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On Wind Speed and its Distribution Pattern: A Case Study of Some Selected Cities in Delta State, Nigeria

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P A P E R I N F O

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Wind is a significant weather variable and its study has gained convincing attention recently due to its increasing importance as a source of renewable energy as well as its role in various natural phenomena like erosion, precipitation, and spread of wildfires. This paper investigates wind speed distribution in Delta State, Nigeria using a nonparametric statistical technique for ten consecutive years spanning from 2011 to 2020 across three stations. The nonparametric statistical approach is the kernel density estimation with focus on Gaussian kernel estimator. The results of the investigated period revealed that wind speed in Asaba that is located in Delta North is higher in comparison with the wind speed in Patani which is situated in Southern region of the State while the wind speed is low at Sapele in Delta Central. Therefore, installation of wind power generation system is more profiting in the Northern part because the amount of wind energy generated is determine by the wind speed. Again, the performance of agricultural or industrial activities that depend on wind speed for their proper execution is optimum in 2018 while the least performances were recorded in 2015 and 2016 respectively for the period explored.

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NOMENCLATURE

AMISE	Asymptotic mean integrated squared error	NiMet	Nigerian Meteorological Agency
Kph	Kilometer per hour	$R(K)$	Roughness of kernel
$\hat{f}(y)$	Kernel estimator	$R(f'')$	Roughness of unknown probability function
h_y	Smoothing parameter	$\mu_2(K)^2$	Moment of kernel

INTRODUCTION

Several energy sources such as coal and crude oil exist as sources of power generation but these sources have been identified globally as sources of pollution to the environment as a result of the outflow of carbon dioxide (CO_2). Irrespective of the global awareness on greenhouse gas emission, the release of carbon dioxide (CO_2) into the environment is a major challenge because of the wastes generated by industries [1]. An increase in human population and industrialization urgently requires alternative sources of energy generation to eliminate the reliance on fossil fuels with its associated environmental pollution. As a result of the negative impacts of fossil fuels on the environment, governmental parastatals and nongovernmental agencies globally have guaranteed the reduction of their greenhouse gas emission to zero percent within the next three decades and this is in accordance with the recommendation of the Intergovernmental Panel on Climate Change to reduce the planet's warming [2]. Renewable energy sources therefore become the main alternatives to the traditional sources and one of the known sources is the wind energy which may be used either for agricultural or industrial purposes. Wind is air in motion which is a product of distinctive warming of the surface of the earth that produces diverse pressure in the

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atmosphere [3]. Wind energy is one of the popular renewable energy sources whose demand is increasing globally with most countries investing in wind farms for electricity generation. Nonetheless, wind energy as a renewable energy can only be exploited maximally in regions that possesses high wind speeds [4].

One of the mostly applied renewable energies for over a period of twenty-five years is the wind energy due to its natural friendliness and affordability. Wind speed is mainly utilized by wind energy turbines in the generation of energy for household and industrial uses [5]. As a result of the importance of wind, a good knowledge of wind speed is paramount and has attracted several researchers. One of the major challenges of meteorologists is accurate prediction of wind speed owning to the variability and randomness of wind; however, numerous predictive models have been suggested by researchers [6]. The traditional sources of energy like petroleum resources are contributing increasingly to environmental pollution and depletion of the ozone layer, hence wind energy is attracting momentous attention owing to its low cost-effectiveness. The efficient and effective utilization of wind energy can only be properly harnessed with timely and dependable wind speed forecasting techniques. Howbeit, there is the problem of accurate prediction of wind speed due to its randomness, intermittency, and instability [7, 8].

The focus on wind as one of the renewable energy sources and this is attributed to its clean nature and other numerous gains to mankind. The clean nature of wind energy and its low cost of generation unlike fossil fuel has greatly contributed to the wide attention that it has received [9]. In spite of the high cost of fossil fuels generation, the environmental pollution associated with its generation is a serious challenge. Hence; it is imperative to consider renewable energy sources such as wind, geothermal, biomass, tidal and solar for the generation of electricity since these energy sources are reliable in mitigating energy crises and also reducing environmental problems [10]. Wind energy is a clean source of energy and its extraction has long been used and traceable to pre-historic era. The energy from wind has also been found to be of great uses in agriculture particularly in pumping of water from water bodies for irrigation and grinding of grains [11]. Currently, global application and request for wind energy is seriously increasing due to its clean and exhaustless nature and also has been environmentally-safe as a perfect substitute for fossil fuels.

In 2015, the United Nations General Assembly (UNGA) clearly outlined the general guide lines on the sustainable development goals (SDG'S) about planet earth. The vision 2030 that consists of three components has one of its vital components as sustainable energy and environment in which case the green energy is the focal point due to its reliability, affordability and accessibility. The aim of vision 2030 is to ensure that there is availability of energy in the future through renewable sources with minimal negative effects on the environment [12]. Recently, the whole world is increasing its pattern of electricity generation through renewable sources wherein wind energy generation has occupied a leading position over other renewable sources. Wind energy is a natural and irregular source of energy and due to its irregular nature, the efficiency is somewhat low in comparison with other conventional energy sources. Nevertheless, conventional sources are associated with the problems of environmental pollution and climate contamination and this makes wind energy to be advantageous [13]. Wind energy is one of the popular renewable energy sources with several benefits like preservation of environment and integrated energy applications. In the last decade, renewable energy sources have contributed more than 25% of the total energy consumption worldwide and this has improved the socio-economic gains and proper usage of public funds in nations wherein they are operational because of low cost of generation [14]. Several nations of the world are trading the part of renewable energy sources for electricity generation and this pattern is on an increase globally [15].

Wind energy is viewed as green innovation because it has a negligible negative consequence on the environment. Industrial machines used in several energy utilization segments are frequently generating corrupted gases that pollute the atmosphere and the surroundings which ultimately leads to global warming and the resulting effects amounting to climate change that is the greatest threat to human existence [16]. On the global perspective, it is typically imagined and accepted that the effects of wind power on the environment is always positive which is at variance with the conventional practice of generating power from fossil fuels. Nonetheless; all forms of energy sources do have an impact on its surroundings and the economy and the wind energy is also inclusive [17]. As a results of the increasing demand of wind power within the last decades and its potential future demand, it is pertinent to have a systematic appraisal of its impacts on the environment and economy by evolving techniques to mitigate the negative impacts for the general advancement of humanity ecologically and economically. Ongoing researches are targeted towards the advantages of wind energy with only few researchers considering some unforeseen negative environmental impacts such as noise pollution, greenhouse gas emissions and land surface influence amongst others [17, 18].

As a result of the global increasing demand of electricity consumption and the low cost of electricity generation through wind energy with the associated increasingly cost of electricity generation from fossil fuel accompanied with its negative environmental impacts, the achievement of the affordable and clean energy of the United Nations Sustainable Development Goal (SDG) will only be realistic when attention is fully deviated from the fossil fuel. Generally, the generation of electricity via renewable energy sources like wind energy will significantly lead to improvement and protection of the environment [19]. Despite the fact that wind energy is one of the vital renewable sources of electricity generation, its dependability can be hampered greatly by the impacts of climate change. The global yearning for wind energy as a perfect substitute for fossil fuel in relation to power generation should consider the interconnectivity between wind energy and climate change because the availability of wind resources can be affected by climate change owing to possible changes in the future [20]. Several studies have established that climate change have the potentials of affecting the supply of wind energy and excessive natural events like heavy rainfall, heat waves, wet snow and extreme droughts are capable of reducing the supply of wind energy and thereby causing disruptions that ultimately affect the quality and regularity of supply of energy [21, 22]. Hence, knowledge of the accessibility of wind resources and susceptibility to climate change is a requirement for the demand of renewable energy resources particularly wind energy. One of the undeniable facts about climate change and wind resources is that the availability of wind resources can be affected by climate change due to its variability and several studies have proven the impacts of climate change on wind speed and energy [23–26].

Wind energy is the backbone of power generation system that provides essential and dependable services in the energy sector. Wind power is also regarded as the bedrock of energy sources in electricity production that is capable of replacing the conventional system of electricity generation using fossil fuels. The current demand of electricity for global infrastructure is greatly on the increase and future clean power generation depends on wind energy. In the interim, wind energy is ever-increasing in electricity generation which will undoubtedly expand the pace of infrastructural development globally [27–29]. Despite the importance and demand for renewable resources like wind, the concern of continuity is critical in the realization of clean energy because the available resources must meet the energy demands for purposes of heating homes and powering cities. Although renewable resources do not deplete, nevertheless the long-run usage should be critically evaluated [30–32]. Wind energy has been widely accepted as a cheap and reliable renewable energy resource, the limitation of its application is that occasionally it may be irregular in supply in some part of the world especially during winter months when the demand for electricity is very high while the supply of wind is weak [33, 34].

As a nation, Nigeria is at the verge of having energy crisis with incessant dependence on the traditional sources of energy. Irrespective of the enormous capital investment on electricity generation by the Nigerian government, the supply of electricity has been insufficient for the growing population and a large percentage of the populace do not have access to steady supply of electricity. The erratic supply that characterizes the Nigerian electricity system have in no small measure affected the population and the growth of the economy which aggravated the poverty level of the citizenry and the nation [35]. It is therefore imperative that other renewable sources of energy like wind that have been discovered as a major source of energy for electricity generation should be urgently considered by the Nigeria government for developmental purposes. Wind energy can provide electricity for several rural communities in Nigeria and can also serve as a way out of the epileptic power supply at cost-effective manner. The economic and agricultural activities of rural areas can be improved if there is a constant power supply.

Wind energy is one of the important renewable resources but besides being a significant renewable resource, wind plays a fundamental role in season determination in Nigeria. The dry season in Nigeria is usually between November to February in the Southern part while the Northern part experiences its dry season between October to April with the other months of the year been wet season and these two seasons are majorly regulated by wind. The wind that brings rainy season is known as South-West trade wind and it is a dust free wind that emanates from the Atlantic Oceans. Similarly, the North-East trade wind occurs from November till February and in some cases can be extended to March and is typically accompanied with dust (Harmattan) that brings the dry season [36]. Seasonal variations are primarily determined by wind and it should be noted that wind is also responsible for the transportation of clouds, fog, water vapor and precipitation. Wind speed is the main driver of seasons in Nigeria and it ranges from 2m/s to 9.5m/s such that the speed is low in Southern part and increases gradually towards the Northern part of Nigeria [37, 38]. The investigation of wind speed as a climatic variable is therefore very crucial owing to the huge potentials of wind energy when harnessed maximally. This paper examines the distribution of wind speed statistically across Delta State using three selected locations/stations with the nonparametric kernel density estimation technique.

Several studies have been carried out on weather parameters such as temperature, relative humidity and rainfall in Delta State while wind speed is oftentimes neglected due to the inability of private individuals and government to harness the potential benefits of wind energy. The global renewable energy drive is a clarion call of which Nigeria as a nation should not be exempted. The study conducted by Idris et al. [35] investigated the availability of wind energy resources for the generation of power across several locations in Nigeria and the results of the study revealed that southern Nigeria has low wind speed besides the coastal areas while northern

Nigeria depicts wind speed that is capable of generating electricity for large-scale uses. Similarly, the research performed by Oyewole and Aro [36] on wind energy has established that Nigeria has the potentials of installation of wind energy system that is capable of generating electricity for household and industrial uses. In the same vein, Danlami et al. [37] discussed wind speed in relation to seasonal variation particularly in the north-eastern part of Nigeria and discovered that wind speed varies temporally and spatially with latitudes. Again, Elemo et al. [38] provided a comprehensive information on the inter-connectivity amongst maximum wind speed known as gusty winds and average wind speed in Abuja, Nigeria.

MATERIAL AND METHODS

The investigated data is the daily wind speed collected from the archives of the Nigerian Meteorological Agency (NiMet) in Delta State from January 1st to December 31st of 2011 to 2020 [39]. The nonparametric probability density method of data estimation is applied in analyzing the data with the Gaussian kernel function. The choice of the nonparametric approach is hinged on the fact that wind speed data are naturally provided and the Gaussian kernel function which is one of the prominent methods of data analysis is of immerse applications because it is frequently used in modeling real-life occurrences. The compact form of the one-dimensional kernel estimator is:

$$\hat{f}(\mathrm{y}) = \frac{1}{nh_\mathrm{y}}\sum_{i=1}^{n} K\left(\frac{\mathrm{y}-\mathrm{Y}_i}{h_\mathrm{y}}\right), \quad (1)$$

with $K(\cdot)$ representing the kernel function, h_y is the bandwidth that controls the smoothness of the estimate, n is the sample size, y is usually the interval of the data while Y_i are the observations to be investigated [40]. The application of kernel estimator in data analytics is contingent on the bandwidth for its successful implementation and numerous bandwidths selectors have been regularly introduced by researchers [41]. The kernel estimator in Equation (1) is mostly a probability density function that satisfies the following axioms

$$\int K(\mathrm{y})d\mathrm{y} = 1, \int \mathrm{y}K(\mathrm{y})d\mathrm{y} = 0 \text{ and } \int \mathrm{y}^2 K(\mathrm{y})d\mathrm{y} \neq 0. \quad (2)$$

The conditions in Equation (2) implies that kernel functions are probability density functions with the resulting integral always one as well as a mean of zero and variance that is not zero. The performance of the kernel estimator can be accessed by several performance metrics but the asymptotic mean integrated squared error (AMISE) is mostly used due to its mathematical tractability. The AMISE comprises of two components; asymptotic integrated variance and asymptotic integrated squared bias which is of the form

$$AMISE\left(\hat{f}(\mathrm{y})\right) = \frac{R(K)}{nh_\mathrm{y}} + \frac{1}{4}\mu_2(K)^2 h_y^4 R(f''). \quad (3)$$

In Equation (3), $R(K)$ is the roughness of kernel while $\mu_2(K)^2$represents the kernel variance and $R(f'') = \int f''(\mathrm{y})^2 dy$ is the roughness of the unknown probability function which is the Gaussian kernel function in this study [42–46]. The value of the AMISE can be ascertained by the optimum bandwidth given as

$$h_{\mathrm{y-AMISE}} = \left[\frac{R(K)}{\mu_2(K)^2 R(f'')}\right]^{1/(d+4)} \times n^{-1/(d+4)}. \quad (4)$$

The numerical value of Equation (4) usually produces the smallest AMISE value. Accurate selection of the bandwidth is crucial in kernel estimation techniques and numerous researchers have addressed this challenge with recent novel approaches [47–49]. The roughness of the Gaussian distribution is of the form

$$R(f'') = \int f''(\mathrm{y})^2 dy = \frac{1}{\sigma^{(d+4)}}\left\{\left(2\sqrt{\pi}\right)^{-d}\left(\frac{d}{2}+\frac{d^2}{4}\right)\right\} = \left(\frac{d(d+2)}{4\left(2\sqrt{\pi}\right)^d}\right)\sigma^{-(d+4)} \quad (5)$$

Hence, if the univariate Gaussian kernel function is employed with the numerical values of its roughness and variance, then the bandwidth in Equation (4) becomes

$$h_{\mathrm{y-AMISE}} = 1.06\sigma \times n^{-5}, \quad (6)$$

where σ is the standard deviation of the observations and n is the sample size. The bandwidth in Equation (6) is often called the normal reference rule. The choice of the Gaussian distribution is due to its computational advantages unlike other distributions with complex computational process and implementation. A plethora of studies on climatic variables have been investigated by several authors using different statistical approaches and with novel findings [50–52].

Location of study area

The three locations investigated are Asaba in Delta North, Patani in Delta South and Sapele in Delta Central. Asaba is located in Oshimili South local government area and it is the seat of government of Delta State while Sapele is the administrative headquarters of Sapele local government area. Patani is also the local government headquarters of Patani local government area [53]. The locations/stations considered in terms of regional divisions with their latitudes and longitudes as well as the period of investigation are in Table 1.

Delta State is one of the States situated in the oil rich Niger Delta region which is in the South-South geopolitical Zone of Nigeria. The State is located on latitude 5° North of the equator and longitude 6° East and occupied an estimated landmass of $22{,}159{,}000\mathrm{m}^2$ with a population of about 4,098,398 people by the National Population Census of 2006 [54] and a current population of over 5.5 million people. The State comprises of twenty-five Local Government Areas (LGA) and the administrative headquarters of Delta State is Asaba which is located in the Northern part of the State. Delta State has

Table 1. Station, regional division, latitude, longitude and period of the data examined

S/N	Station	Region Division	Country	Latitude	Longitude	Period of Data
1.	Asaba	Delta North	Nigeria	6°11′53.66″N	6°43′54.73″E	2011–2020
2.	Patani	Delta South	Nigeria	5°13′38.06″N	6°11′32.57″E	2011–2020
3.	Sapele	Delta Central	Nigeria	5°53′38.58″N	5°40′35.98″E	2011–2020

boundaries with five States, Edo State towards the North and Ondo State in the North-West while to the East is Anambra State and on the South is Bayelsa State with the South-East being Rivers State. Also, towards the South-West, Delta State is bounded by the Bight of Benin that occupies almost 160km of the States in the coastline [53] (see Figure 1).

Generally, Delta State has low land with no noticeable hills or mountains in the Southern part and the climate ranges from humid in the South to sub-humid in the Northern part with a reduction in humidity towards the North which usually proceeds increasing dry season. However; in Northern part of the State, there are noticeable hills and mountains especially in Ika and Aniocha local government areas. Typically, the temperature of Delta State is between 25°C and 28°C and it exhibits similar climatic characteristics with the other States in Niger Delta region [55]. The climatic condition of Delta State is commonly known for two distinctive seasons; namely rainy season and dry season. The rainy season commences from April to October with some days experiencing no rain in the month of August known as August break while the dry season begins from November to March. The vegetation of Delta State varies between the mangrove swamps with the evergreen forest and with annual rainfall of 2265mm in the coastal regions and 1905mm in the core North [56].

RESULTS AND DISCUSSION

The descriptive statistics of the wind speed data obtained from the three locations are in Table 1. The analysis of the data numerically and graphically is with the aid of

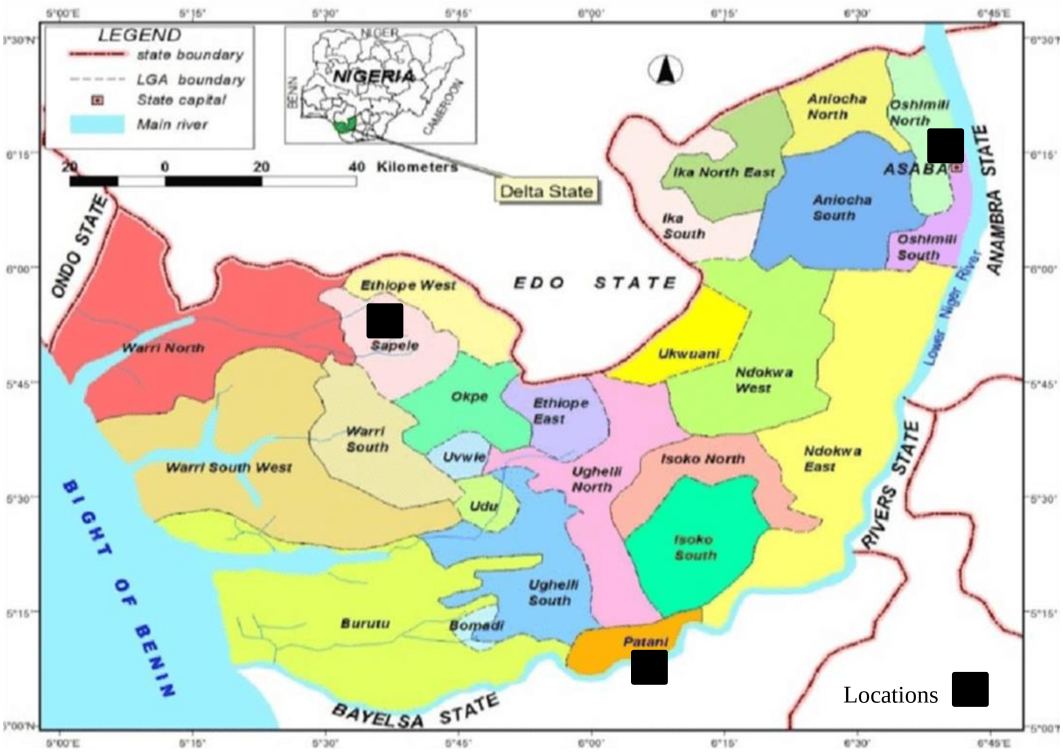

Figure 1. The Map of Delta State showing the study areas and Neighboring States [53]

Mathematica version 12 software. Data visualization is vital in statistics due to the fact that inherent statistical features of data can be revealed and decisions or policies can be made in respect of the available information.

The standard deviation which determines the spread of the data clearly revealed that the wind speed data of Asaba are well spread unlike the standard deviations of the data of Patani and Sapele that consistently maintained a low standard deviation values. Also noted in Table 2 is the mean values of the period investigated and from the results, the mean of Asaba is the largest amongst the three locations followed by Patani while Sapele produces the least mean values. Again, this pattern is the same for the study periods in the three locations which is an indication that the standard deviations and mean values of wind speed decreases from the North to Southern part. The decrease in values of standard deviations and mean values from North to the Southern part is occasioned by the magnitude of the wind speed from the three locations. A critical examination of the results in Table 2 vividly reveals that wind speed of Asaba is higher than other locations both in minimum and maximum values of the

Table 2. Descriptive statistics of wind speed (Kph) of the three locations for the ten years

Years	n	Locations	Min.	Max.	Mean	SD	Skewness	Kurtosis
2011	365	Asaba	3.18	13.79	6.8369589	1.9644801	0.60929032	3.0229189
		Patani	3.05	13.22	6.5579178	1.8843763	0.60629042	3.0110750
		Sapele	2.99	12.94	6.4196164	1.8424394	0.60669871	3.0173608
2012	366	Asaba	3.18	12.73	8.2906011	1.8988334	–0.0546665	2.4631249
		Patani	3.05	12.20	7.9524590	1.8201345	–0.0605264	2.4624608
		Sapele	2.99	11.94	7.7830874	1.7798427	–0.0580397	2.4618768
2013	365	Asaba	4.24	12.73	8.5205753	1.6475675	–0.2375930	2.6064059
		Patani	4.07	12.20	8.1695068	1.5829696	–0.2492211	2.6112694
		Sapele	3.98	11.94	7.9874906	1.5530507	–0.2407086	2.5961824
2014	365	Asaba	4.24	12.73	8.3394521	1.7493951	0.07156209	2.5155393
		Patani	4.07	12.20	7.9994795	1.6763256	0.06580284	2.5163554
		Sapele	3.98	11.94	7.8292055	1.6395087	0.06722714	2.5153086
2015	365	Asaba	3.18	12.73	7.6121369	1.4960813	0.15197139	3.2518065
		Patani	3.05	12.20	7.3030958	1.4356338	0.14450480	3.2378548
		Sapele	2.99	11.94	7.1475068	1.4031603	0.14855832	3.2456170
2016	366	Asaba	4.24	10.61	7.3305464	1.4564389	0.16154471	2.5108345
		Patani	4.07	10.17	7.0325137	1.3979693	0.15614583	2.4987404
		Sapele	3.98	9.95	6.8832240	1.3663724	0.15895108	2.5050553
2017	365	Asaba	4.24	13.79	7.8539452	1.8535294	0.56473964	3.2219064
		Patani	4.07	13.22	7.5341369	1.7771117	0.55799577	3.2121775
		Sapele	3.98	12.94	7.3737808	1.7374899	0.56155364	3.2187315
2018	365	Asaba	4.24	14.85	8.3281918	2.0392818	0.17259155	2.5282339
		Patani	4.07	14.24	7.9880822	1.9544981	0.16819476	2.5278643
		Sapele	3.98	13.94	7.8181369	1.9113705	0.16975843	2.5283703
2019	365	Asaba	4.24	12.73	7.7809863	1.6271769	0.36538105	3.2196014
		Patani	4.07	12.20	7.4647123	1.5603469	0.35770789	3.2068282
		Sapele	3.98	11.94	7.3052603	1.5256288	0.36089850	3.2132834
2020	366	Asaba	4.24	13.79	8.0638798	1.6207979	0.61951992	3.5935222
		Patani	4.07	13.22	7.7360109	1.5538087	0.61170504	3.5836933
		Sapele	3.98	12.94	7.5712022	1.5197554	0.61570029	3.5862047

period examined and that shows the Northern part of the State experiences more wind than the Central and Southern parts.

On skewness of the wind speed, the investigated periods revealed that data of two years, that is, 2012 and 2013 were negatively skewed as presented in Table 2 and this is also in accordance with their kernel estimates as displayed in Figures 2b and 3a, respectively. Apart from 2012 and 2013 that are negatively skewed, all other years of the investigated periods are positively skewed with the positive skewness been obviously noticed in 2011, 2017, 2019 and 2020 as shown in Table 2 and their kernel estimates respectively. On the investigation of the peaks of the kernel estimates, the kurtosis which measures the peak of the data clearly shows that the kurtosis values were high for 2011, 2015, 2017, 2019 and 2020 as shown in Table 2 and this is also seen in their respective kernel estimates. Again, it should be noted that the highest kurtosis values are recorded in 2020 while the least values are recorded in 2012.

The kernel estimates of the investigated data in the three locations are in Figures 2 to 6 and the kernel estimates of the three locations obviously display similarities in most of the years.

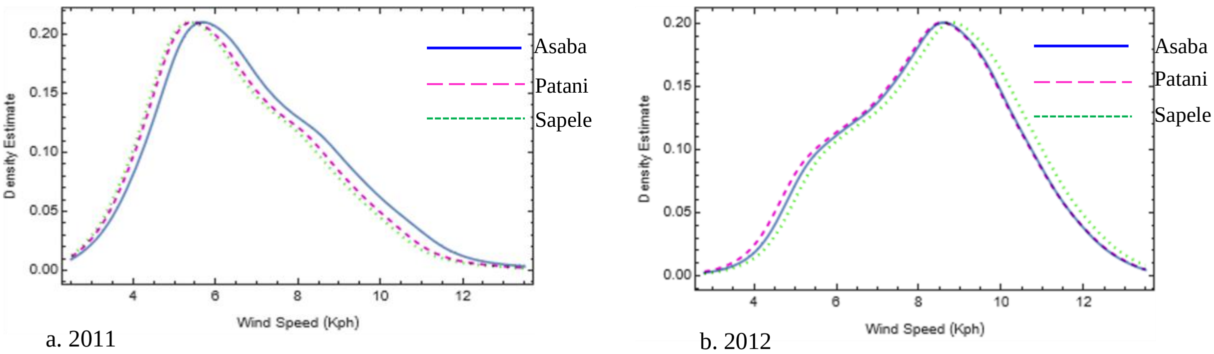

Figure 2. Kernel estimates of wind speed (Kph) data of the three selected cities for 2011 and 2012

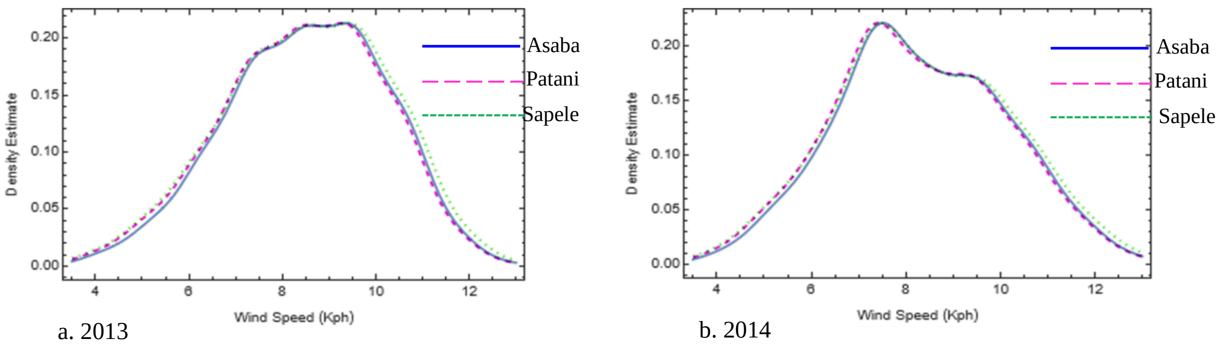

Figure 3. Kernel estimates of wind speed (Kph) data of the three selected cities for 2013 and 2014

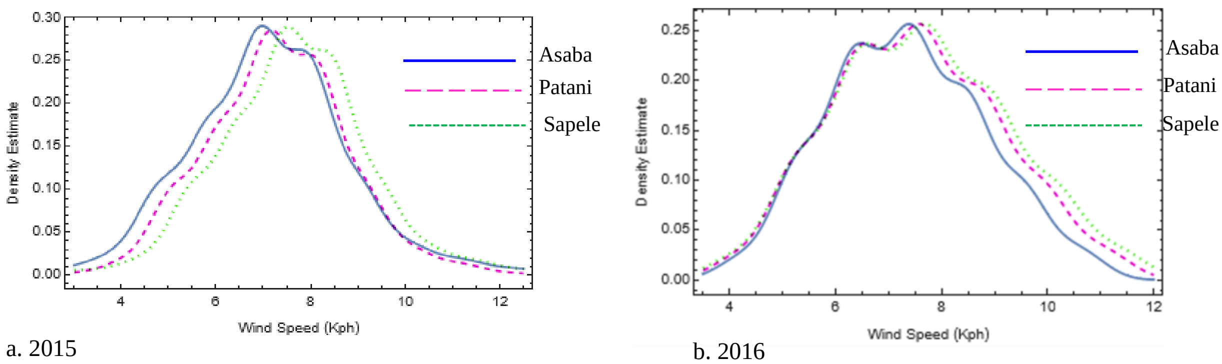

Figure 4. Kernel estimates of wind speed (Kph) data of the three selected cities for 2015 and 2016

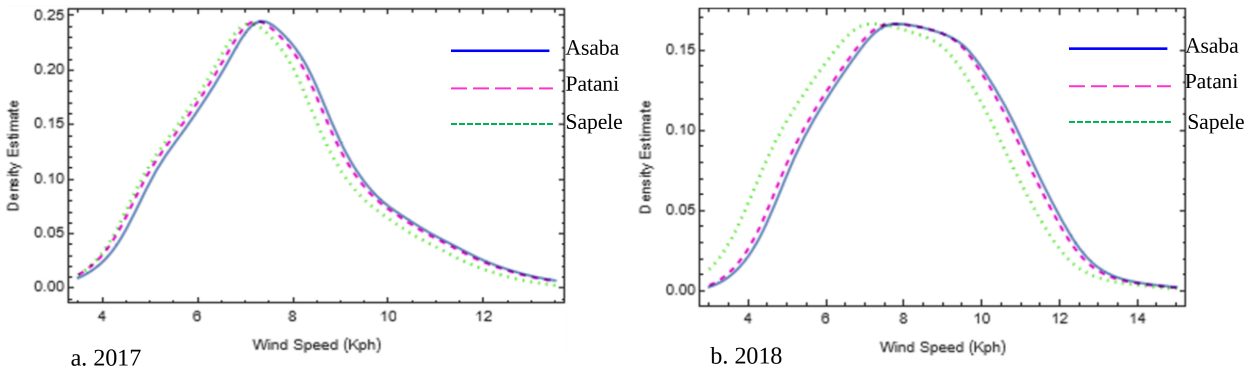

Figure 5. Kernel estimates of wind speed (Kph) data of the three selected cities for 2017 and 2018

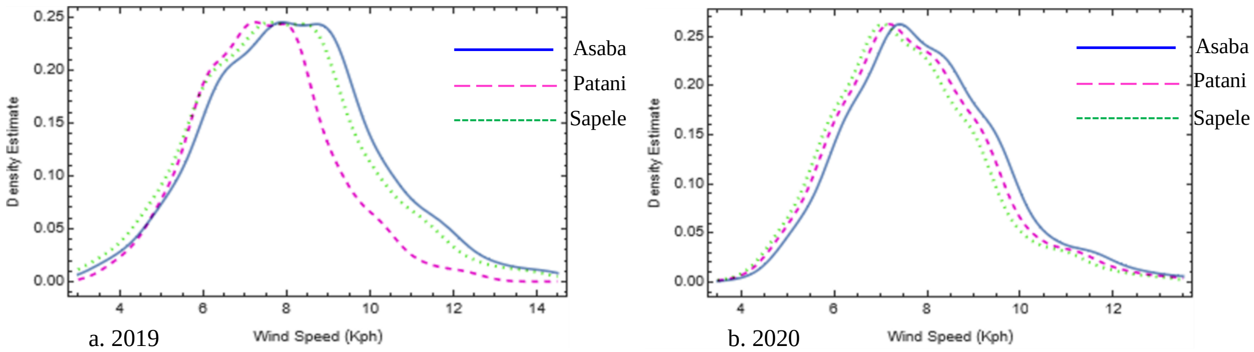

Figure 6. Kernel estimates of wind speed (Kph) data of the three selected cities for 2019 and 2020

The similarities of the kernel estimates are demonstration of the wind speed pattern in Delta State since the three locations are from the North, Central and Southern part of the State. Despite the similarities depicted by the kernel estimates of the three locations, the numerical assessments using the asymptotic mean integrated squared error (AMISE) as the performance metric has affirmed that the wind speed is higher in some years and locations. The bandwidths of the wind speed of Asaba, Patani and Sapele are denoted by h_a, h_p and h_s as well as their respective AMISE values are in Table 3. The bandwidths of Asaba are larger than the bandwidths of the other locations but with the least AMISE values. Again, as observed in Table 2, the numerical results in Table 3 also established that the wind speed in Asaba is higher than the wind speed of other locations and this is due to the production of the least AMISE values in all the studied periods. The locations with the smallest AMISE values are statistically regarded as the best locations with respect to the variables investigated [57, 58]. In the period under consideration, the minimum AMISE values are in 2018 and 2011 and this can be interpreted statistically that activities which depend on wind speed were productive in 2018 and 2011 than other years. The year with the best performance is 2018 because it produces the least AMISE values and can also be seen in the kernel estimates of the three locations. Moreover, 2018 is the year with the highest wind speed of 14.85 in Asaba, 14.24 in Patani and 13.94 in Sapele as shown in Table 2 which is followed by 2011 and 2017, respectively.

Again, the largest AMISE values were produced in 2016 across all the locations of which Asaba is 0.002033481, Patani is 0.002118531 and Sapele is 0.002167521. These values are higher than other values of the period studied. Statistically, it implies that activities which were wind speed reliant may not have performed optimally due to the inadequate supply of wind recorded. The numerical support of the AMISE values is also summarized in Table 2 where the wind speed of 2016 is the least across the locations investigated in which Asaba is 10.61, Patani is 10.17 while Sapele is 9.95. The immediate year in terms of weak performance in relation to the AMISE is 2015 with higher AMISE values in comparison with the other years investigated besides 2016. It should be noted that the numerical performances of 2015 and 2016 using the AMISE are well supported by the similarity of the kernel estimates of 2015 and 2016 as depicted in Figure 4.

Table 3. Bandwidths and AMISE of wind speed (Kph) of the three locations for ten years

Years	n	h_a Asaba	h_p Patani	h_s Sapele	$AMISE_a$ Asaba	$AMISE_p$ Patani	$AMISE_s$ Sapele
2011	365	0.639406	0.613334	0.599684	0.001510899	0.001575126	0.001610979
2012	366	0.617701	0.592099	0.578993	0.001559716	0.001627155	0.001663991
2013	365	0.536256	0.515231	0.505493	0.001801523	0.001875039	0.001911161
2014	365	0.569399	0.545617	0.533633	0.001696666	0.001770617	0.001810378
2015	365	0.486951	0.467275	0.456706	0.001983937	0.002067471	0.002115318
2016	366	0.473788	0.454767	0.444489	0.002033481	0.002118531	0.002167521
2017	365	0.603294	0.578421	0.565525	0.001601340	0.001670199	0.001708287
2018	365	0.663753	0.636157	0.622120	0.001455478	0.001518615	0.001552881
2019	365	0.529619	0.507867	0.496567	0.001824098	0.001902225	0.001945513
2020	366	0.527255	0.505463	0.494385	0.001827274	0.001906053	0.001948762

This study investigates the distribution of wind speed across Delta State using three specific locations. One of the most important benefits of wind energy which is electricity generation that is economical, clean and inexpensive have not been harnessed in Delta State. Apart from the natural functions of wind speed such as evaporation and regulation of landmass temperature, the State government as a matter of urgency should invest massively on wind farm for the generation of electricity towards the realization of the developmental agenda of the State in particular and contributing in general to the achievement of the seventeen sustainable development goals.

CONCLUSION AND RECOMMENDATIONS

This study reveals the pattern of wind speed distribution across Delta State using three designated locations. The wind speed is higher in Asaba which is situated in the Northern part of the State and with lowest values in Sapele located in Central part of the State while Patani in the South show values that are higher than Sapele but lower Asaba. The highest value of wind speed within the period investigated is recorded in Asaba with a numerical value of 14.85Kph in 2018 while the least value is 2.99Kph recorded in Sapele in 2011, 2012 and 2015. The statistical and numerical verification of wind speed distribution in Delta State in the last decade shows that Northern part of Delta State experiences more wind than the Southern part with high wind speed producing smaller AMISE values and vice-versa.

Irrespective of the undeniable role of wind energy in electricity generation, the authors suggest that government and private individuals should investigate the effects of other climatic parameters on wind speed before designing and installing wind power generating system in any location. This is because the amount of wind energy generated depends primarily on the wind speed. Hence, installation of wind power generation system in Asaba is highly recommended and will be profiting than Patani and Sapele respectively due to their low wind speed.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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Persian Abstract

چکیده

باد یک متغیر آب و هوایی قابل توجه است و مطالعه آن اخیراً به دلیل اهمیت روزافزون آن به عنوان منبع انرژی تجدیدپذیر و همچنین نقش آن در پدیده‌های مختلف طبیعی مانند فرسایش، بارش و گسترش آتش‌سوزی مورد توجه قانع کننده قرار گرفته است. این مقاله توزیع سرعت باد را در ایالت دلتا، نیجریه با استفاده از یک تکنیک آماری ناپارامتریک برای ده سال متوالی از سال ۲۰۱۱ تا ۲۰۲۰ در سه ایستگاه بررسی می‌کند. رویکرد آماری ناپارامتریک، تخمین چگالی هسته با تمرکز بر تخمین‌گر هسته گاوسی است. نتایج دوره مورد بررسی نشان داد که سرعت باد در آسابا واقع در دلتای شمالی در مقایسه با سرعت باد در پاتانی که در منطقه جنوبی ایالت قرار دارد بیشتر است در حالی که سرعت باد در ساپله در دلتای مرکزی کم است. بنابراین نصب سیستم تولید برق بادی در قسمت شمالی سود بیشتری دارد زیرا میزان انرژی باد تولیدی با سرعت باد تعیین می‌شود. مجدداً، عملکرد فعالیت‌های کشاورزی یا صنعتی که برای اجرای صحیح آن‌ها به سرعت باد وابسته هستند در سال ۲۰۱۸ بهینه است در حالی که کمترین عملکرد به ترتیب در سال‌های ۲۰۱۵ و ۲۰۱۶ برای دوره مورد بررسی ثبت شده است.