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INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/10581

DOI URL: <http://dx.doi.org/10.21474/IJAR01/10581>



RESEARCH ARTICLE

IMPACT OF ROUGHNESS VARIABILITY OVER WIND POWER ASSESSMENT IN THE WHITE HEADLAND

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Manuscript Info

Manuscript History

Received: 22 December 2019

Final Accepted: 25 January 2020

Published: February 2020

Key words:-

Wind Power, Wind Atlas, Modeling Potential, Wind Roughosity, Windographer

Abstract

The purpose of this study is to assess the wind power at the site of the white headland (Nouadhibou, Mauritania); the data from the site covers eleven years at height 10 m above ground level AGL. They have been made available by (Merra-2), the Modern-Era Retrospective analysis for Research and Applications V.02. In the aim of wind power classification of the site, the data must be extrapolated for height 50 m (AGL) as recommended by USA standard specifications. However, the roughness, for this particular desert site is variable over seasons, for the reason of the sand motion, the short-term measurements of wind speed data at two or more height levels will deduct it. Those data are made available by the S.N.I.M (National Company of Mining Industry) farm for one year, 2016 at 10, 50, and 55 m AGL, but those were not complete, so we use the Kalman filtering to control, predict and complete all gaps. The study conducted by wind data (speed, direction) with 10 minutes as steep of the measurements. The research shows that prevailing winds oriented to the north-north-west (NNW) direction. The Weibull has found the setting that was determined by the likelihood, and standard deviation methods are the most suitable for a better coefficient of determination. Those parameters are obtained for height 50 m AGL as recommended by USA standard specifications; the wind power decided as excellent.

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Introduction:-

The Mauritanian government has put in place a scenario for mitigating greenhouse gas emissions by introducing renewable energy. A target of 129 MW has been set for wind technology by 2030 [1]. The achievement of such an objective requires, beforehand, the determination of the deposit of the country. As a guide as it is will serve any promoter wishing to invest in the wind power in Mauritania [2, 3].

The wind energy industry requires a vision on the availability of potential on a wind atlas, and several countries are looking to complete this work with the required quality [4, 5]. The city of Nouadhibou, located in the northwest of Mauritania [6, 7], is considered to be the windiest city in the country, and it is a candidate for assessment atlas.

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However, due to the absence of a reliable and precise Mauritanian wind atlas, further studies on the evaluation of wind energy in Mauritania are necessary.

The results of the study presented by Matthieussent et al. and Dhaya et al. [8, 9] believe that Mauritania has good wind potential.

This work has never done, especially when it comes to characterizing the wind power according to an international standard such as that adopted by an atlas of the United States. In the other hand, the soil of Mauritania in general and Nouadhibou, in particular, is not stable; the movement of dunes characterizes it. Therefore, it has a considerable effect on the logarithmic profile of wind speeds.

So, the variability of the roughness of the ground must be estimated accurately, to have a precise extrapolation at the desired height following the standards in force.

The study of the potential and the management of the wind energy generated on a site considered is of acute sensitivity. So, several parameters integrated, notably the turbulence intensity and the gust factor [10,11]. However, the roughness of the soil rarely taken into account, and it is often taken as a constant in that a flat, open, or closed field. The roughness parameter omission leads to errors in the estimation of the potential on the one hand. On the other hand, investment and maintenance costs in additional sophisticated means of regulation and management of food add to the budget [12]. This limitation is well-posed in the study of wind deposit in Mauritania.

The evaluation of the wind potential according to international standards, requires wind measurement data at a well-determined height. Still, wind measurement data are mainly available at the height of 10 m, the extrapolation to the highly needed for the norm involves a term linked to the theory of the atmospheric boundary layer of MoninObukhov, which is roughness [13], The equation 1 expresses the relationship between wind speed and the corresponding altitude. It is among the most used formulas in this field.

$$V_2 = V_1 \frac{\ln\left(\frac{z_1}{z_0}\right) - \Psi_m\left(\frac{z_1}{L}\right)}{\ln\left(\frac{z_2}{z_0}\right) - \Psi_m\left(\frac{z_2}{L}\right)}$$

The universal function Ψ_m canceled under neutral atmospheric conditions of stability [14]. Several researchers studied the extrapolation of the wind speed from a height z_1 to the height z_2 , including notably Justus and Mikhail, in 1976 [15, 16, 17]. The roughness z_0 quickly deduced from the previous expression. It is generally constant throughout the year depending on the nature of the terrain: Flat (ice, snow, and ocean), open (Airports, dry cropland, low grass), rough (Forests and orchards), or closed (Villages and suburbs).

Wind data and Methodology:

Primary meteorological data from Modern-Era 2:

The White Headland is a peninsula about fifty-five kilometers long, shared between Mauritania (to the east) and Morocco (to the west), the side of Mauritania land located with the following geographic coordinates: Latitude 20° 56 North longitudes 17° 02 W and with an elevation of 0 m AGL [18]. Its climate is moderate and humid throughout the year at a rate of 15 to 17 Centigrades in winter, and from 18 to 23 degrees in other seasons when the rain is less like the rest of the desert areas. The displacement of dunes will undoubtedly affect its atmosphere, as mentioned in the work of Beyoud et al. [19].

This location is almost an island. The terrain appearance changes the whole year continuously. During this period, a very significant change in soil texture generally observed. It results in displacements of the dunes, which incites to advance the hypothesis of fluctuating in roughness according to the seasons the whole year.

The Modern-Era Retrospective Analysis Web Service for Research and Applications, version 2 (MERRA-2), has been providing data available worldwide for 40 years and is regularly updated about a month's delay [20]. We are

authorized to use the meteorological data processed in this study. Those data are available and provided by the SoDa-pro web service. It is a broker to many services gathering altitude and meteorological data, sun/earth geometry, atmosphere components, and typical years of atmosphere attributes. The Modern-Era Retrospective analysis, Version 2 (MERRA-2) hosted by NASA and generated by the Goddard Space Flight Center, and make available worldwide for Research and Applications, it delivers time series of some data such as temperature (at 2 m), relative humidity RH (at 2 m AGL), pressure (at 2 m AGL), wind speed and direction (at 10 m, AGL), and others concerning the rainfall, Snowfall. All data given are with a time step of 1 hour, one day or one month, and a spatial resolution of approximately 50 km. The data are available since Jan. 1980 and regularly updated with about one month of delay.



Figure 1:- White headland location.

Also, the most interests information in this study is the wind data available speed and direction (at 10 m AGL). The extracted data is hourly; the spatial resolution is approximately 50 km. From where the data of 11 years obtained for the studied site, the location selected for this present study.

These data come in the form of CSV files, which saved in an hourly way. The processed data from the Nouadhibou meteorological site at the height of 10 m provided by the MERRA-2 covering 11 years, from 01/01/2009 to 31/10/2019. Table 1 shows the rate of validated data.

Table 1:- Analysis of the data from the Reference site.

Setting designation	Data Disponibility	Validity	Recovery rate
Direction	94,944	94,944	100
Wind Speed	94,944	94,944	100

Local wind data of SNIM farm:

However, the roughness parameter is not available in this database and even more, impossible to calculate it with a single level of measurement. In this situation, a short-term measurement campaign at two levels (50 and 55 m AGL) requested from the site of the wind power farm of the National Society of the Mining Industry SNIM, less than 200 m from the airport from Nouadhibou. So, the data measured and recorded during the year of 2016 according to the requested levels obtained. In the aim to compute the roughness parameter, on the other hand, the estimation of the wind power of this site has been conducted regarding the standard USA (2011) developed in the context of the report Wind Energy Resource Atlas of the United States [21, 22].

It should summarize that the wind speeds measured at the height of 10 m above the ground extracted from Merra-2 web service, an extrapolation to the height 50 m AGL will carry out, based on roughness parameter calculated by data from a nearby site called the wind farm of the National Society of the Mining Industry SNIM.

Table 2:- Analysis of SNIM wind farm site data.

Designation of parameters	Data available	Validated data	Coverage rate
Wind speed (SNIM farm)	2928	2384	77.20%

Gap Rebuilt on the SNIM wind farm measurement data:

We used the wind speed data measured by the SNIM wind farm, but we found that these data are missing an estimated part of 22.8%, as mentioned in the coverage rate in table 2. To reconstruct a data set in a precise way, we opted for the Kalman filter prediction model. After the treatment of gaps by using the Kalman filtering approach, as presented in figure 2.

To build a complete set of more precise data relating to the data which were delivered to us by SNIM. The coverage rate of these data is estimated to be around 77.2%.

Classic models may not be reliable because they are generally defined to minimize the average error over a long period of measurements. On the other hand, the Kalman filter model, or the Kolmogorov-Zurbenko model, can be essential and useful alternatives in this area.

The type of exponential smoothing of the Kalman filter does not seek to minimize the average error of the history but to minimize the average error of the future.

Furthermore, and we chose the Kalman filter. Also, it can provide a stable forecast of missing SNIM data. Thus, this will allow us to cover a full year of the measures. Also, the variance using a model whose parameters or state variables can vary. [23, 24]: The Kalman filter process described in figure 2 :

The covariance matrix of the initial state is a variable independent of the noise of the system, and it is considered Gaussian. So, we took that corresponds to the altitude level of 10 m AGL

To predict the estimate according to the model. The Kalman filter takes up the previous estimation of the parameters and the error and predicts the new parameters and the new error according to the system model; This prediction updated with the new measures. These noisy measurements, in their default state, will make it possible to obtain an estimate of the parameters and the error from the prediction model.

The updates allow errors to be corrected as soon as they are detected.

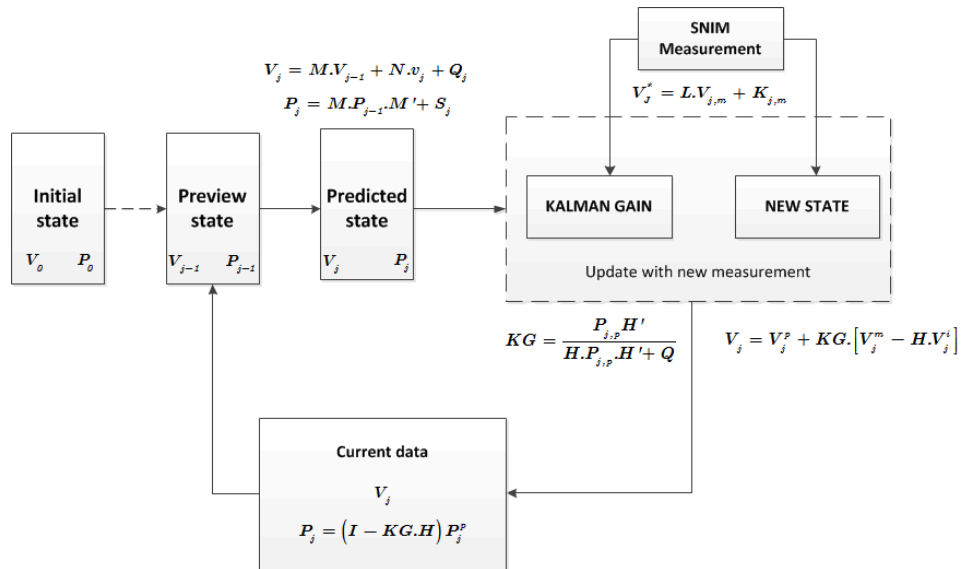


Figure 2:- The Kalman filters process for treatments of gaps in wind data.

The principle of the Kalman filter is to estimate at each instant (t_j) the wind speed vector V_j by knowing the measurements V_m, j observed up to date j .

$$V_j^p = V_{j-1} + Q_j$$

$$P_j^p = M.P_{j-1}.M' + S_j$$

The mathematical model governing this work is the Weibull probability density distribution widely used by the wind industry [25], the distribution described in the appendix. Unlike conventional analysis use, the analysis of wind atlases based on the limited range of wind power density classes. Each wind power class represents the range of wind power densities likely to be encountered at exposed sites in an area designated as having this wind energy class. Table 1 gives the power density limits for the wind power classes used in the regional atlas for the reference at 50 m AGL [26].

Extrapolation of Weibull setting to 50 m above the ground:

The evaluation of the wind potential at the height of 50 m above the ground requires the transformation of the Weibull setting. Estimating the coefficient c at another height uses the following governing equations of the extrapolation process from height 50m to 55 m AGL, as shown in figure 2, highlight the governing equations of the extrapolation process from height 50 to 55 m. the MoninObukhov formula gives the distribution wind speed at several levels. We supposed that atmospheric conditions of stability are neutral. When the roughness coefficient computed, We will use the Justus and Mikhail's approach to extrapolate the Weibull parameters.

In 1985, for any height, Mikhail [16] gave the expression of the exponent (m''), taking into account the roughness, with the roughness coefficient (z_0), defined as the height from which the friction speed slows down the wind speed whose geometric mean (z_g).

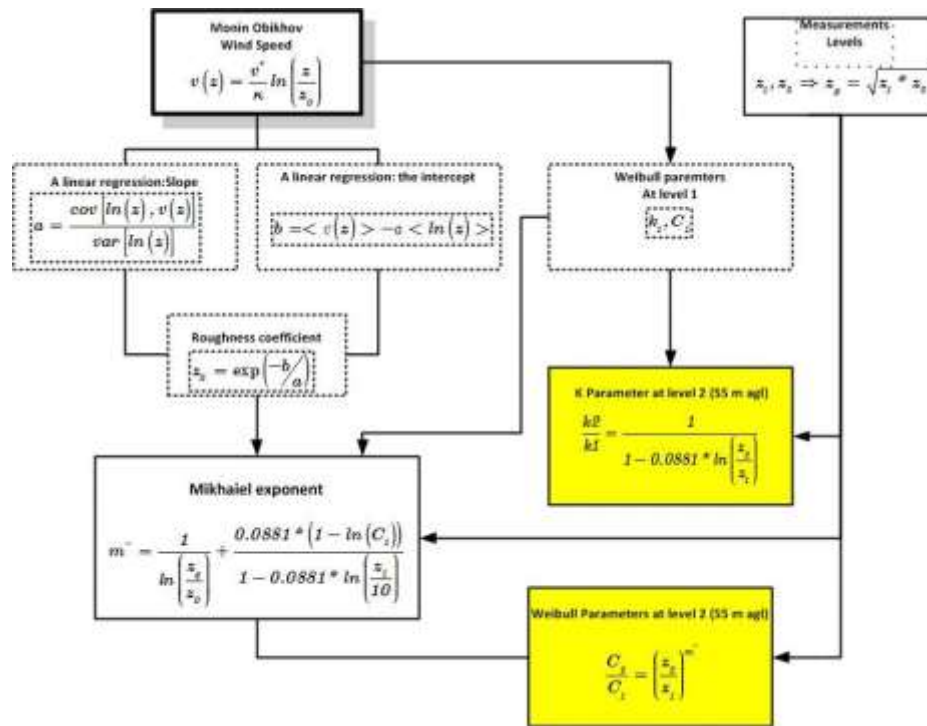


Figure 3:- Process of extrapolation of Weibull parameters setting to 50 m above the ground.

Results and Discussions:-

Diagnostic of atmosphere and its impacts over Roughness:

The first results of the atmosphere diagnostic analyzed, and its pieces of information about Roughness highlighted in Figures 5 and 6. In these desert regions and similarly, for the Nouadhibou peninsula, the sand, displaced in a privileged direction, will accumulate to form dunes from one season to another. The most natural dune is the barkhan presented in figure 4. The barkhan seen in the plan is a crescent-shaped dune. more or less significant.



Figure 4:- The natural dune at the Boulanour region (about 80 km from Nouadhibou:) the barkhan dunes.

In fact, by the successive collapses, the sand rises along the windward slope and accumulates so much by falling on the steep leeward slope that the avalanche angle reached. The sand crumbles by forming a flow which restores balance by accumulating at the base of the dune. It is these successive landslides that move the dune forward.

On the other hand, the wind carries sand from the desert to the atmosphere, then the observation of the movement of the dunes throughout the year can reflect in the corresponding intuitive amount of particles in the sky. Figure 5 represents more than 76% of sand, and 12% of sulfates in all types of aerosols are present in suspension in the sky.

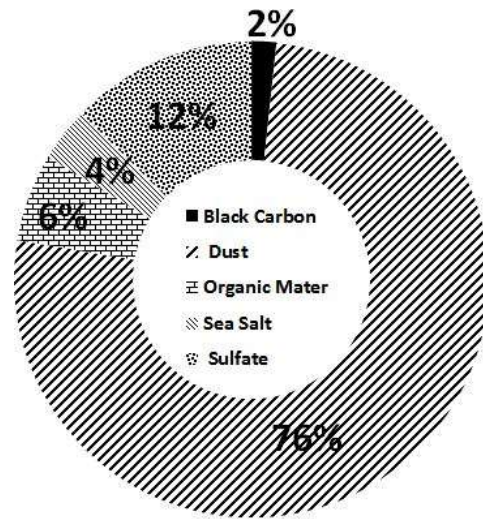


Figure 5:- The distribution of kinds of atmospheric aerosols presented from 2009 to 2019.

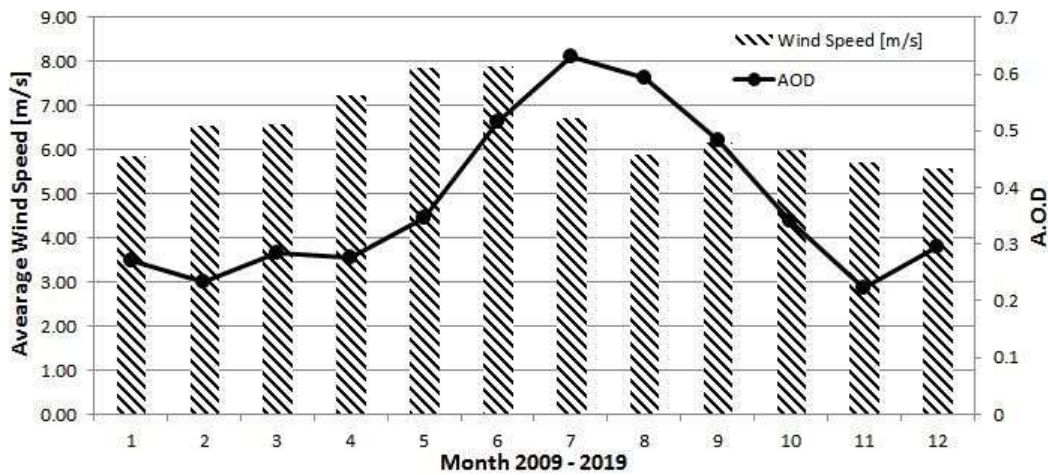


Figure 6:- the monthly distribution of atmospheric aerosols and the monthly average of wind speed from 2009 to 2019.

Besides, the results of an analysis of atmospheric aerosol data during the year presented in figure 6. It shows that the aerosols optical depth increases during the summer season and decreases during the other seasons.

First hypothesis: the roughness is not constant; it must determine for each season.

Data processing:

Data collection discussed in section 2.1, which is the heart of our task. For our task, we will focus only on the wind speed. The data will be processed and analyzed by the Windographer software[27]. This software allows us to analyze, view, and validate data wind [28].

Figure 7 shows the variation in multi-year wind speeds of the site studied (from 2009 to 2019) at the height of 10 m AGL. This figure shows that the behavior of wind speeds is pseudo-periodic. The maximum speed recorded for the year 2012 with 13.02 m/s and the minimum speed in 2017 with 0.3 m/s.

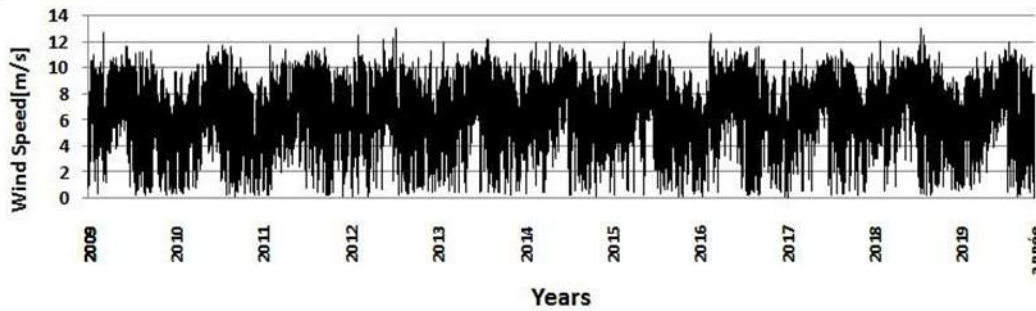


Figure 7:- Variation in the hourly average speed of multi-year winds.

The climate of Mauritania segmented into three distinguishes seasons [29]: the hot, dry season (April- June), the rainy season (July-October), and the cold, dry season (November-March). Figure 10 illustrates the daily evolution of the wind speed. It shows that the estimated average varies between 6.35 and 7.25 m/s at respectively 19 and 23. The minimum speed is 5.25 m/s at 15h. the curve shows four paces.

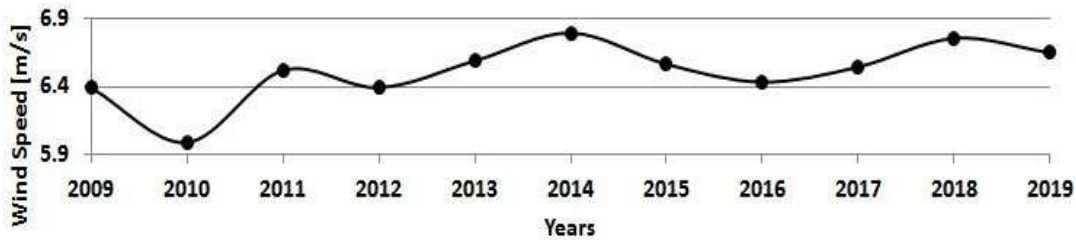


Figure 8:- Variation of three-hour wind speeds for the 11 years of observation.

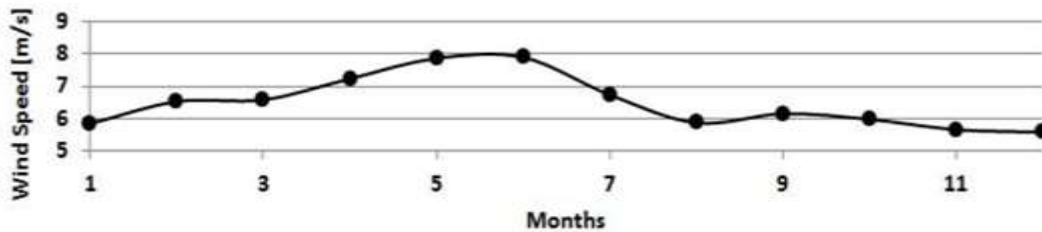


Figure 9:- Monthly variation of wind speed.

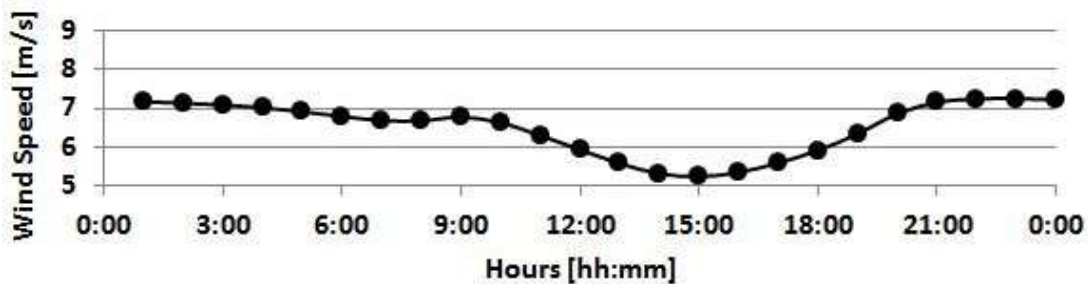


Figure 10:- Daily variation of wind speed.

The first observed from midnight to midi, period during which the wind speed decreases from 7.2 m/s to 6 m/s. Then, from 3 p.m.to 11 p.m. Where the wind speed increases to the maximum value of 7.24 m/s and another from 6 p.m. to 9 p.m., where a slight decrease in the speed of wind followed by growth until midnight to reach 7.2 m/s. This phenomenon mainly explained by the gradual rise in temperature over the day on the Atlantic coast, caused by the local winds added to the Azores winds. On the other hand, the wind rose represented the figure 11 the direction of the dominant wind speeds, which shows that the dominant winds oscillate between the North with an estimated frequency of 15% and the North North East (NNE) with a frequency of around 85%. The speed varies between

7.012 and 13 m/s, under the effect of the trade winds with the general direction NNE. This result corroborates the studies made by Leroux [30], showing that the trade winds blow practically continuously with a speed which increases from April to August due to the ascent of the Azores anticyclone and the disappearance of the anticyclone Saharan. These trade winds limited by the intertropical fronts [31].

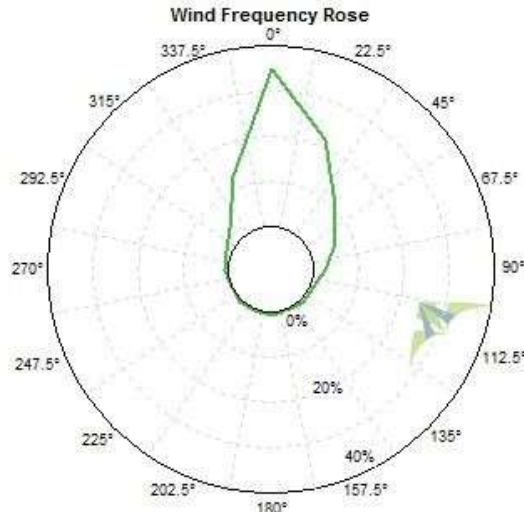


Figure 11:- The global winds wind rose.

From table 3 generated by the Windographer software we can obtain:

1. The average wind speed over 11 years for each season of the year,
2. The Weibull parameters (k and c) and the power of the wind at the height of 10 m AGL.

Table 2:- Analysis of SNIM wind farm site data.

Setting	seasons			Total	Unit
	S – I	S – II	S – III		
$\langle V_{10} \rangle$	6.409	7.168	5.711	6.509	[m/s]
k_{10}	3.448	3.687	2.770	3.306	
C_{10}	7.128	7.942	6.415	7.252	[m/s]
P_{10}	211.7	289.4	167.3	226.0	[W/m ²]

We also observe that the global average speed estimated at 6.509 m/s with a wind potential of 226 W/m² and the global average speed of the 11 years of wind speed measurement produces 28% more potential compared to the annual average during the hot, dry season (II). The average speed observed is 6.409 m/s with a potential of 6.32% less compared to the global average during the cold, dry season, an increase of 10, 26% less potential during the rainy season. The form factor is substantially constant, and it has done between 2.77 and 3.7, which means that the wind is almost stable.

Figure 12 shows the Weibull distribution curves according to the methods applied. The results of the setting and the potential at the height of 10 m AGL collated in Table 4.

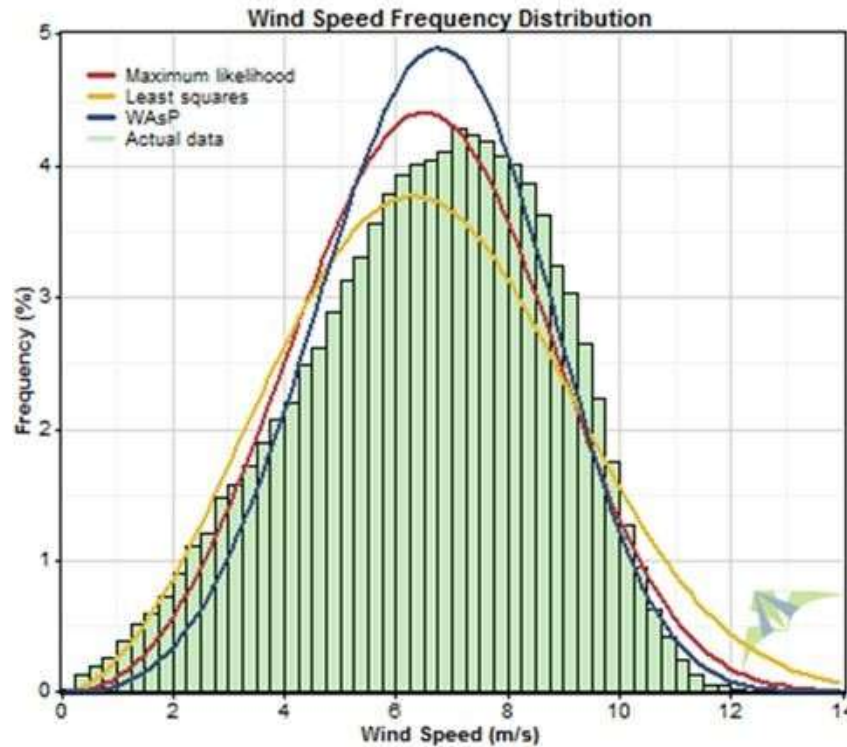


Figure 11:- Weibull curves obtained by applied methods.

Table 4:- Potential of the site for the period 2009-2019 at 10 m above the ground by the different methods.

Methods	Likelihood Maximum	Less square	Standard deviation
k_{10}	3.306	2.815	3.767
C_{10} [m/s]	7.252	7.370	7.347
P_{10} [W/m ²]	225.2	252.4	226.0

Extrapolation of wind data to 50 m AGL:

Extrapolating the potential to the height of 50 m AGL requires knowledge of the wind profile of the site studied, in particular the roughness and the friction speed.

Extrapolating the potential to the height of 50 m AGL requires knowledge of the wind profile of the site studied, in particular the roughness and the friction speed.

The site wind profile determined according to standard conditions [32]. So we got the results of a wind measurement companion to calculate the coefficients. The roughness of the soil in Nouadhibou determined for each month, season, and year. The estimate is based on the hypothesis of atmospheric neutrality according to the stability through the logarithmic profile. Figure 13 depicts the variation of the average friction speed and the roughness parameters. The data measured and recorded in 2016 respond to the heights of 10, 50, and 55 m above the ground, on the site of the wind power plant of the National Society of the Mining Industry "SNIM" less than 200 m from the airport from Nouadhibou.

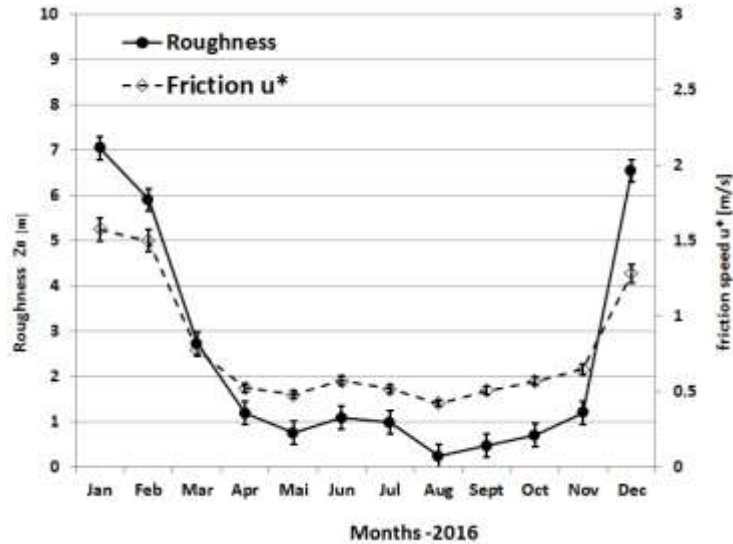


Figure 13:- Roughness and friction speed from SNIM data 2016.

The roughness of the soil in Nouadhibou determined for each month, season, and year. The estimate is based on the hypothesis of atmospheric neutrality according to the stability through the logarithmic profile (equation 1). From Table 5, we can see that z_0 is essential during the dry season with a value of 0.6 m following the terrain of high roughness.

Table 5:- Roughness of each season calculated "SNIM."

Season/Data	Hot season	wet season	Cold season	Total
Roughness (z_0)	0.220218	0.159922	0.246028	0.209746

During this season, the region experiences an uplift of sand, which indeed causes movement and displacement of the dunes. While the rainy season, the ground becomes very rough by the adhesion of the grains of sand and remains stuck to the ground. Besides, it appears that the soil structure of Nouadhibou is variable over a year. It goes from a flat structure to a rough structure between the middle and the end of the year. Then, it becomes very rough at the beginning of the following year and this, periodically.

Table 6 shows the roughness and the exponent of the extrapolation given by (m^n) for each.

Table 6: shows the roughness and the exponent of the extrapolation given by (m^n) for each.

Setting	Seasons			Total	Unit
	S-I	S-II	S-III		
Z_0	0.220218	0.159922	0.246028	0.209746	[m]
k_{10}	3.448	3.687	2.770	3,306	
c_{10}	7.128	7.942	6,415	7,252	[m/s]
c_{50}/c_{10}	1.360	1,00	1,16	1,19	
k_{50}/k_{10}	0.820	1,00	1,00	0,83	
$\langle V_{50} \rangle$	9.130	9.272	8.486	9.123	[m/s]
k_{50}	3.300	3.755	2.688	3.233	
c_{50}	10.170	10.262	9.540	10.167	[m/s]
P_{50}	622.200	621.000	558.2	626.7	[W/m ²]
Class	Extraordinary	Extraordinary	Excellent	Extraordinary	

Various probability distribution functions have been proposed in order to perform statistical analyzes on wind speeds and directions in order to estimate the wind potential existing at a given season presented in the figure algorithm referenced by 2.4. The results in the Weibull parameters at the height of 50 m and, therefore, the potential

at this standardized height Figure 14. The wind potential of Nouadhibou is in a good class during the dry season, with a wind potential slightly exceeding 600 W/m².

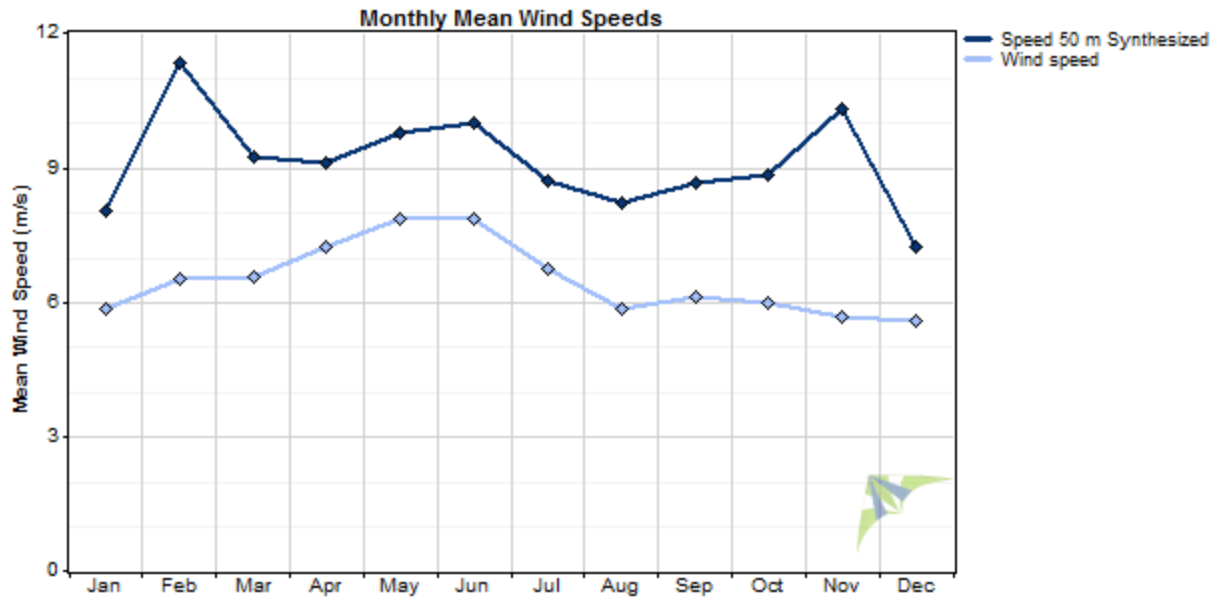


Figure 14:- Wind data synthesized at the height of 50 m by extrapolation of the height.

We note in Table 7 that the more the wind speed increases, the more the sand dust rises in the atmosphere causing a displacement of the dunes negatively impacting the wind potential.

Table 7:- Monthly classification of wind potential.

Months	k ₁₀	C ₁₀	Z ₀ [m]	C ₅₀	k ₅₀	P ₁₀	P ₅₀	Class
Unit		[m/s]		[m/s]		[W/m ²]	[W/m ²]	
January	3,21	6,52	0.200	8.99	3.21	165,37	433,49	Good
February	3,65	7,24	0.343	12.57	3.64	217,89	1141,11	Exceptional
March	3,69	7,30	0.210	10.23	3.69	222,76	613,05	Extraordinary
April	4,70	7,91	0.143	9.96	4.70	273,37	543,69	Excellent
May	5,85	8,50	0.136	10.58	5.84	333,54	643,23	Extraordinary
June	5,40	8,56	0.149	10.88	5.40	342,84	701,51	Extraordinary
July	2,85	7,55	0.161	9.78	2,85	269,77	586,37	Excellent
August	2,53	6,61	0.210	9.28	2,53	194,29	535,20	Excellent
September	2,83	6,90	0.212	9.70	2,83	206,62	574,05	Excellent
October	3,38	6,65	0.245	9.87	3,38	173,26	563,93	Excellent
November	3,42	6,31	0.373	11.50	3,42	146,83	888,83	Exceptional
December	3,08	6,24	0.160	8.08	3,08	147,94	319,64	Average

Conclusion:-

The wind power at Nouadhibou is very significant. It varies from the middle class in the rainy season to the exceptional class in the dry season. At 50 m in height, the winds blow in the same North-North-West direction (NNW) at speeds varying between 7 and 11 [m/s]. The Weibull c scale parameter varies between 8.08 [m/s] and 12.57 [m/s], and the form factor varies between 2.53 and 5.84. From 10 to 50 [m], the power density varies from simple to quadruple. The wind power of the site studied, therefore, turns out to be favorable for the installation of wind turbines.

Acknowledgments:-

The authors would like to thank the head of SNIM (“The National Industrial and Mining Company”), for providing data exploited in this work.

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