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Wind Speed Modeling for Informed Asthma Management in Maiduguri, Nigeria

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ABSTRACT

This study investigates wind speed modeling in Maiduguri, Nigeria, with the objective of eliciting informed asthma management. Six probability distributions—Weibull, Gumbel, Logistic, Lognormal, Normal, and Gamma—were fitted to monthly wind speed data using the fitdistrplus package in R. Goodness-of-fit was assessed with the Anderson-Darling statistic, while model selection was done using AIC, BIC, and absolute log-likelihood values. The Weibull distribution emerged as the most robust model for 10 months of the year, with Normal and Gamma distributions performing best in April and September, respectively. Results indicated a negative correlation between wind speed and asthma prevalence, $r= -0.502$,p-value=0.09, emphasizing the influence of pollutants and seasonal conditions on asthma triggers. Findings suggest tailored management strategies, such as protective gear and facemasks during dusty periods and warm clothing during the cold season, to mitigate asthma attacks.

1. Introduction

Asthma is a multi-factorial disease that, in different individuals, can be aggravated by allergens, stress, exercise, infection, air pollution, and weather. The most common type of asthma is allergic asthma, a chronic inflammatory disorder of the airways that is driven by maladaptive T helper 2 and T helper 17 immune responses against harmless airborne substances in genetically susceptible individuals (Thunderstorm Asthma, 2017). The prevalence are higher in children while morbidity and mortality are higher in adults (Dharmagel *et al*., 2019). Wind is a major carrier of many air pollutants that are important allergens to asthma patients. It is a conveyor of substances such as pollen, animal dander, mold, dust, and smoke, to mention just a few, and these are asthma attack triggers. Pollen dispersal is favored by windy conditions, low relative humidity, low precipitation and higher temperatures (Laaidi, 2001).

An analysis of the prevalence data on asthma patients was conducted at the General Hospital in Hong Local Government Area of Adamawa State (Akano and Nwosu, 2001). In Southern California an investigation was conducted to determine the relationship between Santa Ana wind conditions and the number of visits for asthma at an emergency department (Stephen, 1996). It was noted that the rate of visits to the emergency department for asthma increased during the Santa Ana winds when compared to other weather conditions. It was concluded that although the magnitude of the increase in the number of visits to the emergency department was small, it occurred at the time when typical inciters of respiratory diseases should be at their minimum. A similar study conducted on school children aged 5 – 14 years who attended for asthma exacerbation showed that a number of cases were related to weather conditions, including wind speed (Daniel *et al*., 2013). In Borno State, a multiple regression of the number of reported cases of asthma attack on weather variables has shown that evaporation, relative humidity, seasonal changes in weather conditions and wind speeds were significantly effective in triggering asthma attack (Nwosu *et al*., 2012); the time to recovery from asthma attack and hospitalization was exponentially distributed with an average of 4 days.

Maiduguri is located at latitude 11.85°N and longitude 13.12°E, and at an elevation of 325m above sea level. It is characterized by very harsh weather conditions. Every season comes with it unique weather features that are incomparable to other places in the sub-region, for instance, Biu, Yola, Gombe, and so on. The winds during the different seasons usher in different challenges to people with respiratory problems, particularly asthma. The onset of the dry season in October marks the beginning of the harmattan period that is characterized by cold, dusty and dry northeasterly winds, see Figure 1. This and many other pollutants brought in by the winds incite asthma attack during this period. As the region regains clear

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visibility by the end of February, high temperatures begin to set in. Air mass begins to drop and the winds, blowing at high speed over loose soils with low vegetation cover, do bring in some other pollutants including pollen and fungal spores that are linked to asthma (Price *et al*., 2020). The onset of the rainy season from May ending to June is characterized by sand and dust storms. Winds blowing at very high speed do bring in highly dense dust that is capable of reducing visibility to less than 100 m; see Figure 2. This dust can penetrate even airtight doors and windows, thus posing great challenge to asthmatics and people with other respiratory problems (Ajay, 2020).

This study is unique in that it attempts to find a probability distribution that is appropriate for describing the wind speed pattern of Maiduguri on a monthly basis. This will help to characterize the wind speed that is the carrier of pollutant spread of this area; and consequently, contribute to the understanding of the epidemiology of asthma in Maiduguri and environs.

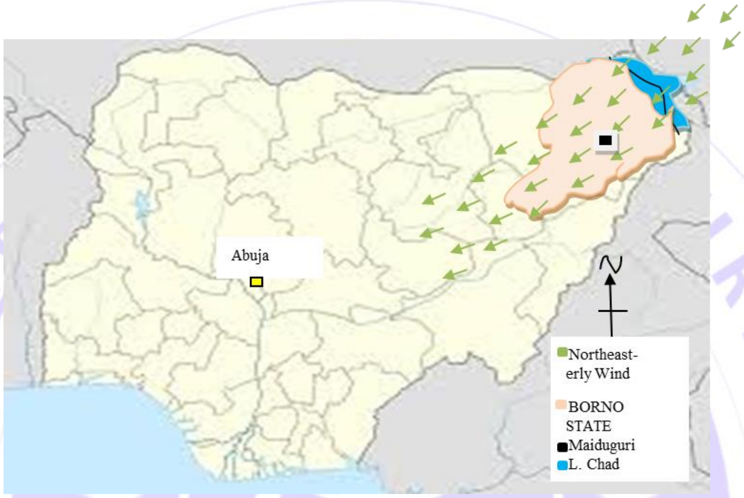

Figure 1: Map of Nigeria showing North-Easterly Winds

Figure 2: Images of Sand and Dust Storm in Maiduguri taken from Different Locations

The intent of this study is to model the wind speed in Maiduguri that is a major carrier of numerous air pollutants. The major aim is to provide insightful information to policy makers in the health sector to enable them plan and give guidance to asthmatics on the ways to control and manage their health conditions during the life threatening periods of highly polluted winds. It will also help to trigger the exploration of ways to predict asthma outbreak by health professionals so as to provide early warnings to asthmatics.

The data used in the study were the wind speed data of Maiduguri given in Gongsin and Saporu (2016). The wind speed data were monthly average wind speed in metres per second collected at the Nigerian Meteorological Agency (NiMET) office at the International Airport Maiduguri. The data were monthly records covering from September 1985 to December 2011. The second data set that contains the monthly number of reported cases of asthma from 1984 to 1997 were also obtained from Nwosu *et al*. (2012); the data were collected from selected hospitals in Borno State.

2. Methods

Six probability distributions, namely Weibull, Gumbel, Logistics, Lognormal, Normal and Gamma, were fitted to the wind speed data of Maiduguri. The density functions of these distributions are given in equations 1 – 6 below.
The density function of the Weibull distribution is given by

$$f_X(x) = \frac{\beta}{\alpha}\left(\frac{x}{\alpha}\right)^{\beta-1} exp\left(-\left(\frac{x}{\alpha}\right)^{\beta}\right) \tag{1}$$

where $x > 0, \alpha > 0, \beta > 0$.
The density function of the Gumbel distribution is given by

$$f_X(x) = \frac{1}{\beta} exp\left(-\frac{x-\mu}{\beta} - exp\left(-\frac{x-\mu}{\beta}\right)\right) \tag{2}$$

where $x > 0, \mu \geq 0, \beta > 0$.
The density function of the logistic distribution is given by

$$f_X(x) = \frac{exp\left(-\frac{x-\mu}{\alpha}\right)}{\alpha\left(1 + exp\left(-\frac{x-\mu}{\alpha}\right)\right)^2} \tag{3}$$

where $x > 0, \alpha > 0, \mu \geq 0$.
The log-normal density function is given by

$$f_X(x) = \frac{1}{x\beta\sqrt{2\pi}} exp\left(-\left(\frac{\ln x - \mu}{\beta\sqrt{2}}\right)^2\right) \tag{4}$$

where $x > 0, \mu \geq 0, \sigma > 0$, $\mu = \frac{1}{n}\sum_{i=1}^{n} \ln x_i$, $\beta = \sqrt{\frac{1}{n}\left[\sum_{i=1}^{n}(\ln x_i)^2 - \left(\frac{1}{n}\sum_{i=1}^{n} \ln x_i\right)^2\right]}$
The normal density function is given by

$$f_X(x) = \frac{1}{\beta\sqrt{2\pi}} exp\left(-\left(\frac{x-\mu}{\beta\sqrt{2}}\right)^2\right) \tag{5}$$

where $x > 0, \mu \geq 0, \sigma > 0$
The gamma density function is given by

$$f_X(x) = \frac{\beta^{\alpha}}{\Gamma_{(\alpha)}} x^{\alpha-1} exp(-\beta x) \tag{6}$$

where $x > 0, \alpha > 0, \beta > 0$.
The choice of these distributions was informed by the fact that wind speed data are life time data that are described by extreme value distributions, especially the Weibull distribution (Gongsin and Saporu, 2016). The inclusion of the other distribution is to introduce robustness in the choice of density function(s) that can best describe the wind speed data sets. Parameter estimates of the distributions were determined in R using the **fitdistrplus** package. The Anderson-Darling statistic was used to determine the goodness of fit of each distribution to the monthly wind speed data of Maiduguri; it is given by

$$A^2 = -\frac{1}{n}\sum_{j=1}^{n}(2j-1)\left\{\ln\left(F\left(x_{(j)}\right)\right) + \ln\left(1 - F\left(x_{(n-j+1)}\right)\right)\right\} - n \tag{7}$$

where $F\left(x_{(\cdot)}\right)$ is the fitted distribution function at the ordered wind speed values. The choice of the statistic in (7) was informed by its ability to test the goodness of fit of the assumed distribution comparison with the empirical cumulative distribution function.
Having determined the goodness of fit of each distribution to the wind speed data, the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and the absolute log-likelihood $|LL|$ values were used to determine the best model that is appropriate for each month among distributions that fitted the data. The model that best fits the wind speed data of each month was used to estimate the average wind speed and standard error for the month.

3. Results

3.1 Model Fitting

The results of the parameter estimation, goodness-of-fit test and model selection criteria are given in Table 1. From the table, the following observations are made

i. The density functions 1 – 6 have successfully fitted the wind speed data of Maiduguri in all the months of the year, with the exception of the Gumbel and lognormal distributions. The density plots superimposed on the histogram of the wind speed data in Figure 3 supports the results in Table 1. Whereas the Gumbel distribution did not provide good fit to the wind speed data in the month of January only, the lognormal distribution did not provide good fit in the months of January and May. This does not imply that the distributions did not fit the whole wind speed data, since the lognormal distribution that performed below the other distributions underperformed in no more than 16.7% of the months.

ii. The model that provided the best fit is the Weibull distribution, which the model selection criteria had adjudged the best model in 10 out of the 12 months of the year. However, the Normal and Gamma distributions were the best models in April and September, respectively. This confirms the finding in Gongsin and Saporu (2016), who showed that the Weibull distribution is the best model for describing wind speed data sets in Maiduguri.

3.2 Wind Speed and Asthma

As reported by Nwosu *et al*. (2012), the wind in Maiduguri has significant influence on reported cases of asthma. By determining that the Weibull distribution is the best model for describing the wind speed data of Maiduguri, the characteristics of air pollutants in circulation can be determined to help in understanding the nature of pollutant spread in the area. For the purpose of this study, the months of the year in Maiduguri are categorized into three seasons as indicated by the upward-open braces in Figure 4. They are defined as follows:

i. Cold season comprises the months of October ending through most part of February and is characterized by harsh cold, dry and harmattan-dusty air.

ii. Hot season has dry and clear weather conditions as its main features and starts at the end of February and last through May ending. It is characterized by clear visibility and high temperatures in the range of 37 – 43°C.

iii. Wet season begins from June through September ending; it is characterized by thunderstorm especially in the months of June and July, and heavy rains in August and September, with highest peak up to 193.2 mm.

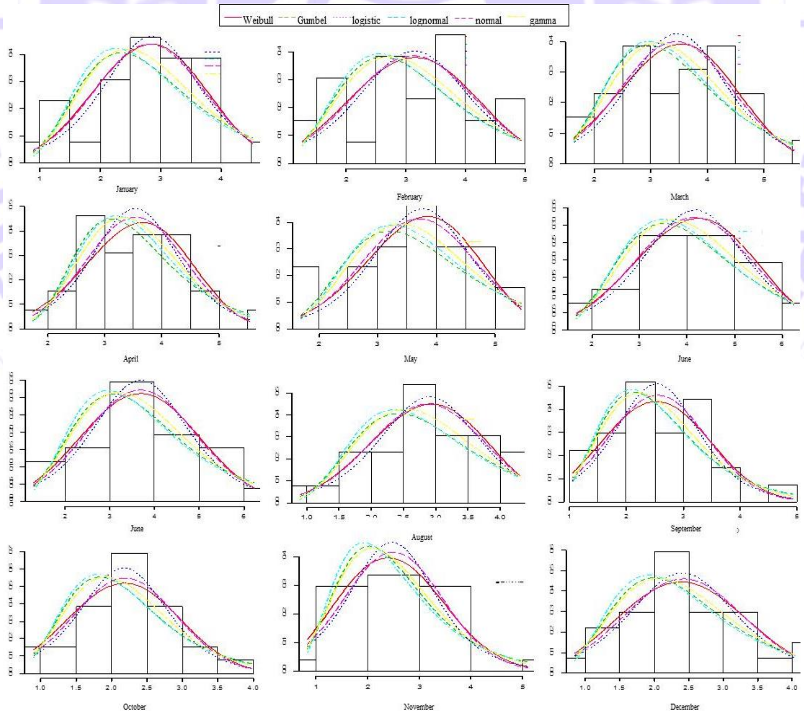

Figure 3: ***Density Plots of fitted Weibull, Gumbel, Logistic, Lognormal, Normal and Gamma Distributions***

Table 1: Parameter Estimates, Good-of-Fit Test and Information Criteria

Month	**PDF**	**Parameter Estimates (standard errors)**			**Goodness of Fit Test**		**Model Selection Criteria**			**Best Model**
		α	β	μ	AD^{2*}	Remark	AIC	BIC	|LL|	
Jan	Wei	3.56 (0.571)	3.13 (0.181)		0.405	GF	72.3	74.8	34.1	Weibull
	Evd		0.919(0.131)	2.35 (0.189)	0.781	*NF*	77.8	80.3	36.9	
	Logi	0.536 (0.086)		2.85 (0.186)	0.385	GF	74.4	76.9	35.2	
	Lnor		0.387(0.054)	0.969(0.076)	0.951	*NF*	78.8	81.3	37.4	
	Nor		0.912(0.126)	2.81 (0.179)	0.394	GF	73.0	75.5	34.5	
	Gam	2.77 (0.776)	7.78 (2.11)		0.712	GF	75.9	78.4	36.0	
Feb	Wei	3.44 (0 .545)	3.48 (0.209)		0.262	GF	78.5	81.1	37.3	Weibull
	Evd		.945 (0.144)	2.60(.200)	0.470	GF	81.9	84.5	39.0	
	Logi	0.620 (0.099)		3.14 (0.216)	0.306	GF	81.4	83.9	38.7	
	Lnor		.370 (0.051)	1.08 (0.073)	0.550	GF	82.0	84.6	39.0	
	Nor		1.03 (0.143)	3.12 (0.202)	0.276	GF	79.4	81.9	37.7	
	Gam	2.60 (0.728)	8.10 (2.20)		0.411	GF	80.4	82.9	38.2	
Mar	Wei	3.92 (0.608)	3.81 (0.201)		0.174	GF	77.0	79.6	36.5	Weibull
	Evd		0.945(0.139)	2.95(0.197)	0.520	GF	80.6	83.1	38.3	
	Logi	0.587(0.094)		3.47(0.203)	0.226	GF	79.0	81.5	37.5	
	Lnor		0.318(0.044)	1.19(0.062)	0.542	GF	80.1	82.6	38.1	
	Nor		0.996(0.138)	3.45(0.195)	0.205	GF	77.6	80.1	36.8	
	Gam	3.13(0.876)	10.8(2.95)		0.387	GF	78.6	81.2	37.3	
Apr	Wei	4.45(0.667)	3.88(0.180)		0.147	GF	71.1	73.7	33.6	Normal
	Evd		0.821(0.119)	3.11(0.171)	0.293	GF	73.2	75.7	34.6	
	Logi	0.509(0.082)		3.53(0.176)	0.168	GF	71.9	74.4	33.9	
	Lnor		0.261(0.036)	1.23(0.051)	0.231	GF	72.1	74.6	34.0	
	Nor		0.875(0.121)	3.54(0.172)	0.132	GF	70.9	73.4	33.6	
	Gam	4.37(1.22)	15.5(4.25)		0.164	GF	71.2	73.7	33.6	
May	Wei	4.07(0.184)	4.54(0.720)		0.248	GF	74.9	77.4	35.5	Weibull
	Evd		1.00(0.142)	3.20(0.209)	0.910	GF	82.2	84.7	39.1	
	Logi	0.555(0.091)		3.76(0.190)	0.262	GF	76.8	79.3	36.4	
	Lnor		0.301(0.042)	1.27(0.059)	0.913	*NF*	81.4	83.9	38.7	
	Nor		0.967(0.134)	3.71(0.190)	0.316	GF	76.0	78.5	36.0	
	Gam	3.35(0.935)	12.4(3.40)		0.670	GF	79.0	81.5	37.5	
Jun	Wei	3.83(0.605)	4.58(0.247)		0.174	GF	88.2	90.7	42.1	Weibull
	Evd		1.21(0.176)	3,51(0.251)	0.510	GF	92.9	95.4	44.4	
	Logi	0.729(0.117)		4.17(0.252)	0.200	GF	90.3	92.7	43.2	
	Lnor		0.340(0.047)	1.37(0.067)	0.569	GF	92.8	95.3	44.4	
	Nor		1.24(0.172)	4.14(0.243)	0.187	GF	88.9	91.4	42.4	
	Gam	2.34(0.655)	9.68(2.64)		0.388	GF	90.8	93.3	43.4	
Jul	Wei	3.31(0.513)	4.11(.256)		0.210	GF	88.5	91.0	42.3	Weibull
	Evd		1.19(0.172)	3.07(0.247)	0.499	GF	92.1	94.7	44.1	
	Logi	0.714(0.117)		3.69(0.244)	0.181	GF	89.8	92.3	42.9	
	Lnor		0.339(0.054)	1.24(0.076)	0.654	GF	93.1	95.6	44.5	
	Nor		1.24(0.172)	3.69(0.243)	0.195	GF	89.0	91.5	42.5	
	Gam	2.06(0.577)	7.58(2.06)		0.409	GF	90.6	93.1	43.3	
Aug	Wei	3.75(0.599)	3.19(0.175)		0.212	GF	70.9	73.4	33.5	Weibull
	Evd		0.905(0.128)	2.42(0.189)	0.583	GF	77.0	79.5	36.5	
	Logi	0.518(0.084)		2.90(0.179)	0.202	GF	72.7	75.2	34.4	
	Lnor		0.372(0.052)	.996(0.073)	0.717	GF	78.2	80.7	37.1	
	Nor		0.886(0.123)	2.87(0.174)	0.202	GF	71.5	74.0	33.8	
	Gam	2.96(0.829)	8.50(2.31)		0.469	GF	74.9	77.5	35.5	
Sep	Wei	3.17(0.459)	2.85(0.183)		0.248	GF	72.5	75.1	34.3	Gamma

	Evd		0.776(0.113)	2.13(0.158)	0.423	GF	73.5	76.1	34.8	
	Logi	0.491(0.078)		2.53(0.165)	0.231	GF	73.0	75.6	34.5	
	Lnor		0.367(0.050)	.873(0.071)	0.495	GF	73.7	76.3	34.8	
	Nor		0.866(0.118)	2.55(0.167)	0.239	GF	72.8	75.4	34.4	
	Gam	3.18(0.876)	8.11(2.16)		0.335	GF	72.4	74.9	34.2	
Oct	Wei	3.27(0.489)	2.44(0.155)		0.263	GF	60.9	63.4	28.5	Weibull
	Evd		0.663(0.098)	1.83(0.138)	0.461	GF	62.5	65.0	29.2	
	Logi	0.412(0.068)		2.17(0.140)	0.227	GF	61.6	64.1	28.8	
	Lnor		0.363(0.050)	.723(0.071)	0.534	GF	62.7	65.2	29.3	
	Nor		0.727(0.101)	2.19(0.143)	0.254	GF	61.2	63.7	28.6	
	Gam	3.82(1.07)	8.36(2.27)		0.357	GF	61.2	63.7	28.6	
Nov	Wei	2.81(0.413)	2.81(0.203)		0.300	GF	77.4	80.0	36.7	Weibull
	Evd		0.842(0.124)	2.04(0.171)	0.399	GF	78.4	81.0	37.2	
	Logi	0.556(0.087)		2.48(0.189)	0.380	GF	79.1	81.7	37.6	
	Lnor		0.422(0.057)	0.834(0.081)	0.502	GF	79.1	81.7	37.5	
	Nor		0.960(0.131)	2.50(0.185)	0.341	GF	78.4	81.0	37.2	
	Gam	2.51(0.692)	6.27(1.66)		0.370	GF	77.6	80.1	36.8	
Dec	Wei	2.72(0.178)	3.10(0.472)		0.250	GF	72.1	74.7	34.1	Weibull
	Evd		0.791(0.116)	2.00(0.161)	0.368	GF	74.6	77.2	35.3	
	Logi	0.510(0.081)		2.41(0.173)	0.289	GF	74.5	77.1	35.2	
	Lnor		0.401(0.055)	.812(0.077)	0.477	GF	75.2	77.8	35.6	
	Nor		0.867(0.118)	2.43(0.167)	0.276	GF	72.9	75.5	34.5	
	Gam	2.88(0.793)	6.98(1.85)		0.323	GF	73.3	75.9	34.7	

$*$ compared to the critical value 0.740, GF = Good Fit, ***NF*** = Not Fit, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, $|LL|$ = Absolute Log-Likelihood value

The mean rate of wind speed and its standard errors, based on parameter estimates, can be obtained, respectively, using the relation

$$\hat{R}_w = \begin{cases} \hat{\alpha} g_1, & X \sim Weibull \\ \hat{\mu}, & X \sim Normal \\ \dfrac{\hat{\beta}}{\hat{\alpha}}, & X \sim Gamma \end{cases} \tag{8}$$

and

$$se(\hat{R}_w) = \begin{cases} \dfrac{\hat{\alpha}}{n}\sqrt{g_2 - g_1^2}, & X \sim Weibull \\ \dfrac{\hat{\beta}}{n}, & X \sim Normal \\ \dfrac{1}{\hat{\alpha}}\sqrt{\dfrac{\hat{\beta}}{n}}, & X \sim Gamma \end{cases} \tag{9}$$

where $g_k = \Gamma_{\left(1+\frac{k}{\hat{\beta}}\right)}, k = 1, 2.$

Employing the estimated values of parameters for the respective models in the respective months gives the mean rate of wind speed and its standard errors in Table 2.

Table 2: Mean Rate of Wind Speed, its Standard Errors and Reported Cases of Asthma

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\hat{R}_w$	3.19	3.09	3.54	3.54	3.72	3.50	3.00	3.36	2.55	2.90	2.50	2.43
$se(\hat{R}_w)$	0.043	0.038	0.040	0.172	0.036	0.033	0.032	0.044	0.176	0.049	0.037	0.033
No of cases◂	51	46	53	33	36	35	59	71	56	119	88	55

◂ Source: Nwosu *et al.*, 2012

The plots of the standardized (Z-score) values of mean rate of wind speed and reported cases of asthma are given in Figure 4.

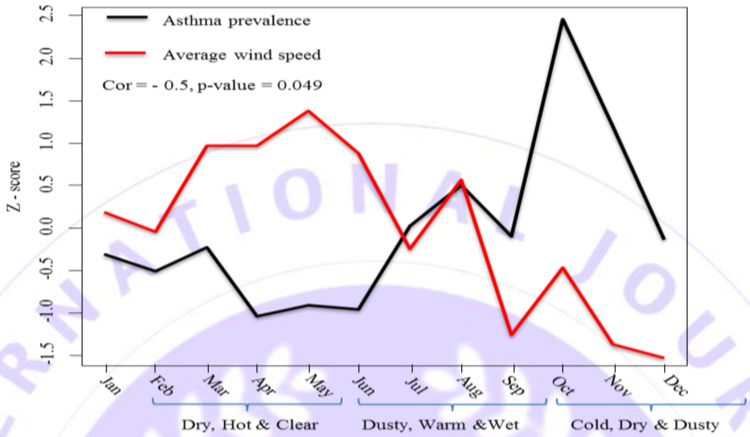

Figure 4: Line Graphs of the Z-scores of Wind Speed and Number of Reported Cases of Asthma

Figure 4 presents the relationship between standardized values of estimated wind speeds and reported cases of asthma. It can be seen that the standardized reported cases of asthma is increasing at the time that the standardized mean wind speed is decreasing. This shows an inverse relationship (or a negative correlation) between the number of reported cases of asthma attack and the mean rate of wind speed ($r = -0.502, p-value = 0.09$). The plots suggest that factors other than wind speed could be responsible for asthma attack in Maiduguri. The pollution of the air by the dust during the harmattan period and the onset of cold brought in by the northeasterly winds from October to December could be a more reliable suspect triggering asthma attack.

4. Discussion

The Weibull distribution proved most effective, aligning with previous findings reported in Gongsin and Saporu (2016), particularly for characterizing wind speed in arid regions. Seasonal variations were categorized into three distinct periods: the cold, hot, and wet seasons, each with unique wind and environmental characteristics influencing asthma prevalence. These enabled analysis base on the seasonal variations. Higher wind speeds, particularly during the hot season, were associated with lower asthma prevalence, likely due to the dispersal of pollutants. Conversely, lower wind speeds in the cold season coincided with higher asthma cases, attributed to dusty, cold air acting as triggers. This finding differs slightly from that of the previous study that was reported by Nwosu *et al*. (2012). This pattern could be due to global warming, and underscores the dual role of wind in both spreading and mitigating exposure to asthma-inducing factors.

The study highlights the need for public health interventions to account for these dynamics. For instance, asthma patients could benefit from early warnings during sandstorms and protective measures during cold, dusty periods. Additionally, further research into the interaction between pollutants and seasonal variations is essential for a comprehensive understanding of asthma etiology.

5. Conclusion

This study fits six probability distributions to wind speed datasets to derive the best model that describes seasonal wind speed in Maiduguri. The objectives of the study is to determine the relationship between estimated wind speed and the prevalence of asthma with the view of making suggestions that can help in asthma management. Model fits to the wind speed data showed the Weibull model is compatible with wind speed data of Maiduguri. The study also found a negative correlation between wind speed and prevalence of asthma ($r = -0.502, p - value = 0.09$). This suggests that increasing wind speed associates with low prevalence of asthma; that is, the pollutants in the wind is the more important factor, than speed of the wind, in determining asthma attacks in Maiduguri. The negative correlation between wind speed and prevalence of asthma is not surprising for Maiduguri, because during the period of highest wind speed there is accompanying sandstorm which could provide early warning to asthma patients to put on nose masks in order to prevent attack. Seasons with lowest level of wind speed associates with highest prevalence of asthma. This again is not surprising for Maiduguri as the northeasterly winds prevailing during this period brings in its train dried dusty air and cold, which are asthma triggers. Consequently, for effective management of asthma it is suggestive that patients should wear both nose masks and warm clothing during this period.

Pollutants in the wind and colds are found to be asthma triggers. Hence, how these two factors interact in order to influence asthma attack needs further studies that will contribute immensely to the understanding of asthma etiology. This will in turn provide an invaluable platform for the management of asthmatics.

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