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RELATIONSHIP BETWEEN MEAN SURFACE WIND PATTERN AND HEAVY RAINFALL DAYS IN GUINEA SAVANNA ECOLOGICAL ZONE OF NIGERIA

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Abstract

This study was aimed at assessing the relationship between mean surface wind pattern (both direction and speed) on heavy rainfall days in the Guinea Savanna Ecological Zone of Nigeria (GSEZN). Daily surface wind and rainfall (mm) data, 1981-2015 (35 years) for nine (9) meteorological stations in the study area were collected from Nigerian Meteorological Agency, Abuja and used for this research. The statistical methods such as spatial aggregation for all the data collection points-mean, standard deviation (SD), regression and correlation coefficients were used for analysis. Frequency count was used to determine total and mean surface wind direction on heavy rainfall days. Findings revealed that the South-West trade wind had the highest frequency of occurrence on heavy rainfall days, while the North-East trade wind had the least. The highest average wind speed on heavy rainfall days of 6.58-9.36 m/s occurred on Jos Plateau (highland), 5.31-6.58 m/s occurred at the eastern part of the study area (Ibi), while the lowest of 3.59-5.31 m/s occurred on lowland of Minna and Ilorin. Pearson correlation coefficient between mean heavy rainfall and mean wind direction was .272 (weak positive correlation) and -.155 (negative correlation) for mean wind speed. Kendall tau_b correlation was .078 between mean heavy rainfall and mean wind direction (negligible correlation) and -.041 (negative correlation) between mean heavy rainfall and mean wind speed. The Spearman rho correlation showed negligible correlation (.100) between mean heavy rainfall and mean wind speed, while negative correlation (-.034) existed between mean heavy rainfall and mean wind speed. The regression between mean wind direction and mean wind speed on heavy rainfall days were 24% and 74%. The SD for mean wind direction, mean wind speed and heavy rainfall were 25, 7.3 and 4.0. Recommendations of this study included similar studies to be conducted in other regions of Nigeria, there is need for heavy rainfall and wind forecasts to serve as early warning tool; and Pearson correlation coefficient gave better results hence should be used for future study on the relationship between weather variables.

Key words: Heavy rainfall, relative humidity, evaporation, wind, sunshine

1. Introduction

Rainfall is seasonal in the Guinea Ecological Zone of Nigeria. Heavy rainfall is one of the derived rainfall parameters which affect both man and his environment directly and indirectly especially, through erosion and flooding. Heavy rainfall is an accumulated rain over a place in a day which is greater than or equal to (≥) 50 mm (Audu *et al.*, 2018; Audu *et al.*, 2019a). The study of Audu *et al.* (2018) confirmed a significant positive trend in heavy rainfall over the Guinea Savanna Zone of Nigeria. Likewise, Audu *et al.* (2019b) opined that, highest monthly heavy rainfall over GSZN occurs in August, while 1996-2000 had the highest mean heavy rainfall days (Audu *et al.*, 2020).

Wind is a major weather variable which affects other variables in the atmosphere. Wind refers to air in motion and has both direction and speed which are in turn affected by the season and as such, varies over time and space. There are other factors such as vegetation and topography that affect both surface direction and wind speed. According to Musa et al. (2013), if global pattern changes; local wind patterns would also change. This was corroborated by Ismail et al. (2015a) who discovered variability in wind speed over Ibadan and average annual maximum wind speed of about 5.8 m/s in 2008 with a minimum of 1.2 m/s which occurred twice in 1998 and 2011.

In Nigeria, there are two (2) main wind systems that affect weather especially, rainfall. Origin and direction of surface wind follows the pressure belts which vary spatially and temporally. Generally, winds blow from high to low pressure belts. St. Helena and Azores high cells are the two (2) sub-tropical pressure systems whose interactions determine movements of moisture laden winds from Gulf of Guinea and dry continental wind from Sahara Desert in the troposphere over Nigeria.

The horizontal movement of wind transfers heat, dust, cold and moisture from one place to another at the surface, upper level or both, while its vertical motion transfers heat, cold and moisture upward and downward. According to Nieuwolt (1975), the troposphere has a shallow depth around the equator, hence horizontal air movements prevail in the troposphere and the masses of air transported parallel to the earth’s surface are many times larger than those carried by vertical air currents. The vertical air currents are responsible for the transportation of heat and moisture from the lowest levels and change the stability conditions of the air masses. Also, Orji (2016) observed that, the south-west monsoons which are prominent at wet season are moisture-laden southwesterly winds of oceanic origin which complement the occurrence of cloud formation, precipitation and thunderstorms (TSs). It was corroborated by Audu (2019a) who stated that, south-westerly wind (SWW) which blows across the Atlantic Ocean transports moisture into Nigeria and results in rainy season. This moisture system is been sustained by adequate heat energy provided by high sunshine hours and intensities. To corroborate this, Akinsanola *et al*. (2013) opined that, increase surface heating over West Africa at summer is a major factor responsible for the generation of monsoon flow. Southwesterly winds are controlled by pressure gradient between the Sahara Heat Low (SHL) and Saint Helena High (SHH). Oke *et al*. (2015) remarked that, extreme winds are usually classified by their phenomenological causes (tornadoes, thunderstorms, tropical systems and extra-tropical systems) as generation and nature of these wind events is different. For infrastructure design, wind speeds are associated with a nominal averaging time of three (wind gust), height of 10 m and open terrain.

In rainy season, winds may blow gently or forcefully (squalls and gusts). This leads to unprecedented catastrophe such as the destruction of building, trees and other materials along their trajectories. Nigeria Meteorological Agency (NiMet, 2012) observed that, squalls with speeds of 35 knots and higher are usually experienced during the beginning and cessation of the rainy season in Nigeria. In 2012, these winds of between 60-70 knots were experienced between February in the south and June in the north. According to NiMet (2013), by the 1st quartre of 2013; there was an incidence of high winds caused by rainstorm over southern parts of Nigeria with devastating impacts on infrastructure. Wind, especially the speed during rainfall is capable of drifting clouds and its rain over a large area as well as causing havoc. Vanguard, (February 28, 2018) cited in NiMet (2018) opined that windstorm destroyed over 321 houses in Yala LGA, Cross Rivers State, Nigeria which rendered over 5000 people homeless due to down pour that lasted over four (4) hours and was accompanied by forced wind and thunderstorms with villages of Ipolo, Mfuma, Wanudu and Ntrigom severely affected.

Evaporation and transpiration (evapotranspiration) are key factors contributing to the availability of moisture, mostly at lower atmosphere (troposphere). According to International Glossary of Hydrology (IGH, 1992) and International Meteorological Vocabulary (IMV, 1992) both cited in World Meteorological Organisation (WMO-No. 8, 2008), actual evaporation is the quantity of water evaporated from an open water surface or from wet ground. Transpiration on the other hand is the process by which water from vegetation is vapourised into the atmosphere. It is expressed as the mass or volume of liquid water evaporated per area in unit of time (a day), usually as equivalent depth of liquid water evaporated per unit of time from the whole area and depending on the type of instrument, usual measuring accuracy is 0.1 to 0.01 (WMO, 2003 cited in WMO-No. 8, 2008). This process was earlier explained in Hadley Cell Model (HCM) by Nieuwolt (1975) where it was stated that, excess heat energy is converted into kinetic energy near the equator and large proportion is also used in evaporation and carried with the moving air masses as latent heat which is released at condensation. Also, during evapotranspiration, water vapour is carried upward by air movements. To corroborate this, Ayoade (1988) opined that to maintain the evaporation process, air turbulence ensures moistened air lying over evaporating surface is removed and replaced by fresh-relatively dry air by air turbulence.

During rainfall, the upper horizontal wind blows or pushes the mobile clouds which facilitate the spread of rain to areas along its trajectory. Wind is also important in the determination of the onset and cessation of rains. South-West wind in early part of the year indicates onset of rains, while North-East wind signifies the outbreak of harmattan. In a study conducted by Omotosho (2002), it was detected that; the wind change at lower level (surface-700Hpa) must be negative and between 5-20 m/s, while the upper level (700-400 Hpa) must be positive and between 0-10 m/s for at least 3 weeks to ensure rainy season would begin two (2) weeks afterwards. To corroborate this, Idowu & Omotosho (2010) detected that, onset of rain is about forty-two (42) days after the date V-component of wind at 925 hpa becomes positive. Ismail *et al*. (2015b) observed that the probabilities of wind speed in recent years over Ibadan were less than 0.40 (2.5 years return).

The occurrence of rain over a particular area is a function of several interactive factors which can be broadly classified into two (2) namely meteorological and synoptic factors/features. Among the meteorological factors is wind. In a research conducted by Sambo *et al*. (2016), it was discovered that; mean daily wind speed for recent climate were 3.50, 2.76, 5.52 and 2.08 ms^{-1}, but 3.57, 3.06, 5.44 and 2.99 ms^{-1} for the past climate in Eket, Uyo, Calabar and Ikom indicating a decrease except for Calabar. The sudden outburst of wind (gust) tends to have high speed and has impact on high rainfall in Nigeria. Olaniyan & Afiesimama (2013) detected the impact of winds at 850mb and 700mb levels on heavy rainfall in Nigeria.

Several studies have been conducted on wind across Nigeria such as Adaramola & Oyewole (2011); Ongoma (2014); Muhire *et al*. (2014); Oyewole & Aro (2018). The study of Ozeogwu *et al*. (2017) detected that, measured surface wind speeds were reported almost half of upper wind speeds. None of these studies attempted to look into the relationship between mean surface wind pattern and heavy rainfall days in GSEZN, hence this research was intended to bridge this research gap. Our study therefore answered the following research questions:

1. what is the relationship between the mean surface wind direction and heavy rainfall days over GSEZN?
2. what is the relationship between the mean surface wind speed and heavy rainfall days over GSEZN?

This study was aimed at analysing the relationship between mean surface wind pattern and heavy rainfall days in GSEZN, while the objectives include; to determine the relationship between mean surface wind direction and heavy rainfall days as well as to determine the relationship between mean surface wind speed and heavy rainfall days.

2. Methodology

2.1 The Study Area

The Guinea Savanna Ecological Zone of Nigeria (GSEZN) lies between longitudes 3^o-15^oE and latitudes 9^o-10^o5^1 N (Figure 1). It is found in the central part and the largest vegetation zone in Nigeria. It is bordered to the north by the Sudano-Sahalian Zone of Nigeria (SZN) and to the south by the Rain Forest Zone of Nigeria (RFZN). There are two (2) seasons in the area, namely; wet and dry (Balogun *et al*, 2020). There are both inter-annual and inter-seasonal rain variations in the region (Audu *et al.*, 2018).

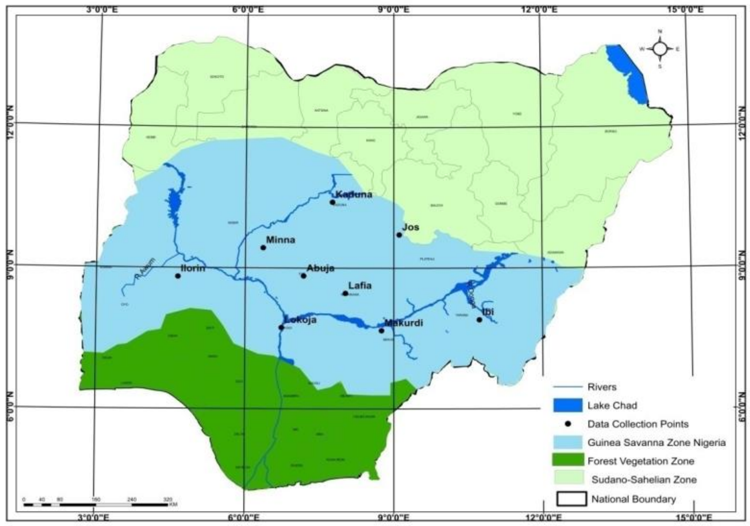

Figure 1: Nigeria showing the study area

Source: Audu (2019)

2.2 Source of Data

Secondary data used for this research were obtained from the Nigerian Meteorological Agency, Abuja.

2.3 Data

Daily surface wind m/s (direction and speed) and rainfall data for the period of thirty-five (35) years (1981-2015) in Makurdi, Lokoja, Ibi, Ilorin, Lafia, Abuja, Minna, Jos and Kaduna synoptic meteorological stations were used for this study. The heavy rainfall data were extracted from daily rainfall through the use of micro soft excels. All the cells containing the considered data were selected. The conditional formatting was chosen, while cells rules were highlighted and equal to or greater than (≥) was clicked. The available text box with the desired threshold value of ≥ 50 mm was then clicked and all the dates with that rainfall were extracted. Data on wind were also extracted using the same method. Wind directions were later converted into degrees.

2.4 Data Analysis

Data are presented in tables and figures for easy comprehension and analysed using various statistical methods such as spatial aggregation for all the data collection points-mean, standard deviation, regression and correlation coefficients. In determining the total surface wind direction over the study area, total wind direction for each data collection point was first determined with equation 1.

$$STsuU = \sum_{i=1}^{N} ssU_i \qquad 1$$

Before determining the total surface wind direction over the study area, mean wind direction per station was first computed with equation 2.

$$\overline{SU} = \frac{\sum_{i=1}^{N} ssU_i}{N} \quad 2$$

In equations 1 and 2, $STsuU$ = station total wind direction, ssU = surface wind direction ; $\overline{sU}$= mean wind direction for a station ; i = 1, 2, ……… N ; N= number of years (35).

Before determining the mean surface wind direction over the study area, the total surface wind direction over the study area was first calculated using equation 3.

$$RTsuU = \sum_{i=1}^{N} RSU_i \quad 3$$

Where: $RTsuU$ = Regional total surface wind direction ; RSU = Regional surface wind direction ; i = 1, 2, ………………. N ; N= total number of stations (9) in the study area.

To determine the average wind direction over the study area, eqn. 4 was applied.

$$\overline{SU} = \frac{\sum_{i=1}^{N} RSU_i}{N} \quad 4$$

Where:

$\overline{SU}$= mean surface wind direction for the region ; RSU = regional surface wind direction ; i = 1, 2, ………………. N ; N= total number of stations (9) in the study area.

To determine the mean surface wind speed (m/s) over the study area, total surface wind speed over each station was first computed using equation 5.

$$STswsp = \sum_{i=1}^{N} swsp \quad 5$$

Surface average wind speed (m/s) per station was derived using equation 6.

$$\overline{swsp} = \frac{\sum_{i=1}^{N} swsp}{N} \quad 6$$

In equations 5 and 6, $STswsp$ =station total surface wind speed ; $\overline{swsp}$ = average surface wind speed for a station ; $swsp$ = surface wind speed ; i =1, 2, … N

N= Total number of years (35).

Before determining the mean surface regional (zonal) wind speed, total regional surface wind speed was first calculated with equation 7.

$$RTswsp = \sum_{i=1}^{N} Rwsp \quad 7$$

In calculating average surface wind speed over the region, equation 8 was used.

$$\overline{Rwsp} = \frac{\sum_{i=1}^{N} Rwsp}{N} \quad 8$$

In equations 7 and 8, $RTswsp$ = Regional total wind speed ; $\overline{Rwsp}$ = Regional mean wind speed ; i =1, 2, … N ; N= total number of stations (9).

In order to determine the ordinal relationship between wind direction/speed patterns and heavy rainfall, Pearson, Kendall tau (Tau-b) and Spearman rho statistics were used. The three (3) correlations were used to allow for comparison among them so as to suggest the one with the best correlation. Values of Tau-b range from -1 to +1. A value of zero depicts absence of association. The Kendall Tau-b coefficient is defined as shown eqn. 9.

$$TB = \frac{n_c - n_d}{\sqrt{(n_0 - n_1)(n_0 - n_2)}} \quad 9$$

Where:

$n_0 = n(n-1)/2$; $n_1 = \sum_i t_i (t_i - 1)/2$; $n_2 = \sum_j u_j - 1)/2$

$n_c = Number\ of\ concordant\ pairs$

$n_d = Number\ of\ discordant\ pairs$ $t_i = Number\ of\ tied\ values\ in\ the\ i^{th}\ group\ of\ ties\ for\ the\ first\ quantity$

$u_j = Number\ of\ tied\ values\ in\ the\ i^{th}\ group\ of\ ties\ for\ the\ 2nd\ quantity$

Spearman rho (r_s) correlation coefficient was calculated thus:

$$r_s = 1 - \frac{6\sum d_1^2}{n(n^2-1)} \qquad 10$$

Where: r_s= Spearman's rank correlation coefficient correlation coefficient

d_i = difference between the two ranks of corresponding values.

n =number of observations

The Pearson correlation coefficient was calculated as follows:

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2 \sum(y_i-\bar{y})^2}} \qquad 11$$

$n = number\ of\ stations\ under\ consideration$

Where: r = correlation coefficient x_i = values of the x variable in a sample,

$\bar{x}$ = mean of the values of the x variable y_i = values of the y variable in a sample

$\bar{y}$ = mean of the values of the y variable. Standard deviation (SD) was used to show how much the members of a group differ from the mean value for the group. It is expressed as thus:

$$SD = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad 12$$

Where: $SD = Standard\ deviation$ $\sum = summation$ $x = Set\ of\ numbers\ in\ a\ data$; $\bar{x} = Mean\ of\ the\ set\ of\ numbers\ in\ the\ data$

3. Results and Discussion

Table 1: Frequency of total surface wind direction on heavy rainfall days over Guinea Savanna Ecological Zone of Nigeria (GSEZN)

Station/wind direction	Calm	North	North-East	East	South-East	South	South-West	West	North-West
Makurdi	14	02	02	01	03	16	54	43	00
Lokoja	38	05	04	06	10	28	48	07	03
Ibi	03	00	01	04	04	13	49	24	03
Ilorin	11	01	00	03	10	30	66	11	00
Lafia	03	01	00	02	02	09	19	26	00
Abuja	14	09	01	00	09	03	31	10	23
Minna	15	06	00	02	16	11	44	06	05
Jos	04	01	02	01	03	00	13	10	26
Kaduna	04	00	00	02	05	05	34	30	04

Source: Authors' computation, 2021

On Table 1, all wind directions were observed on heavy rainfall days over Makurdi except the North-West (NW), while South-West (SW) has the highest frequency and closely followed by the West trade wind. All wind directions were observed on heavy rainfall days over Lokoja with the SW trade wind having the highest frequency, while the

NW had the least. In Ibi, all wind directions were observed on heavy rainfall days except the North trade wind. However, SW trade wind had the highest frequency followed by West trade wind. With the exception of the NE and NW winds that were not observed on heavy rainfall days in Ilorin, all other wind directions occurred with the SW trade wind having the highest frequency. Over Lafia, with the exception of the NE and NW trade winds that did not occur on heavy rainfall days; all other wind directions were experienced with the West trade wind having the highest frequency followed by SW trade wind.

In furtherance of the results analysis on Table 1, East trade wind recorded zero (0) occurrence on heavy rainfall days over Abuja, while all other wind directions occurred with the SW trade wind dominating. NE and North trade winds had zero (0) occurrence on heavy rainfall days over Kaduna, while all other wind directions were experienced with the SW dominating and followed by the SE trade wind. With the exception of the NE trade wind that had zero (0) frequency on heavy rainfall days over Minna, all other wind directions occurred with the SW having the highest and followed by calm wind direction. Over Jos, South wind direction recorded zero (0) occurrence, NW wind direction recorded the highest frequency and followed by SW on heavy rainfall days.

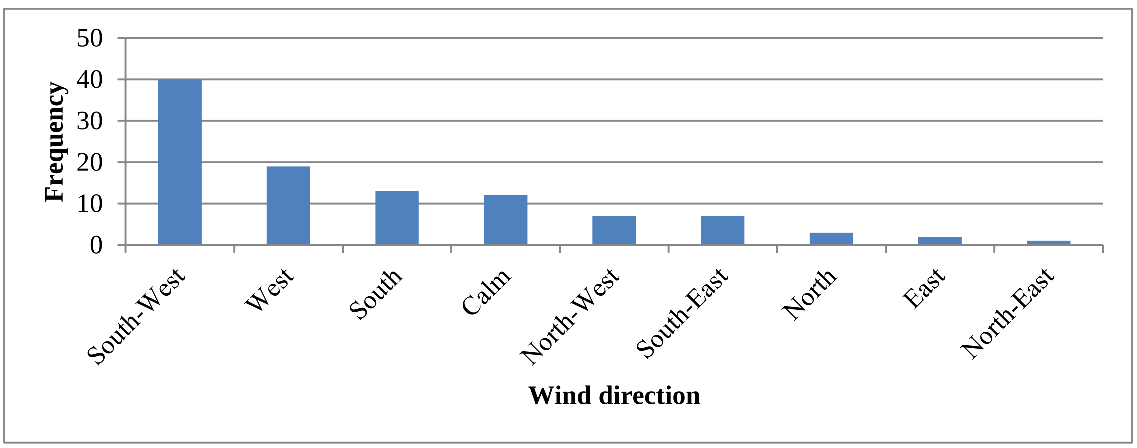

Figure 2: Frequency of mean wind direction on heavy rainfall days over the study area
Source: Authors' computation, 2021

Figure 2 showed the mean frequency of regional average surface wind direction over the study area (GSEZN) on heavy rainfall days. SW trade wind had the highest frequency of 40 followed by West trade wind (19), South (13), calm (12), North-West (NW) and South-East (SE, 7 each), North (3), East (2) and North-East (NE, 1).

In Figure 3, the mean wind direction over the study area on heavy rainfall days comprises of the mean wind direction and speed. The mean direction is predominantly SW. In the analysis of the mean wind speed, the highest was recorded on Jos Plateau (6.58-9.36 m/s), followed by the eastern part of the study area (5.31-6.58 m/s). The highest mean wind speed was recorded highland, while the least was recorded on lowland.

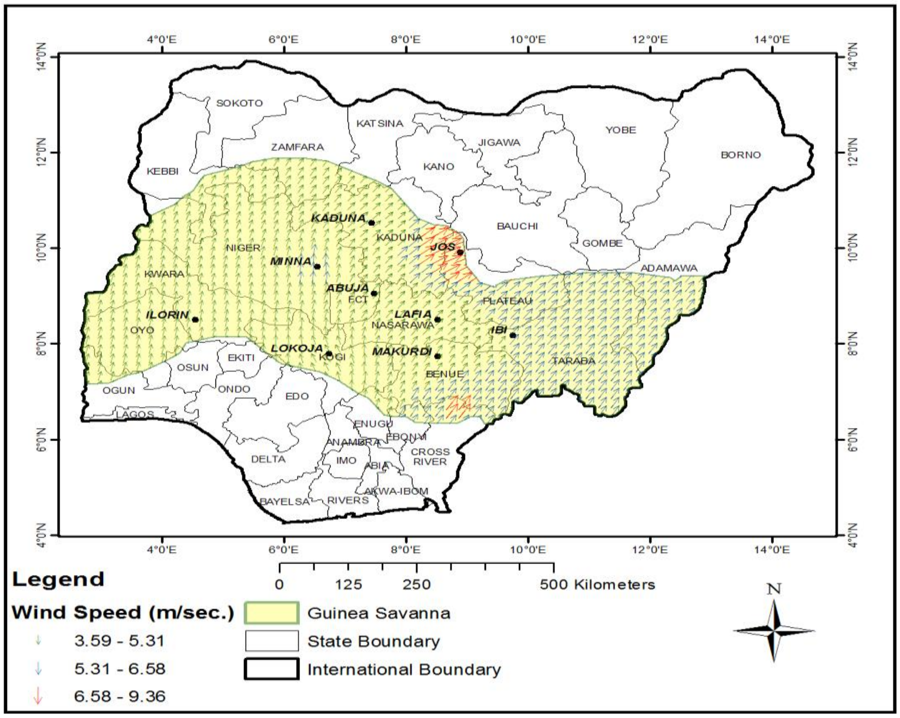

Figure 3: Mean wind pattern (direction & speed) on heavy rainfall days over GSEZN
Source: Authors' computation, 2021

The descriptive statistics on mean wind (direction and speed) and mean heavy rainfall displayed in Table 2 depict that wind direction is 205 which is approximately south-west wind when converted into the 16 cardinal points. This agrees with the result on Figure 2. The mean wind speed is 41.5 m/s, while the standard deviations for all variables are low.

Table 2: Descriptive Statistics of mean wind pattern on heavy rainfall days in GSEZN

Weather variables/statistics	Mean	Standard deviation	N (years)
Mean wind direction	205	25.0	35
Mean wind speed	41.5 m/s	7.3	35
Mean heavy rainfall	68.3 mm	4.0	35

Source: Authors' computation, 2021

The Pearson correlation analysis shown in Table 3 depicts weak positive correlation between mean wind direction and heavy rainfall days, while it is negative between mean heavy rainfall and mean wind speed. There exists a negligible correlation between mean wind direction and mean wind speed.

Table 3: Pearson Correlation Coefficient of wind pattern and heavy rainfall days in GSEZN

Weather variable	Mean wind direction	Mean wind speed	N (years)
Mean heavy rainfall	.272	-.155	35
Sig. (2-tailed)	.114	.373	35
Mean wind direction	1	.004	35
Sig. (2-tailed)		.983	35
Correlation is significant at the 0.05 level (2-tailed)			

Source: Authors' computation, 2021.

In Table 4, the Kendall tau_b correlation coefficient between mean wind direction and mean heavy rainfall days has negligible correlation, while mean heavy rainfall and mean wind speed are negatively correlated. On the other hand, mean wind direction and mean wind speed have weak positive correlation.

Table 4: Kendal tau_b Correlation Coefficient of wind pattern and heavy rainfall days in GSEZN

Weather variable	Mean wind direction	Mean wind speed	N (years)
Mean heavy rainfall	.078	-.041	35
Sig. (2-tailed)	.513	.733	35
Mean wind direction	1.000	.029	35
Sig. (2-tailed)	.	.809	35
Correlation is significant at the 0.05 level (2-tailed)			

Source: Authors' computation, 2021

In Table 5, the Spearman rho correlation coefficient showed negligible correlation between mean heavy rainfall and mean wind speed, negative correlation between mean heavy rainfall and mean wind speed and weak positive correlation between mean wind direction and mean wind speed on heavy rainfall days.

Table 5: Spearman rho Correlation Coefficient of wind pattern and heavy rainfall days in GSEZN

Weather variable	Mean wind direction	Mean wind speed	N (years)
Mean heavy rainfall	.100	-.034	35
Sig. (2-tailed)	.568	.848	35
Mean wind direction	1.000	.034	35
Sig. (2-tailed)	.	.848	35
Correlation is significant at the 0.05 level (2-tailed)			

Source: Authors' computation, 2021

In Table 6 (regression), there is an observable positive relationship of 24% and 74% respectively between mean wind direction and mean wind speed with heavy rainfall days. By implication, there are other meteorological and synoptic factors which relate positively with heavy rainfall over the study area, especially the south-west trade wind which supplies the largest quantity of the atmospheric moisture. The correlation (*r*) is 15.5% for mean wind direction and 27.2% for mean wind speed. The adjusted R^2 was obtained as a result of the application of an inbuilt correctional factor. In Table 6, because hypotheses were not compared and no model testing of goodness of fit was done; *P* value is not required.

Table 6: Relationship between mean wind direction and speed with mean heavy rainfall in GSEZN

Model Summary				
Model	*r*	R^2	Adjusted R^2	Std Error of the Estimate
1. Mean wind direction	.155[a]	.024	-.005	4.0261
2. Mean wind speed	.272[a]	.074	.046	3.9222
a. Predictors: (Constant), Mean wind direction/speed				

Source: Authors computation, 2021.

The study of Akinsanola *et al*. (2013) proved a strong link between the prevailing wind and area of highest rainfall. The result of this study revealed that all wind directions including calm wind were observed on heavy rainfall days. The dominance of south west (SW) wind is a confirmation of other previous studies over Nigeria. This wind blows across the Atlantic Ocean and transport large volume of moisture needed for rain occurrence over the study area (see NiMet, 2019). In a research conducted by Audu *et al*. (2013), Lokoja observed rainfall of about 11.0 mm and wind direction was South-easterly. The result of a research conducted by Audu *et al*. (2016) revealed that, on 3rd July, 2014 that Abuja experienced rainfall; wind direction at the surface was south westerly, while at 700 hpa, it was easterly and described as the African Easterly Jet (AEJ) which is a fast-moving wind with 33 knots. The study of Ongoma (2014) associated easterly winds with rainfall in Kenya. The opposing North-East trade wind on the other hand with the least frequency on heavy rainfall days blows across the Sahara Desert hence it is dry (Olanrewaju, 2010) with less moisture. Other wind directions observed on heavy rainfall days is an indication that, it is not only the SW wind that is observable on heavy rainfall days over the study area. This also implies that, there are other factors aside wind directions which impact on heavy rainfall.

Several studies have been conducted on wind speed across Nigeria. Adaramola & Oyewole (2011) opined that, highest mean wind speed in Northern Nigeria is about 7.5 m/s. According to Audu *et al*. (2019b), minimum wind speed needed for most wind turbines to operate is from 3.0-4.0 m/s and in Makurdi, monthly mean wind speed varies from 3.51 m/s in November and 5.87 m/s in April. Oyewole & Aro (2018) remarked that daily mean wind speed for Jos, Kano and Ilorin is from 13-18 ms^{-}1. According to this study, highest mean wind speed on heavy rainfall days occurred at higher elevation of Jos Plateau followed by eastern part which is also elevated, while the lowest was observed in lowland of western part of the study area (6.58-9.36 m/s, 5.31-6.58 m/s and 3.59-5.31 m/s respectively). Variations in results obtained in these researches could be due to the difference in elevations as wind speed is higher on highlands. This result corroborated the study of Ozeogwu *et al*. (2017) which observed that measured surface wind speeds were reported almost half of upper wind speeds. They also observed lowest wind speed of 1.3 m/s over Bida which is at the western part of this study area. Olaniyan & Afiesimama (2013) observed the impact of winds at 850mb and 700mb levels on heavy rainfall in Nigeria. During rainfall, sudden outburst of wind (gust) tends to have high speed.

4. Conclusion and Recommendations

This study was conducted to ascertain the relationship between the pattern of mean surface wind (both direction and speed) on heavy rainfall days over the GSEZN. Daily surface wind and rainfall data (1981-2015) for nine (9) meteorological stations in the study area were collected from NiMet. Results were presented in tables as well as figures and analysed using various statistical means such as frequency count, mean, standard deviation, regression and correlation coefficients. Findings revealled that, even though all wind directions were observed on heavy rainfall days; the South-West trade wind has the highest frequency, while the North-East trade wind has the lowest frequency. The highest average wind speed of 6.58-9.36 m/s occurred on Jos Plateau (highland), 5.31-6.58 m/s occurred on the eastern part of the study area, while the lowest wind speed of 3.59-5.31 m/s occurred at the lowland (western part of the study area). Pearson correlation coefficient showed weak positive correlation of .272 between mean heavy rainfall and mean wind direction and negative correlation of -.155 between mean heavy rainfall and mean wind speed. Kendall tau_b correlation showed negligible correlation of .078 between mean heavy rainfall and mean wind speed, while mean heavy rainfall and mean wind speed are negatively correlated (-.041). The Spearman rho correlation showed negligible correlation of .100 between mean heavy rainfall days and mean wind speed, while negative correlation of -.034 exists between mean heavy rainfall and mean wind speed. The regression between mean wind direction and mean wind speed with mean heavy rainfall are 24% and 74%, while SD for mean wind direction, mean wind speed and mean heavy rainfall are 25, 7.3 and 4.0. Recommendations of this study include similar studies to be conducted in other regions of Nigeria to give a wholistic picture across the country. There is need for heavy rainfall and wind (both wind direction and speed) forecasts to serve as early warning tools. Pearson correlation coefficient produced higher values hence should be used for future studies on the relationship between weather variables.

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