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Assessment of wind potential energy of four major cities in Cote d'ivoire using satellite data from 2015 to 2022

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ABSTRACT

In Côte d'Ivoire, the use of renewable energy is becoming a major challenge in the context of climate change and global warming. Therefore, the aim of this study is to characterize the wind profile for potential energy in Abidjan, Man, Bouaké and Korhogo of Côte d'Ivoire using satellite data. Wind speed and direction data from Copernicus Centre from 2015 to 2022 are used for these major cities. The frequency method is used to build wind rose and power density formula to estimate the potential energy for each city, at ground level (10 m) and in particular level at 100 m and 500 m. The results showed a slightly wind speed and direction variation from 2015 to 2022. This suggests that wind has a seasonal (wet and dry) evolution over the year. However, wind speeds increase for each city with the altitude. The higher average wind speed is observed in Abidjan with a power density of 58 W/m^2. The lower wind speed and power density are observed in Man, Bouaké and Korhogo. So, the coastline of Côte d'Ivoire has the higher wind energy resource than the inland regions of the country.

1. Introduction

Electrical energy is indispensable for all socio-economic activities. This socio-economic development is often followed by atmospheric pollution due to the greenhouse gases emitted by the various types of energy used (Ming et al., 2024). Climate change is becoming an increasingly pressing issue. As a result, one COP after another reminds us of the need to preserve the environment and the climate (GUGLIELMO, et al., 2023). In addition to preserving climate, it is also necessary to diversify energy sources to ensure our energy sovereignty (PRAENE, et al., 2021). Côte d'Ivoire is not on the sidelines of sustainable development objectives.

Côte d'Ivoire's currently produces 70 % of its energy for domestic use and plans to increase this to 99 % up to 2030, including 42 % from renewable energy. ((MPE), 2016). With the quick increase in population, major cities of Cote d'Ivoire, such as Abidjan, Bouaké, Man and Korhogo request huge amounts of energy to maintain and improve the level of their economic activities.

Numerous studies are conducted in Africa in generally and west Africa in particularly (Awanou et al 1991, Bilal B et al 2008, Bekele G et al 2009, Oyedepo et al 2012, Ben U. C. et al 2021, Asamoah et al 2023) in order to evaluate the potential of wind power in this area of the world. Evaluation of wind speed was conducted in the coastal regions of Ghana. The results show a wind speed varying between 3 m/s and 9 m/s (Muyiwa S. Adaramola, 2014). It has been suggested that with suitable selection of wind power generators such as wind turbine model CF-100 (with cut-in wind of 2.2 m/s and rated wind speed of 9.5 m/s), wind energy could be also used to improve the mix of energy in the electrical production of the country (Muyiwa S. Adaramola, 2014) (Sarpong, 2015). In another study conducted in non-coastal areas, notably

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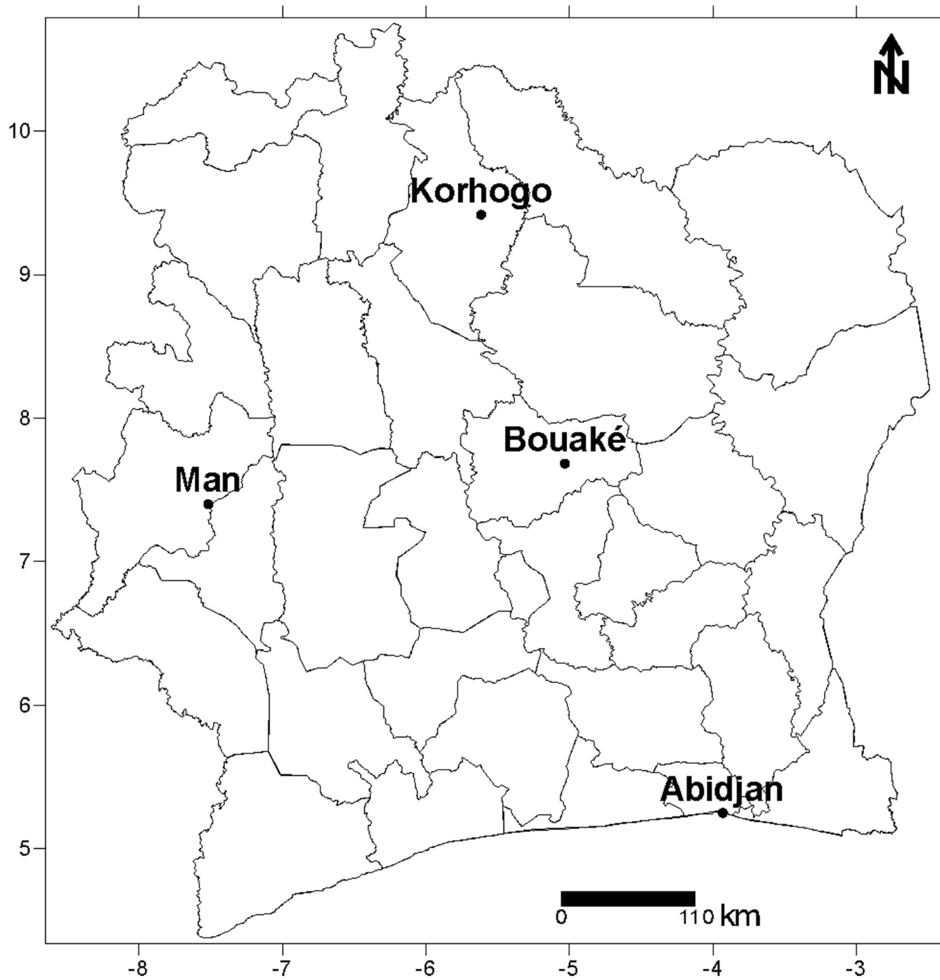

Fig. 1. Location of the four main cities of the study in Côte d'Ivoire.).
Source: Bureau National d'Etudes Techniques et de Développement (BNETD

different cities of Mali, lower wind speed between 3.1 m/s and 5.5 m/s was obtained at various heights from 20 m to 50 m (Ivan Nygaard, et al., 2017).

According to Côte d'Ivoire's state-owned energy management company, in order to meet its energy needs while protecting the environment in line with its international climate change commitments, Côte d'Ivoire is focusing on diversifying its energy sources by promoting green energy, in particular hydropower, biomass and solar energy (CI-ENERGIE, 2019). Côte d'Ivoire has wind every year, but wind energy is not developed and not used by the population. During the year, Côte d'Ivoire is blown by two major air masses, the monsoon and the harmattan (TAUPIN, et al., 2002) since this country is a part of the Gulf of Guinea. The monsoon is an oceanic wind that blows from South, while the harmattan blows from Northeast from Sahelian regions. Assessing the energy available from these winds is an essential step not only in estimating the size of the wind resource, but also in identifying suitable sites for wind turbine installation in the country. Recent study showed that maximum wind speed in Yamoussoukro, central part of Côte d'Ivoire varies between 3.02 and 4.96 m/s depending on the month of year (Jean-Michel Soumien Kouadio, 2024). In this study, a measuring station was used to collect wind data in an urban area. Then, Souleymane TUO et al.(2023) showed that the wind in the region of Man is relatively weak with wind speed lower than 2 m/s at 10 m from the ground. The city of Man is one of Côte d'Ivoire's mountainous regions (Souleymane TUO, 2023).

However, these studies remain localised. In addition, they were carried out at an altitude of 10 m. Wind resource prospecting at many altitudes higher than 10 m is essential. Recently, Mariam et al. showed by comparing in situ data recorded at 10 m from ground level in Man synoptic station that COPERNICUS satellite data are reliable and can therefore be used to assess wind energy potential in Côte d'Ivoire (Mariam, et al., 2023). In addition, they proposed the use of satellite data to assess wind energy at different levels, thus compensating the lack of large-scale measurement stations in the country. This study uses satellite data to assess wind energy resources at different levels in Abidjan, Bouaké, Man and Korhogo, located in the South, Center, West and North of Côte d'Ivoire respectively. Fig. 1 shows the location of the selected cities for this study in Côte d'Ivoire.

Abidjan, Bouaké, Man and Korhogo belong to the main homogenous rainfall pattern zones of Côte d'Ivoire according to the study of (COULIBALY, et al., 2019). The lack of observed wind data in these cities (synoptic stations) due to breakdown of the wind materials, led to exploring satellite data of Copernicus Center in this study. In addition, these cities are urbanized and densely populated. Industrialization, trade, services and transport dominate the economic activities in these cities. The topographic pattern of Côte d'Ivoire is generally dominated by plains and plateaus, except the Western part of the country where there are high mountains reaching more than 1,000 m, such as Mount Nimba (1,752 m).

Table 1
Coordinates of the study cities.

Stations	Longitudes (°)	Latitudes (°)	Altitude (meters)
Korhogo	−5.62	9.42	381
Bouaké	−5.07	7.73	375
Man	−7.52	7.40	339
Abidjan	−3.93	5.25	7

Source: Société d'exploitation et de développement aéroportuaire aéronautique et météorologique (SODEXAM).

2. Data and methods

2.1. Data

Hourly wind data at different levels for 10 m; 100 m and 500 m from 2015 to 2022 are used in this work. This parameter has two components: speed and direction. These data were extracted for Abidjan, Bouaké, Man and Korhogo in the Copernicus climate database (HERSBACH, et al., 2023). The coordinates of the cities are given in Table 1.

2.2. Methods

2.2.1. Frequency analysis for wind roses

Frequency analysis for wind roses is used to obtain annual wind roses for each station. For this, wind roses are run with hourly data from 2015

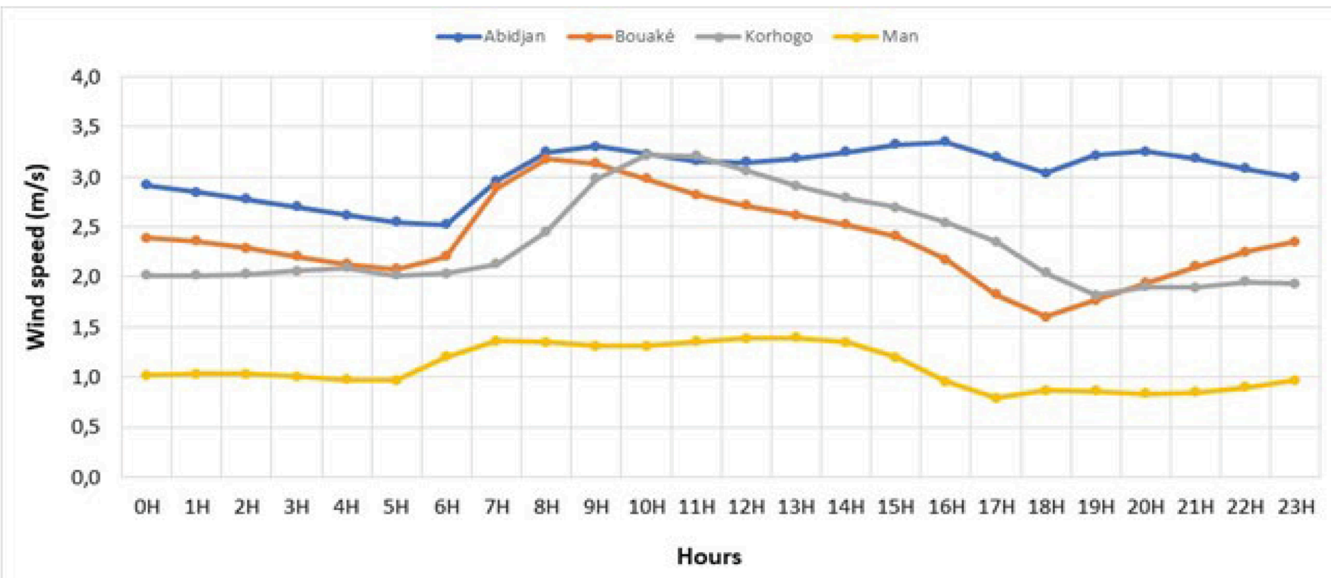

Fig. 2. Evolution of hourly wind speed in Abidjan, Bouaké, Korhogo and Man. Source: Our treatments, 2024.

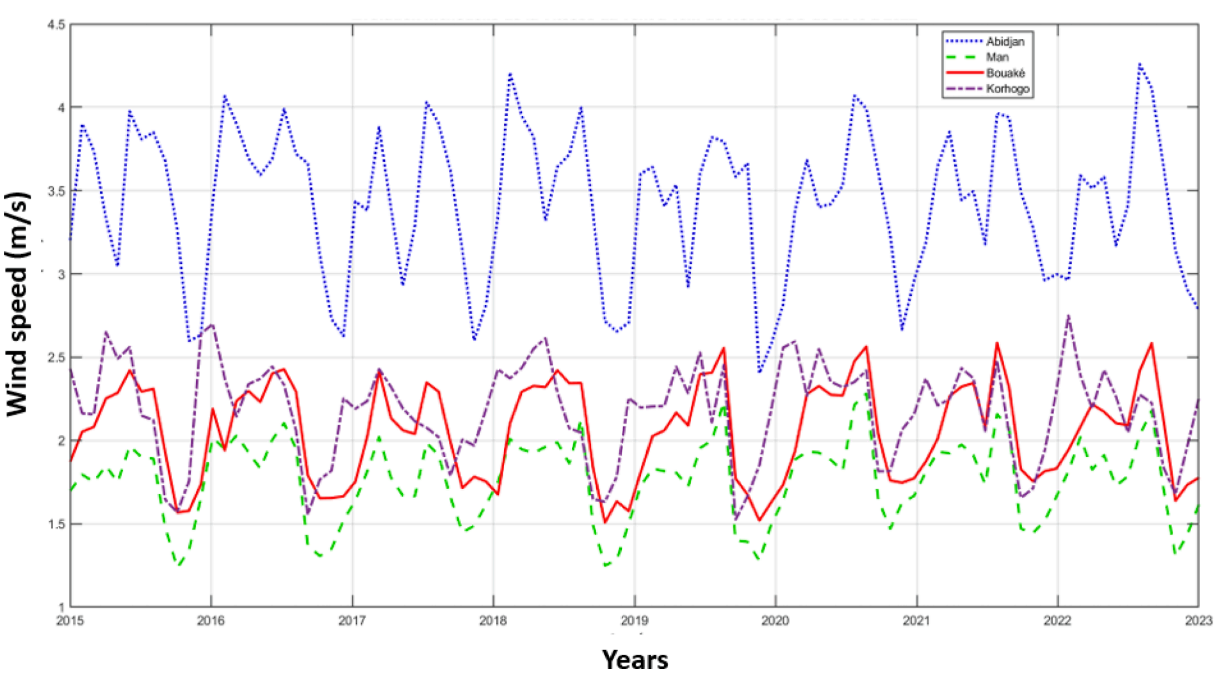

Fig. 3. Interannual evolution of wind speed at the surface (level 10 m) in Abidjan, Bouaké, Man and Korhogo. Source: Our treatments, 2024.

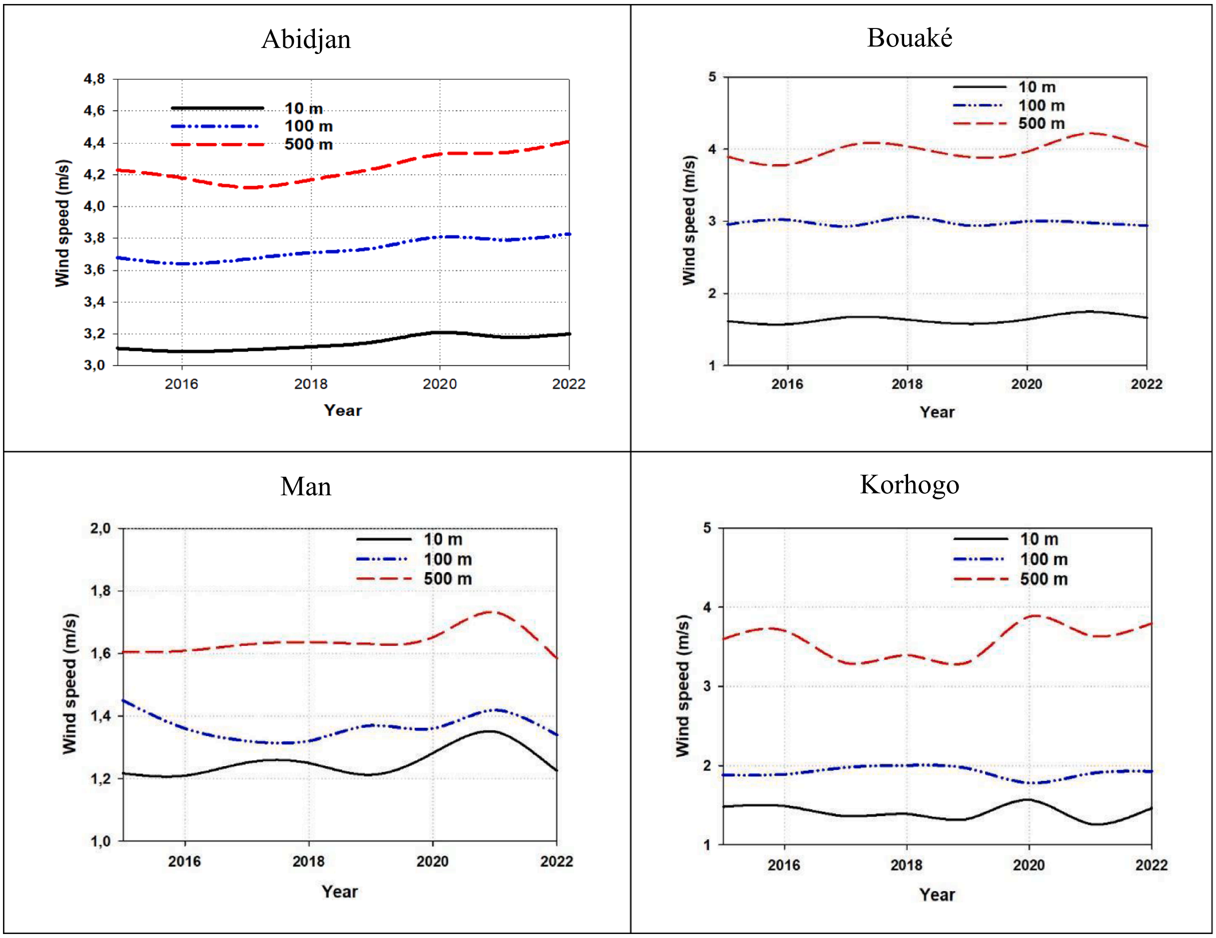

Fig. 4. Evolution of wind speed profile for Abidjan, Bouaké, Man and Korhogo at 10 m, 100 m and 500 m level from 2015 to 2022. Source: Our treatments, 2023.

to 2022. Wind roses show the dominant wind directions and speeds at a given time and location.

2.2.2. Power density method

Power density is a key parameter for assessing the wind potential of an area. Considering the air density $\rho = 1.225$ kg/m^3 and the average wind speed $\underline{V}$, the available power density is estimated by equation (TIESSE, 2020) (Adaramola et al 2014; TIESSE 2020)

$$P_{rec} = \frac{1}{2} \times \rho \times \underline{V}^3$$

The power density of wind is be calculated for three levels (10; 100 and 500 m). This density is also determined for each station.

3. Results and discussion

3.1. Hourly wind speed

Hourly wind speeds over one year at 10 m are analysed for Abidjan, Bouaké, Korhogo and Man. This analysis aims to show the period of maximum and minimum wind speeds for these locations.

Fig. 2 shows the evolution of hourly wind speed in Abidjan, Bouaké, Korhogo and Man. In Abidjan, hourly wind speeds vary from 2.5 to 3.3 m/s. The minimum speed is reached in the morning at 6H and the maximum in the afternoon at 16H. In Bouaké, hourly wind speeds vary from 1.6 to 3.2 m/s. The minimum speed is obtained at 18H in the afternoon and the maximum at 8H in the morning. In the locality of Korhogo, hourly wind speeds vary from 1.8 to 3.2 m/s. The minimum speed is reached at night at 19H and the maximum in the morning at 10*H*. For Man, hourly wind speeds vary from 0.8 to 1.4 m/s. The minimum speed is reached at 17H in the afternoon and the maximum in the afternoon at 13H.

3.2. Interannual variability of wind speed at 10; 100 and 500 m levels

Fig. 3 shows interannual variability of wind speed from 2015 to 2022 for Abidjan, Man, Bouaké and Korhogo in Cote d'Ivoire at the surface (level 10 m).

This Fig. 3 shows that the surface wind speed in Abidjan is higher than Bouaké, Korhogo and Man over the period from 2015 to 2022. In Abidjan, the lowest wind speed is 2.4 m/s in 2020, while the highest is 4.3 m/s in 2022. These results are in line with those published by the ECOWAS Renewable Energy Policy Baseline Report (CEDEAO, 2012). This high wind speed in Abidjan is due to its proximity to the Gulf of Guinea. Sea winds are stronger. The monsoon is a wet, strong wind that can provide considerable mechanical energy, making it ideal for wind farms. In Bouaké, Man and Korhogo, the lowest velocity value is 1.3 m/s and the highest is 2.7 m/s. Man has the lowest wind speed from 2015 to 2022. These ranges of wind speed in Abidjan, Bouaké, Man and Korhogo show that the velocity of wind is lower in Côte d'Ivoire. So, in the Center, West and North of Cote d'Ivoire, wind speed decreases with the presence of numerous obstacles at the surface (Ólafsson, 2000). This could explain why the wind is so weak in Man, a mountainous and forested area.

Although there are similarities in the interannual variation of wind speeds in different locations, it is important to note that a particular type of wind dominates each location. Wind in Côte d'Ivoire is made up of two major air masses: the monsoon and the harmattan. The monsoon is a

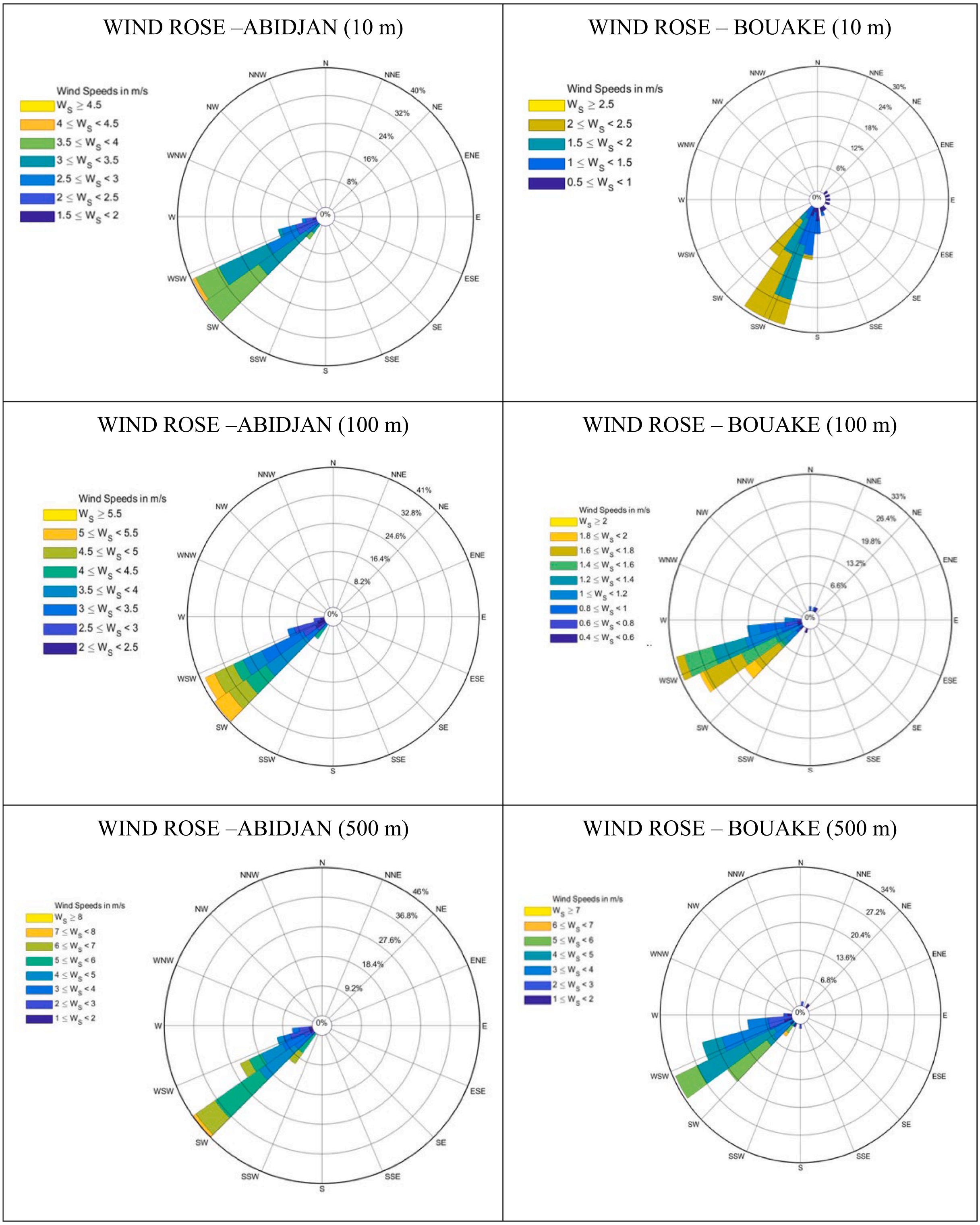

Fig. 5. Wind roses at 10 m, 100 m and 500 m levels in Abidjan and Bouaké. Source: Our treatments, 2023.

humid oceanic wind. It is more intense in the south, while the harmattan, dry, hot Sahelian wind dominates the North of the country (TAUPIN, et al., 2002). The predominance of each wind during the year is determined by the position of the intertropical front (ITF). Thus, the total wind speed at a given time of year in a given locality is dependent on the intensity of each of these two types of wind.

After this analysis, it is necessary to explore the profile of wind speed for different levels in Abidjan, Bouaké, Man and Korhogo. Fig. 4 shows only the variation of wind speed in Abidjan at 10 m, 100 m and 500 m from 2015 to 2022.

Fig. 4 shows that wind speed increases with the level (altitude) in Abidjan, Bouaké, Man and Korhogo. Determining the altitude from which wind speed is strong is an important parameter for wind turbine size. It also determines both the choice of the mast's height and the length of blades. To reach high altitudes, it's therefore essential to study vertical wind turbines. Wind speed is much higher for Abidjan than

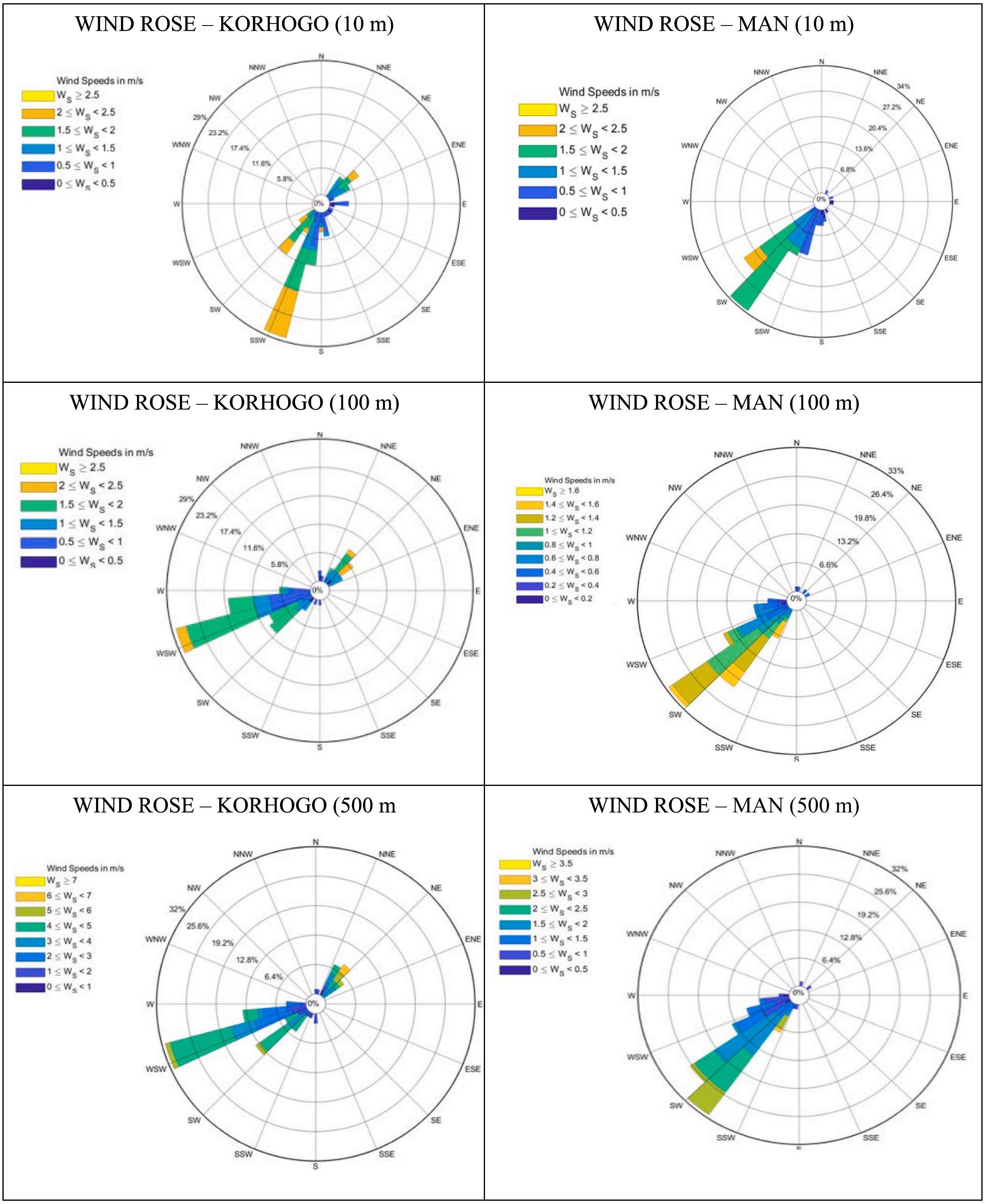

Fig. 6. Wind roses at 10 m; 100 m and 500 m in Korhogo and Man. Source: Our treatments, 2023.

Bouaké, Man and Korhogo. So, Abidjan seems to be the best zone to implement Enercon wind turbines models (Soulouknga, 2022) or other model (Muyiwa S. Adaramola, 2014). Some wind turbines generally start to run at least with 2 m/s, and masts of varying heights (Mohamadi et al 2021, Ugur et 2013, Casini M. 2015; Pallabazzer 1995). In fact, average wind speed at the surface (10 m) in Abidjan is more than 2 m/s. In Bouaké, Korhogo and especially Man, it is essential to explore high altitudes to get the minimum speed of 2 m/s for starting up industrial turbines. This result suits with the conclusion of (Mariam, et al., 2023) where they suggest exploring mountain peaks to increase wind turbine production for wind power in Côte d'Ivoire and particularly in the Tonpki region (Western part of Côte d'Ivoire). The knowledge of wind direction is very important for the implementation of turbines for wind power. Also, in Cote d'Ivoire there are two types of wind depending on seasons. So, the next section will explore wind dominant direction through wind roses at different levels.

3.3. *Wind roses at 10 m; 100 m and 500 m levels*

Figs. 5 and 6 show wind roses at 10 m, 100 m and 500 m for Abidjan,

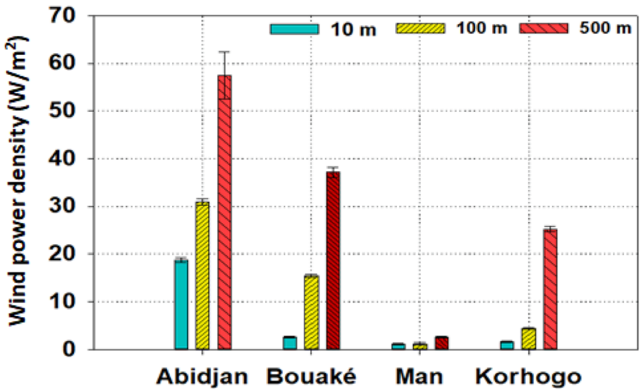

Fig. 7. Wind power density as a function of height in Abidjan, Bouaké, Man and Korhogo. Source: Our treatments, 2024.

Bouaké, Man and Korhogo. They show the wind direction at different altitudes in each of the cities considered. Ayua et al (2023) presented a similar study on certain regions of Gambia.

Wind roses of Abidjan, Bouaké, Man and Korhogo indicate the frequency of wind direction according to the speed distribution for levels 10; 100 and 500 m. In Abidjan, winds of 3.5 m/s to 4 m/s blow from the Southwest. These are monsoon winds. This type of wind also blows in Man, but at relatively low speeds of between 1.5 and 2 m/s. Winds in Bouaké are generally south-westerly. This suggests that the monsoon also governs Bouaké. The monsoon is the south-westerly wind that blows in the north-east of Côte d'Ivoire. This type of wind is therefore dominant in the southern (Abidjan), central (Bouaké) and western (Man) regions. However, in Korhogo, in the north of the country, two dominant wind directions are detected: north-easterly and south-westerly. These correspond to harmattan and monsoon winds respectively. In fact, the wind roses for Korhogo show that the intensity of the monsoon is reduced compared with the wind roses for Abidjan. In addition, a north-easterly wind appears, indicating the presence of the harmattan. As one moves away from the coastal regions, the monsoon becomes less intense and the harmattan increases.

For Abidjan, Bouaké and Man, the dominante wind direction is Southwest for all levels. This confirms that the dominant wind in these regions is monsoonal. In Korhogo, two dominant wind directions are visible: South-westerly and North-easterly. The North-easterly direction indicates the dominance of harmattan. This confirms that Korhogo is generally blown by both monsoon and harmattan winds. Generally, whatever the level and the stations, the dominant direction of wind is Southwest and Northeast. The wind roses also show that wind speeds increase with altitude. It is therefore advisable to favour the high hills to capture high wind speeds for wind farm siting.

After characterizing wind speed and direction for different levels in Abidjan, Bouaké, Man and Korhogo, it is important to analyse the potential of wind to contribute to the production of wind power. This is important because wind power is considered as a renewable energy which can be implemented in Cote d'Ivoire.

3.4. *Wind power at different altitudes*

Fig. 7 shows wind power densities at different altitudes 10 m; 100 m and 500 m for Abidjan, Bouaké, Man and Korhogo.

For Abidjan, Bouaké, Man and Korhogo, power density is low at 10 m near the surface. However, it increases significantly with height. In Abidjan, power density varies from 19 W/m^2 at 10 m to 58 W/m^2 at 500 m. In Abidjan, Bouaké and Korhogo, power density is almost tripled between 10 m and 500 m altitude. In Man, power density remains low even at 500 m. The wind is globally considered as calm in this city (Souleymane TUO, 2023). This may be due to the topographical characteristics of the typically mountainous in this Western part of Cote d'Ivoire. Indeed, the Man region is surrounded by mountain ranges. These mountains seem to create an obstacle to the circular movement of the wind, thus reducing its power. For this reason, it would be wise for this area to make use of the mountain peaks. These mountains can reach heights of over 1000 m (Naon, 2019).

4. Conclusion

This work is carried out to assess wind energy potential for Abidjan, Bouaké, Man and Korhogo in Côte d'Ivoire, using satellite data. The availability of satellite data at different altitudes made it possible to overcome the limitations of ground observations. The study showed that wind speed in Abidjan is higher than the wind in Bouaké and Korhogo. Abidjan has a density of 58 W/m^2 at an altitude of 500 m, compared to 38 W/m^2 and 27 W/m^2 for Bouaké and Korhogo respectively. Man has the lowest wind potential, with only 3 W/m^2 at 500 m. Furthermore, wind speed and power density increase with the altitude Abidjan, Bouaké, Man and Korhogo.

CRediT authorship contribution statement

Daouda Kone: Methodology, Conceptualization. **Souleymane Tuo:** Writing – original draft. **Kolotioloma Alama Coulibaly:** Writing – review & editing. **Bi Tra Olivier Gore:** Validation, Software. **Kouakou Bernard Dje:** Software, Data curation. **Mariam Traore:** Visualization, Investigation. **Boko Aka:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jksus.2024.103579.

Data availability

Data will be made available on request.

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