NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF MECHANICAL ENGINEERING

ASSESSMENT OF SOLAR ENERGY AND WIND POTENTIAL IN THE RED SEA STATE, SUDAN

M.Sc. THESIS

Mohamedalmojtba Hamid Ali Abdalla

Nicosia

December, 2021

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Supervisor

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December, 2021

Approval

We certify that we have read the thesis submitted by Mohamedalmojtba Hamid Ali Abdalla, titled **"(ASSESSMENT OF SOLAR ENERGY AND WIND POTENTIAL IN THE RED SEA STATE, SUDAN)**" and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Educational Sciences.

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Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Mohamedalmojtba Hamid Ali Abdalla

16/12/2021

Acknowledgments

I would like to express my deep and sincere gratitude to my research supervisor, Assoc. Prof. Dr. Youssef KASSEM, for giving me the opportunity to do research and providing invaluable guidance throughout this research. His dynamism, vision, sincerity, and motivation have deeply inspired me. He has taught me the methodology to carry out the research and to present the research works as clearly as possible. It was a great privilege and honor to work and study under his guidance. I am extremely grateful for what he has offered me. I would also like to thank him for his friendship, empathy, and great sense of humor.

My gratitude goes to Assoc. Prof. Dr. Hüseyin ÇAMUR for offers of advice and encouragement throughout the thesis work. Likewise, I would like to extend a special thank you to all other faculty members and staff in the Mechanical Engineering Department, who have given such great effort and guidance.

I am very much thankful to my parents and all other family members for their love, prayers, caring, and sacrifices for educating and preparing me for my future. I am extremely grateful to my mom, the first person that taught me my first words in this life, may her soul rest in peace.

I am very much thankful to my father my best friend in this life, for his love, understanding, prayers to me, without his wisdom and guidance, I'd be lost. His motivation has deeply inspired me, He taught me how to be strong and kind, I'm so lucky to have someone as loving as you in my life. And his big continuing support to complete this research work. . Also I express my thanks to my sisters, brothers, for their support and valuable prayers.

I am very much thankful and from the bottom of my heart, I would like to express my special thanks of gratitude to my fiancee for her love, Patience, understanding, prayers, and continuing support to complete this research work. Thanks for standing beside me on this journey. I would like to say thanks to my friends and my research colleagues, Adnan Othman ALHAJ, for his genuine support throughout this research work. Finally, my thanks go to all the people who have supported me to complete my education journey and the research work directly or indirectly.

Mohamedalmojtba Hamid Ali Abdalla

Abstract

Assessment Of Solar Energy And Wind Potential In The Red Sea State, Sudan

Mohamedalmojtba Hamid Ali Abdalla

MA, Department of Mechanical Engineering

December, 2021, 86 pages

This research investigated the potential and economic validity of wind and solar energy at 17 selected locations in the Red sea state, Sudan, for the first time. To this aim, NASA database was utilized. The results demonstrated that vertical axis wind turbines would be a good solution for electricity generation for building in the selected locations. Additionally, it is found that the chosen areas are suitable for installing photovoltaic (PV) systems due to the high-value solar radiation. Moreover, the economic viability of small-scale wind and PV systems for rooftop buildings in the selected regions is investigated. For a financial analysis of wind turbines, the performance of different characteristics of vertical axis winds was evaluated based on the determination of capacity factor and energy production cost. For the economic validity of installing PV systems, RETScreen Expert software was used. The results indicate that the annual production energy from wind turbines and solar power is within the range of 158.50-29063.93kWh and 6648-15533 kWh, respectively. This amount of energy output would help to reduce the effect of global warming and enhance the sustainable technological development of the country. Moreover, the results indicate that model#9 (Vertical Axis Wind Generator-V) with a capacity of 5kW has the lowest cost value (0.08703-0.01025 $/kWh) compared to the other selected turbines for the studied locations. Besides, the average energy production cost is within the range of 0.036-0.049 $/kWh for PV systems. In the end, it is concluded that using small-scale renewable energy systems will help reduce the dependency on fossil fuels, the effect of global warming, and enhance the country's sustainable technological development.

Key Words: Red Sea state; Sudan; grid-connected; rooftop PV system; RETScreen Software.

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List of Abbreviations

PDF:	probability density function
CDF:	Cumulative Distribution Function
GHI:	Global Horizontal Irradiation
DNI:	Direct Normal Irradiation
PV:	Photovoltaic Systems
NASA:	National Aeronautics and Space Administration
K-S:	Kolmogorov-Smirnov
A-D:	Anderson-Darling
C-s:	Chi-Squared
WPD:	Wind Power Density
EPC:	Energy Production Cost
PVC:	Present Value of Costs
SD:	Standard Deviation
CV:	Coefficient of Variation
PVGIS:	Photovoltaic Geographical Information System
SEDC:	Sudanese Electricity Distribution Company Ltd
CSP:	Concentrating Solar Power

CHAPTER I

Introduction

This chapter includes the background, purpose of the study, limitations related descriptions of the research

Background

Humanity has always needed energy. Conventional fossil fuels served this purpose until recently. As a result of greenhouse gas emissions, the use of fossil fuels has polluted the environment and contributed to climate change (Riahi et al. 2017). According to Vijayavenkataraman et al. (2012) and Arreyndip and Joseph (2018), utilizing renewable energy as an alternative energy source will help to reduce the environmental problems, essentially air pollutions due to increasing fossil fuel consumption. Research has shown that renewable energy like solar and wind reduces greenhouse gas emissions (GHG) significantly. For instance, Schnitzer et al. (2007) the use of solar thermal energy was found to be an essential step toward achieving sustainable zero-emission production in the sector. Shahsavari and Akbari (2018) found that Renewable energy sources offer a strong potential for supplying a growing share of future energy growth while reducing greenhouse gas emissions, according to the study.Shahsavari et al. (2018) concluded that generating electricity via solar systems could help Iran safeguard its environment. Recently, solar energy has long been regarded as one of the best renewable energy sources due to its economic viability and environmental benefits. There have been numerous studies that have looked into the possibility of solar energy in order to generate power in various countries around the world. For example, Adnan et al. (2012) Pakistan's solar energy potential was assessed using data from fifty-eight meteorological sites spread across the country. Researchers found that power could be generated every month in the southern Punjab, Sindh, and Balochistan regions on an area of 100 m2. Martín-Pomares et al. (2017) In Qatar, the potential for solar energy as a source of electricity was examined. The findings revealed that a large-scale grid-connected PV system is a viable option for power generation in the country. Kassem et al. (2019) Wind and solar energy potential was investigated in three Northern Cyprus cities. Based on the results of the study, it appears that solar energy can generate large amounts of electricity in urban areas.

Kassem et al. (2018) studied a grid-connected wind/PV project in two regions of Northern Cyprus with a capacity of 12MW. According to the results, the selected regions are more likely to benefit from wind energy than other types of energy. A 50MW wind/PV system was evaluated at various locations throughout Libya by Kassam et al. (2020a). Based on the results, the PV system is an economic option compared to the wind system for electricity generation in the country.

Purpose of the Study

In addition to reducing electricity consumption and dependence on utility power, grid-connected systems are an attractive way to increase electricity generation from renewable energy sources. Solar and wind energy are examples of renewable energy sources for household electricity. The findings of the literature review reveal a clear lack of utilizing wind and solar systems for households in Sudan. In addition, according to the authors' review, no studies are evaluating the viability of grid-connected wind and PV systems as building power sources in the country. Thus, the purpose of this study is to find out whether grid-connected wind and PV have a long-term technological, economic, and environmental significance, systems in 17 selected regions in the Red Sea state of Sudan.

To achieve this, meteorological data from the National Aeronautics and Space Administration (NASA) database has been utilized to identify a suitable zone for constructing wind and PV systems in the chosen state. For the feasibility of the PV system, several economic indices, such as net present value, payback duration, yearly life cycle savings, and internal rate of return, are available, In terms of performance indicators for electrical power generation facilities, the Levelized Cost of Energy has been considered.

The study used the RETScreen Experts software in order to achieve these goals. Furthermore, when a wind turbine is used to generate energy, the present value of costs technique is utilized to calculate the cost of production.

Limitations

In this study, it is essential to acknowledge the limitations of this work. First, the financial parameters were assumed based on historical values in the literature. Second, the influence of various parameters such as dust, irradiation intensity, air temperature, and relative humidity was neglected due to the limitation of RETScreen software.

CHAPTER II

Sudan

Research related conceptual definitions, descriptions and information related to the subject that already exists in the literature are given in this chapter.

Sudan

Sudan (Figure 2.1), is a country in northeast Africa that is officially known as the Republic of Sudan. Among its borders are Chad, the Central African Republic, Eritrea, Libya, Egypt, Ethiopia, South Sudan, and the Red Sea. In terms of population, it has approximately 45,233,702 million residents and occupies 1,886,068 square kilometres (728,215 square miles), making it Africa's third-largest country in terms of area. Until the secession of South Sudan in 2011, it was Africa's and the Arab League's largest country by area. Since then, Algeria has held both titles. Khartoum, Khartoum Bahri, and Omdurman are the three cities that compose Sudan's capital. Sudan's capital is the city of Khartoum. Sudan is one of the developing countries in Africa.

Sudan, which stretches across the Red Sea, is geographically located at the crossroads of Sub-Saharan Africa and the Middle East. Sudan is bordered on three sides by Libya and Egypt, on the other by Chad, Central African Republic, South Sudan, Ethiopia, and Eritrea, and on the east by Libya and Egypt. Sudan's capital Khartoum is where the white and blue Niles meet and combine to form The Nile River, which flows through Sudan and Egypt to the Mediterranean Sea. South Sudan's separation brought with it a series of economic shocks since the Nile basin is from Darfur to Kassala via the Blue Nile and the Kordofan States, with deserts in the far north, fertile land in the Nile valleys, the Gezira region, and across the remainder of the country for farming and livestock breeding. Over half of Sudan's government revenue, as well as 95% of its exports, came from oil money. Consequently, the economy has not grown as fast and consumer prices have increased at a double-digit rate, which has led to low economic growth. Along with higher gasoline prices, has resulted in lower economic growth.

Figure 2.1

Map of Sudan

There are different kinds of climates in Sudan, including hyperacid climates in the north and tropical wet-and-dry climates in the southwest. Regardless of the place, temperatures do not change much by season; the most important climatic variables are precipitation and the length of the wet and dry seasons. There are two kinds of airflows that dominate the wet and dry seasons: dry northern winds from the Sahara and the Arabian Peninsula or moist southwesterly winds from the Congo River basin and southeasterly winds from the Indian Ocean in January and March. There has been little rain in Sudan, except in an area of northeastern Sudan where breezes from the Mediterranean have brought a little precipitation.

Southern Sudan experienced severe rain and thunderstorms by early April, due to the wet south westerlies. Humid air will reach Khartoum in July, and by August, its usual northern limit will be near Abu Hamad, though it may approach the Egyptian border in certain years. Humid air flow is weaker as it moves north. During September, the northeasterlies move south, and they reach their peak by the end of December. In Khartoum the rainy season lasts three months (July, August, September), when the yearly rainfall averages 161 millimetres. In Atbarah the rains last only for two months (August, 74 millimetres). It is possible that the arrival of south-westerly may be delayed or cancelled in central Sudan. Sometimes completely absent.

When the dry season comes to a close, temperatures are at their highest. The sky is clear and the air is dry. The further south, on the other hand, enjoys year-round high temperatures despite having just a short dry season. May and June are the warmest months in Khartoum, The average high temperature is 43 °C with a maximum temperature of 49 °C. Sudan's north has extremely hot daytime temperatures all year, besides in the northwest, the winter months of January and February get some precipitation. The highlands are normally colder, and central and northern Sudan's high midday temps during the dry season fall swiftly after dusk. In January, Khartoum's lows average 15 degrees Celsius. (59 degrees Fahrenheit) and have sunk to as low as 6 degrees Celsius (42.8 degrees Fahrenheit) during the passage of a cold front. When the moist southwesterly flow initially arrives in central Sudan, the haboob, a powerful sandstorm, might occur (May through July). By the afternoon heat, the moist, unstable air condenses into thunderstorms.

The first down flow of air of an approaching storm creates a huge yellow/red wall of sand and clay, which temporarily causes vision to dim. In Sudan's central and northern deserts, there is year-round sunshine that reaches over 4,000 n degrees, which makes it one of the driest and sunniest places on Earth hours Cloudless skies are most likely to occur in the best of situations, or approximately 91 percent of the time. It is possible for decades to pass without rain in the areas surrounding Wadi Halfa and next to the Egyptian border.

During their summers, they also experience some of the hottest temperatures in the world. Average high temperatures rise above 40 °C during four to nearly six months each year, with peaks at around 45 °C (113 °F).

Energy situation in Sudan

Sudan's electric power sector has a substantial generation shortfall, resulting in frequent power outages, As a result, the electricity demand outweighs the present supply. At present, the country's electricity-generating (see Table 2.1) capacity consists of 13,133 GWh (64% from hydro, 23% from steam, 10% from combined cycle, 2% from Diesel, 1% from interchange) according to Sudanese Electricity Distribution Company Ltd (SEDC). Electrical energy is transmitted through two portions that are interconnected called the Blue Nile network and the western network (White Nile network). Most of the regions, such as the Red Sea state are suffering from power outages in the summer season, particularly Portsudan city, an industrial city and needs regular electrical stability, that has heavy power outages, over six hours, during the daytime due to the schedule of the Sudanese Electricity Distribution Company Ltd (SEDC), schedule. Due to this reason, the residential are using generators as power sources during the outage of power.

In addition, west of Sudan such as Darfur states, Al Fashir city, Nyala city, Al Junaynah city, Kordofan states, El Obeid City, and El Fula city, Kaduqli city and so on are suffering from outage of power. Furthermore, the national electrical network does not cover some regions, mainly rural areas. Thus, these regions rely on small-diesel fuel power generators.

In general, citizens suffer because of power outages, especially in the summer period, where the outages sometimes extend to about 6 hours per day. Besides, the industrial sector suffers from the instability of the electric current because the instability of the current affects the production process costs. As result, most commercial factory owners rely on huge generators to provide electricity in times of power outages.

Table 2.1

The Country's Electricity Generating Capacity in Sudan

Type Generation	Plant	Capacity
Thermal	13 thermal power plants with a different type of generation steam turbines, gas turbines, combined cycle, and diesel	1,650 MW
Hydro	Sinnar Dam Power plant	15 MW
	El Girba Dam Power plant	17.8 MW
	Roseires Dam Power plant	280 MW
	Jabel Awlia Dam Power plant	30.4 MW
	Merowe Dam Power plant	1250 MW

In order to solve the electricity crisis in the country, renewable energy sources such as wind and solar energy can be a viable alternative. As shown in Figures 2.1-2.3, the direct normal irradiation (DNI) values and the global horizontal irradiation (GHI) values vary from 1800 kWh/m2 to 2500 kWh/m2 and 1700W/m2 to 2300W/m2, respectively (see Figures 2.1-2.3). Based on GHI and DNI values, the country has high solar resources and was categorized as good, excellent, or outstanding based on Kassem et al. (2020). Moreover, according to the wind atlas map, it is discovered that the density of wind power is within the range of 17-700W/m2 at 10m height (Figures 2.4 and 2.5). The highest values of wind energy density have been observed in the red sea state of Dongola and Northern Kordofan, Sudan.

Furthermore, Researchers have studied the potential of solar and wind energy in various regions of Sudan (Omer. 1997; Elagib et al. 1998; Elagib and Mansell 1999; Omer. 1999; Omer. 2000; Williams et al. 2000; Omer. 2000; Omer and Braima 2001; Omer. 2002; Omer. 2003; Omer. 2005; Omer. 2006; Omer. 2006; Omer. 2008; Chong-Yu Xu et al. 2009; Omee. 2013; Salih et al. 2014; Salih and Aydrous. 2015; Khadam et al. 2016; Rabah et al. 2016; Elzubeir. 2016; Omer. 2016; Langodan et al. 2016; Ali. 2018; Abdelgadir et al. 2018; Elkadeem et al. 2019; Osman and Sevinc. 2019; Abdeen et al. 2019; Smieee et al. 2019; Saeed et al. 2019; Hamza and Abdelatif. 2020; Fadlallah and Serradj. 2020; Fadlallah et al. 2021; Abdalla and Özcan. 2021). Taking into account the previous scientific studies, the following conclusions can be drawn:

Researchers found that utilizing the solar power system in Sudan is limited to simple applications like water pumping systems for irrigation in agriculture.

- The hybrid system (diesel fuel-renewable energy) would help to Reduce fuel consumption and lead to be more Sustainable Development.
- Researchers indicated that the solar power system could solve the Electricity crisis and reduce the CO_2 emissions in the country.
- It has never been studied whether wind and solar energy at a small Scale can be viable in Sudan's Red Sea state.

Figure 2.2

Global Horizontal Irradiation Map In Sudan

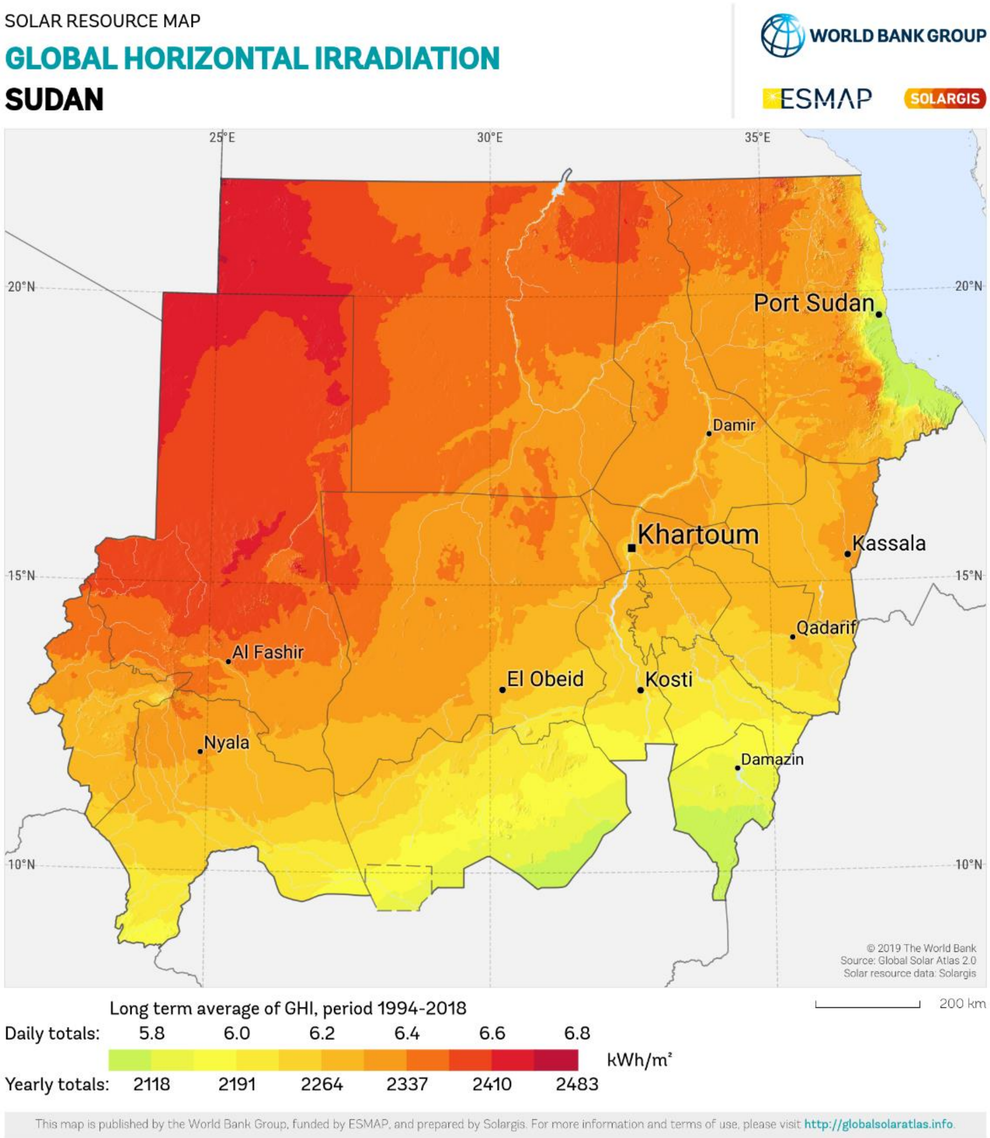


Figure 2.3

Direct Normal Irradiation Map In Sudan

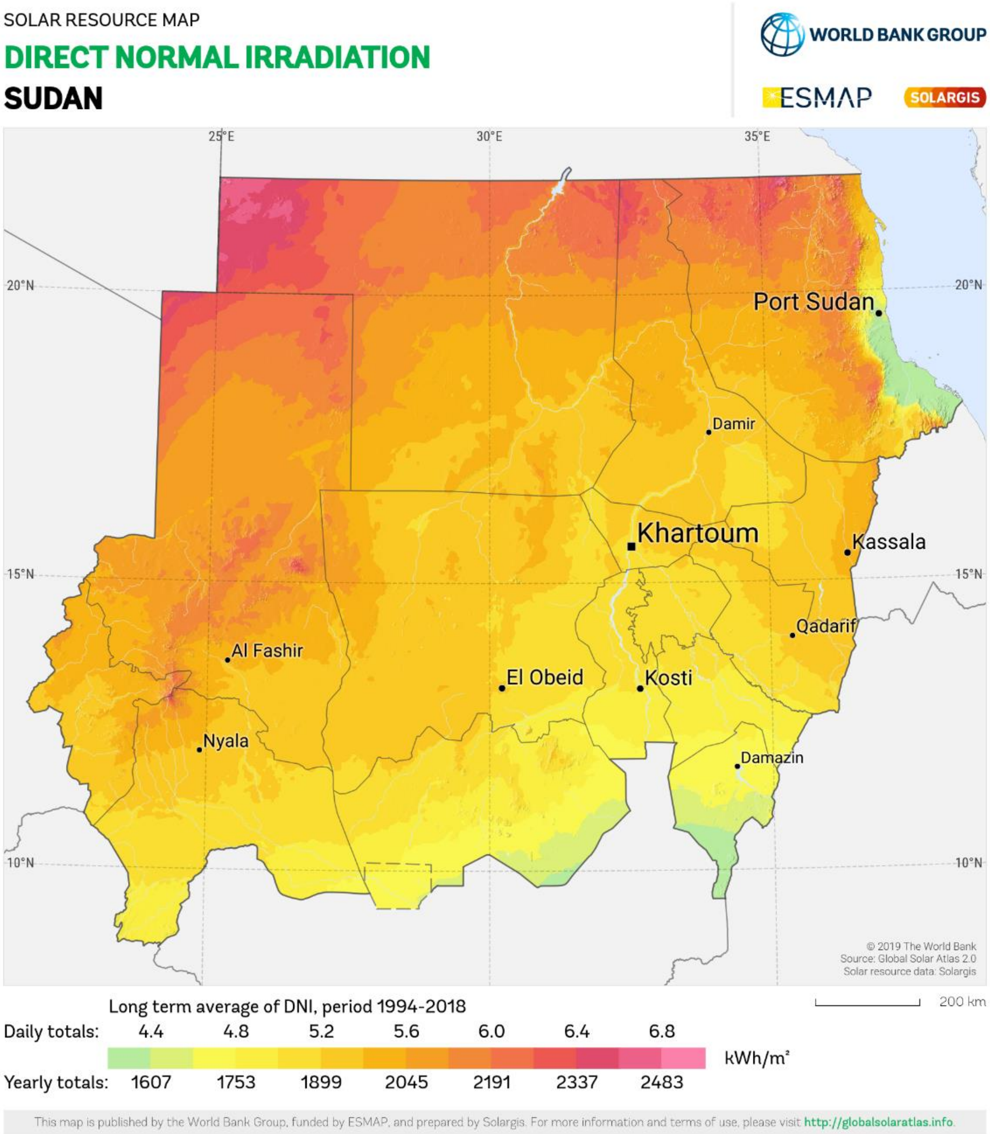


Figure 2.4

PV Power Output Map in Sudan

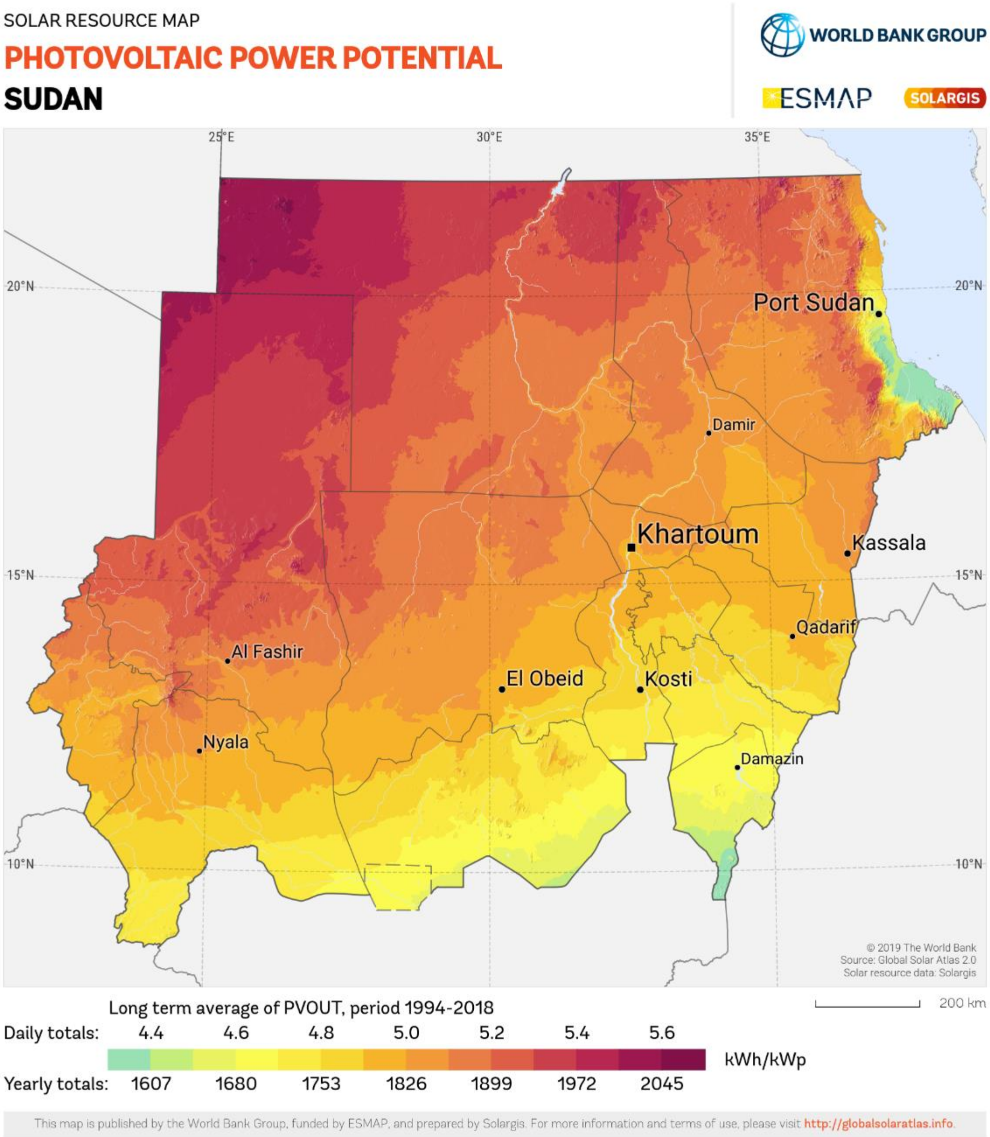


Figure 2.5

Mean Wind Speed Map in Sudan

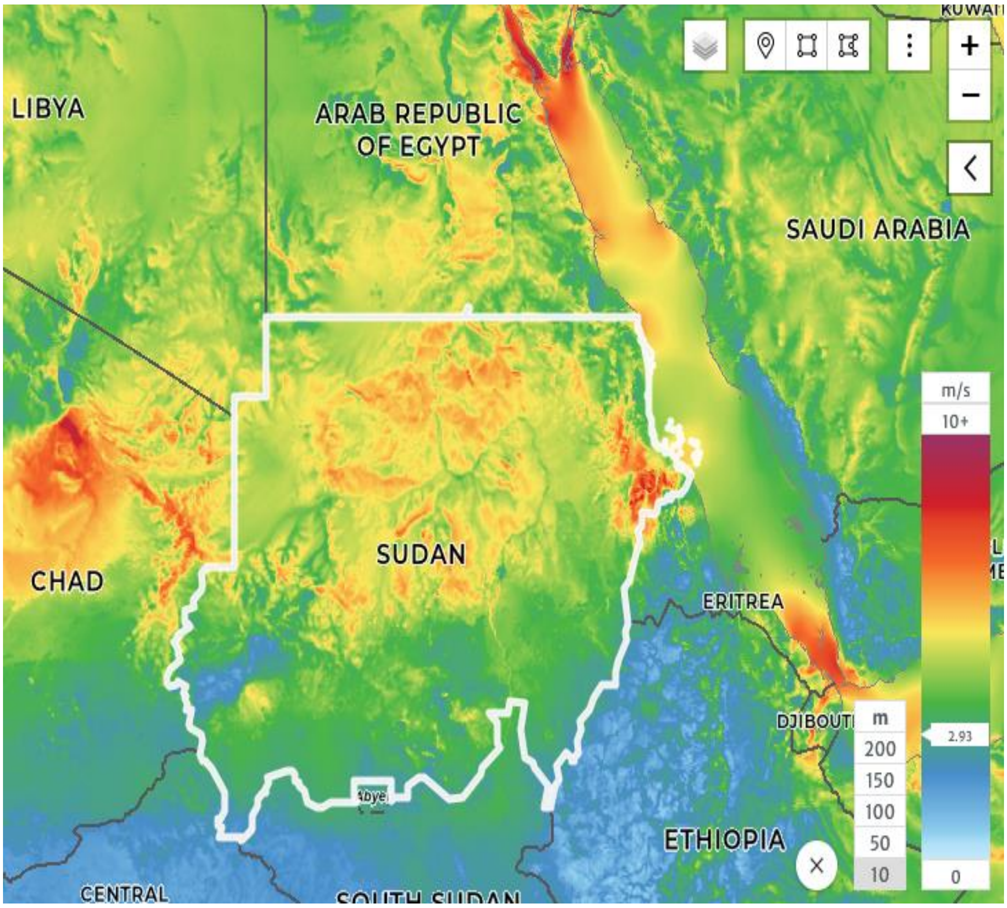
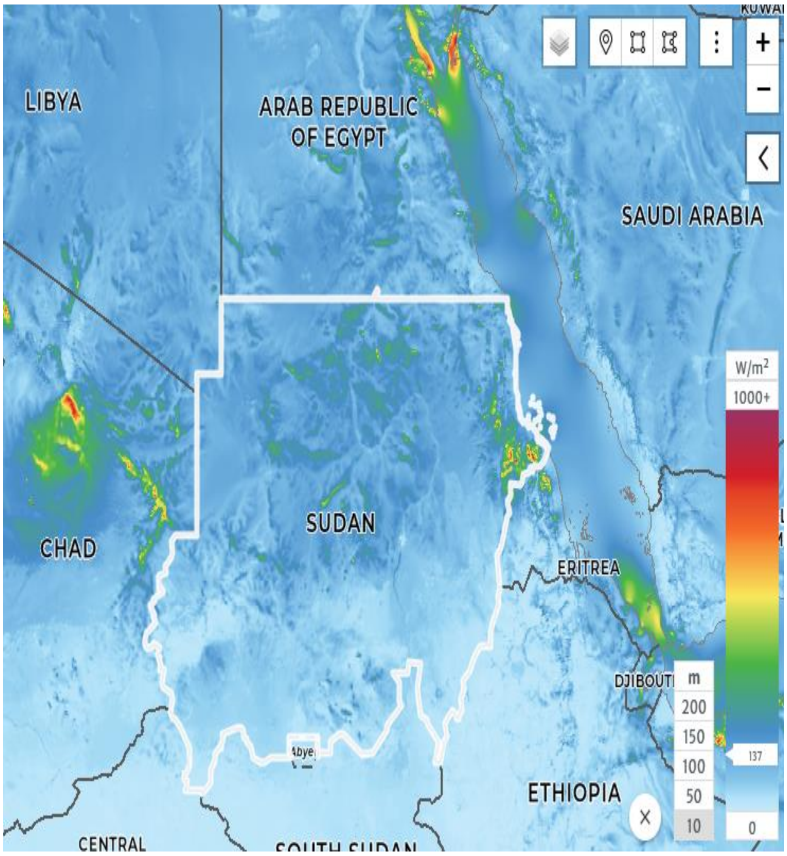


Figure 2.6

Mean Wind Power Density Map in Sudan



Renewable Energy in Sudan

Sudan is known around the world for its abundant sunshine and pleasant environment, making it an ideal location for solar energy. During Sudan's summer, the average daily solar radiation is 5.8 - 7.2 kWh/m2, which could be an important source of energy to substitute oil, electricity, wood, and charcoal, and to assist in rural development and to improve rural living conditions.

Solar irradiance, which is required to generate solar electricity, is abundant in practically all parts of Sudan. Irradiation from the sun is highest in the north and east of Sudan. In the Red sea state, Dongola, and Northern Kordofan, Sudan, the highest values of wind power density have been observed. Sudan has a 780-kilometer-long coastline with significant solar radiation and wind potential, which could be advantageous if wind turbines ranging from 10 to 100 meters in height are employed to generate electricity. It was found that Sudan's energy sector contributes significantly to total carbon dioxide emissions and total sulfur dioxide emissions.

Consequently, renewable energy projects are resulting in a worldwide decline in carbon dioxide levels. Renewable energy is derived from continuously and sustainably regenerated natural resources. Generally, photovoltaics, wind and hydropower are the most interesting sources to examine in Sudan. According to previous statements, hydropower stations generate approximately 64% of total energy from hydropower and 23% from steam. Sudan has the potential to benefit from other resources, particularly solar and wind, although hydropower is the only renewable energy source capable of producing electricity. Sudan has some projects in renewable energy in the west such as, Al Fashir 5 MW Solar PV Power Plant and 2X5MWp Solar Projects (Al Fashir & Al Deain). This project located in 9 km east of AlFashir city, Latitude: 13.37° N, Longitude: 25.2° E. the area of this Project about 135,000 square meters and the Capacity around 5.27 MW (Figure 2.6).

Furthermore, this area receives a lot of sunlight. Especially the Solar Radiation in this project about 2,392.20 Kwh/m2. Also Some citizens use solar energy, and solar energy is also used in the agricultural field, particularly for water pumps.

Figure 2.7

Al Fashir 5 MW Solar PV Power Plant

CHAPTER III

Methodology

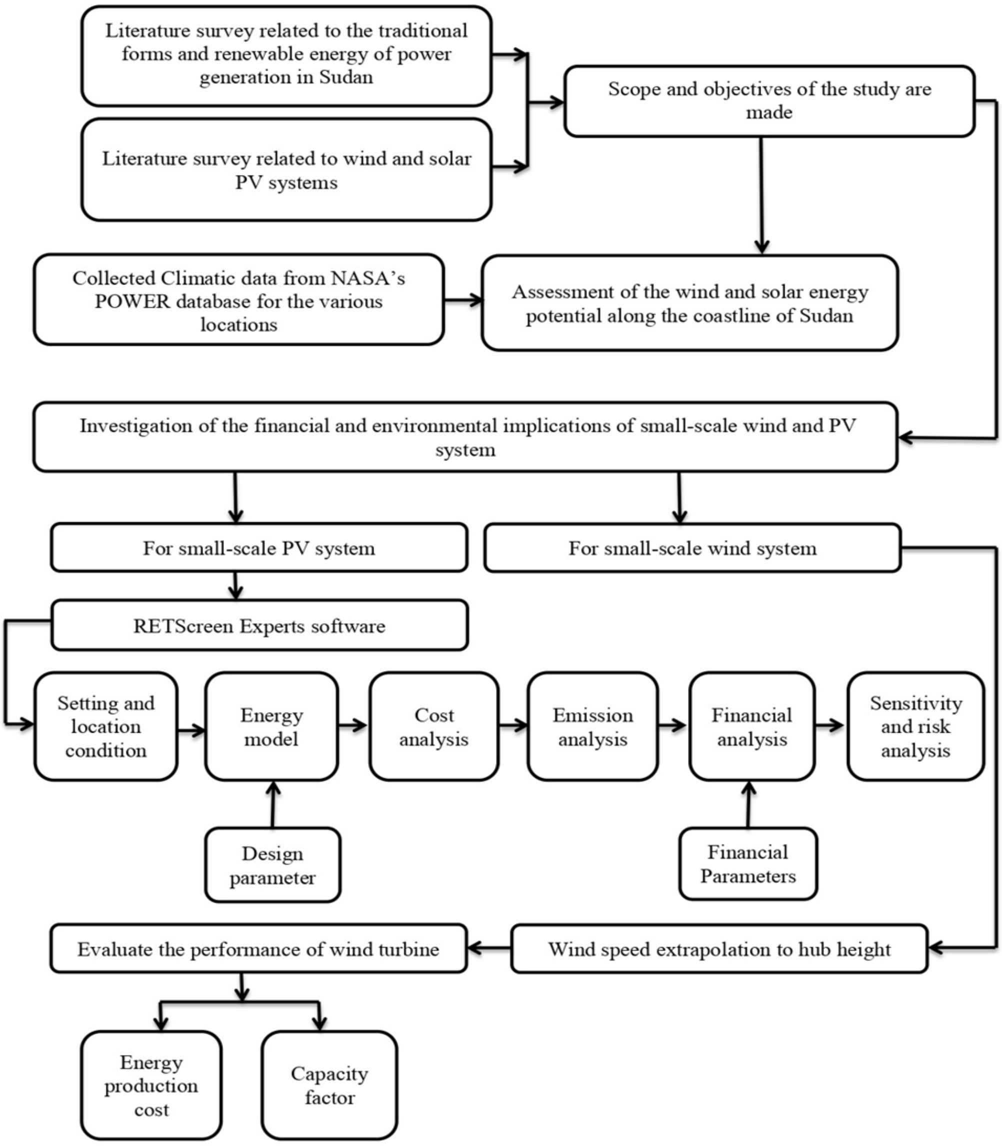
This chapter provides information about the data collection and analysis procedures as well as how the findings are analysed.

Material and Methods

In this section, the potential for solar and wind energy is examined in Sudan's Red Sea state. In addition, the economic validity of grid-connected solar and wind systems is investigated. This study's methodology is schematically shown in Figure 3.1.

Figure 3.1

Schematic Description for the Proposed Methodology



Data and Study Area

As the third-largest country in Africa (see Figure 3.2), Sudan covers an area of 1.8 million square kilometres. Sudan's coastline measures 853 meters long. It has a tropical climate, with large daily and seasonal temperature changes. The climatic zones range from arid desert in the north to semi-arid in the far south, which is influenced by the monsoons. The maximum temperature in summer ranges from 37°C to 44°C, and between 18°C and 21°C in the coldest months. In Table 3.1, the selected regions are described, as well as their coordinates and altitude. Several studies evaluated the wind energy potential (Arreyndip et al. 2016, Rafique et al. 2018, Gökçekuş et al. 2019) and solar energy potential (Owolabi et al, 2019; Kassem et al. 2019; Kassem et al. 2020c; Kassem et al. 2018; Kassem et al. 2020d) in different locations using the NASA database.

Moreover, there is good agreement between NASA's database and measurement data of global solar irradiation according to the previous scientific researches (Kassem et al. 2020b; Belkilani et al. 2018; Gairaa and Bakelli 2013). Therefore, NASA average monthly wind and solar data are used for estimating wind and solar energy potential.

Figure 3.2

Map of Sudan (Red Sea State)

Table 3.1

Geographical Coordinates and Altitude of 17 Locations

Location number	Name of location	Latitude [°N]	Longitude [°E]	Elevation [m]
Location 1	Bi'r Shalatayn	23.040	35.508	42
Location 2	Aalaba Nature Reserve	22.998	35.565	28
Location 3	Bi'r al Hasa	22.960	35.660	2
Location 4	Sudanese Halayeb petrol	22.614	35.952	22
Location 5	Halaib Sudan	22.430	36.341	28
Location 6	Abdo Coffee	22.401	36.420	1
Location 7	Halayeb	22.220	36.641	11
Location 8	Fudukwan	21.750	36.738	216
Location 9	Marsa Oseif	21.768	36.862	15
Location 10	Dungunab	21.1058	37.1192	9
Location 11	Muhammad Qol	20.9052	37.1587	4
Location 12	Arb'at	19.8667	37.1833	21
Location 13	Portsudan	19.5903	37.1902	13
Location 14	Suakin	19.1040	37.3293	2
Location 15	Trinkitat	18.6833	37.7167	5
Location 16	Tokar	18.4260	37.7275	24
Location 17	Afflanda	18.0500	38.4167	10

Procedure of wind energy analysis

The wind speed characteristics at the specific location have been studied by several scientific researchers (Alayat et al. 2018; Kassem et al. 2019; Khan et al.2019; Alavi et al.2016; Masseran et al. 2015; Ouarda et al. 2015). In the literature, the most used distribution functions are Weibull, Gamma, Lognormal, Logistic, Log-Logistic, Inverse Gaussian, Generalized Extreme Value, Nakagami, Normal, Rayleigh, generalized Gamma distribution, exponential, and Kappa distribution functions. Therefore, 37 distribution functions are utilized to evaluate the characteristics of the wind speed at the selected locations. The probability density function (PDF) and cumulative distribution function (CDF) expressions for the various distribution models are listed in Appendix A. Furthermore, the maximum-likelihood technique was used to compute the parameters of the chosen distribution models.

Goodness-of-Fit test

The expression of the Kolmogorov-Smirnov (K-S) test, the Anderson-Darling (A-D) test, and the Chi-squared (C-s) test are given in Eqs. (3.1)- (3.3). These tests were used to find a suitable model for analyzing the wind speed distribution.

Kolmogorov-Smirnov (K-S) test

$$D = \max_{1 \le i \le n} \left(F(x_i) - \frac{i-1}{n}, \frac{i}{n} - F(x_i) \right) \quad (3.1)$$

$$F_n(x) = \frac{1}{n} \times (Number\ of\ observation \le x) \quad (3.2)$$

Anderson-Darling (A-D) test

$$A^2 = -n - \frac{1}{n} \sum_{i=1}^{n} (2i-1) \times \left[lnF_X(x_i) + ln\big(1 - F_X(x_{n-i+1})\big) \right] \quad (3.3)$$

Where $F_X(x_i)$ is the cumulative distribution function of the proposed distribution at x_i, for *i* = 1, 2, . . . , *n*.

Chi-squared (C-s) test

$$\mathcal{X}^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \quad (3.4)$$

Where O_i is the observed frequency for bin *i*, and E_i is the expected frequency for bin i calculated by

$$E_i = F(x_2) - F(x_1) \quad (3.5)$$

Where F is the cumulative distribution function of the probability distribution being tested, and x_1, x_2 are the limits for bin *i*.

Moreover, for designing the wind farm, the wind power density (WPD) is calculated to assess the potential of wind power. Eqs. (3.6) and (3.7) are utilized to determine the WPD.

$$\frac{P}{A} = \frac{1}{2} \rho v^3 \quad (3.6)$$

$$\frac{P}{A} = \frac{1}{2} \rho v^3 f(v) \quad (3.7)$$

Furthermore, the average WPD can be determined using Eq. (3.8)

$$\frac{\bar{P}}{A} = \frac{1}{2} \rho \bar{v}^3 \quad (3.8)$$

where P is wind power density in W, $\bar{P}$ is mean wind power density in W, A is swept area in m^2, ρ is the air density in kg/m^3, $f(v)$ is the probability density function (PDF), and $\bar{v}$ is the mean wind speed in m/s.

Moreover, the ratio of average power output (E_{out}) to the rated power of wind turbine (E_r) is called the capacity factor (C_f) and it can be calculated as given below.

$$C_f = \frac{E_{out}}{E_r} = \frac{Mean\ output\ power\ over\ a\ specific\ period}{rate\ power\ of\ wind\ turbine} \quad (3.10)$$

$$E_{out} = \sum_{i=1}^{n} P_{wt(i)}\, t \quad (3.11)$$

$$P_{wt(i)} = \begin{cases} P_r \dfrac{v_i^2 - v_{ci}^2}{v_r^2 - v_{ci}^2} (v_{ci} \le v_i \le v_r) \\ \dfrac{1}{2}\rho A C_p v_r^2 (v_r \le v_i \le v_{co}) \\ 0 \qquad (v_i \le v_{ci} and v_i \ge v_{co}) \end{cases} \quad (3.12)$$

$$E_r = P_r . t \quad (3.13)$$

$$C_p = 2\frac{P_r}{\rho A v_r^3} \quad (3.14)$$

where t is the number of hours in the period under consideration, where v_i is the vector of possible wind speed at a given site, $P_{wt(i)}$ is the vector of the corresponding wind turbine output power (W),P_r is the rated power of the turbine (W), v_{ci} is the cut-in wind speed (m/s), $v_r$is the rated wind speed (m/s) and v_{co} is the cut-out wind speed (m/s) of the wind turbine.

Moreover, the energy production cost (EPC) from the wind turbine can be calculated based on the present value of costs (PVC) and capacity factor as shown in Eq. (3.15).

$$EPC = \frac{PVC}{E_r \times CF} \quad (3.15)$$

$$PVC = \left[I + C_{omr}\left(\frac{1+i}{r-i}\right) \times \left[1 - \left(\frac{1+i}{1+r}\right)^n\right] - S\left(\frac{1+i}{1+r}\right)^n \right] \quad (3.16)$$

where r is the discount rate, i is the inflation rate, n is the machine life as designed by the manufacturer, $C_{omr}$is the cost of operation and maintenance, I is the investment summation of turbine price and other initial costs, including provisions for civil work, land, infrastructure, installation and grid integration and S is the scrap value of the turbine price and civil work.

Solar energy analysis procedure

This work examines how grid-connected PV systems can be utilized for electricity generation in selected buildings. A PV system's power generating factor, energy demand, solar PV energy requirement, PV module sizing, and inverter sizing are all essential factors (Kassem et al. 2020).

$$Power\ generating\ factor = \frac{solar\ irradiance \times sunshine\ hour}{standard\ test\ condition\ irradiance} \qquad (3.17)$$

$$Energy\ demand = Energy\ consumption\ of\ all\ loads \qquad (3.18)$$

$$Solar\ PV\ energy\ required = peak\ energy\ requirement \times energy\ lost\ in\ the\ system \qquad (3.19)$$

$$total\ watt\ peak\ ratting = \frac{Solar\ PV\ energy\ required}{panel\ generation\ factor} \qquad (3.20)$$

$$PV\ module\ size = \frac{total\ watt\ peak\ ratting}{PV\ output\ power\ rating} \qquad (3.21)$$

$$Inverter\ sizing = peak\ energy\ requirement \times 1.3 \qquad (3.22)$$

CHAPTER IV

Findings and Discussion

This chapter presents the findings based on the collected data.

Wind energy characteristics

A summary of the descriptive statistics for each region (mean, maximum, minimum, SD, CV, skewness, and kurtosis) can be found in Table 4.1. It was observed that the mean wind speed was between 2.88 and 5.17 m/s. Wind speed values are highest and lowest respectively at locations 7 and 5. Based on Table 4.1, the coefficients of variation also range from 2.23 to 7.19.

Furthermore, the lowest and highest values of wind speed are recorded at locations 11 and 5, respectively, with a value of 1.87m/s and 6.16m/s, respectively, as shown in Figure 4.1. Additionally, location 5 has the highest annual wind speed (i.e. 5.17 m/s) in comparison to the other locations.

Table 4.1

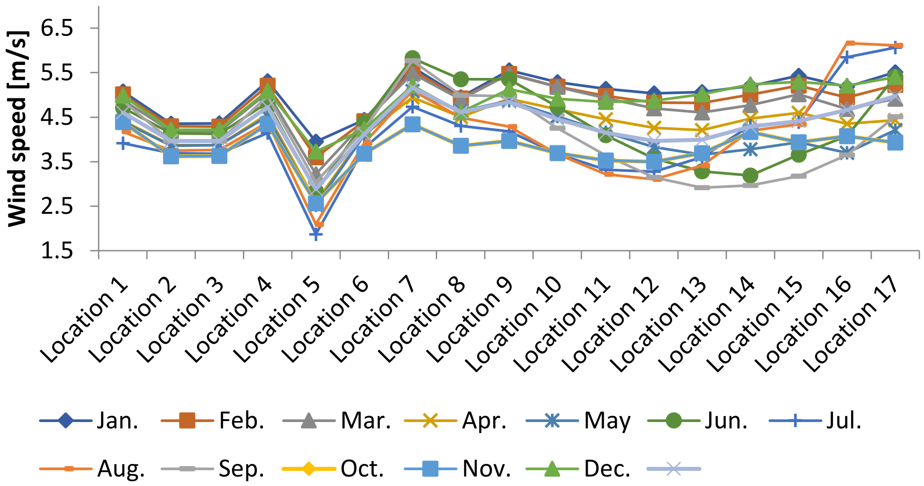
Descriptive Statistics of Wind Speed Data for the Investigation Period

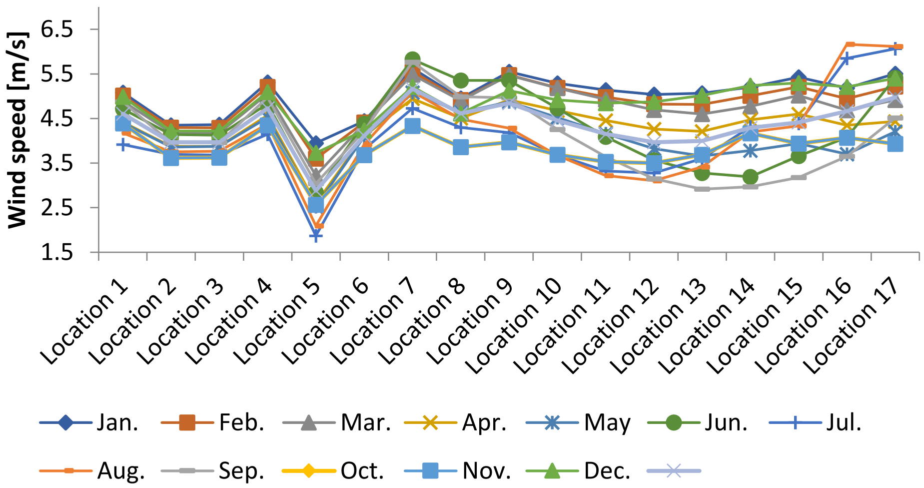
Location Number	Mean	SD	CV	Min.	Max.	S	K
1	4.6049	0.1805	3.92	4.2854	5.1048	0.58	0.33
2	3.964	0.1151	2.9	3.7759	4.2943	0.96	0.9
3	3.9641	0.1147	2.89	3.7709	4.2957	0.93	0.88
4	4.7299	0.171	3.61	4.4624	5.1653	0.81	0.3
5	2.8818	0.2073	7.19	2.6045	3.3957	0.66	-0.35
6	4.1134	0.1303	3.17	3.9122	4.444	0.91	0.13
7	5.1663	0.2269	4.39	4.768	5.7092	0.86	0.52
8	4.6142	0.2109	4.57	4.2785	5.1831	0.97	0.69
9	4.8441	0.2247	4.64	4.5117	5.4086	0.92	0.31
10	4.4569	0.1929	4.33	4.1887	4.9288	0.84	0.04
11	4.1524	0.1505	3.62	3.9144	4.4964	0.66	-0.17
12	3.9672	0.1035	2.61	3.7262	4.1601	0.14	-0.16
13	3.9964	0.0889	2.23	3.7498	4.1212	-0.68	-0.16
14	4.2882	0.1305	3.04	4.0387	4.5212	0.02	-1.02
15	4.4097	0.1088	2.47	4.1452	4.6134	-0.32	-0.14
16	4.6621	0.171	3.67	4.2737	4.9758	-0.06	-0.61
17	4.9694	0.1616	3.25	4.6413	5.2729	-0.15	-0.78

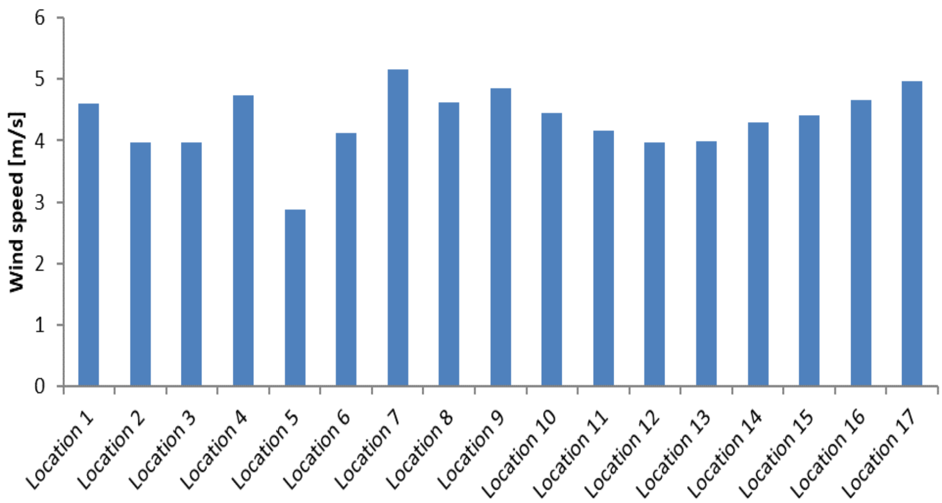
Min. : Minimum
Max.: Maximum
S: Skewness
K: Kurtosis

Figure 4.1

Average Wind Speed; (a) Annual Wind Speed and (b) Monthly Wind Speed Data







As mentioned previously, the parameters of the selected distribution models were calculated using the maximum-likelihood approach. Also, K-S, A-D, and C-s tests were used to find the best distribution function. Generally, the minimum value of K-S, A-D, and C-s tests will define the best distribution that fits the wind speed data.

The parameter of the used models and K-S, A-D, and C-s tests are summarized as shown in appendix B. Besides, Table 4.2 summarizes the best distribution functions that gave the best fit to the actual data. Based on the findings, it is observed that Wakeby distribution has the lowest value of K-S, A-D, and C-s, which is considered as the best distribution function to analyze the characteristics of wind speed for all selected locations.

Table 4.2

The Best Model (Rank #1) For Studying the Characteristics of Wind Speed

Location	Distribution function	Goodness of Fit K-S	A-D	C-S
	Gen. Pareto	-	0.3256	-
1	Wakeby	0.10717	-	-
	Weibull	-	-	2.85E-06
	Wakeby	0.12866	-	-
2	Wakeby	-	0.26023	-
	Pearson 5	-	-	9.77E-06
	Wakeby	-	0.2426	-
3	Wakeby	0.2426	-	-
	Longnormal	-	-	4.6E-06
	Beta	-	-	9.39E-06
4	Wakeby	-	0.2567	-
	Dagum (4P)	0.13964	-	-
	Gen.Extreme	-	0.23376	-
5	Weibull (3P)	0.14415	-	-
	Log-Logistic	-	-	2.20E-04
	Wakeby	0.13024	-	-
6	Wakeby	-	0.31623	-
	Gumbel Min	-	-	4.84E-04
	Gen.Extreme	0.09977	-	-
7	Gen. Extreme	-	0.2033	-
	Rayleigh	-	-	5.96E-04
	Gumbel Min	0.13513	-	-
8	Wakeby	-	0.24862	-
	Beta	-	-	2.79E-08
	Wakeby	0.13104	-	-
9	Wakeby	-	0.34034	-
	Weibull	-	-	4.14E-06
	Wakeby	0.17057	-	-
10	Wakeby	-	0.46282	-
	Burr	-	-	0.01582
	Wakeby	0.13104	-	-
9	Wakeby	-	0.34034	-
	Weibull	-	-	4.14E-06
	Wakeby	0.17057	-	-
10	Wakeby	-	0.46282	-
	Burr	-	-	0.01582
	Wakeby	0.11742	-	-
11	Wakeby	-	0.31179	-
	Beta	-	-	1.40E-04
	Wakeby	0.13715	-	-
12	Wakeby	-	0.36497	-
	Pareto	-	-	0.02431

Table 4.2 (Continued)

Location	**Distribution function**	**Goodness of Fit**		
		K-S	**A-D**	**C-S**
13	Log-Logistic	0.16815	-	-
	Wakeby	-	0.35794	-
	Exponential	-	-	0.06183
14	Cauchy	0.13568	-	-
	Gen. Extreme	-	0.24203	-
	Weibull	-	-	0.00249
15	Log-Gamma	0.13893	-	-
	Gen. Extreme	-	0.25506	-
	Weibull	-	-	0.00847
16	Log-Logistic	0.13467	-	-
	Wakeby	-	0.21704	-
	Beta	-	-	7.52E-08
17	Gen.Extreme	0.12468	-	-
	Wakeby	-	0.2546	-
	Beta	-	-	1.71E-05

According to the previous studies, the air density value is assumed to be 1.23kg/m3. Hence, the average value of WPD is determined by using Eq. (3.8). Table 4.3 summarized the value of mean, SD, CV and WPD for the best distribution models (Table 5). Based on the results of WPD, ranging from 13.950 W/m2 (location 5) to 84.459 W/m2 (location 7), consequently, the wind energy potential at the selected location is categorized as poor (class 1) (Kassem et al., 2019). The buildings can therefore be equipped with a small-scale wind turbine for generating electricity from wind energy.

Table 4.3

Parameter Values of the Best Distribution Functions over the Investigated Period at 10 m Height.

No.	**Distribution functions**	**Parameters**					
		mean [m/s]	**SD [m/s]**	**CV**	**S**	**K**	**WPD [W/m^2]**
#1	Actual	4.605	0.181	3.920	0.580	0.330	59.809
	Wakeby	-	-	-	-	-	-
	Gen. Pareto	4.605	0.379	0.082	-0.287	-1.173	59.809
	Weibull	4.544	0.445	0.098	-0.723	0.802	57.448
# 2	Actual	3.964	0.115	2.900	0.960	0.900	38.151
	Wakeby	3.964	0.275	0.069	0.093	-1.163	38.151
	Wakeby	3.964	0.275	0.069	0.093	-1.163	38.151
	Pearson 5	3.964	0.257	0.065	0.260	0.127	38.151
#3	Actual	3.964	0.115	2.890	0.930	0.880	38.154
	Wakeby	3.964	0.272	0.069	0.130	-1.142	38.154
	Wakeby	3.964	0.272	0.069	0.130	-1.142	38.154
	Longnormal	3.964	0.252	0.064	0.191	0.065	38.154
# 4	Actual	4.730	0.171	3.610	0.810	0.300	64.813
	Beta	4.730	0.393	0.083	-0.009	-1.429	64.813
	Wakeby	4.730	0.404	0.085	0.090	-1.164	64.813
	Dagum (4P)	4.758	0.466	0.098	1.673	12.553	65.967
# 5	Actual	2.882	0.207	7.190	0.660	-0.350	14.659
	Weibull (3P)	2.882	0.615	0.213	0.534	0.080	14.654
	Gen.Extreme	2.882	0.676	0.235	0.472	0.203	14.659
	Log-Logistic	2.835	0.812	0.286	1.569	8.526	13.950
#6	Actual	4.113	0.130	3.170	0.910	0.130	42.629
	Wakeby	4.113	0.293	0.071	-0.495	-1.023	42.629
	Wakeby	4.113	0.293	0.071	-0.495	-1.023	42.629
	Gumbel Min	4.113	0.283	0.069	-1.140	2.400	42.629
# 7	Actual	5.166	0.227	4.390	0.860	0.520	84.459
	Gen.Extreme	5.166	0.540	0.104	-0.667	0.315	84.459
	Gen. Extreme	5.166	0.540	0.104	-0.667	0.315	84.459
	Rayleigh	5.166	2.701	0.523	0.631	0.245	84.459
# 8	Actual	4.614	0.211	4.570	0.970	0.690	60.172
	Gumbel Min	4.614	0.451	0.098	-1.140	2.400	60.172
	Wakeby	-	-	-	-	-	-
	Beta	4.614	0.451	0.098	-0.019	-1.266	60.172

Table 4.3 (Continued)

No.	Distribution functions	Parameters					
		mean [m/s]	SD [m/s]	CV	S	K	WPD [W/m^2]
# 9	Actual	4.844	0.225	4.640	0.920	0.310	69.622
	Wakeby	4.844	0.614	0.127	-0.428	-1.083	69.622
	Wakeby	4.844	0.614	0.127	-0.428	-1.083	69.622
	Weibull	4.760	0.720	0.151	-0.523	0.306	66.050
#10	Actual	4.457	0.193	4.330	0.840	0.040	54.226
	Wakeby	4.457	0.650	0.146	-0.072	-1.213	54.226
	Wakeby	4.457	0.650	0.146	-0.072	-1.213	54.226
	Burr	4.466	0.617	0.138	-0.569	0.408	54.558
#11	Actual	4.152	0.151	3.620	0.660	-0.170	43.853
	Wakeby	4.152	0.722	0.174	0.126	-1.144	43.853
	Wakeby	4.152	0.722	0.174	0.126	-1.144	43.853
	Beta	4.152	0.703	0.169	0.050	-1.553	43.853
#12	Actual	3.967	0.104	2.610	0.140	-0.160	38.244
	Wakeby	3.967	0.747	0.188	0.455	-0.790	38.244
	Wakeby	3.967	0.747	0.188	0.455	-0.790	38.244
	Pareto	4.032	1.264	0.313	5.841	217.230	40.148
#13	Actual	3.996	0.089	2.230	-0.680	-0.160	39.094
	Log-Logistic	3.944	0.901	0.228	1.190	5.089	37.577
	Wakeby	3.996	0.740	0.185	0.391	-0.883	39.094
	Exponential	3.996	3.996	1.000	2.000	6.000	39.094
# 14	Actual	4.288	0.131	3.040	0.020	-1.020	48.298
	Cauchy	-	-	-	-	-	-
	Gen. Extreme	4.288	0.752	0.175	-0.601	0.190	48.298
	Weibull	4.187	0.849	0.203	-0.343	-0.009	44.962
# 15	Actual	4.410	0.109	2.470	-0.320	-0.140	52.521
	Log-Gamma	4.416	0.751	0.170	0.763	1.101	52.761
	Gen. Extreme	4.410	0.745	0.169	0.000	-0.283	52.521
	Weibull	4.299	0.796	0.185	-0.403	0.083	48.657
#16	Actual	4.662	0.171	3.670	-0.060	-0.610	62.066
	Log-Logistic	4.567	0.930	0.204	1.043	4.111	58.352
	Wakeby	3.496	0.856	0.184	0.681	-0.361	26.162
	Beta	4.662	0.820	0.176	0.367	-1.255	62.066
# 17	Actual	4.969	0.162	3.250	-0.150	-0.780	75.165
	Gen.Extreme	4.969	0.804	0.162	0.023	-0.277	75.165
	Wakeby	4.969	0.790	0.159	0.026	-1.192	75.165
	Beta	4.969	0.768	0.155	0.089	-1.483	75.165

Solar energy characteristics

The amount of solar radiation, such as Global horizontal irradiation (GHI) and direct normal irradiation (DNI), and air temperature (AT) are important factors in evaluating the performance of PV systems. Based on the value of GHI and DNI, the solar resource at a specific location is categorized in Table 4.4.

Table 4.4

Classification of Solar Energy

Class	**Annual GHI [kWh/m^2]**
1 (Poor)	<1191.8
2 (marginal)	1191.8-1419.7
3 (fair)	1419.7-1641.8
4 (good)	1641.8-1843.8
5 (excellent)	1843.8-2035.9
6 (outstanding)	2035.9-2221.8
7 (superb)	>2221.8
Class	**Annual DNI [kWh/m^2]**
1 (Poor)	<936.9
2 (marginal)	936.9-1255.7
3 (fair)	1255.7-1546.8
4 (good)	1546.8-1840.9
5 (execllent)	1840.9-2149.9
6 (outstanding)	2149.9-2533.7
7 (superb)	>2533.7

Tables 4.5 and 4.6 summarize the average monthly of GHI and DNI for all selected locations. It is found that the monthly GHI values are varied from 2189kWh/m2 to 2421 kWh/m2. It is observed that locations 2 and 16 have the maximum and minimum value of GHI and DNI with a value of 2412 kWh/m2 and 2594 kWh/m2 and 2189 and 1943 kWh/m^2, respectively.

Moreover, as indicated in Tables 8 and 9, the solar resources in the selected sites are classed as good, exceptional, or terrific potential classes. The solar resource in location 2 and location 7 were classified as superb (class 7). As a result of the high GHI and DNI values, it is concluded that the selected locations are suitable for establishing large-scale or small-scale solar systems. As a result, Solar PV/flat-plate and CSP systems are suitable for installation in all of the specified regions.

Moreover, location 17 and location 1 had the maximum and minimum AT values of 32.47 and 28.35 °C, respectively, as shown in Table 4.5.

Table 4.5

Value of GHI for All Locations

Month	**Location**								
	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**
1	151	152	152	149	146	144	145	148	151
2	164	165	164	162	160	159	160	163	165
3	214	215	215	211	210	210	210	212	214
4	228	228	228	227	226	224	223	223	223
5	242	243	243	242	242	238	238	237	235
6	244	244	244	242	239	236	236	235	231
7	246	246	246	243	241	236	234	233	229
8	232	233	232	230	227	225	223	223	220
9	211	211	211	210	209	207	206	206	205
10	188	188	188	186	186	186	186	187	188
11	154	154	153	151	149	148	150	153	155
12	144	143	143	138	136	135	138	142	144
Annual	2418	2421	2420	2393	2372	2347	2348	2363	2359
Classification	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6
Month	**Location**								
	#10	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**	
1	147	149	147	139	135	127	119	131	
2	162	164	161	154	148	140	135	147	
3	211	214	215	209	207	200	187	195	
4	219	222	223	219	222	219	213	215	
5	234	235	235	230	233	234	230	225	
6	228	227	224	218	219	220	216	215	
7	225	222	217	210	213	214	212	210	
8	216	214	209	205	206	208	205	204	
9	201	202	202	197	201	203	201	200	
10	186	192	193	189	193	190	191	192	
11	152	157	154	148	148	148	150	153	
12	141	143	140	133	132	126	129	138	
Annual	2321	2340	2320	2253	2257	2229	2189	2224	
Classification	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6	

Table 4.6

Value of DNI for All Locations

Month	Location								
	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**
1	197	196	197	186	174	170	172	177	182
2	197	198	196	189	182	176	178	183	187
3	237	238	236	229	223	221	221	226	226
4	227	229	230	228	224	215	214	216	215
5	223	225	227	225	222	212	211	210	208
6	236	237	237	233	223	214	211	210	201
7	235	236	236	229	220	208	202	201	192
8	215	216	214	210	202	195	189	191	184
9	216	217	216	212	206	202	198	197	192
10	209	209	208	201	200	197	197	199	199
11	200	197	194	186	177	175	181	186	187
12	200	197	195	180	170	167	173	182	183
Annual	2592	2594	2587	2508	2423	2351	2347	2379	2357
Classification	Class 7	Class 7	Class 7	Class 6	Class 6	Class 6	Class 6	Class 6	Class 6
Month	**Location**								
	#10	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**	
1	177	170	159	149	128	116	105	130	
2	188	180	174	164	142	127	120	144	
3	231	224	222	220	203	191	167	185	
4	221	213	216	218	211	209	193	204	
5	219	206	209	211	206	212	203	201	
6	208	193	186	186	177	184	175	180	
7	197	177	167	165	159	165	162	166	
8	186	169	160	161	152	158	153	157	
9	193	184	181	180	176	182	178	180	
10	202	203	204	204	198	193	195	203	
11	185	184	174	167	154	154	160	171	
12	181	173	162	152	137	126	134	156	
Annual	2389	2277	2214	2176	2045	2017	1943	2076	
Classification	Class 6	Class 6	Class 6	Class 6	Class 5	Class 5	Class 5	Class 5	

Table 4.7

Value of Average Temperatures for All Selected Locations

Month	Location								
	#1	#2	#3	#4	#5	#6	#7	#8	#9
1	20.23	20.27	20.27	21.68	21.92	21.94	22.01	22.49	23.18
2	21.92	21.94	21.94	23.01	23.33	23.35	23.38	23.73	24.18
3	24.58	24.59	24.59	24.93	25.7	25.71	25.76	25.81	26.18
4	27.66	27.66	27.66	27.66	28.76	28.78	28.79	28.78	28.86
5	31.09	31.09	31.09	30.48	32.05	32.06	32.08	32.21	32.51
6	33.83	33.83	33.83	33.08	34.83	34.83	34.83	35.08	35.73
7	35.23	35.23	35.23	34.59	36.06	36.07	36.08	36.36	36.86
8	35.64	35.65	35.65	34.83	36.55	36.58	36.58	36.73	37.38
9	32.97	32.98	32.98	32.73	33.99	34	34.05	34.27	34.92
10	29.43	29.45	29.45	29.93	31.02	31.02	31.05	31.05	31.06
11	25.73	25.77	25.77	26.7	27.32	27.33	27.39	27.48	27.89
12	21.93	21.97	21.97	23.61	23.74	23.77	23.84	24.26	24.91
Annual	28.35	28.37	28.37	28.6	29.6	29.62	29.65	29.85	30.3
Month	**Location**								
	#10	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**	
1	23.28	23.35	23.66	24.67	24.64	24.67	24.64	25.64	
2	24.54	24.57	24.61	25.62	25.61	25.38	25.34	26.15	
3	26.4	26.45	26.25	27.1	27.1	27.09	27.09	27.68	
4	29.11	29.13	28.69	29.08	29.08	29.79	29.75	30.28	
5	32.9	32.92	32.35	32.34	32.33	32.83	32.83	33.66	
6	36.48	36.51	36.05	36.47	36.47	36.3	36.28	37.66	
7	38.39	38.45	37.89	38.38	38.36	37.7	37.66	40.21	
8	39.03	39.08	38.65	39.2	39.18	38.16	38.12	40.68	
9	35.52	35.54	35.09	35.64	35.64	35.4	35.39	37.22	
10	31.26	31.29	30.79	31.69	31.69	31.67	31.67	33.27	
11	27.65	27.69	27.51	28.56	28.54	28.66	28.64	29.91	
12	24.77	24.83	24.98	25.93	25.9	25.98	25.98	27.32	
Annual	30.78	30.82	30.54	31.22	31.21	31.13	31.12	32.47	

Economic analysis

The economic validity of wind and solar systems is examined in this section. On the basis of recent market data in the country and cost prices in the literature, it has been estimated that both systems will cost around USD 3300.

As mentioned previously, low-cut-in wind turbines are being considered as one of the most attractive approaches to reducing electricity crises, and they can be installed on the roofs of buildings. In this study, a comparison of different types of wind turbines was conducted before selecting the selected turbine. In this research, ten small vertical axis wind turbines are being tested. Table 4.8 summarizes the characteristics of the selected wind turbines.

A typical household area in this study ranges from 400m2 to 600m2, while the average number of floors varies between 2 and 6. Hence, assume that the selected building consists of two floors, i.e. the household's height is about 10 meters. All models are shown in Figure 5 with the annual output energy, the capacity factor, and the energy unit cost per kWh based on the PVC method.

The wind turbine model of #9, with its annual output of 158.50 kWh, and the wind turbine model of #1, with its annual output of 29063.93 kWh, respectively, achieve the highest and lowest values of annual energy output. In addition, as illustrated in Figure 4.2, the maximum capacity factor is 58.10% with model #2.

It is important to estimate the cost of energy ($/kWh) prior to determining which model is the most suitable.

Because of the difficulty of gathering precise information about wind turbine costs, the literature was consulted to get a sense of wind turbine costs. A cost comparison was conducted with the other selected turbines for the investigated locations and found that model #9 (Vertical Axis Wind Generator-V) has the lowest cost value.

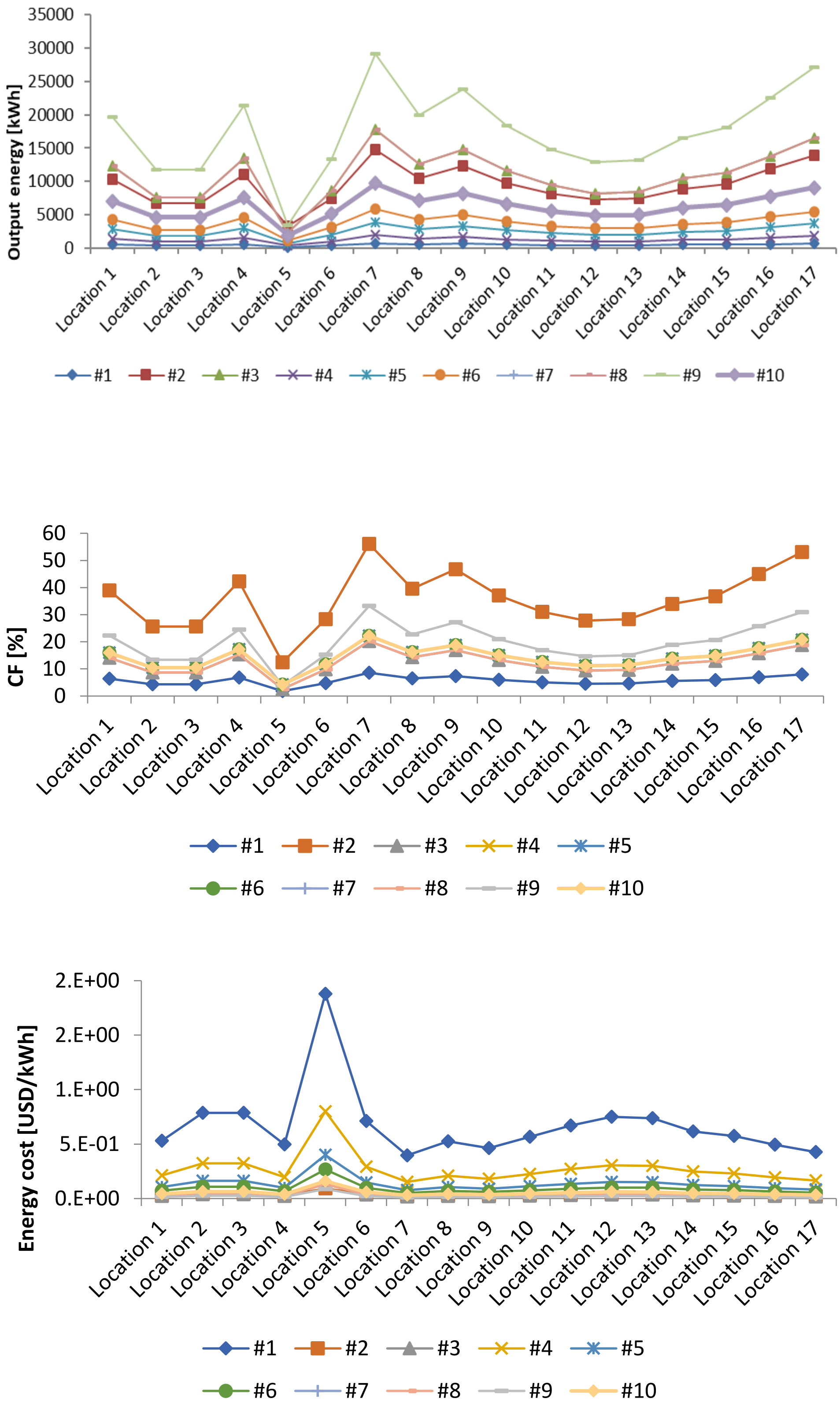
Table 4.8

Specifications of Small-Scale Vertical Wind Turbines

Model No.	**#1**	**#2**	**#3**
Model	WS-4B & 4C 1-2 kW	3000W Vertical Axis Wind Turbine	10kw H-Type Vertical Axis Wind
Rated power [kW]	1 kW	3kw	10kw
Rated wind speed [m/s]	18 m/s	9.0m/s	12m/s
Cut-in wind speed [m/s]	2 m/s	1.0m/s	2.5m/s
Model No.	**#4**	**#5**	**#6**
Model	1kw AC Three-Phase Vertical	2kw AC Three-Phase Vertical	3 kW AC Three-Phase Vertical
Rated power [kW]	1kw	2kw	3kw
Rated wind speed [m/s]	12m/s	12m/s	12m/s
Cut-in wind speed [m/s]	2m/s	2m/s	2m/s
Model No.	**#7**	**#8**	**#9**
Model	5kw AC Three-Phase Vertical	10kW AC Three-Phase Vertical	Vertical Axis Wind Generator V
Rated power [kW]	5kw	10kw	5KW
Rated wind speed [m/s]	12m/s	12m/s	10m/s
Cut-in wind speed [m/s]	2m/s	2.5m/s	2.5m/s
Model No.	**#10**		
Model	AC-120V 5kw Vertical Axis Wind		
Rated power [kW]	5 kw		
Rated wind speed [m/s]	12m/s		
Cut-in wind speed [m/s]	2m/s		

Figure 4.2

Annual Output Energy, the Capacity Factor, and Energy Production Cost for All Locations



Moreover, by using a grid-connected system, residential electricity users can reduce their electricity consumption and dependence on utility power, while generating more electricity through renewable energy sources like solar energy. The findings of the literature review reveal a clear lack of proposed solar PV systems for households living in Sudan.

SUNTECH-450 Watt, a grid-connected PV system manufactured by Suntech Power, was selected for the proposed small-scale system. Considering its efficiency and availability, it was chosen for this study. Table 4.9 summarizes the specification of the selected module.

The total number of modules and the area required for the proposed system is 12 modules and 27m2. The proposed PV system is equipped with a 5kW, 93% efficient, and directly connected to the grid through an inverter (Kassem et. al 2021).

Table 4.9

PV Module Specification

Item	**Specification**
Manufacturer	Suntech Power (China)
Model	STPXXXS-B72/Vnh
Nominal power [W]	450 W
Open-circuit voltage [V]	49.2 V
Short-circuit current [A]	11.61 A
Maximum system voltage	1500 V DC (IEC)
Maximum series fuse rating	20 A
Module area [m^2]	2.18
Efficiency [%]	20.7%
Warranty [Year]	25-year
Cost [USD]	210

According to the literature, PVGIS (Photovoltaic Geographical Information System) simulation tools can provide optimal orientation angles (tilt and azimuth). In PVGIS, the best azimuth and slope angles were found to be 35° and 0° respectively. As Mehmood et al. (2014) and Khandelwal and Shrivastava (2017) indicate, solar radiation and the number of clear sunny days have the greatest impact on the annual energy and capacity factor of PV systems. Consequently, the economic feasibility of the developed system was investigated using RETScreen software.

Table 4.10 shows the performance of the 5kW grid-connected solar system including the annual Electricity Exported to the grid (AEEG) in kWh, capacity factor (CF) in %, simple payback (EP) in year, equity payback (EP) in year, net present value (NPV) in USD, annual life cycle savings (ALCS) in USD/year, energy production cost (EPC) in USD/kWh, gross annual GHG emission reduction (GAER GHG) in tCO2, GHG reduction cost (GHG RC) in tCO2/USD, Car and light trucks not used (CALTNU) in tCO2, Litters of gasoline not consumed (LOGNC) in tCO2, Barrels of crude oil not consumed (BOCONC) in tCO2, People reducing energy use by 20% (PREUB) in tCO2, Acres of forest absorbing carbon (AOFAC) in tCO2, Hectares of forest absorbing carbon (HOFAC) and Tons of waste recycled (TOWR) in tCO2. It is found that the value of EG is within the range of 6648-15533kWh for the proposed system. The highest value of EG is found in Location 14, while the lowest value is found in Location 17.

Furthermore, as indicated in Table 4.11, the CF values among both systems range from 16.63 % up to 20.14 %. These findings can be backed up by other scientific researchers who investigated the possibility of a grid-connected PV system. For example, Kazem and Khatib (2012) discovered that the projected Photovoltaic system in Oman had a CF of 16-23 %. Obeng et al. (2020) also discovered that the CF of grid-connected PV systems using various technologies ranged from 15.37 % up to 15.75.

Furthermore, Mohammadi et al. (2018) discovered that the CF of grid-connected Photovoltaic systems with various sun-tracking modes ranged from 17.54 to 27.42 %. As a result, the value obtained from the current investigation for each location can be determined to be compatible with acceptable values.

As a result, installing a grid-connected rooftop PV system throughout the Red Sea state's 17 locations is technically feasible.

Furthermore, the economic and environmental elements are estimated to assess the effectiveness of the aforementioned proposed systems. Financial metrics such as inflation rate (10.13%), discount rate (12.68%), reinvestment rate (16.01%), debt ratio (70%), and debt interest rate (5.88%) are used as input variables in this study. Table 4.11 summarizes the major findings of the designed system's economic performance of a 5kW grid-connected rooftop PV system.

The acquired results revealed that the suggested systems had a positive net present value, indicating that the project is viable. According to Owolabi et al.

(2019) and Mohammadi et al. (2019), it must be fiscally and economically feasible (2018). Furthermore, based on the internal rate of return, which is a measure of a project's profitability, the proposed projects in the selected sites are deemed to be economically viable (Owolabi et al. 2019, Rehman et al. 2017). Furthermore, the equity payback (EP) and simple payback (SP) periods are between 1.4 and 2.0 years and 3.7 and 5.0 years, respectively. These findings suggest that photovoltaic systems in all regions are financially viable.

Moreover, the Emission Analysis Worksheet is used to measure the reduction of greenhouse gas (GHG) emissions resulting from the solar PV system. In addition, it is utilized to estimate the revenue that may occur from the sales of the GHG reduction emission as shown in Table 4.10.

Furthermore, the electricity production cost (EPC) varies between 0.036 USD/kWh and 0.049 USD/KWh. In comparison with the literature (Adaramola (2015), Sinha and Chandel (2016), Bahrami et al. (2017), Hammad et al. (2017), Bhakta and Mukherjee (2017), Talavera et al. (2019), Fakher Alfahed et al. (2019), Martinopoulos (2020), Tarigan (2020), Abada et al. (2020), Kassem et al. (2019), Kassem et al. (2020a), Çamur et al. (2021), Current study).

The EPC values of the suggested systems are determined to be within the range of the literature's highest (3.165$/kWh) and lowest (0.0199$/kWh) LCOE values. It has been observed that the established systems provide a very great insight into the project's financial viability for all regions.

Moreover, the acquired findings revealed that the suggested 5kW Photovoltaic power system may be developed at a reasonable cost due to the good economic results.

Table 4.11

Financial Parameters Performance of 5kW Grid-Connected Of Solar System

Parameter	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**
AEEG	9014	9014	8989	8988	8962	8959
CF	19.10	19.10	18.76	18.76	19.00	19.00
SP	3.7	3.7	3.7	3.7	3.7	3.7
EP	1.4	1.4	1.4	1.4	1.4	1.4
NPV	5332	5485	5454	5331	5432	5429
ALCS	712	729	728	712	725	725
ENC	0.038	0.036	0.036	0.038	0.036	0.036
GAER GHG	1.8	1.8	1.8	1.8	1.8	1.8
GHG RC	-387	-396	-396	-387	-396	-396
CALTNU	0.3	0.3	0.3	0.3	0.3	0.3
LOGNC	789.8	790.1	789.7	789.6	787.5	787.2
BOCONC	4.3	4.3	4.3	4.3	4.3	4.3
PREUB	1.8	1.8	1.8	1.8	1.8	1.8
AOFAC	0.4	0.4	0.4	0.4	0.4	0.4
HOFAC	0.2	0.2	0.2	0.2	0.2	0.2
TOWR	0.6	0.6	0.6	0.6	0.6	0.6
Parameter	**Location 7**	**Location 8**	**Location 9**	**Location 10**	**Location 11**	**Location 12**
AEEG	8953	8737	8696	8644	8329	8284
CF	19.00	18.95	18.85	18.80	18.70	18.65
SP	3.7	3.8	3.8	3.8	4	4
EP	1.4	1.4	1.5	1.4	1.5	1.5
NPV	5421	5234	5074	5152	4876	4837
ALCS	724	699	678	688	651	646
ENC	0.036	0.037	0.039	0.037	0.039	0.039
GAER GHG	1.8	1.8	1.8	1.8	1.7	1.7
GHG RC	-396	-391	-381	-389	-382	-381
CALTNU	0.3	0.3	0.3	0.3	0.3	0.3
LOGNC	786.4	767.6	763.8	759.4	731.8	727.8
BOCONC	4.3	4.2	4.1	4.1	4	3.9
PREUB	1.8	1.8	1.8	1.8	1.7	1.7
AOFAC	0.4	0.4	0.4	0.4	0.4	0.4
HOFAC	0.2	0.2	0.2	0.2	0.2	0.2
TOWR	0.6	0.6	0.6	0.6	0.6	0.6
Parameter	**Location 13**	**Location 14**	**Location 15**	**Location 16**	**Location 17**	
AEEG	8243	15533	6689	6671	6648	
CF	18.56	20.14	17.56	17.42	16.63	
SP	4	3.8	4.9	4.9	5	
EP	1.5	1.4	2	2	2	
NPV	4801	5242	3439	3423	3406	
ALCS	641	700	459	457	455	
ENC	0.039	0.037	0.048	0.048	0.049	
GAER GHG	1.7	1.8	1.4	1.4	1.4	
GHG RC	-380	-391	-336	-335	-335	
CALTNU	0.3	0.3	0.3	0.2	0.2	
LOGNC	724.2	768.4	587.5	586	584.2	
BOCONC	3.9	4.2	3.2	3.2	3.2	
PREUB	1.7	1.8	1.4	1.4	1.4	
AOFAC	0.4	0.4	0.3	0.3	0.3	
HOFAC	0.2	0.2	0.1	0.1	0.1	
TOWR	0.6	0.6	0.5	0.5	0.5	

Table 4.12

Electricity Tariffs in the Sudan and Electricity Production Cost Wind and Solar Systems

Power generation	**User type**	**Tariff (US$c/kWh)**	**Comments**
Grid	Residential and agricultural	1.8	For 0-100kWh
		2.3	For 100-200 kWh
		2.7	Above 200 kWh, for each 3.80kWh
	Industrial	5.4	Flat rate
	Commercial	3.6	Flat rate
Wind system	Residential, agricultural, Industrial and Commercial	87.03-10.25	Flat rate and depends on the location
Solar system	Residential, agricultural, Industrial and Commercial	36.00-49.00	Flat rate and depends on the location

CHAPTER V

Conclusion and Recommendations

This study investigated the potential and validity of grid-connected wind and PV systems in the Red Sea state in Sudan. For wind energy potential, it was investigated how well 37 distribution functions predicted wind speed characteristics at various locations. The distribution parameters were calculated using the maximum likelihood method. Moreover, the power-law model and present value cost method were used. For solar energy potential, the annual value of global solar radiation and direct normal radiation were calculated to classify the solar resource in the selected locations. Additionally, the feasibility of a small-scale PV system was evaluated using RETScreen software. In the end, it conclude that:

- The lowest value, based on the goodnesfit, the lowest value was Obtained by Wakeby model.
- Rooftop wind turbines are regarded as a good option for producing Electricity from the wind for buildings that have low cut-in points, Primarily because they have low wind power densities.
- The selected areas are appropriate for installing large-scale/small-Scale solar systems.
- The annual electrical energy from wind turbines and solar energy is Within the range of 158.50-29063.93kWh and 6648-15533 kWh, Respectively, which help to reduce GHG emissions.
- The results showed that model #9 (Vertical Axis Wind Generator-V) With a capacity of 5kW has the lowest EPC value, ranging from 0.08703 to 0.01025 $/kWh, compared to the other selected Turbines. Furthermore, PV systems had cost estimates ranging From 0.036 to 0.049 $/kWh on average. As a whole, the proposed Systems provide more energy for the same price as those offered By electricity companies.

However, the utilization of small-scale renewable energy systems will help reduce the dependency on fossil fuel, the effect of global warming, and enhance the sustainable technological development of the country.

Finally, the results of this paper demonstrate that a small-scale grid-connected rooftop wind and PV system in the Red seas state can solve the electricity crisis, reduce the consumption of fossil fuel and environmental pollution by minimizing the emission of CO2. Investing in the energy and building sectors can benefit from the findings of this research, as can speeding up the transition towards a more sustainable future.

Limitations and Future work

In this study, it is essential to acknowledge the limitations of this work. First, the financial parameters were assumed based on historical values in the literature. Second, the influence of various parameters such as dust, irradiation intensity, air temperature, and relative humidity was neglected due to the limitation of RETScreen software.

The financial criteria were first assumed based on published historical values. Second, because to the limitations of RETScreen software, the impact of different characteristics such as dust, irradiation intensity, air temperature, and relative humidity was overlooked.

There was no consideration of land availability in the present study. Future studies will determine whether land is available for massive grid-connected PV systems as a result of this. Future studies should also examine the impact of financial parameters, such as discount rates and inflation rates, on investment. Furthermore, the interaction between the distribution grid and the PV system should be examined in order to understand the impact of grid-connected PV systems on the distribution grid.

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Appendices

Appendix A
Expression of PDF and CDF used in the current study

Table S1. Expression of PDF and CDF used in the current study

Distribution function	Probability Density Function	Cumulative Distribution Function
Beta	$f(v) = \frac{1}{B(\alpha_1, \alpha_2)} \frac{(v-a)^{\alpha_1 - 1}(b-v)^{\alpha_2 - 1}}{(b-a)^{\alpha_1 + \alpha_2 - 1}}$	$F(v) = I_z(\alpha_1, \alpha_2)$
Four-Parameter Burr	$f(v) = \frac{\alpha k \left(\frac{v-\gamma}{\beta}\right)^{\alpha - 1}}{\beta \left(1 + \left(\frac{v-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$	$F(v) = 1 - \left(1 + \left(\frac{v-\gamma}{\beta}\right)^{\alpha}\right)^{-k}$
Three-Parameter Burr	$f(v) = \frac{\alpha k \left(\frac{v}{\beta}\right)^{\alpha - 1}}{\beta \left(1 + \left(\frac{v}{\beta}\right)^{\alpha}\right)^{k+1}}$	$F(v) = 1 - \left(1 + \left(\frac{v}{\beta}\right)^{\alpha}\right)^{-k}$
Cauchy	$f(v) = \left(\pi\sigma\left(1 + \left(\frac{v-\mu}{\sigma}\right)^2\right)\right)^{-1}$	$F(v) = \frac{1}{\pi} arctan\left(\frac{v-\mu}{\sigma}\right) + 0.5$
Four-Parameter Dagum	$f(v) = \frac{\alpha k \left(\frac{v-\gamma}{\beta}\right)^{\alpha k - 1}}{\beta \left(1 + \left(\frac{v-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$	$F(v) = 1 - \left(1 + \left(\frac{v-\gamma}{\beta}\right)^{-\alpha}\right)^{-k}$
Three-Parameter Dagum	$f(v) = \frac{\alpha k \left(\frac{v}{\beta}\right)^{\alpha k - 1}}{\beta \left(1 + \left(\frac{v}{\beta}\right)^{\alpha}\right)^{k+1}}$	$F(v) = 1 - \left(1 + \left(\frac{v}{\beta}\right)^{-\alpha}\right)^{-k}$
Three-Parameter Erlang	$f(v) = \frac{(v-\gamma)^{m-1}}{\beta^m \Gamma(m)} exp\left(-\frac{v-\gamma}{\beta}\right)$	$F(v) = \frac{\Gamma_{(v-\gamma)/\beta}(m)}{\Gamma(m)}$
Two-Parameter Erlang	$f(v) = \frac{(v-\gamma)^{m-1}}{\beta^m \Gamma(m)} exp\left(-\frac{v}{\beta}\right)$	$F(v) = \frac{\Gamma_{(v)/\beta}(m)}{\Gamma(m)}$
Two-Parameter Exponential	$f(v) = \lambda\, exp(-\lambda(v-\gamma))$	$F(v) = 1 - exp(-\lambda(v-\gamma))$
One-Parameter Exponential	$f(v) = \lambda\, exp(-\lambda v)$	$F(v) = 1 - exp(-\lambda v)$
Three-Parameter Gamma	$f(v) = \frac{(v-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} exp\left(-\left(\frac{v-\gamma}{\beta}\right)\right)$	$F(v) = \frac{\Gamma_{(v-\gamma)/\beta}(\alpha)}{\Gamma(\alpha)}$
Two-Parameter Gamma	$f(v) = \frac{R^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} exp\left(-\left(\frac{v}{\beta}\right)\right)$	$F(v) = \frac{\Gamma_{R/\beta}(\alpha)}{\Gamma(\alpha)}$
Generalized Extreme Value	$f(v) = \begin{cases} \frac{1}{\sigma} exp\left(-\left(1 + k\frac{v-\mu}{\sigma}\right)^{-1/k}\right)\left(1 + k\frac{v-\mu}{\sigma}\right)^{-1-1/k} & k \neq 0 \\ \frac{1}{\sigma} exp\left(-\frac{v-\mu}{\sigma} - exp\left(-\frac{v-\mu}{\sigma}\right)\right) & k = 0 \end{cases}$	$F(v) = \begin{cases} exp\left(-\left(1 + k\frac{v-\mu}{\sigma}\right)^{-1/k}\right) & k \neq 0 \\ exp\left(-exp\left(-\frac{v-\mu}{\sigma}\right)\right) & k = 0 \end{cases}$
Four-Parameter Generalized Gamma	$f(v) = \frac{k(v-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} xp\left(-\left(\frac{v-\gamma}{\beta}\right)^k\right)$	$F(v) = \frac{\Gamma_{((v-\gamma)/\beta)^k}(\alpha)}{\Gamma(\alpha)}$
Three-Parameter Generalized Gamma	$f(v) = \frac{k(v)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} xp\left(-\left(\frac{v}{\beta}\right)^k\right)$	$F(v) = \frac{\Gamma_{((v)/\beta)^k}(\alpha)}{\Gamma(\alpha)}$
Three-Parameter Weibull	$f(v) = \left(\frac{\alpha}{\beta}\right)\left(\frac{v-\gamma}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{v-\gamma}{\beta}\right)^{\alpha}\right)$	$F(v) = 1 - exp\left(-\left(\frac{v-\gamma}{\beta}\right)^{\alpha}\right)$
Two-Parameter Weibull	$f(v) = \left(\frac{\alpha}{\beta}\right)\left(\frac{v}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{v}{\beta}\right)^{\alpha}\right)$	$F(v) = 1 - exp\left(-\left(\frac{v}{\beta}\right)^{\alpha}\right)$
One-Parameter Rayleigh	$f(v) = \frac{v}{\sigma^2} exp\left(-\frac{1}{2}\left(\frac{v}{\sigma}\right)^2\right)$	$F(v) = 1 - exp\left(-\frac{1}{2}\left(\frac{v}{\sigma}\right)^2\right)$
Nakagami	$f(v) = \frac{2m^m}{\Gamma(m)\Omega^m} v^{2m-1} e^{\left(-\frac{m}{\Omega}G^2\right)}$	$F(v) = \frac{\gamma\left(m, \frac{m}{\Omega}v^2\right)}{\Gamma(m)}$

Table S1. Continued

Distribution function	PDF	CDF
Generalized Logistic	$f(v)=\begin{cases}\dfrac{\left(1+k\frac{v-\mu}{\sigma}\right)^{-1-1/k}}{\sigma\left(\left(1+k\frac{v-\mu}{\sigma}\right)^{-1/k}\right)^2} & k\neq 0\\ \dfrac{\exp\left(-\frac{v-\mu}{\sigma}\right)}{\sigma\left(1+\exp\left(-\frac{v-\mu}{\sigma}\right)\right)^2} & k=0\end{cases}$	$F(v)=\begin{cases}\dfrac{1}{\left(1+k\frac{v-\mu}{\sigma}\right)^{-1/k}} & k\neq 0\\ \dfrac{1}{1+\exp\left(-\frac{v-\mu}{\sigma}\right)} & k=0\end{cases}$
Generalized Pareto	$f(v)=\begin{cases}\frac{1}{\sigma}\left(-\left(1+k\frac{v-\mu}{\sigma}\right)^{-1-1/k}\right) & k\neq 0\\ \frac{1}{\sigma}exp\left(-\frac{v-\mu}{\sigma}\right) & k=0\end{cases}$	$F(R)=\begin{cases}1-\left(1+k\frac{v-\mu}{\sigma}\right)^{-1-1/k} & k\neq 0\\ 1-exp\left(-\frac{v-\mu}{\sigma}\right) & k=0\end{cases}$
Maximum Extreme Value Type 1	$f(v)=\frac{1}{\sigma}exp\left(-\frac{v-\mu}{\sigma}-exp\left(-\frac{v-\mu}{\sigma}\right)\right)$	$F(v)=exp\left(-exp\left(-\frac{v-\mu}{\sigma}\right)\right)$
Minimum Extreme Value Type 1	$f(v)=\frac{1}{\sigma}exp\left(\frac{v-\mu}{\sigma}-exp\left(-\frac{v-\mu}{\sigma}\right)\right)$	$F(v)=1-exp\left(-exp\left(-\frac{v-\mu}{\sigma}\right)\right)$
Three-Parameter Inverse Gaussian	$f(v)=\sqrt{\frac{\lambda}{2\pi(v-\gamma)}}exp\left(-\frac{\lambda(v-\gamma-\mu)^2}{2\mu^2(v-\gamma)}\right)$	$F(v)=\Phi\left(\sqrt{\frac{\lambda}{R-\gamma}}\left(\frac{v-\gamma}{\mu}-1\right)\right)+\Phi\left(-\sqrt{\frac{\lambda}{R-\gamma}}\left(\frac{v-\gamma}{\mu}+1\right)\right)exp\left(\frac{2\lambda}{\mu}\right)$
Log-Gamma	$f(v)=\frac{\left(ln(v)\right)^{\alpha-1}}{R\beta^{\alpha}\Gamma(\alpha)}exp\left(\frac{-ln(v)}{\beta}\right)$	$F(v)=\frac{\Gamma_{(ln(v)/\beta)^k}(\alpha)}{\Gamma(\alpha)}$
Logistic	$f(v)=\frac{exp\left(-\frac{v-\mu}{\sigma}\right)}{\sigma\left\{1+exp\left(-\frac{v-\mu}{\sigma}\right)\right\}^2}$	$F(v)=\frac{1}{1+exp(-v)}$
Two-Parameter Inverse Gaussian	$f(v)=\sqrt{\frac{\lambda}{2\pi(R-\gamma)}}exp\left(-\frac{\lambda(v-\mu)^2}{2\mu^2R}\right)$	$F(v)=\Phi\left(\sqrt{\frac{\lambda}{R-\gamma}}\left(\frac{v}{\mu}-1\right)\right)+\Phi\left(-\sqrt{\frac{\lambda}{R-\gamma}}\left(\frac{v}{\mu}+1\right)\right)exp\left(\frac{2\lambda}{\mu}\right)$
Three-Parameter Lognormal	$f(v)=\frac{1}{(v-\gamma)\sigma\sqrt{2\pi}}exp\left[-\frac{1}{2}\left(\frac{ln(v-\gamma)-\mu}{\sigma}\right)^2\right]$	$F(v)=\Phi\left[\frac{ln(v-\gamma)-\mu}{\sigma}\right]$
Two-Parameter Lognormal	$f(v)=\frac{1}{v\sigma\sqrt{2\pi}}exp\left[-\frac{1}{2}\left(\frac{ln(v)-\mu}{\sigma}\right)^2\right]$	$F(v)=\frac{1}{2}+erf\left[\frac{ln(v)-\mu}{\sigma\sqrt{2}}\right]$
Log-Pearson 3	$f(v)=\frac{1}{R\lvert\beta\rvert\Gamma(\alpha)}\left(\frac{ln(v)-\gamma}{\beta}\right)^{\alpha-1}exp\left(-\frac{ln(v)-\gamma}{\beta}\right)$	$F(v)=\frac{\Gamma_{(ln(v)-\gamma)/\beta}(\alpha)}{\Gamma(\alpha)}$
Normal	$f(v)=\frac{1}{\sqrt{2\pi\sigma^2}}exp\left(-\frac{v-\mu}{2\sigma^2}\right)$	$F(v)=\frac{1}{2}\left[1+erf\left(\frac{v-\mu}{\sigma\sqrt{2}}\right)\right]$

Table S1. Continued

Distribution function	PDF	CDF
Log-Logistic	$f(v) = \left(\left(\frac{\beta}{\alpha}\left(\frac{v}{\alpha}\right)^{\beta-1}\right) \Big/ \left(1+\frac{v}{\alpha}\right)^{\beta} \right)^{2}$	$F(v) = \frac{1}{\left(1+\frac{v}{\alpha}\right)^{-\beta}}$
Two-Parameter Rayleigh	$f(R) = \frac{v-\gamma}{\sigma^2} exp\left(-\frac{1}{2}\left(\frac{v-\gamma}{\sigma}\right)^{2}\right)$	$F(v) = 1 - exp\left(-\frac{1}{2}\left(\frac{v-\gamma}{\sigma}\right)^{2}\right)$
Wakeby	$R(v) = \xi + \frac{\alpha}{\beta}\left(1-(1-v)^{\beta}\right) - \frac{\gamma}{\delta}\left(1-(1-v)^{\delta}\right)$	

Appendices

Appendix B
Distribution parameters

Table S1. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 1

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	$\alpha_1=0.80303$ $\alpha_2=0.55576$ $a=3.9165$ $b=5.0813$	0.16112	3	2.3135	30	3.40E-05	2
2	Burr	$k=399.44$ $\alpha=15.614$ $\beta=6.9965$	0.23404	29	0.49498	21	3.3211	36
3	Burr (4P)	$k=534.81$ $\alpha=578.4$ $\beta=173.53$ $\gamma=-166.87$	0.2392	30	0.49873	22	3.0678	35
4	Cauchy	$\sigma=0.28796$ $\mu=4.6119$	0.18547	8	0.61378	28	0.03032	4
5	Dagum	$k=0.01052$ $\alpha=883.59$ $\beta=5.0967$	0.23275	28	0.39317	3	2.083	33
6	Dagum (4P)	$k=261.29$ $\alpha=256.53$ $\beta=89.771$ $\gamma=-87.692$	0.51403	35	4.9272	37	4.827	37
7	Erlang	$m=152$ $\beta=0.03019$	0.19697	19	0.47758	13	0.05171	11
8	Erlang (3P)	$m=120$ $\beta=0.0329$ $\gamma=0.6427$	0.20271	22	0.5073	23	0.05154	10
9	Exponential	$\lambda=0.21716$	0.57281	36	4.7101	35	0.74049	29
10	Exponential (2P)	$\lambda=1.4528$ $\gamma=3.9165$	0.33111	32	3.5944	34	0.6327	28
11	Gamma	$\alpha=152.53$ $\beta=0.03019$	0.18409	5	0.44963	7	0.06948	19
12	Gamma (3P)	$\alpha=123.93$ $\beta=0.03285$ $\gamma=0.52779$	0.19355	16	0.47706	12	0.06104	17
13	Gen. Extreme Value	$k=-0.44649$ $\sigma=0.41221$ $\mu=4.4993$	0.19792	21	0.36983	2	0.03242	5
14	Gen. Gamma	$k=1.0097$ $\alpha=160.17$ $\beta=0.03019$	0.1912	12	0.48226	15	0.06347	18
15	Gen. Gamma (4P)	$k=3.6026$ $\alpha=15.54$ $\beta=2.3972$ $\gamma=-0.49504$	0.19533	18	0.45937	11	0.04948	9
16	Gen. Logistic	$k=-0.08693$ $\sigma=0.21496$ $\mu=4.6359$	0.22185	26	0.48645	19	1.425	31
17	Gen. Pareto	$k=-1.3808$ $\sigma=1.7519$ $\mu=3.869$	0.16054	2	0.3256	1	0.07309	21
18	Gumbel Max	$\sigma=0.29071$ $\mu=4.4371$	0.21609	25	0.74691	29	0.12323	25
19	Gumbel Min	$\sigma=0.29071$ $\mu=4.7727$	0.24122	31	0.53422	25	3.0624	34
20	Inv. Gaussian	$\lambda=702.39$ $\mu=4.6049$	0.1915	13	0.44938	6	0.09642	23
21	Inv. Gaussian (3P)	$\lambda=4.0509E+5$ $\mu=37.251$ $\gamma=-32.648$	0.19457	17	0.48051	14	0.05218	12
22	Log-Gamma	$\alpha=342.96$ $\beta=0.00444$	0.18449	6	0.45652	10	0.09071	22
23	Log-Logistic	$\alpha=17.259$ $\beta=4.5486$	0.18536	7	0.52985	24	0.04126	7
24	Log-Logistic (3P)	$\alpha=9.7150E+7$ $\beta=2.1064E+7$ $\gamma=-2.1064E+7$	0.20981	24	0.4851	18	0.05344	13
25	Log-Pearson 3	$\alpha=18.55$ $\beta=-0.01911$ $\gamma=1.8785$	0.19723	20	0.41779	4	0.04252	8
26	Logistic	$\sigma=0.20556$ $\mu=4.6049$	0.20866	23	0.5533	26	0.03741	6
27	Lognormal	$\sigma=0.07879$ $\mu=1.524$	0.19158	14	0.48371	17	0.07139	20
28	Lognormal (3P)	$\sigma=0.03416$ $\mu=2.3486$ $\gamma=-5.8695$	0.19353	15	0.48261	16	0.06084	16
29	Nakagami	$m=39.447$ $\Omega=21.332$	0.18614	9	0.45581	8	0.0596	15
30	Normal	$\sigma=0.37285$ $\mu=4.6049$	0.18796	10	0.43662	5	0.05615	14
31	Pareto	$\alpha=6.2957$ $\beta=3.9165$	0.34626	33	3.1258	32	0.54684	27
32	Pareto 2	$\alpha=132.22$ $\beta=585.32$	0.58595	37	4.8886	36	0.92152	30
33	Rayleigh	$\sigma=3.6741$	0.43342	34	3.3678	33	0.02902	3
34	Rayleigh (2P)	$\sigma=0.61088$ $\gamma=3.8181$	0.19096	11	0.55494	27	0.13391	26
35	Wakeby	$\alpha=7501.1$ $\beta=1930.0$ $\gamma=1.6859$ $\delta=-1.3404$ $\xi=0$	0.10717	1	2.9792	31	0.09653	24
36	Weibull	$\alpha=12.408$ $\beta=4.7355$	0.1758	4	0.45602	9	2.85E-06	1
37	Weibull (3P)	$\alpha=8.233$ $\beta=2.5858$ $\gamma=2.1715$	0.22695	27	0.49375	20	1.5058	32

Table S2. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 2

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.41759 α_2=0.46525 a=3.6169 b=4.3506	0.16667	8	3.7647	29	1.54E-04	1
2	Burr	k=263.1 α=17.526 β=5.6116	0.17617	15	0.43275	19	0.48977	29
3	Burr (4P)	k=7.6821 α=0.95069 β=2.3199 γ=3.6169	0.23666	29	7.8281	34	N/A	
4	Cauchy	σ=0.20254 μ=3.9231	0.18602	22	0.54855	23	0.02456	13
5	Dagum	k=114.53 α=22.957 β=3.0348	0.32906	33	2.4351	25	4.5148	32
6	Dagum (4P)	k=0.23897 α=2.4412 β=0.66517 γ=3.6169	0.20911	28	7.5104	33	N/A	
7	Erlang	m=220 β=0.01798	0.17599	14	0.37167	9	0.00866	10
8	Erlang (3P)	m=1 β=0.30229 γ=3.6169	0.23951	30	3.2848	27	0.56006	30
9	Exponential	λ=0.25227	0.59846	36	4.8295	30	0.1242	17
10	Exponential (2P)	λ=2.8814 γ=3.6169	0.19521	24	9.7328	37	0.30955	27
11	Gamma	α=220.47 β=0.01798	0.16607	7	0.36683	6	0.26913	24
12	Gamma (3P)	α=0.49601 β=0.70771 γ=3.6169	0.26036	31	7.9667	35	N/A	
13	Gen. Extreme Value	k=-0.23712 σ=0.2733 μ=3.8593	0.15161	3	0.31214	3	0.00282	6
14	Gen. Gamma	k=1.0118 α=234.99 β=0.01798	0.17488	13	0.41884	16	0.27352	26
15	Gen. Gamma (4P)	k=1.0855 α=0.63503 β=0.36828 γ=3.6169	0.32868	32	9.6407	36	N/A	
16	Gen. Logistic	k=0.02628 σ=0.15864 μ=3.9571	0.17369	12	0.40347	12	0.00314	7
17	Gen. Pareto	k=-0.89755 σ=0.87321 μ=3.5038	0.12866	2	0.26023	2	0.2374	19
18	Gumbel Max	σ=0.20815 μ=3.8438	0.20259	27	0.51942	22	0.01294	11
19	Gumbel Min	σ=0.20815 μ=4.0841	0.19886	26	0.61404	24	1.8195	31
20	Inv. Gaussian	λ=873.94 μ=3.964	0.15739	4	0.37239	10	0.32004	28
21	Inv. Gaussian (3P)	λ=7.2695 μ=0.81806 γ=3.1459	0.19122	23	0.4192	17	0.00856	9
22	Log-Gamma	α=416.68 β=0.0033	0.17005	11	0.36536	4	8.72E-04	3
23	Log-Logistic	α=21.847 β=3.9217	0.18237	18	0.40753	13	0.03261	14
24	Log-Logistic (3P)	α=4.8953 β=0.77743 γ=3.153	0.17962	17	0.39935	11	0.01361	12
25	Log-Pearson 3	α=15992.0 β=5.3272E-4 γ=-7.1442	0.16767	9	0.36583	5	0.00181	4
26	Logistic	σ=0.14719 μ=3.964	0.1846	20	0.50627	21	0.26169	23
27	Lognormal	σ=0.0645 μ=1.3752	0.17666	16	0.41783	15	0.00186	5
28	Lognormal (3P)	σ=0.20007 μ=0.24161 γ=2.6652	0.18538	21	0.41422	14	7.13E-04	2
29	Nakagami	m=55.314 Ω=15.778	0.16491	6	0.36809	7	0.25526	22
30	Normal	σ=0.26697 μ=3.964	0.16197	5	0.37025	8	0.24766	21
31	Pareto	α=11.168 β=3.6169	0.19548	25	2.8828	26	0.27006	25
32	Pareto 2	α=270.66 β=1052.6	0.60482	37	4.9141	31	0.15926	18
33	Rayleigh	σ=3.1628	0.47998	35	3.5562	28	0.06796	16
34	Rayleigh (2P)	σ=0.37835 γ=3.4939	0.1841	19	0.46354	20	0.00783	8
35	Wakeby	α=0.87321 β=0.89755 γ=0 δ=0 ξ=3.5038	0.12866	1	0.26023	1	0.2374	20
36	Weibull	α=15.349 β=4.0514	0.16866	10	0.42722	18	3.86E-02	15
37	Weibull (3P)	α=0.47184 β=0.14514 γ=3.6169	0.38587	34	5.5215	32	N/A	

Table S3. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 3

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.43104 α_2=0.50146 a=3.6246 b=4.3592	0.16667	15	3.9201	27	6.91E-05	2
2	Burr	k=113.35 α=17.72 β=5.3312	0.17261	19	0.38951	17	0.10832	11
3	Burr (4P)	k=1.8420E+12 α=1.0075 β=4.9831E+11 γ=3.6241	0.1944	26	1.6319	24	0.39068	30
4	Cauchy	σ=0.19597 μ=3.9283	0.18241	22	0.5077	22	0.02604	8
5	Dagum	k=93.574 α=28.323 β=3.1649	0.40548	32	4.4786	28	5.2715	35
6	Dagum (4P)	k=0.43596 α=1.7696 β=0.41599 γ=3.6246	0.24885	29	5.4625	31	1.2709	32
7	Erlang	m=226 β=0.01751	0.15955	11	0.33394	9	0.21064	16
8	Erlang (3P)	m=1 β=0.33955 γ=3.6246	0.18806	23	5.6592	32	0.34809	28
9	Exponential	λ=0.25226	0.59922	36	4.8374	29	0.12804	12
10	Exponential (2P)	λ=2.9452 γ=3.6246	0.18807	24	9.7419	35	0.34814	29
11	Gamma	α=226.42 β=0.01751	0.1505	7	0.33086	5	0.23863	20
12	Gamma (3P)	α=0.51216 β=0.37405 γ=3.6246	0.41258	33	11.228	36	N/A	
13	Gen. Extreme Value	k=-0.21935 σ=0.26723 μ=3.8585	0.13953	3	0.28403	3	0.25052	22
14	Gen. Gamma	k=1.0119 α=241.46 β=0.01751	0.15897	10	0.37941	13	0.24414	21
15	Gen. Gamma (4P)	k=1.3076 α=0.42718 β=0.38474 γ=3.6246	0.42503	34	12.21	37	N/A	
16	Gen. Logistic	k=0.03646 σ=0.15659 μ=3.9547	0.16052	12	0.36192	11	0.25058	23
17	Gen. Pareto	k=-0.85928 σ=0.83426 μ=3.5154	0.12961	2	0.2426	2	0.20607	15
18	Gumbel Max	σ=0.20541 μ=3.8456	0.19032	25	0.49856	21	0.00781	6
19	Gumbel Min	σ=0.20541 μ=4.0827	0.1951	27	0.57095	23	1.7622	33
20	Inv. Gaussian	λ=897.56 μ=3.9641	0.14189	4	0.3377	10	0.28535	26
21	Inv. Gaussian (3P)	λ=7.324 μ=0.81185 γ=3.1523	0.1789	21	0.39972	18	0.0041	4
22	Log-Gamma	α=428.4 β=0.00321	0.15517	9	0.33192	7	3.57E-03	3
23	Log-Logistic	α=22.381 β=3.9214	0.173	20	0.38423	15	0.04484	9
24	Log-Logistic (3P)	α=5.4749 β=0.85369 γ=3.0807	0.16747	16	0.37641	12	0.00514	5
25	Log-Pearson 3	α=4216.7 β=0.00102 γ=-2.9394	0.15299	8	0.33135	6	0.25713	25
26	Logistic	σ=0.14525 μ=3.9641	0.16827	17	0.4561	20	0.23686	19
27	Lognormal	σ=0.06362 μ=1.3753	0.16105	13	0.3795	14	0.25539	24
28	Lognormal (3P)	σ=0.20591 μ=0.19867 γ=2.7185	0.17203	18	0.38497	16	4.60E-06	1
29	Nakagami	m=56.734 Ω=15.778	0.14899	6	0.3308	4	0.22552	18
30	Normal	σ=0.26345 μ=3.9641	0.14588	5	0.33286	8	0.21835	17
31	Pareto	α=11.426 β=3.6246	0.20026	28	2.8934	25	0.30514	27
32	Pareto 2	α=270.66 β=1052.6	0.6056	37	4.9223	30	0.16372	13
33	Rayleigh	σ=3.1629	0.4814	35	3.5689	26	0.06298	10
34	Rayleigh (2P)	σ=0.33607 γ=3.6246	0.25769	30	7.7842	34	0.80816	31
35	Wakeby	α=0.83426 β=0.85928 γ=0 δ=0 ξ=3.5154	0.12961	1	0.2426	1	0.20607	14
36	Weibull	α=15.716 β=4.0481	0.1615	14	0.40404	19	2.56E-02	7
37	Weibull (3P)	α=0.79353 β=0.23072 γ=3.6246	0.32244	31	6.4455	33	1.9966	34

Table S4. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 4

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.60171 α_2=0.5958 a=4.1442 b=5.3099	0.16185	13	1.7665	28	9.39E-06	1
2	Burr	k=186.84 α=14.27 β=7.0738	0.19579	28	0.42888	14	0.72389	29
3	Burr (4P)	k=417.15 α=1.8389 β=20.229 γ=4.0517	0.17448	23	0.4219	13	0.04357	23
4	Cauchy	σ=0.31594 μ=4.6915	0.16665	17	0.58851	26	0.00319	11
5	Dagum	k=123.05 α=14.416 β=3.1062	0.3078	34	2.1547	29	3.8922	35
6	Dagum (4P)	k=0.19511 α=4.8211 β=1.1188 γ=4.1442	0.13964	1	3.8536	34	N/A	
7	Erlang	m=144 β=0.03268	0.17262	20	0.40811	10	3.30E-04	3
8	Erlang (3P)	m=4 β=0.20947 γ=3.9306	0.1644	16	0.43881	21	0.08931	26
9	Exponential	λ=0.21142	0.58362	37	4.6799	37	0.85713	30
10	Exponential (2P)	λ=1.7073 γ=4.1442	0.20752	29	2.9401	32	1.1438	33
11	Gamma	α=144.73 β=0.03268	0.15337	5	0.38703	5	0.0014	7
12	Gamma (3P)	α=3.8158 β=0.20947 γ=3.9306	0.17734	25	0.41442	11	0.04961	24
13	Gen. Extreme Value	k=-0.23855 σ=0.40175 μ=4.5764	0.14068	2	0.33219	3	0.00205	8
14	Gen. Gamma	k=1.0123 α=153.85 β=0.03268	0.16152	12	0.43802	20	0.00138	6
15	Gen. Gamma (4P)	k=1.7495 α=0.47926 β=0.98699 γ=4.1442	0.20849	30	4.3643	36	N/A	
16	Gen. Logistic	k=0.02547 σ=0.23302 μ=4.7202	0.16057	10	0.43792	19	5.91E-04	5
17	Gen. Pareto	k=-0.90065 σ=1.286 μ=4.0533	0.14116	4	0.2567	2	0.00721	16
18	Gumbel Max	σ=0.30655 μ=4.553	0.19169	27	0.53723	24	0.04145	21
19	Gumbel Min	σ=0.30655 μ=4.9069	0.21892	31	0.5918	27	2.1851	34
20	Inv. Gaussian	λ=684.55 μ=4.7299	0.16337	14	0.39581	9	0.00823	17
21	Inv. Gaussian (3P)	λ=50.792 μ=1.9639 γ=2.766	0.17545	24	0.46288	23	0.04105	20
22	Log-Gamma	α=346.65 β=0.00447	0.15824	9	0.38712	6	5.72E-03	14
23	Log-Logistic	α=17.709 β=4.6643	0.1728	21	0.44072	22	0.004	12
24	Log-Logistic (3P)	α=6.5475 β=1.5306 γ=3.1617	0.16678	19	0.43127	15	0.02541	18
25	Log-Pearson 3	α=5477.3 β=-0.00113 γ=7.7149	0.1539	6	0.38605	4	0.0026	9
26	Logistic	σ=0.21676 μ=4.7299	0.17951	26	0.53844	25	1.0926	32
27	Lognormal	σ=0.07974 μ=1.5507	0.16391	15	0.43765	18	0.00279	10
28	Lognormal (3P)	σ=0.11515 μ=1.1832 γ=1.4435	0.16673	18	0.43651	17	5.39E-03	13
29	Nakagami	m=36.482 Ω=22.514	0.15548	7	0.38844	8	3.69E-04	4
30	Normal	σ=0.39317 μ=4.7299	0.16069	11	0.38815	7	4.54E-05	2
31	Pareto	α=7.7506 β=4.1442	0.22429	33	2.3426	30	1.0234	31
32	Pareto 2	α=229.59 β=1197.0	0.54776	36	4.2943	35	0.42915	28
33	Rayleigh	σ=3.7739	0.45279	35	3.3136	33	0.07954	25
34	Rayleigh (2P)	σ=0.47881 γ=4.1442	0.22018	32	2.3785	31	0.03208	19
35	Wakeby	α=1.286 β=0.90065 γ=0 δ=0 ξ=4.0533	0.14116	3	0.2567	1	0.00721	15
36	Weibull	α=12.49 β=4.8546	0.15687	8	0.43427	16	3.56E-01	27
37	Weibull (3P)	α=1.8648 β=0.77014 γ=4.0452	0.17313	22	0.4192	12	0.04157	22

Table S5. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 5

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.77935 α_2=0.82228 a=1.8702 b=3.9491	0.18537	26	2.5242	32	3.34E-01	29
2	Burr	k=53.583 α=5.2003 β=6.7195	0.18517	25	0.3284	21	0.22738	25
3	Burr (4P)	k=394.61 α=2.1259 β=23.454 γ=1.6324	0.14617	2	0.26871	13	0.01423	15
4	Cauchy	σ=0.37115 μ=2.7181	0.17814	21	0.51072	28	0.01747	16
5	Dagum	k=1.0792 α=7.5983 β=2.7782	0.15567	10	0.26533	9	0.01276	13
6	Dagum (4P)	k=0.15893 α=5.1958 β=1.9209 γ=1.8702	0.24238	31	1.8087	31	0.07281	23
7	Erlang	m=20 β=0.14401	0.14999	6	0.24649	4	3.39E-03	4
8	Erlang (3P)	m=12 β=0.17849 γ=0.6771	0.17487	20	0.32988	22	5.75E-04	2
9	Exponential	λ=0.34701	0.47742	37	3.4491	36	0.63036	34
10	Exponential (2P)	λ=0.98854 γ=1.8702	0.30795	34	3.1419	34	0.26434	26
11	Gamma	α=20.011 β=0.14401	0.15091	8	0.24636	3	0.0036	6
12	Gamma (3P)	α=12.352 β=0.17849 γ=0.6771	0.14982	5	0.26372	7	0.00804	10
13	Gen. Extreme Value	k=-0.14071 σ=0.61317 μ=2.6036	0.15241	9	0.23376	1	0.00538	8
14	Gen. Gamma	k=1.0153 α=20.956 β=0.14401	0.15871	16	0.26804	12	0.00348	5
15	Gen. Gamma (4P)	k=3.1187 α=0.26216 β=2.0412 γ=1.8702	0.26541	32	4.1952	37	N/A	
16	Gen. Logistic	k=0.08262 σ=0.37486 μ=2.8304	0.1567	12	0.25724	6	1.64E-03	3
17	Gen. Pareto	k=-0.69473 σ=1.7313 μ=1.8602	0.19168	27	0.35303	25	0.05395	22
18	Gumbel Max	σ=0.50229 μ=2.5919	0.1497	4	0.33719	24	0.03004	18
19	Gumbel Min	σ=0.50229 μ=3.1717	0.22877	30	0.70224	29	2.2352	36
20	Inv. Gaussian	λ=57.667 μ=2.8818	0.18131	23	0.30124	20	0.57991	33
21	Inv. Gaussian (3P)	λ=135.31 μ=3.7486 γ=-0.8668	0.18459	24	0.29959	19	0.49714	32
22	Log-Gamma	α=20.727 β=0.04994	0.1671	17	0.29119	17	3.84E-02	21
23	Log-Logistic	α=6.6387 β=2.73	0.20433	29	0.35413	26	2.20E-04	1
24	Log-Logistic (3P)	α=7.7966 β=2.8223 γ=-0.00125	0.15807	14	0.26596	10	0.00989	11
25	Log-Pearson 3	α=122.26 β=-0.02056 γ=3.549	0.15055	7	0.24234	2	0.00579	9
26	Logistic	σ=0.35517 μ=2.8818	0.19235	28	0.33636	23	0.30373	28
27	Lognormal	σ=0.21767 μ=1.0351	0.14677	3	0.26522	8	0.01073	12
28	Lognormal (3P)	σ=0.15299 μ=1.3861 γ=-1.1644	0.15784	13	0.26794	11	4.11E-03	7
29	Nakagami	m=5.1845 Ω=8.6851	0.15836	15	0.2544	5	3.45E-01	30
30	Normal	σ=0.64421 μ=2.8818	0.17263	18	0.27715	16	2.97E-01	27
31	Pareto	α=2.4449 β=1.8702	0.35159	35	2.8378	33	0.8611	35
32	Pareto 2	α=125.24 β=381.88	0.45764	36	3.2395	35	0.41085	31
33	Rayleigh	σ=2.2993	0.28517	33	1.5905	30	0.03359	20
34	Rayleigh (2P)	σ=0.9573 γ=1.6766	0.15578	11	0.27343	15	0.01876	17
35	Wakeby	α=189.68 β=94.564 γ=1.3468 δ=-0.50159 ξ=0	0.17953	22	0.29566	18	0.03158	19
36	Weibull	α=4.7131 β=3.0353	0.17438	19	0.38419	27	1.23E-01	24
37	Weibull (3P)	α=2.1549 β=1.4209 γ=1.6231	0.14415	1	0.27048	14	0.01282	14

Table S6. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 6

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.44349 α_2=0.33739 a=3.6811 b=4.4423	0.16667	10	4.0933	32	0.00332	7
2	Burr	k=445.09 α=19.133 β=5.826	0.1869	23	0.46478	14	0.00391	8
3	Burr (4P)	k=1449.3 α=1216.2 β=264.16 γ=-258.34	0.18763	24	0.45096	9	8.01E-04	2
4	Cauchy	σ=0.18582 μ=4.197	0.2064	30	0.61897	28	0.11243	14
5	Dagum	k=0.00591 α=1749.2 β=4.4492	0.19066	28	0.43495	8	1.89E-01	16
6	Dagum (4P)	k=0.09093 α=4.1073 β=0.95065 γ=3.6811	0.39672	34	10.304	37	N/A	
7	Erlang	m=211 β=0.01941	0.18878	26	0.55543	26	1.874	21
8	Erlang (3P)	m=107 β=0.02642 γ=1.2927	0.16695	11	0.54052	23	N/A	
9	Exponential	λ=0.24311	0.59136	36	4.8227	33	N/A	
10	Exponential (2P)	λ=2.3133 γ=3.6811	0.28163	32	10.27	36	2.1302	22
11	Gamma	α=211.97 β=0.01941	0.16506	9	0.49341	15	N/A	
12	Gamma (3P)	α=152.4 β=0.02233 γ=0.70843	0.17166	15	0.53148	20	N/A	
13	Gen. Extreme Value	k=-0.58049 σ=0.32567 μ=4.0525	0.13958	3	0.3236	3	0.01132	10
14	Gen. Gamma	k=1.0093 α=222.78 β=0.01941	0.17229	17	0.53397	22	N/A	
15	Gen. Gamma (4P)	k=2.1565E+7 α=3.6504 β=1.0347E+7 γ=-1.0347E+7	0.18207	20	0.45987	11	0.01137	11
16	Gen. Logistic	k=-0.15326 σ=0.15935 μ=4.1547	0.16831	13	0.40749	4	0.00967	9
17	Gen. Pareto	k=-1.724 σ=1.6806 μ=3.4964	0.13024	2	0.31623	2	0.00289	6
18	Gumbel Max	σ=0.22029 μ=3.9862	0.21673	31	1.0163	29	1.4804	18
19	Gumbel Min	σ=0.22029 μ=4.2406	0.18569	22	0.42863	7	4.84E-04	1
20	Inv. Gaussian	λ=871.9 μ=4.1134	0.15608	5	0.49612	17	N/A	
21	Inv. Gaussian (3P)	λ=5.1625E+5 μ=33.736 γ=-29.625	0.17284	19	0.51059	18	N/A	
22	Log-Gamma	α=409.56 β=0.00345	0.1702	14	0.51556	19	1.5101	20
23	Log-Logistic	α=20.011 β=4.0749	0.18966	27	0.54613	25	1.4809	19
24	Log-Logistic (3P)	α=4.7391E+7 β=7.8770E+6 γ=-7.8770E+6	0.1533	4	0.46384	12	0.061	13
25	Log-Pearson 3	α=14.975 β=-0.01803 γ=1.6821	0.16089	7	0.40809	5	0.02835	12
26	Logistic	σ=0.15577 μ=4.1134	0.18321	21	0.56364	27	0.16561	15
27	Lognormal	σ=0.0668 μ=1.412	0.17219	16	0.543	24	0.4523	17
28	Lognormal (3P)	σ=0.03366 μ=2.0862 γ=-3.9439	0.17272	18	0.53284	21	N/A	
29	Nakagami	m=54.824 Ω=16.993	0.16811	12	0.49564	16	N/A	
30	Normal	σ=0.28253 μ=4.1134	0.16375	8	0.4643	13	N/A	
31	Pareto	α=9.189 β=3.6811	0.28992	33	3.583	31	N/A	
32	Pareto 2	α=270.66 β=1052.6	0.61127	37	5.1027	34	N/A	
33	Rayleigh	σ=3.282	0.46687	35	3.55	30	N/A	
34	Rayleigh (2P)	σ=0.38318 γ=3.6811	0.19744	29	6.8497	35	N/A	
35	Wakeby	α=1.6806 β=1.724 γ=0 δ=0 ξ=3.4964	0.13024	1	0.31623	1	0.00289	5
36	Weibull	α=14.429 β=4.2185	0.15769	6	0.42213	6	0.00101	4
37	Weibull (3P)	α=3.5146E+7 β=7.5623E+6 γ=-7.5623E+6	0.18778	25	0.45438	10	8.44E-04	3

Table S7. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 7

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.60499 α_2=0.47972 a=4.3361 b=5.8247	0.16667	28	5.9955	35	3.46E-01	28
2	Burr	k=470.63 α=12.972 β=8.65	0.13459	10	0.2754	10	0.34757	29
3	Burr (4P)	k=421.03 α=192.12 β=79.793 γ=-71.924	0.12341	4	0.2645	7	0.29267	25
4	Cauchy	σ=0.33996 μ=5.2269	0.1646	26	0.3811	25	0.02836	8
5	Dagum	k=0.00793 α=966.05 β=5.8348	0.16262	25	0.29038	11	0.07438	18
6	Dagum (4P)	k=0.41151 α=9.6100E+7 β=1.8546E+7 γ=-1.8546E+7	0.12654	6	0.2542	6	0.35997	30
7	Erlang	m=101 β=0.05075	0.17956	30	0.42445	28	2.10E-01	21
8	Erlang (3P)	m=147 β=0.04098 γ=-0.8559	0.1582	21	0.35821	22	3.56E-02	13
9	Exponential	λ=0.19356	0.56799	37	4.5278	34	0.22786	22
10	Exponential (2P)	λ=1.2045 γ=4.3361	0.26917	33	10.601	37	0.80202	36
11	Gamma	α=101.8 β=0.05075	0.15451	17	0.34376	19	0.03828	15
12	Gamma (3P)	α=136.94 β=0.04261 γ=-0.66977	0.15893	22	0.35838	23	0.03486	12
13	Gen. Extreme Value	k=-0.51349 σ=0.58384 μ=5.0376	0.09977	1	0.2033	1	0.40803	31
14	Gen. Gamma	k=1.0087 α=105.96 β=0.05075	0.1599	23	0.36614	24	0.0363	14
15	Gen. Gamma (4P)	k=3.4498 α=11.993 β=2.8527 γ=-0.64301	0.15346	16	0.31984	15	0.02317	5
16	Gen. Logistic	k=-0.12067 σ=0.29476 μ=5.2258	0.1311	7	0.24622	4	4.08E-01	32
17	Gen. Pareto	k=-1.5489 σ=2.7312 μ=4.0948	0.1066	2	0.21814	3	0.28237	24
18	Gumbel Max	σ=0.39924 μ=4.9359	0.19172	31	0.87115	30	0.47115	33
19	Gumbel Min	σ=0.39924 μ=5.3968	0.12643	5	0.27297	9	0.28024	23
20	Inv. Gaussian	λ=525.94 μ=5.1663	0.14173	11	0.35437	21	0.06715	17
21	Inv. Gaussian (3P)	λ=1.8147E+6 μ=76.382 γ=-71.214	0.15291	15	0.32355	16	0.02746	7
22	Log-Gamma	α=259.35 β=0.00631	0.15596	19	0.38658	27	1.15E-01	19
23	Log-Logistic	α=14.034 β=5.0844	0.16632	27	0.45701	29	4.84E-01	34
24	Log-Logistic (3P)	α=10533.0 β=3080.3 γ=-3075.1	0.14562	13	0.30356	13	0.03311	11
25	Log-Pearson 3	α=11.524 β=-0.02995 γ=1.9827	0.13306	9	0.24871	5	0.01445	3
26	Logistic	σ=0.2823 μ=5.1663	0.17013	29	0.35044	20	0.01767	4
27	Lognormal	σ=0.09735 μ=1.6375	0.16091	24	0.38449	26	0.04392	16
28	Lognormal (3P)	σ=0.03189 μ=2.7407 γ=-10.336	0.15565	18	0.34265	18	3.21E-02	10
29	Nakagami	m=26.843 Ω=26.931	0.1562	20	0.33773	17	3.02E-02	9
30	Normal	σ=0.51204 μ=5.1663	0.14769	14	0.299	12	2.64E-02	6
31	Pareto	α=5.8639 β=4.3361	0.2867	34	3.7828	32	0.69664	35
32	Pareto 2	α=229.59 β=1197.0	0.56405	36	4.4792	33	0.19905	20
33	Rayleigh	σ=4.1221	0.42492	35	3.0804	31	5.96E-04	1
34	Rayleigh (2P)	σ=0.60506 γ=4.3361	0.25013	32	7.5011	36	9.97E-01	37
35	Wakeby	α=2.1894 β=3.4317 γ=1.3075 δ=-1.0392 ξ=4.0311	0.10939	3	0.20833	2	0.31704	26
36	Weibull	α=10.12 β=5.3417	0.14394	12	0.30979	14	6.62E-03	2
37	Weibull (3P)	α=17.128 β=7.0665 γ=-1.6787	0.13128	8	0.26969	8	0.33261	27

Table S8. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 8

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.87855 α_2=0.8598 a=3.8593 b=5.3529	0.18422	28	9.3585	36	2.79E-08	1
2	Burr	k=28.293 α=12.801 β=6.227	0.14107	3	0.27319	5	0.19916	7
3	Burr (4P)	k=220.62 α=5.8286 β=5.7706 γ=2.5009	0.15019	9	0.30154	9	0.25959	15
4	Cauchy	σ=0.26629 μ=4.6714	0.14293	4	0.36176	13	0.40805	31
5	Dagum	k=0.32455 α=33.428 β=4.9723	0.14781	7	0.26914	4	0.19936	8
6	Dagum (4P)	k=0.58477 α=4.7234E+7 β=9.4499E+6 γ=-9.4499E+6	0.15341	11	0.26604	3	0.25997	16
7	Erlang	m=104 β=0.04413	0.17725	27	0.43631	26	3.16E-01	25
8	Erlang (3P)	m=127 β=0.039 γ=-0.33116	0.16	14	0.39207	20	2.69E-01	17
9	Exponential	λ=0.21672	0.56674	36	4.558	33	2.2613	34
10	Exponential (2P)	λ=1.3248 γ=3.8593	0.31426	33	10.741	37	0.2082	9
11	Gamma	α=104.55 β=0.04413	0.16032	15	0.3893	18	0.27559	19
12	Gamma (3P)	α=191.07 β=0.03168 γ=-1.4445	0.16796	23	0.39683	22	0.29455	22
13	Gen. Extreme Value	k=-0.49473 σ=0.5028 μ=4.4984	0.14795	8	0.28848	7	0.17962	6
14	Gen. Gamma	k=1.0087 α=108.87 β=0.04413	0.16587	21	0.40467	24	0.27744	20
15	Gen. Gamma (4P)	k=2.9876 α=42.82 β=2.3878 γ=-3.7617	0.16468	19	0.36365	15	0.32104	27
16	Gen. Logistic	k=-0.11134 σ=0.25613 μ=4.6618	0.14474	5	0.25682	2	2.41E-01	12
17	Gen. Pareto	k=-1.5012 σ=2.2893 μ=3.6989	0.20365	30	4.0697	32	N/A	
18	Gumbel Max	σ=0.35185 μ=4.4111	0.19647	29	0.99181	29	0.1416	4
19	Gumbel Min	σ=0.35185 μ=4.8173	0.13513	1	0.31374	10	0.15447	5
20	Inv. Gaussian	λ=482.42 μ=4.6142	0.14773	6	0.40379	23	0.22247	10
21	Inv. Gaussian (3P)	λ=6.1131E+5 μ=48.539 γ=-43.924	0.16195	18	0.3627	14	0.31031	24
22	Log-Gamma	α=230.97 β=0.0066	0.16526	20	0.45131	27	2.25E-01	11
23	Log-Logistic	α=14.497 β=4.5299	0.21512	31	0.56968	28	3.65E-01	29
24	Log-Logistic (3P)	α=2.5781E+8 β=5.8808E+7 γ=-5.8808E+7	0.17358	25	0.39065	19	0.37867	30
25	Log-Pearson 3	α=10.533 β=-0.03091 γ=1.8502	0.13891	2	0.28726	6	0.27348	18
26	Logistic	σ=0.24879 μ=4.6142	0.17646	26	0.34352	12	0.32176	28
27	Lognormal	σ=0.09605 μ=1.5246	0.16663	22	0.43	25	0.25613	13
28	Lognormal (3P)	σ=0.03221 μ=2.5996 γ=-8.8455	0.16147	16	0.37752	17	2.90E-01	21
29	Nakagami	m=27.441 Ω=21.477	0.1619	17	0.3728	16	2.99E-01	23
30	Normal	σ=0.45126 μ=4.6142	0.15391	13	0.33785	11	3.19E-01	26
31	Pareto	α=5.7436 β=3.8593	0.32883	34	4.0615	31	2.4793	35
32	Pareto 2	α=132.22 β=585.32	0.58061	37	4.7449	34	2.6048	36
33	Rayleigh	σ=3.6816	0.42273	35	3.1312	30	7.06E-01	32
34	Rayleigh (2P)	σ=0.54614 γ=3.8593	0.25429	32	7.5178	35	1.36E+00	33
35	Wakeby	α=3.7466 β=2.7315 γ=0.02224 δ=0.66228 ξ=3.5443	0.15389	12	0.24862	1	0.1084	3
36	Weibull	α=10.625 β=4.748	0.17172	24	0.39662	21	7.11E-02	2
37	Weibull (3P)	α=5.7487 β=2.2687 γ=2.5178	0.15116	10	0.30103	8	0.25712	14

Table S10. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 10

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.28386 α_2=0.30121 a=3.673 b=5.2887	0.17812	4	0.86405	23	2.70E-01	5
2	Burr	k=386.76 α=8.6435 β=9.4118	0.22197	14	0.58301	5	0.01582	1
3	Burr (4P)	k=2.6501 α=0.70685 β=1.6325 γ=3.673	0.31466	30	5.4766	35	N/A	
4	Cauchy	σ=0.44803 μ=4.6175	0.19015	6	0.64828	11	0.65272	24
5	Dagum	k=206.71 α=7.5123 β=1.8971	0.32029	31	1.8029	26	3.6858	32
6	Dagum (4P)	k=0.14319 α=2.4568 β=1.1593 γ=3.673	0.43299	34	7.729	36	N/A	
7	Erlang	m=48 β=0.0923	0.21456	8	0.68396	16	4.11E-01	19
8	Erlang (3P)	m=1 β=0.78502 γ=3.673	0.31244	29	3.8071	29	2.99E+00	30
9	Exponential	λ=0.22437	0.56138	36	4.1349	30	2.2957	27
10	Exponential (2P)	λ=1.2757 γ=3.673	0.31241	28	5.2076	34	3.0022	31
11	Gamma	α=48.289 β=0.0923	0.22288	15	0.66488	14	0.34626	10
12	Gamma (3P)	α=0.66527 β=0.60322 γ=3.673	0.44358	35	8.9722	37	N/A	
13	Gen. Extreme Value	k=-0.32187 σ=0.67495 μ=4.2354	0.20485	7	0.52385	4	0.39733	18
14	Gen. Gamma	k=1.011 α=50.406 β=0.0923	0.23081	20	0.71798	19	0.34209	8
15	Gen. Gamma (4P)	k=0.68079 α=0.94309 β=0.51275 γ=3.673	0.35694	32	3.2095	28	N/A	
16	Gen. Logistic	k=-0.021 σ=0.37477 μ=4.4698	0.21803	10	0.60919	8	3.94E-01	17
17	Gen. Pareto	k=-1.0858 σ=2.414 μ=3.2996	0.17057	2	0.46282	2	0.46463	21
18	Gumbel Max	σ=0.50007 μ=4.1682	0.25938	26	1.1268	25	0.21402	2
19	Gumbel Min	σ=0.50007 μ=4.7455	0.21933	13	0.60931	9	0.5158	23
20	Inv. Gaussian	λ=215.22 μ=4.4569	0.23906	23	0.71482	18	0.23155	3
21	Inv. Gaussian (3P)	λ=1.0110E+5 μ=33.694 γ=-29.237	0.2299	19	0.67392	15	0.36482	12
22	Log-Gamma	α=102.21 β=0.01453	0.22578	17	0.72778	21	2.94E-01	6
23	Log-Logistic	α=9.4179 β=4.3416	0.17552	3	0.65437	12	4.96E-01	22
24	Log-Logistic (3P)	α=1.4653E+8 β=5.6241E+7 γ=-5.6241E+7	0.21928	12	0.59616	6	3.42E-01	9
25	Log-Pearson 3	α=56.102 β=-0.01961 γ=2.5847	0.21893	11	0.61758	10	0.35581	11
26	Logistic	σ=0.35361 μ=4.4569	0.23085	21	0.72205	20	0.38041	15
27	Lognormal	σ=0.14061 μ=1.4847	0.23206	22	0.7451	22	0.3197	7
28	Lognormal (3P)	σ=0.0543 μ=2.423 γ=-6.8435	0.22984	18	0.70796	17	3.68E-01	13
29	Nakagami	m=12.753 Ω=20.241	0.22445	16	0.66062	13	3.70E-01	14
30	Normal	σ=0.64137 μ=4.4569	0.21755	9	0.59902	7	3.90E-01	16
31	Pareto	α=5.4441 β=3.673	0.30911	27	4.6128	32	2.7856	29
32	Pareto 2	α=132.22 β=585.32	0.56269	37	4.1524	31	2.3217	28
33	Rayleigh	σ=3.5561	0.41341	33	2.5006	27	7.50E-01	26
34	Rayleigh (2P)	σ=0.91964 γ=3.3104	0.25184	25	0.92557	24	2.44E-01	4
35	Wakeby	α=2.414 β=1.0858 γ=0 δ=0 ξ=3.2996	0.17057	1	0.46282	1	0.46463	20
36	Weibull	α=6.6572 β=4.68	0.18069	5	0.51046	3	7.11E-01	25
37	Weibull (3P)	α=0.59981 β=0.75069 γ=3.673	0.24316	24	4.8731	33	N/A	

Table S11. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 11

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.41703 α_2=0.43938 a=3.2187 b=5.1362	0.13038	3	1.1591	27	1.40E-04	1
2	Burr	k=285.47 α=7.0105 β=9.9439	0.19636	24	0.51659	18	0.65086	15
3	Burr (4P)	k=3.4242E+6 α=1.0425 β=1.7533E+6 γ=3.2152	0.18624	19	0.61137	24	0.02621	5
4	Cauchy	σ=0.54713 μ=4.0775	0.18057	14	0.56849	21	0.25345	9
5	Dagum	k=189.77 α=6.6913 β=1.6496	0.23085	30	0.84424	26	0.44318	11
6	Dagum (4P)	k=0.31565 α=2.1086 β=1.3623 γ=3.2187	0.25321	31	4.5479	35	N/A	
7	Erlang	m=34 β=0.11915	0.20427	26	0.56614	20	5.78E-01	13
8	Erlang (3P)	m=1 β=0.93363 γ=3.2187	0.19059	23	1.7714	28	1.80E-02	4
9	Exponential	λ=0.24082	0.53936	36	3.8966	33	2.2114	32
10	Exponential (2P)	λ=1.071 γ=3.2187	0.19057	22	2.8062	32	0.01798	3
11	Gamma	α=34.85 β=0.11915	0.17566	10	0.44484	6	0.92781	23
12	Gamma (3P)	α=0.65538 β=1.0045 γ=3.2187	0.32473	34	5.7912	37	N/A	
13	Gen. Extreme Value	k=-0.22127 σ=0.70982 μ=3.8727	0.16294	5	0.3872	3	0.78486	18
14	Gen. Gamma	k=1.0148 α=36.736 β=0.11915	0.18619	18	0.50013	17	1.0098	25
15	Gen. Gamma (4P)	k=1.1911 α=0.39039 β=1.8671 γ=3.2187	0.30512	33	5.4129	36	N/A	
16	Gen. Logistic	k=0.03536 σ=0.41551 μ=4.1282	0.18502	17	0.48773	15	8.16E-01	20
17	Gen. Pareto	k=-0.86338 σ=2.2215 μ=2.9602	0.11742	2	0.31179	2	0.66677	16
18	Gumbel Max	σ=0.54843 μ=3.8359	0.18629	20	0.57404	22	1.4813	30
19	Gumbel Min	σ=0.54843 μ=4.469	0.21859	29	0.74931	25	0.58234	14
20	Inv. Gaussian	λ=144.71 μ=4.1524	0.1982	25	0.47991	12	1.242	28
21	Inv. Gaussian (3P)	λ=6.6243 μ=1.5799 γ=2.5725	0.17486	9	0.48091	13	0.13568	8
22	Log-Gamma	α=68.356 β=0.02063	0.17094	7	0.44087	5	1.12E+00	27
23	Log-Logistic	α=8.4652 β=4.0144	0.16403	6	0.45919	9	4.86E-01	12
24	Log-Logistic (3P)	α=2.6695 β=1.1336 γ=2.8604	0.14999	4	0.46516	10	7.02E-02	6
25	Log-Pearson 3	α=5629.9 β=-0.00227 γ=14.21	0.17341	8	0.43902	4	0.9978	24
26	Logistic	σ=0.3878 μ=4.1524	0.20589	27	0.5988	23	0.8761	22
27	Lognormal	σ=0.16333 μ=1.4104	0.18225	15	0.49646	16	1.0852	26
28	Lognormal (3P)	σ=0.38148 μ=0.55866 γ=2.2776	0.17622	11	0.48335	14	1.43E+00	29
29	Nakagami	m=9.0149 Ω=17.696	0.1792	13	0.45515	7	8.60E-01	21
30	Normal	σ=0.70339 μ=4.1524	0.18333	16	0.45568	8	7.94E-01	19
31	Pareto	α=4.1421 β=3.2187	0.21309	28	2.1581	29	0.00611	2
32	Pareto 2	α=270.66 β=1052.6	0.56236	37	4.2011	34	2.795	33
33	Rayleigh	σ=3.3132	0.37619	35	2.1582	30	7.85E-02	7
34	Rayleigh (2P)	σ=0.98733 γ=2.9293	0.18818	21	0.54219	19	1.51E+00	31
35	Wakeby	α=2.2215 β=0.86338 γ=0 δ=0 ξ=2.9602	0.11742	1	0.31179	1	0.66677	17
36	Weibull	α=5.9627 β=4.3652	0.17771	12	0.46952	11	2.76E-01	10
37	Weibull (3P)	α=0.74859 β=0.74033 γ=3.2187	0.2606	32	2.1939	31	2.9396	34

Table S13. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 13

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.60876 α_2=0.60279 a=2.9153 b=5.0668	0.18879	7	2.0012	30	3.36E-01	9
2	Burr	k=0.42936 α=14.573 β=3.4807	0.17897	5	0.378	8	0.64383	30
3	Burr (4P)	k=265.52 α=1.81 β=30.045 γ=2.7675	0.19912	11	0.38946	11	0.63439	29
4	Cauchy	σ=0.37954 μ=3.687	0.21654	19	0.93796	28	0.13687	5
5	Dagum	k=4.3561 α=7.2872 β=3.0291	0.18784	6	0.36388	4	0.68083	32
6	Dagum (4P)	k=0.21906 α=2.8171 β=1.7982 γ=2.9153	0.29286	33	5.2108	37	N/A	
7	Erlang	m=30 β=0.13094	0.19266	8	0.45451	22	3.22E-01	8
8	Erlang (3P)	m=4 β=0.35439 γ=2.4967	0.17668	4	0.47137	24	5.00E-01	19
9	Exponential	λ=0.25023	0.51784	36	3.8263	34	0.06183	1
10	Exponential (2P)	λ=0.92502 γ=2.9153	0.21858	21	3.0605	33	0.21646	7
11	Gamma	α=30.521 β=0.13094	0.2291	24	0.41749	16	0.42589	15
12	Gamma (3P)	α=4.2316 β=0.35439 γ=2.4967	0.19626	9	0.37445	7	0.62884	28
13	Gen. Extreme Value	k=-0.10644 σ=0.66678 μ=3.6755	0.20741	16	0.36195	3	0.49802	18
14	Gen. Gamma	k=1.0178 α=32.442 β=0.13094	0.23828	27	0.46712	23	0.42499	14
15	Gen. Gamma (4P)	k=2.4742 α=0.33201 β=1.8243 γ=2.9153	0.23913	28	4.9736	36	N/A	
16	Gen. Logistic	k=0.10332 σ=0.41534 μ=3.9249	0.22497	23	0.43726	18	4.38E-01	16
17	Gen. Pareto	k=-0.62542 σ=1.8039 μ=2.8865	0.17658	3	0.35794	2	0.79063	33
18	Gumbel Max	σ=0.56401 μ=3.6708	0.20287	13	0.41253	14	0.61168	26
19	Gumbel Min	σ=0.56401 μ=4.3219	0.30499	34	0.99538	29	4.4434	35
20	Inv. Gaussian	λ=121.97 μ=3.9964	0.25358	30	0.44728	21	0.58766	24
21	Inv. Gaussian (3P)	λ=24.2 μ=2.3282 γ=1.6681	0.2044	15	0.38768	9	0.58809	25
22	Log-Gamma	α=57.735 β=0.02374	0.20924	18	0.37328	6	5.50E-01	21
23	Log-Logistic	α=8.1835 β=3.8479	0.16815	1	0.43794	19	3.40E-01	11
24	Log-Logistic (3P)	α=4.0855 β=1.6597 γ=2.2104	0.19847	10	0.37322	5	6.68E-01	31
25	Log-Pearson 3	α=504.73 β=0.00803 γ=-2.6816	0.21879	22	0.38935	10	0.50261	20
26	Logistic	σ=0.39882 μ=3.9964	0.2664	32	0.60388	27	0.33965	10
27	Lognormal	σ=0.17268 μ=1.3705	0.22959	25	0.44238	20	0.46982	17
28	Lognormal (3P)	σ=0.2927 μ=0.83823 γ=1.5846	0.20884	17	0.39539	13	5.72E-01	22
29	Nakagami	m=7.6903 Ω=16.451	0.23355	26	0.43594	17	3.74E-01	13
30	Normal	σ=0.72337 μ=3.9964	0.24732	29	0.47894	25	3.41E-01	12
31	Pareto	α=3.328 β=2.9153	0.25387	31	2.6194	32	0.11625	3
32	Pareto 2	α=270.66 β=1052.6	0.52695	37	3.9405	35	0.09861	2
33	Rayleigh	σ=3.1886	0.34161	35	2.0679	31	1.40E-01	6
34	Rayleigh (2P)	σ=1.0408 γ=2.6976	0.21798	20	0.41311	15	5.82E-01	23
35	Wakeby	α=1.8039 β=0.62542 γ=0 δ=0 ξ=2.8865	0.17658	2	0.35794	1	0.79063	34
36	Weibull	α=5.7246 β=4.1988	0.20369	14	0.55364	26	1.29E-01	4
37	Weibull (3P)	α=1.8349 β=1.3936 γ=2.7565	0.20245	12	0.38976	12	0.62651	27

Table S14. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 14

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.81051 α_2=0.58177 a=2.9669 b=5.2367	0.16944	12	2.4654	30	3.37E-01	19
2	Burr	k=505.18 α=7.4902 β=10.507	0.1399	5	0.28458	7	0.4492	23
3	Burr (4P)	k=169.6 α=8.6553 β=9.5155 γ=-0.67924	0.13843	4	0.28031	5	0.43083	22
4	Cauchy	σ=0.38443 μ=4.3103	0.13568	1	0.28763	8	0.016	2
5	Dagum	k=0.00282 α=1457.3 β=5.2507	0.15185	8	7.0508	37	N/A	
6	Dagum (4P)	k=0.01184 α=43.563 β=2.4723 γ=2.9669	0.43858	35	3.0285	31	2.8013	27
7	Erlang	m=35 β=0.12216	0.21155	25	0.3955	22	1.05E-01	16
8	Erlang (3P)	m=99 β=0.07322 γ=-2.9385	0.18411	19	0.32644	15	7.45E-02	13
9	Exponential	λ=0.2332	0.49936	36	3.9054	34	N/A	
10	Exponential (2P)	λ=0.75681 γ=2.9669	0.34644	33	3.6368	33	0.67521	26
11	Gamma	α=35.104 β=0.12216	0.20455	24	0.38179	20	0.0961	14
12	Gamma (3P)	α=162.88 β=0.05758 γ=-5.0906	0.19452	21	0.32499	14	0.05831	12
13	Gen. Extreme Value	k=-0.48873 σ=0.81004 μ=4.0992	0.1488	7	0.24203	1	0.48442	25
14	Gen. Gamma	k=1.0037 α=35.573 β=0.12216	0.20378	23	0.38743	21	0.09848	15
15	Gen. Gamma (4P)	k=1.9794 α=92.483 β=1.3389 γ=-8.8996	0.19629	22	0.35311	17	0.03362	5
16	Gen. Logistic	k=-0.10833 σ=0.41383 μ=4.363	0.13597	3	0.25058	2	4.65E-01	24
17	Gen. Pareto	k=-1.486 σ=3.6565 μ=2.8174	0.164	10	0.27104	4	0.43039	21
18	Gumbel Max	σ=0.56432 μ=3.9625	0.24791	29	0.8617	28	N/A	
19	Gumbel Min	σ=0.56432 μ=4.614	0.14161	6	0.32388	13	0.31948	18
20	Inv. Gaussian	λ=150.53 μ=4.2882	0.18194	17	0.41576	23	0.048	9
21	Inv. Gaussian (3P)	λ=1.8577E+6 μ=96.35 γ=-92.062	0.18002	15	0.3205	12	0.04234	6
22	Log-Gamma	α=64.78 β=0.02226	0.23341	28	0.50475	25	N/A	
23	Log-Logistic	α=7.8761 β=4.1468	0.25909	31	0.55479	26	N/A	
24	Log-Logistic (3P)	α=1.4583E+8 β=5.8760E+7 γ=-5.8760E+7	0.15277	9	0.28871	9	4.47E-02	7
25	Log-Pearson 3	α=6.0947 β=-0.07256 γ=1.884	0.16409	11	0.25712	3	0.0312	4
26	Logistic	σ=0.39904 μ=4.2882	0.17397	13	0.31019	11	0.0298	3
27	Lognormal	σ=0.17151 μ=1.4418	0.21555	27	0.42977	24	N/A	
28	Lognormal (3P)	σ=0.03331 μ=3.0323 γ=-16.457	0.1801	16	0.33553	16	5.15E-02	10
29	Nakagami	m=9.8149 Ω=18.869	0.18995	20	0.36202	18	5.23E-02	11
30	Normal	σ=0.72377 μ=4.2882	0.18291	18	0.29734	10	4.49E-02	8
31	Pareto	α=2.8228 β=2.9669	0.36639	34	3.2728	32	N/A	
32	Pareto 2	α=199.94 β=700.12	0.57066	37	5.0835	36	N/A	
33	Rayleigh	σ=3.4215	0.31337	32	2.1943	29	N/A	
34	Rayleigh (2P)	σ=1.1917 γ=2.7519	0.25536	30	0.56485	27	N/A	
35	Wakeby	α=20092.0 β=611.98 γ=2.0698 δ=-0.92202 ξ=-29.566	0.1768	14	4.2908	35	0.10751	17
36	Weibull	α=5.7127 β=4.5257	0.21366	26	0.36554	19	2.49E-03	1
37	Weibull (3P)	α=8.9421 β=5.4143 γ=-0.83037	0.13586	2	0.28349	6	0.42635	20

Table S15. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 15

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.79838 α_2=0.65974 a=3.1769 b=5.4284	0.1427	4	2.4352	32	3.35E-01	21
2	Burr	k=357.31 α=7.3832 β=10.421	0.17884	30	0.36215	24	1.1789	25
3	Burr (4P)	k=241.59 α=2.9887 β=12.901 γ=2.5739	0.162	20	0.30962	18	0.02502	6
4	Cauchy	σ=0.48388 μ=4.3124	0.14122	3	0.45331	29	0.5921	23
5	Dagum	k=0.90588 α=10.936 β=4.4353	0.16827	23	0.30733	14	1.6665	33
6	Dagum (4P)	k=2.5731 α=4.7609E+7 β=2.4661E+7 γ=-2.4661E+7	0.1553	13	0.294	8	0.12578	15
7	Erlang	m=38 β=0.11586	0.14821	9	0.28438	4	1.63E-01	19
8	Erlang (3P)	m=60 β=0.08993 γ=-0.95948	0.17243	27	0.3043	11	1.79E+00	34
9	Exponential	λ=0.22677	0.51346	37	3.9549	36	1.901	36
10	Exponential (2P)	λ=0.81118 γ=3.1769	0.29258	33	3.3848	34	0.10845	14
11	Gamma	α=38.062 β=0.11586	0.15158	10	0.28186	3	0.15729	17
12	Gamma (3P)	α=74.87 β=0.07997 γ=-1.5846	0.15811	15	0.3057	12	0.0229	4
13	Gen. Extreme Value	k=-0.27748 σ=0.74427 μ=4.1445	0.1451	6	0.25506	1	0.02235	3
14	Gen. Gamma	k=1.0116 α=39.702 β=0.11586	0.15948	16	0.30571	13	0.1631	18
15	Gen. Gamma (4P)	k=2.7575 α=7.0305 β=2.4949 γ=-0.56527	0.16775	22	0.30821	15	1.5623	30
16	Gen. Logistic	k=0.00351 σ=0.42292 μ=4.4072	0.16831	24	0.30938	17	1.36E+00	26
17	Gen. Pareto	k=-0.986 σ=2.508 μ=3.1468	0.14674	8	0.3088	16	0.07528	10
18	Gumbel Max	σ=0.5573 μ=4.088	0.16054	18	0.43357	28	0.08994	11
19	Gumbel Min	σ=0.5573 μ=4.7313	0.20201	32	0.57566	30	0.98411	24
20	Inv. Gaussian	λ=167.84 μ=4.4097	0.17328	29	0.30202	9	0.07421	9
21	Inv. Gaussian (3P)	λ=86315.0 μ=34.349 γ=-29.937	0.17262	28	0.31789	22	1.6028	31
22	Log-Gamma	α=78.842 β=0.01866	0.13893	1	0.29185	7	1.03E-01	13
23	Log-Logistic	α=8.8459 β=4.2691	0.16044	17	0.37376	27	1.98E-01	20
24	Log-Logistic (3P)	α=36.858 β=15.226 γ=-10.833	0.16987	26	0.31743	21	1.46E+00	28
25	Log-Pearson 3	α=40.922 β=-0.0259 γ=2.5315	0.1552	12	0.27354	2	0.02678	7
26	Logistic	σ=0.39407 μ=4.4097	0.18383	31	0.37103	26	1.4408	27
27	Lognormal	σ=0.15866 μ=1.4714	0.153	11	0.30327	10	0.1391	16
28	Lognormal (3P)	σ=0.04816 μ=2.6546 γ=-9.8189	0.16932	25	0.31382	20	1.66E+00	32
29	Nakagami	m=9.9772 Ω=19.913	0.15809	14	0.29128	6	2.15E-02	2
30	Normal	σ=0.71476 μ=4.4097	0.1612	19	0.28711	5	1.47E+00	29
31	Pareto	α=3.1695 β=3.1769	0.32576	34	3.0153	33	1.9436	37
32	Pareto 2	α=132.22 β=585.32	0.51115	36	3.9273	35	1.8442	35
33	Rayleigh	σ=3.5184	0.33479	35	2.2385	31	4.68E-01	22
34	Rayleigh (2P)	σ=1.118 γ=2.9844	0.141	2	0.32826	23	9.71E-02	12
35	Wakeby	α=1725.6 β=540.39 γ=2.3604 δ=-0.93102 ξ=0	0.14375	5	6.5019	37	0.06605	8
36	Weibull	α=6.3054 β=4.6211	0.14578	7	0.36547	25	8.47E-03	1
37	Weibull (3P)	α=3.0144 β=2.0711 γ=2.5643	0.16399	21	0.31268	19	0.02439	5

Table S16. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 16

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.50578 α_2=0.75127 a=3.6515 b=6.1633	0.17573	21	1.7203	28	7.52E-08	1
2	Burr	k=0.18981 α=26.676 β=3.8107	0.14839	7	0.3539	19	0.20429	14
3	Burr (4P)	k=9.2108E+8 α=1.0272 β=5.4171E+8 γ=3.6491	0.16663	14	0.57791	23	0.09684	10
4	Cauchy	σ=0.5423 μ=4.4224	0.19514	25	0.59878	24	0.10097	11
5	Dagum	k=165.27 α=7.1068 β=1.9691	0.22203	31	0.82786	25	0.74466	23
6	Dagum (4P)	k=0.11049 α=5.4326 β=1.9485 γ=3.6515	0.23103	32	4.4591	35	N/A	
7	Erlang	m=32 β=0.14417	0.15216	9	0.29213	7	4.60E-01	16
8	Erlang (3P)	m=1 β=1.0098 γ=3.6515	0.17315	20	1.0983	27	8.43E-02	9
9	Exponential	λ=0.21449	0.54307	37	3.8725	33	1.5024	32
10	Exponential (2P)	λ=0.9895 γ=3.6515	0.17295	19	2.7449	31	0.08399	8
11	Gamma	α=32.338 β=0.14417	0.17177	17	0.29116	6	0.57242	19
12	Gamma (3P)	α=0.83641 β=0.90437 γ=3.6515	0.28969	33	5.0335	36	N/A	
13	Gen. Extreme Value	k=-0.0051 σ=0.69622 μ=4.2638	0.14766	6	0.24711	3	0.74559	24
14	Gen. Gamma	k=1.0212 α=34.827 β=0.14417	0.18679	24	0.3356	15	0.68097	21
15	Gen. Gamma (4P)	k=0.70997 α=1.0096 β=0.6649 γ=3.6515	0.3424	34	5.1493	37	N/A	
16	Gen. Logistic	k=0.16665 σ=0.45868 μ=4.5323	0.16556	12	0.29284	8	7.34E-01	22
17	Gen. Pareto	k=-0.42861 σ=1.6665 μ=3.4956	0.14505	3	0.21704	2	0.00696	3
18	Gumbel Max	σ=0.63923 μ=4.2932	0.17225	18	0.29557	9	1.0046	30
19	Gumbel Min	σ=0.63923 μ=5.0311	0.21618	30	0.87068	26	1.545	33
20	Inv. Gaussian	λ=150.76 μ=4.6621	0.19523	26	0.33808	16	0.81594	28
21	Inv. Gaussian (3P)	λ=4.4319 μ=1.5315 γ=3.1307	0.13889	2	0.30878	12	0.00715	5
22	Log-Gamma	α=78.402 β=0.01946	0.16973	16	0.27063	5	7.64E-01	26
23	Log-Logistic	α=9.1227 β=4.4775	0.13467	1	0.35125	18	3.31E-01	15
24	Log-Logistic (3P)	α=2.3998 β=1.0925 γ=3.3574	0.15011	8	0.32437	14	3.39E-02	6
25	Log-Pearson 3	α=39.161 β=0.02753 γ=0.44742	0.16744	15	0.26617	4	0.80528	27
26	Logistic	σ=0.452 μ=4.6621	0.20269	28	0.4137	21	0.59071	20
27	Lognormal	σ=0.16497 μ=1.5257	0.18514	23	0.32363	13	0.75761	25
28	Lognormal (3P)	σ=0.56464 μ=0.26054 γ=3.1559	0.1466	5	0.30613	11	7.00E-03	4
29	Nakagami	m=7.8496 Ω=22.352	0.16601	13	0.29824	10	4.61E-01	17
30	Normal	σ=0.81984 μ=4.6621	0.18008	22	0.34286	17	4.79E-01	18
31	Pareto	α=4.3375 β=3.6515	0.20928	29	2.0645	29	0.04877	7
32	Pareto 2	α=229.59 β=1197.0	0.50309	36	3.4878	32	0.86775	29
33	Rayleigh	σ=3.7198	0.38233	35	2.1177	30	1.55E-01	13
34	Rayleigh (2P)	σ=1.1145 γ=3.2953	0.20007	27	0.37728	20	1.15E+00	31
35	Wakeby	α=1.6665 β=0.42861 γ=0 δ=0 ξ=3.4956	0.14505	4	0.21704	1	0.00696	2
36	Weibull	α=6.3427 β=4.8445	0.15334	11	0.53067	22	1.52E-01	12
37	Weibull (3P)	α=0.96188 β=1.1332 γ=3.6515	0.15242	10	3.9113	34	N/A	

Table S17. Distribution parameters and results of goodness-of-fit tests for all selected distributions for location 17

#	Distribution	Parameters	K-s		A-D		C-S	
			Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	α_1=0.48664 α_2=0.53464 a=3.9277 b=6.1139	0.16667	21	4.8141	33	1.71E-05	1
2	Burr	k=269.9 α=7.6563 β=10.985	0.16071	17	0.33391	9	0.6251	18
3	Burr (4P)	k=2712.2 α=1.2398 β=681.61 γ=3.8754	0.19935	27	0.66141	26	0.08427	7
4	Cauchy	σ=0.55584 μ=5.0598	0.165	20	0.48431	23	0.51146	15
5	Dagum	k=51.876 α=7.3226 β=2.6628	0.18817	24	0.44249	22	0.14313	8
6	Dagum (4P)	k=174.28 α=138.97 β=83.772 γ=-82.593	0.27883	31	1.1749	27	0.74926	20
7	Erlang	m=41 β=0.1187	0.19374	26	0.43775	21	5.31E-01	16
8	Erlang (3P)	m=1 β=1.0415 γ=3.9277	0.21096	29	3.8953	31	2.37E-02	5
9	Exponential	λ=0.20123	0.54632	37	4.0182	32	2.2714	34
10	Exponential (2P)	λ=0.95995 γ=3.9277	0.21087	28	10.177	36	0.02363	4
11	Gamma	α=41.867 β=0.1187	0.14532	8	0.31726	7	0.92747	26
12	Gamma (3P)	α=0.77785 β=0.633 γ=3.9277	0.43819	35	13.926	37	N/A	
13	Gen. Extreme Value	k=-0.27018 σ=0.79963 μ=4.6807	0.12468	1	0.26806	3	0.72732	19
14	Gen. Gamma	k=1.0133 α=44.004 β=0.1187	0.14915	11	0.35454	14	1.0021	29
15	Gen. Gamma (4P)	k=1.1352 α=0.69382 β=1.0091 γ=3.9277	0.34077	32	9.9372	35	N/A	
16	Gen. Logistic	k=0.00759 σ=0.45611 μ=4.9637	0.14752	10	0.32835	8	7.79E-01	21
17	Gen. Pareto	k=-0.96985 σ=2.6686 μ=3.6147	0.13473	3	0.2546	2	0.01225	3
18	Gumbel Max	σ=0.59882 μ=4.6237	0.19125	25	0.53444	25	0.19642	9
19	Gumbel Min	σ=0.59882 μ=5.315	0.18725	23	0.52518	24	0.57733	17
20	Inv. Gaussian	λ=208.05 μ=4.9694	0.15173	12	0.34979	12	1.2026	32
21	Inv. Gaussian (3P)	λ=1202.3 μ=8.6892 γ=-3.7198	0.15537	14	0.3584	15	1.0815	30
22	Log-Gamma	α=103.63 β=0.01536	0.16054	16	0.34165	11	2.76E-01	12
23	Log-Logistic	α=9.4302 β=4.8178	0.18062	22	0.40031	18	4.72E-01	14
24	Log-Logistic (3P)	α=106.85 β=47.976 γ=-43.01	0.15183	13	0.34065	10	8.15E-01	23
25	Log-Pearson 3	α=201.51 β=-0.01102 γ=3.8123	0.14284	6	0.31154	5	0.93581	27
26	Logistic	σ=0.42343 μ=4.9694	0.16419	19	0.40061	19	0.88078	25
27	Lognormal	σ=0.14974 μ=1.5922	0.15661	15	0.36382	17	0.31307	13
28	Lognormal (3P)	σ=0.07487 μ=2.2822 γ=-4.8539	0.14483	7	0.35419	13	9.80E-01	28
29	Nakagami	m=10.824 Ω=25.236	0.13947	4	0.31489	6	8.66E-01	24
30	Normal	σ=0.76801 μ=4.9694	0.1419	5	0.3038	4	7.99E-01	22
31	Pareto	α=4.4616 β=3.9277	0.219	30	3.0912	29	1.1162	31
32	Pareto 2	α=229.59 β=1197.0	0.52865	36	3.8231	30	1.8664	33
33	Rayleigh	σ=3.965	0.38776	34	2.322	28	8.36E-02	6
34	Rayleigh (2P)	σ=1.1073 γ=3.5868	0.16315	18	0.4145	20	2.32E-01	10
35	Wakeby	α=2.6686 β=0.96985 γ=0 δ=0 ξ=3.6147	0.13473	2	0.2546	1	0.01225	2
36	Weibull	α=6.676 β=5.1922	0.14537	9	0.36088	16	2.72E-01	11
37	Weibull (3P)	α=0.44835 β=1.9154 γ=3.9277	0.34608	33	7.4517	34	N/A	

Appendix X

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