).

$$L(p) = \prod_{i=1}^{n} f(x_i; p) \quad (5)$$

Despite this, working with the log-likelihood function from Equation (6) may prove to be a more straightforward method than using the likelihood function [9].

$$L(p) = \log[L(p)] = \sum_{i=1}^{n} \log[f[x_i; p]] \quad (6)$$

3. Data Analysis and Results

3.1. Comparison of Probability Density Functions

For this study, the Akaike information criterion (AIC) was utilized to assess the precision of calculated and observed quantiles. The Akaike information criterion serves as a measurement of forecasting accuracy and comparative excellence of statistical models with a specified dataset. The distribution parameters estimated by the maximum likelihood method are shown in tables 2.

Table 2. *Distribution parameters for the maximum likelihood estimation method*

Distributions	Baghdad	Arbil	Basrah
Weibull	$\alpha = 3.81$ $\beta = 45.12$	$\alpha = 3.36$ $\beta = 53.69$	$\alpha = 4.62$ $\beta = 57.87$
Gumbel	$\alpha = 46.87$ $\beta = 14.45$	$\alpha = 56.22$ $\beta = 16.78$	$\alpha = 59.30$ $\beta = 12.85$
Normal	$\alpha = 41.14$ $\beta = 10.21$	$\alpha = 48.21$ $\beta = 15.16$	$\alpha = 53.01$ $\beta = 12.16$
Nakagami	$\mu = 4.55$ $\omega = 1797$	$\mu = 2.77$ $\omega = 2555$	$\mu = 4.95$ $\omega = 2957$

In this study, the AIC-appropriate method including used to select the best distribution. The maximum likelihood estimation results for selected distributions for the three crucial cities are illustrated in table 3. The density functions for the Weibull, Gumbel, Normal, and Nakagami distributions in three selected cities have been estimated using MLE, based on AIC criteria as depicted in figure 3. According to the obtained results, it is concluded that the best distribution for the maximum wind speed for the cities of Baghdad, Arbil, and Basrah is Nakagami. Considering all of these together, it may be proposed that the Nakagami distribution could be a suitable option for other cities in Iraq, but it is important to be careful when making such a broad statement.

Table 3. *The maximum likelihood estimation results*

Distributions	Baghdad	Arbil	Basrah
	AIC		
Weibull	2195.18	2385.43	2272.21
Gumbel	2344.57	2477.21	2331.31
Normal	2157.41	2385.45	2258.57
Nakagami	**2130.14**	**2365.02**	**2250.01**

4. Conclusions

The evaluation of the frequency of top wind velocities is essential in pivotal sectors such as agriculture, pollution control, and flight management, guiding forthcoming endeavors and choices. The analysis in this study delved into the frequency of max wind speeds experienced in three major cities in Iraq: Baghdad, Arbil, and Basrah. Four distinct probability distributions were chosen and parameter estimation was completed through maximum likelihood methodology. Analyzing the AIC allowed for the evaluation of distribution performances at different quantiles. Upon reviewing the four unique distributions, it was evident that the Nakagami distribution is best suited for cities in Iraq, closely followed by the Normal distribution. The current study definitively demonstrates the significance of examining the frequency of peak wind speeds for meteorological and climatological analyses. The economic losses and vulnerabilities in regions such as Iraq are heavily influenced by the occurrence of peak wind velocities, highlighting the necessity of comprehending and managing wind-related risks. The work that can be done in the future to improve the frequency analysis of and maximum wind speed includes the use of combined distributions. Similar works has been done in the literature[10,11].

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

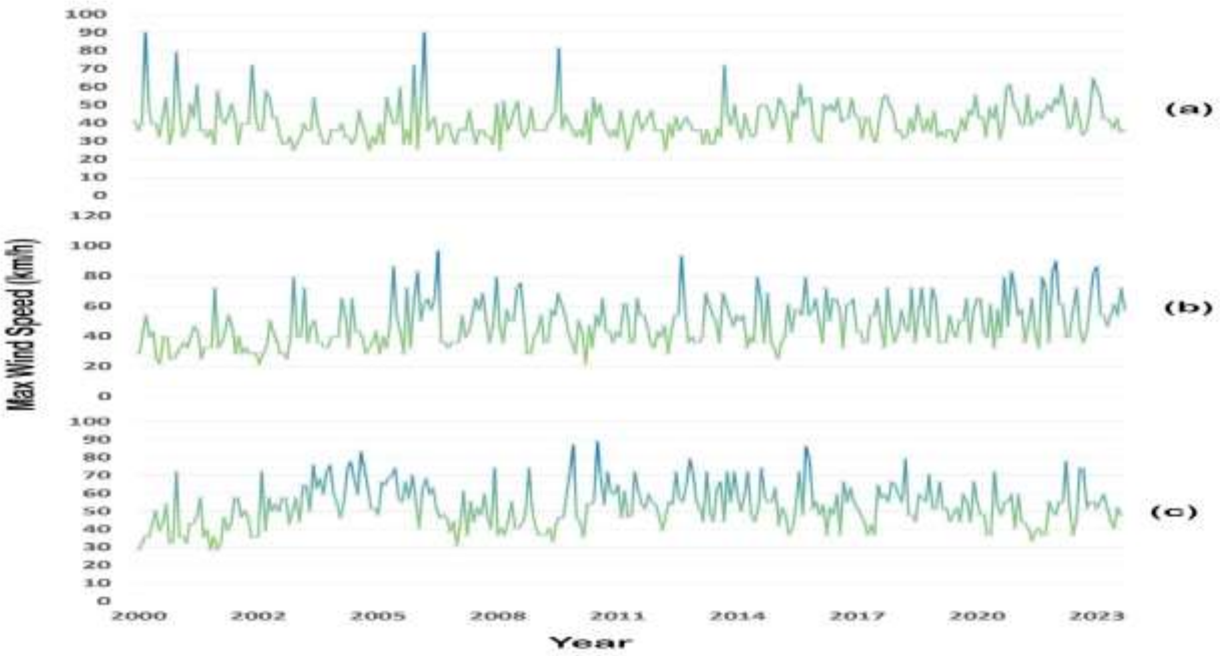

Figure 2. *Monthly max wind speed values in the Baghdad (a), Arbil (b), and Basrah (c) period of 2000-2023*

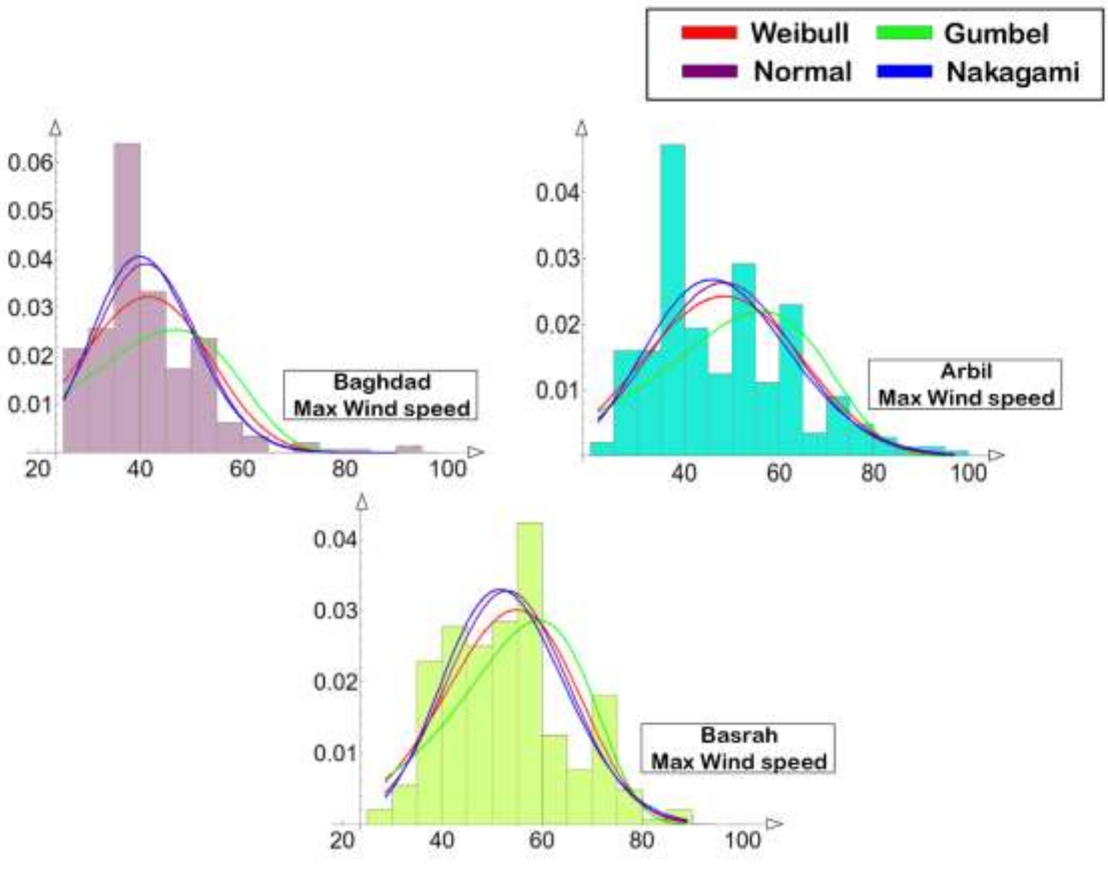

Figure 3. *Histograms and the probability density functions for three selected cities and distribution.*

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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