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STOCHASTIC MODELLING OF WIND SPEED OVER NORTHERN STATES IN NIGERIA

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ABSTRACT

This paper presents a stochastic modeling of wind speed over sixteen (16) Northern states in Nigeria using thirty-seven years (1984-2020) wind speed real time data. A Markov Chain Model was developed for the monthly wind speed state across study locations. In order to obtain the Markov chain transitional probabilities, the wind speed data was categories into various states using the Beaufort wind scale. It was observed that only the first four description of wind speed state A, B, C and D exist in the study locations. Uniform random states were also formed by generating uniform random number. The comparison of monthly simulated and actual wind speed state clearly shows that the model simulated over six months correctly across study locations except Niger. Given a current wind speed state conditions, the stochastic models available in this paper can be adapted to generate future wind speed state condition. The understanding of wind speed state helps in wind turbine design and selection of wind farm sites for wind energy generation.

Keywords: Wind Speed, Markov Chain Model, Stochastic, Transition Matrix, Northern states.

INTRODUCTION

The lower atmosphere is a massive heat engine in which the solar radiation from the Sun causes convection both on a local scale and on a global scale. The disparity in energy delivered at the poles and the equator creates the pressure differences that drive the major wind systems in the Earth's atmosphere. Winds are masses of air in motion. The gravitational, Coriolis and pressure gradient forces can initiate motion of the air. The gravitational force is one of the strongest forces acting on the air parcel and is directed towards the centre of the Earth (Nigel and Peter, 2001). The air above the land heats up more quickly than the air over Water during the day. The warm air over the land enlarges and rises, while the heavier and cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more quickly over land than over water. Today, wind energy is mainly used to generate electricity and is an economical power resource in many countries. According to Agbetuyi *et al.* (2012), wind turbines start generating electricity at wind speed of about 3.0–4.0 m/s. Wind is a clean fuel and wind farms produce no air or water pollution because no fuel is burned. This renewable energy (wind) resource is abundant in Nigeria. If this energy is being harness, it can provide absolute security of energy supply.

There is energy deficiency in Nigeria irrespective of the enormous energy potentials in the country. As a matter of fact, energy has been a major challenge in Nigeria. The energy sectors are not properly managed because of lack of an integrated and comprehensive energy policy in the country (Chidiezie, 2009). Nigeria has been generating electricity using the hydroelectric power which utilizes the potential energy of water from a dam. The water falls into water turbine and the potential energy of water is converted into kinetic energy. This kinetic energy is converted into mechanical energy at the turbine shaft. A hydroelectric generator or alternator is coupled with turbine shaft to convert mechanical energy into electrical energy. It doesn't supply constant hydroelectricity due to insufficiencies of water and also, long transmission line is required to transmit this hydroelectric power from one state to another. Wind energy is an alternative clean energy source compared to fossil fuel, which pollute the lower layer of the atmosphere and in a long run contribute negatively to climate change. Wind analysis gives significant information to researchers involved in renewable energy studies.

According to D'Amico *et al.* (2012), wind speed is stochastic in nature for which a satisfactory model is still lacking. Numerous researchers have studied renewable energies in Nigeria. Amadi and Udo (2015) studied the trends and variations of monthly mean wind speed data in Nigeria. The statistical techniques used for the analyses are Mann Kendall's rank correlation tests, simple linear regression, Pearson's product moment correlations, time series plots, descriptive statistics and bar charts. The Mann Kendall's test results indicate declining trends over the studied period. Other researchers (Fadare, 2008; Odo *et al.*, 2012; Rauff and Nymphas, 2016; Udoakah and Ikafia, 2017) analyzed wind speed data in Nigeria using Weibull distribution in order to investigate the Weibull shape and scale parameters. The objective of this study is simulating monthly wind speed over sixteen (16) Northern states in Nigeria using the Markov Chain model, which differs from previous research. A Markov chain includes different condition states of a system moving from one state to another over time. The behavior of Markov chains can be described by examining the probability transition matrix of the model (Hocaoglu *et al.*, 2008). The rest of this paper is segmented as follows; methodology, result, discussion and conclusion.

METHODOLOGY

STUDY AREA, DATA AND METHODS

The sixteen (16) Northern States considered in this work are Kebbi, Sokoto, Borno, Kastina, Kaduna, Taraba, Yola, Zamfara, Bauchi, Plateau, Yobe, Kano, Niger, Benue, Kogi and FCT (Figure one). Northern Nigeria is conspicuously different from the southern part of the country, with independent customs, security structures, climate and weather and so on. The main rivers found in the North are the Niger and Benue river which converge at Lokoja from where it travels southwards eventually emptying into the Atlantic Ocean.

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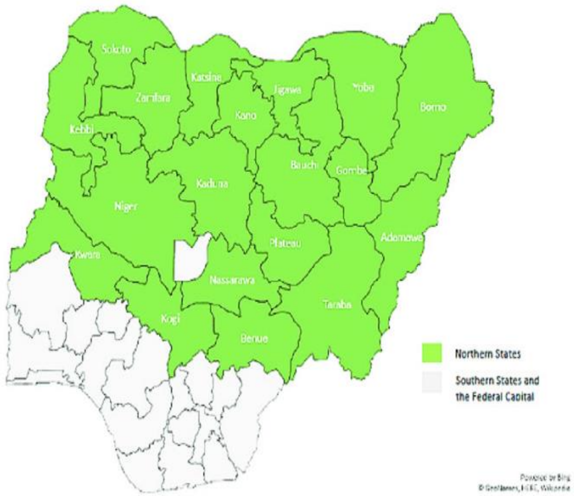

Figure 1: Map showing the 19 Northern states in Nigeria

The daily wind speed data was obtained from National Aeronautics and Space Administration (NASA) (Modern Era Retrospective Analysis Version 2 (MERRA-2)) for the period of thirty-seven (37) years (1984-2020). The wind speed data from 1984-2018 was used in the Markov Chain modeling, while 2019 and 2020 actual wind speed state was used in comparing with the simulated wind speed state. A frequency distribution table was developed using the Beaufort wind scale in Table 1. Each classification is a specific state of wind speed and is denoted by capital alphabet A, B, C, D, E, F, G, H, I, J, K, L and M.

MARKOV CHAIN

Markov chain is a stochastic process $\{X_n, \ \ n = 0,1,2,\dots\dots\}$ that takes on a finite or countable number of possible values, if $X_n = i$, then the process is said to be in state $i$at time$n$. Supposing that the process is in state *i*, there is fixed probability P_{ij}that it will next be in state$j$. That is;

$$P\{X_{n+1} = j|X_n = i, X_{n-1} = i_{n-1},\dots, X_1 = i_1, X_0 = i_0\} =$$

$$P\{X_{n+1} = j|X_n = i\} = P_{ij} \qquad (1)$$

For all states $i_0, i_1,\dots, \ i, \ j$ and $n \geq 0$.

For a first-order Markov chain, the future state $X_{n+1}$is independent of the previous states $X_0, X_1, \dots\dots, X_{n-1}$and depends only on the present state X_n (Ross, 2010).

TRANSITION PROBABILITY MATRIX

A Markov chain transition matrix is a square array describing the probabilities of the chain transiting from one state to another. This transition probability P_{ij} according to Balzter (2000) is given as:

$$P_{ij} = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} \qquad (2)$$

The elements P_{ij} are also called stationary probabilities. They are defined by

$$P(X_n = j / X_{n-1} = i) = p_{ij} \qquad (3)$$

For any value of n ($n = 2, 3 \dots$), the *n*th power of the matrix *P* specify the probabilities p_{ij}^n that the chain will move from state x_i to x_j is called the n-step probability matrix. This is based on the Chapman Kolmogorov equation;
For any $r \leq n$,

$$P_n = (P_{ij})_n = P^{(n)} = \sum_{k=0}^{\infty} P_{ik}^r \, P_{kj}^{n-r} \qquad (4)$$

where$P_n$denotes the matrix of n-step transition probability (Udom, 2010).
The parameter estimation of P_{ij} is given as:

$$P_{ij} = \frac{m_{ij}}{\sum_{j=1}^{n} m_{ij}}$$

where, m_{ij} is the number of times the observed data went from state *i* to state *j*.

In order to calculate the Markov chain transitional probabilities, the wind speed data is first categories into various states using the Beaufort Wind Scale in Table 1. The transition count matrix and transition probabilities matrix were obtained for the sixteen Northern states in Nigeria. This transition probabilities matrix provides the basis of future likely synthetic wind speed states generations. The following steps are necessary for the generation of wind speed states:

(i) Calculate the cumulative probability transition matrix, in which each row ends with 1.
(ii) The primary state is adopted from last state of the actual data and then by using a uniform random number generator, a random value is generated within the range of 0 and 1.
(iii) The future state is obtained where this random value is greater than the cumulative probability of the previous state but less than or equal to the cumulative probability of the following state.

In this way, any desired number of wind speed state can be generated, not the actual value (amount in m/s) of wind speed. For a Markov Chain model, the chance of a future state (X_{n+1}) occurring depends only on the immediate past state (X_n) .

Table 1: Beaufort Wind Scale

Beaufort Number	Description	Knots/hour
0	Calm: smoke rises vertically. (A)	<1
1	Light air: wind direction shown by smoke drift, not by vanes. (B)	1-3
2	Light breeze: wind felt on face, leaves rustle, vanes move. (C)	4-6
3	Gentle breeze: leaves and small twigs move, large wavelets at sea. (D)	7-10
4	Moderate breeze: dust and loose paper lift, small branches move. (E)	11-16
5	Fresh breeze: small leafy trees sway, moderate waves. (F)	17-21
6	Strong breeze: large branches sway, umbrellas difficult to use. (G)	22-27
7	Near gale: whole trees move, inconvenient to walk against. (H)	28-33
8	Gale: small twigs break off, walking impeded, high wave and foam. (I)	34-40
9	Strong gale: slight structural damage. (J)	41-47
10	Storm: considerable structural damage, trees uprooted. (K)	48-55
11	Violent storm: widespread damage. (L)	56-63
12	Hurricane: at sea, visibility badly affected by driving foam and spray. (M)	>64

1 Knots = 0.514 m/s

RESULTS AND DISCUSSION

Analysis of daily wind speed data showed that Kastina had the highest average wind speed of 2.73 m/s, next to it is Borno with 2.61 m/s while Kano recorded the lowest average wind speed with 1.26m/s as presented in Figure 1. The wind in Kebbi, Kano, Niger and FCT can be described as Light air as clearly shown in the Beaufort Number (1) because the wind speed varies from 0.514 – 1.799 m/s (Figure 2).

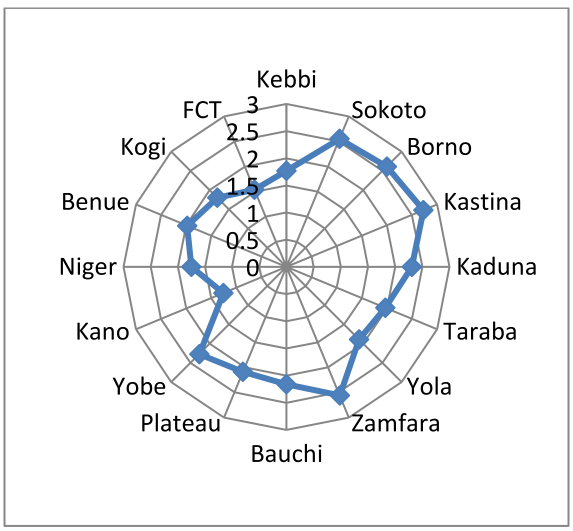

Figure 2: Average Monthly Wind Speed (m/s) across the Northern States in Nigeria.

Thus, the wind direction is shown by smoke drift, not by vanes. In Sokoto, Borno, Kastina, Kaduna, Taraba, Yola, Zamfara, Bauchi, Plateau, Yobe, Benue and Kogi, the movement of air is described as Light breeze (Table 1) as it ranges from 1.799-3.341m/s (Figure 2). Hence, the wind is felt on face, leaves rustle and vanes move. The differential heating between land and sea, local topography and temperature gradients of these Northern states has a huge effect on the nature and variability of the wind speed. Hills and mountains found in Kaduna, Taraba and Bauchi can result to increased wind speed whereas sheltered valleys lead to a reduced wind speed according to Manwell *et al.* (2009).

The wind speed states were generated using the class interval in Beaufort Wind Scale (Table 1). Each classification is a specific state of wind speed and is denoted by capital alphabet A, B, C, D, E, F, G, H, I, J, K, L and M in this study. Observe that only the first four description of wind speed states (A, B, C and D) exist in the sixteen (16) Northern Nigeria as presented in Table 2.

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Table 2: Wind Speed State Classification in the North, Nigeria.

Class Interval	**<0.514**	**0.514 <w <1.799**	**1.799< w < 3.341**	**3.341< w < 5.397**
State	**A**	**B**	**C**	**D**
Bauchi	0.00	117.00	284.00	7.00
Plateau	0.00	159.00	232.00	17.00
Yobe	0.00	97.00	300.00	11.00
Kano	4.00	380.00	24.00	0.00
Niger	0.00	283.00	121.00	4.00
Benue	0.00	131.00	276.00	1.00
Kogi	0.00	170.00	238.00	0.00
FCT	0.00	339.00	69.00	0.00
Kebbi	0.00	174.00	234.00	0.00
Sokoto	0.00	76.00	290.00	42.00
Borno	0.00	56.00	319.00	33.00
Kastina	0.00	46.00	304.00	58.00
Kaduna	0.00	91.00	296.00	21.00
Taraba	0.00	144.00	264.00	0.00
Yola	0.00	172.00	236.00	0.00
Zamfara	0.00	75.00	286.00	47.00

In Figure 3, the transition probability count matrix of wind speed over study locations is clearly presented. It was observed that: Kano consist of 3x3 matrix state A, B and C; Kebbi, Taraba, Yola, Kogi and FCT consist of 2x2 matrix state B and C; lastly Sokoto, Borno, Kastina, Kaduna, Zamfara, Bauchi, Plateau, Yobe, Niger and Benue consist of 3x3 matrix state B, C and D.

State		A	B	C
Kano	A	0	4	0
	B	4	345	24
	C	0	24	6

States		B	C
Kebbi	B	144	42
	C	43	178
Taraba	B	110	43
	C	44	210
Yola	B	146	37
	C	37	18
Kogi	B	132	49
	C	49	177
FCT	B	296	36
	C	37	38

States		B	C	D
Sokoto	B	50	33	0
	C	33	211	33
	D	0	33	14
Borno	B	31	30	0
	C	30	249	29
	D	0	29	9
Kastina	B	23	28	0
	C	28	232	34
	D	0	34	28
Kaduna	B	66	34	0
	C	34	220	23
	D	0	23	7
Zamfara	B	48	33	0
	C	33	208	32
	D	0	32	21

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Bauchi	B	90	34	0
	C	34	228	10
	D	0	10	1
Plateau	B	127	45	0
	C	45	150	18
	D	0	18	4
Yobe	B	68	34	0
	C	34	243	13
	D	0	13	2
Niger	B	237	45	0
	C	46	66	6
	D	0	6	1
Benue	B	91	45	1
	C	47	222	0
	D	0	1	0

Figure 3: Transition count Matrix across Study Locations.

Figure 4 depicts the transition probabilities matrix across study locations. Each element shows the probability of the next wind speed state based on the current wind speed state. The highest probability occurs when the current wind speed state 'C' transit to the next state 'C' in Sokoto, Borno, Kastina, Kaduna, Zamfara, Bauchi, Kebbi, Taraba and Kogi. In Plateau, Yobe, Niger and Benue, the highest probability occurs when the current wind speed state 'D' transit to the next state 'C'. Also, the highest probability occurs when the current wind speed state 'B' transit to the next state 'B' in Yola and FCT. Lastly, in Kano the highest probability occurs when the current wind speed state 'A' transit to the next state 'B' as shown in Figure 4.

State		A	B	C
Kano	A	0.000	1.000	0.000
	B	0.011	0.925	0.064
	C	0.000	0.800	0.200

States		B	C
Kebbi	B	0.774	0.226
	C	0.195	0.805
Taraba	B	0.719	0.281
	C	0.173	0.827
Yola	B	0.798	0.202
	C	0.673	0.327
Kogi	B	0.729	0.271
	C	0.217	0.783
FCT	B	0.892	0.108
	C	0.493	0.507

States		B	C	D
Sokoto	B	0.602	0.398	0.000
	C	0.119	0.762	0.119
	D	0.000	0.702	0.298
Borno	B	0.508	0.492	0.000
	C	0.097	0.808	0.094
	D	0.000	0.763	0.237
Kastina	B	0.451	0.549	0.000
	C	0.095	0.789	0.116
	D	0.000	0.548	0.452
Kaduna	B	0.660	0.340	0.000
	C	0.123	0.794	0.083
	D	0.000	0.767	0.233
Zamfara	B	0.593	0.407	0.000
	C	0.121	0.762	0.117
	D	0.000	0.604	0.396
Bauchi	B	0.726	0.274	0.000
	C	0.125	0.838	0.037
	D	0.000	0.909	0.091
Plateau	B	0.738	0.262	0.000

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	C	0.211	0.704	0.085
	D	0.000	0.818	0.182
Yobe	B	0.667	0.333	0.000
	C	0.117	0.838	0.045
	D	0.000	0.867	0.133
Niger	B	0.840	0.160	0.000
	C	0.390	0.559	0.051
	D	0.000	0.857	0.143
Benue	B	0.664	0.328	0.007
	C	0.175	0.825	0.000
	D	0.000	1.000	0.000

Figure 4: Transition Probabilities Matrix across Study Location

While generating synthetic wind data the cumulative probability transition matrix was computed (Figure 5), in which each row ends with 1. Hence, cumulative summation within each row leads to 1.000. The primary state was adopted from the previous year (December 2018) and using a uniform random number generator, a random value was generated within the range of 0 and 1 (Table 3) over the sixteen Northern states.

State		A	B	C
Kano	A	0.000	1.000	1.000
	B	0.011	0.936	1.000
	C	0.000	0.800	1.000

States		B	C
Kebbi	B	0.774	1.000
	C	0.195	1.000
Taraba	B	0.719	1.000
	C	0.173	1.000
Yola	B	0.798	1.000
	C	0.673	1.000
Kogi	B	0.729	1.000
	C	0.217	1.000
FCT	B	0.892	1.000
	C	0.493	1.000

States		B	C	D
Sokoto	B	0.602	1.000	1.000
	C	0.119	0.881	1.000
	D	0.000	0.702	1.000
Borno	B	0.508	1.000	1.000
	C	0.097	0.906	1.000
	D	0.000	0.763	1.000
Kastina	B	0.451	1.000	1.000
	C	0.095	0.884	1.000
	D	0.000	0.548	1.000
Kaduna	B	0.660	1.000	1.000
	C	0.123	0.917	1.000
	D	0.000	0.767	1.000
Zamfara	B	0.593	1.000	1.000
	C	0.121	0.883	1.000
	D	0.000	0.604	1.000
Bauchi	B	0.726	1.000	1.000
	C	0.125	0.963	1.000
	D	0.000	0.909	1.000
Plateau	B	0.738	1.000	1.000
	C	0.211	0.915	1.000
	D	0.000	0.818	1.000
Yobe	B	0.667	1.000	1.000
	C	0.117	0.955	1.000
	D	0.000	0.867	1.000
Niger	B	0.840	1.000	1.000

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	C	0.390	0.949	1.000
	D	0.000	0.857	1.000
Benue	B	0.664	0.993	1.000
	C	0.175	1.000	1.000
	D	0.000	1.000	1.000

Figure 5: Cumulative Probability Transition Matrix across Study Locations.

Table 3 is obtained where this random value is greater than the cumulative probability of the previous state but less than or equal to the cumulative probability of the following state. Only the wind speed states can be generated and not the exact value of wind speed over study locations. The wind speed states were decomposed according to the empirical distribution in Table 3.

Table 3: Empirical Distribution of Wind Speed States over Study Locations.

Stations	Primary State	Empirical Distribution	Stations	Primary State	Empirical Distribution
Kano	B	$\begin{cases} A, \; if & u < 0.011 \\ B, \; if & 0.011 \le u < 0.936 \\ C, \; if & 0.936 \le u \le 1 \end{cases}$	Kastina	C	$\begin{cases} B, \; if & u = 0.000 \\ C, \; if & 0.000 < u \le 0.767 \\ D, \; if & 0.767 \le u \le 1 \end{cases}$
Kebbi	C	$\begin{cases} B, \; if & u < 0.195 \\ C, \; if & 0.195 \le u \le 1 \end{cases}$	Kaduna	C	$\begin{cases} B, \; if & u < 0.123 \\ C, \; if & 0.123 \le u < 0.917 \\ D, \; if & 0.917 \le u \le 1 \end{cases}$
Taraba	C	$\begin{cases} B, \; if & u < 0.173 \\ C, \; if & 0.173 \le u \le 1 \end{cases}$	Zamfara	D	$\begin{cases} B, \; if & u = 0.000 \\ C, \; if & 0.000 < u \le 0.604 \\ D, \; if & 0.604 \le u \le 1 \end{cases}$
Yola	C	$\begin{cases} B, \; if & u < 0.673 \\ C, \; if & 0.673 \le u \le 1 \end{cases}$	Bauchi	C	$\begin{cases} B, \; if & u < 0.125 \\ C, \; if & 0.125 \le u < 0.963 \\ D, \; if & 0.963 \le u \le 1 \end{cases}$
Kogi	B	$\begin{cases} B, \; if & u < 0.729 \\ C, \; if & 0.729 \le u \le 1 \end{cases}$	Plateau	C	$\begin{cases} B, \; if & u < 0.211 \\ C, \; if & 0.211 \le u < 0.915 \\ D, \; if & 0.915 \le u \le 1 \end{cases}$
FCT	C	$\begin{cases} B, \; if & u < 0.493 \\ C, \; if & 0.493 \le u \le 1 \end{cases}$	Yobe	C	$\begin{cases} B, \; if & u < 0.117 \\ C, \; if & 0.117 \le u < 0.955 \\ D, \; if & 0.955 \le u \le 1 \end{cases}$
Sokoto	D	$\begin{cases} B, \; if & u = 0.000 \\ C, \; if & 0.000 < u < 0.702 \\ D, \; if & 0.702 \le u \le 1 \end{cases}$	Niger	C	$\begin{cases} B, \; if & u < 0.390 \\ C, \; if & 0.390 \le u < 0.949 \\ D, \; if & 0.949 \le u \le 1 \end{cases}$
Borno	C	$\begin{cases} B, \; if & u < 0.097 \\ C, \; if & 0.097 \le u < 0.906 \\ D, \; if & 0.906 \le u \le 1 \end{cases}$	Benue	C	$\begin{cases} B, \; if & u < 0.175 \\ C, \; if & 0.175 \le u < 1 \\ D, \; if & u = 1 \end{cases}$

The comparison of monthly Simulated and Actual wind speed state for the year 2019 and 2020 over study locations are clearly shown in Table 4 and 5 respectively. The state changes with changing the probability where each state is attached with some class interval. The monthly simulated and actual wind speed state for the year 2019 over kano is the same except in September, while for the year 2020, it differs in the months of January and February as shown in Table 4 and 5. Also, the monthly simulated and actual wind speed state for the year 2019 over Zamfara, Kaduna, Borno and Kastina are the same except September and October.

Table 4: Comparison of Monthly Simulated and Actual Wind Speed State for the Year 2019 over Study Locations.

Location	State	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Kano	Simulated	B	B	B	B	B	B	B	B	B	B	B	B
	Actual	B	B	B	B	B	B	B	B	A	B	B	B
Kebbi	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	B	C	C	B	B	B	B	B	C
Taraba	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	B	C	B	B	B	C

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Yola	Simulated	B	B	B	B	B	B	B	B	B	B	B	B
	Actual	B	C	C	C	C	B	B	C	B	B	B	C
Kogi	Simulated	B	B	B	B	B	B	B	B	B	B	B	B
	Actual	B	B	C	C	C	C	B	C	B	B	B	B
F.C.T	Simulated	B	C	B	C	C	C	B	B	C	B	C	C
	Actual	C	C	B	B	B	B	B	B	B	B	B	C
Borno	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	C	B	B	C	C
Sokoto	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	B	B	B	B	C
Kastina	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	C	B	B	C	C
Kaduna	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	C	B	B	C	C
Zamfara	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	C	B	B	C	C
Bauchi	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	B	B	B	B	B	C
Plateau	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	B	B	B	B	B	B	C	C
Yobe	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	B	B	B	B	B	C
Niger	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	B	B	B	B	B	B	B	B	B	C
Benue	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	C	B	B	B	C

The model simulated over 50% wind speed states correctly over study locations except Niger (Table 4). The simulated and actual wind speed state in Niger is the same in January, February and December only, hence the model performed poorly (Table 4). The model performed poorly (simulated less than 50%) in Yola, Abuja, Plateau and Niger, while in Kebbi, Kogi and Bauchi the model simulated six months correctly (Table 5). According to Tong (2010), wind varies with the geographical locations, time of day, season, and height above the earth's surface, weather, and local landforms. Hence, this variation of actual wind caused a variation of the simulated wind speed state in the study locations. The understanding of the wind characteristics (wind speed state) will help in wind turbine design, develop wind measuring techniques, and selection of wind farm sites.

Table 5: Comparison of Monthly Simulated and Actual Wind Speed State for the Year 2020 over Study Locations.

Location	State	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Kano	Simulated	B	B	B	B	B	B	B	B	B	B	B	B
	Actual	C	C	B	B	B	B	B	B	B	B	B	B
Kebbi	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	B	B	B	B	B	B
Taraba	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	C	C	B	B	C	B
Yola	Simulated	B	B	B	B	B	B	B	B	B	B	B	B
	Actual	C	C	C	C	C	C	C	C	B	B	C	B
Kogi	Simulated	B	B	B	B	B	B	B	B	B	B	B	B
	Actual	B	B	C	C	C	C	C	C	B	B	B	B
F.C.T	Simulated	C	B	C	C	C	B	B	C	B	B	C	C
	Actual	C	C	B	B	B	B	B	C	B	B	C	B

Borno	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	D	D	C	C	C	C	C	C	B	B	C	C
Sokoto	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	D	D	C	C	C	C	C	C	B	B	C	C
Kastina	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	D	D	C	C	C	C	C	C	B	B	C	C
Kaduna	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	D	D	C	C	C	C	B	C	B	B	C	C
Zamfara	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	D	D	C	C	C	C	C	C	B	B	C	C
Bauchi	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	B	B	B	B	B	B	C	C
Plateau	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	D	D	C	B	B	B	B	C	B	B	C	C
Yobe	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	C	C	B	B	B	B	C	C
Niger	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	B	B	B	B	B	C	B	B	C	C
Benue	Simulated	C	C	C	C	C	C	C	C	C	C	C	C
	Actual	C	C	C	C	B	C	C	C	B	B	B	B

Conclusion

This study presents a stochastic modeling of wind speed over sixteen (16) northern states in Nigeria using thirty-seven years (1984-2020) wind speed real time data. The results show that only the first four description of wind speed state A, B, C and D exist in the study locations. Also, the comparison of monthly simulated and actual wind speed state clearly shows that the model simulated over six months correctly across study locations except Niger. The main benefit of this method is that the simulated generated wind speed state can be helpful in the study of wind power, wind turbulence, wind shear and wind gust of a wind turbine. The understanding of the wind speed state also helps in the selection of wind farm sites for wind energy generation. Furthermore, the choice of building design especially the roofing sheet should be based on the wind speed state in a region.

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