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ANALYSIS OF RELATIVE HUMIDITY ON HEAVY RAINFALL DAYS IN GUINEA SAVANNA ZONE, NIGERIA

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Abstract

The occurrence of rainfall over a place depends on several factors and relative humidity (RH) is a key determinant. This study was aimed at analysing RH on heavy rainfall days over the Guinea Savanna Zone of Nigeria (GSZN). Nine (9) synoptic meteorological stations (Ilorin, Lokoja, Makurdi, Minna, Abuja, Ibi, Lafia, Jos and Kaduna) were chosen for the purpose of data collection. Daily rainfall (mm) and RH (%), 1981-2015 were obtained from the Nigerian Meteorological Agency, Abuja and used. Rainfall which is ≥50 mm/day was considered heavy in this research. The data were organized in MS excel for analysis. Frequency count of heavy rainfall days, statistical mean, Kendall Tau-b (T_b), Pearson moment correlation (r) and Spearman rho (r_s) correlation coefficients, regression as well as standard deviation (SD) were used to analyse the data; while results were presented in tables. Results revealed that, the threshold relative humidity (%) range on heavy rainfall days is 60-64 (2%), dominant is 80-84 (28%) and maximum is 100 (1%). RH contributed 12.1% to heavy rainfall. The correlation is 0.348, while adjusted R^2 is 12%. The T_b correlation coefficient is 0.260, r is .348, while r_s is 0.346. Standard deviation for both mean RH and mean heavy rainfall are 3 and 4 respectively. The study concluded that, an increase in daily RH would increase the frequency of heavy rainfall over the study area and vice versa. The study recommended that more efforts should be put forward to study the relationship between these two (2) weather variables; daily relative humidity should be forecast over other meteorological stations in Nigeria; and Pearson moment correlation should be adopted in studying the relationship between weather parameters.

Key words: Relative humidity, rainfall, heavy rainfall, water vapour, GSZN

1. Introduction

Rainfall in Nigeria is mostly a function of an interaction between meteorological parameters and synoptic features. Some meteorological parameters influencing rainfall in Nigeria include temperature (T) (Chukwuemeka *et al.*, 2013), relative humidity (RH) and clouds. The synoptic features include, but not limited to El-Nino

Southern Oscillation (ENSO), Atlantic Ocean Surface Temperature (AOST) and Inter Tropical Discontinuity (ITD) (Gbuyiro *et al*. 2002), African Easterly Jet (AEJ), squall lines (Asaniyan, 2006), wind and thunderstorms (Ibrahim, 2006). Emmanuel & Adeyemi (2013) observed that, water vapour is one of the most dynamic variables in the atmosphere which linked the surface and water cycle.

Relative humidity (RH) is a function of temperature as expressed by Clausius-Clapeyron equation (Galewsky *et al*., 2015) cited by (Ajileye *et al*., 2016). Umoh *et al*. (2013) pointed out that, the amount of moisture in air called RH is the percentage of the total water vapour air can hold at a particular air temperature. RH is a major indirect key factor of weather and climate parameters due to its positive role on rain formation. For instance, water resources are important components of the water cycle which are obtained majorly through rainfall which in turn is facilitated by the sufficient percentage of RH. It is a major ingredient of rain which is responsible for the volume of water that precipitates from clouds. It experiences daily, weekly, monthly, decadal and inter/intra annual spacio-temporal variations which in turn impact on the occurrence of rainfall over an area.

The impact of RH on atmospheric variables is probably more on temperature and rainfall. Variability of RH in conjunction with other rain producing systems are the major determinants of the onset, cessation, dry spells, wet spells, amount, intensities and general distribution of rains over an area. Audu *et al*. (2013) averred that, dry season mean RH over Lokoja is about 30%, while that of wet season is about 70%. Generally, mean RH of 30% is too low and 70% RH is sufficient to facilitate rain over an area. This was corroborated by Emmanual & Adeyemi (2013); Adedayo (2016) who in separate studies stated that, the value of water vapour density is low in dry season, whereas it is high in the wet season. This explains the existence of two (2) distinct seasons in the study area. The study of Langa *et al.* (2016) revealed strong relationship between rainfall and RH. Also, Ike & Mbonu (2019) remarked that, Kaduna South experiences a fairly high percentage of RH ranging from 69-82% in the months of May-October with the highest in August, whil other months experience low RH of about 25-47% with the lowest in February. The highest RH in August is hence strongly positively correlated with highest rainfall in August over Nigeria.

Water vapour and the presence of atmospheric solid particles in sufficient quantities result in condensation which eventually leads to rain. Oyewole *et al*. (2014); NiMet (2019) in separate studies averred that, condensation of water vapour occurs in the atmosphere into water droplets in the presence of condensation nuclei such as dust, smoke, salt particles, droplets and sulphuric acid of which salt and sulphuric acid have affinity for water and therefore called hygroscopic nuclei. The presence of sufficient condensation nuclei explains why rainfall is probably experienced even when RH is less than ($<$)100% (saturation point).

The priority areas of rainfall in Nigeria include agriculture and food security, water resources, health, disaster risk reduction, energy resources and transportation. Agriculture in Nigeria especially the commencement of planting period, crop germination, crop maturation and yield are mostly rain depended. Opeyemi *et al*. (2016) discovered that, reduced banana productivity is accompanied by low RH, while the output rises as it increases slightly to about 77%. This was corroborated by Yahaya *et al*. (2020) who noted weak positive relationship between RH and sugarcane production in Adamawa State, Nigeria with Pearson's Product Moment Correlation Coefficient (PPMCC) of 0.1 and concluded that, an increase in RH would increase sugarcane yield. The proclamation of NiMet (2019) agreed with the observation of Umar (2010a) which stated that, boosting of agriculture to achieve self-reliance in food production thereby securing national food security remains very central to the 7-point agenda of President Yar'Addua's administration. The knowledge of derived rainfall parameters in Nigeria as it affects agriculture and water resources is connected to the impact of RH on rainfall.

Heavy rainfall as used in this study is as defined by Audu *et al.* (2019) which implies an accumulated rainfall of ≥50 mm/day (24 hours) over a particular area. Many researches have been conducted on the relationships between rainfall and other weather variables, impact of rainfall and temperature on crop production, flooding, dry spells, drought and outbreak of pests and diseases as they affect agriculture. Examples of such researches include, but not limited to Sawa (2010a,b); Umar (2010b,c); Bello (2010); El-Tantawi (2013). The study of Musa *et al*. (2020) was centred on trend in extreme rainfall and temperature in parts of North Central States, Nigeria. As good as these studies were, they did not analyse mean relative humidity (RH) on heavy rainfall days. This forms the hiatus for this research which answered the following research questions:

1. What is the range of relative humidity on heavy rainfall days in GSZN?

2. What is the relationship between relative humidity and heavy rainfall days in GSZN?

The research aimed at analysing RH (%) on heavy rainfall days in Guinea Savanna Zone, Nigeria (GSZN), while the objectives include; to determine the range of RH on heavy rainfall days and examine the relationship between RH and heavy rainfall days in GSZN.

2. Methodology

2.1 The Study Area

The study area is the entire Guinea Savanna Zone, Nigeria (GSZN) which lies between longitudes 4º–10ºE and latitudes 6º–11º30`N. It is the most central vegetation zone in Nigeria which is bordered to the north by Sudan Savanna and to the south by Rain Forest. The data points chosen for this study include Makurdi, Lokoja, Ibi, Ilorin, Lafia, Abuja, Minna, Jos and Kaduna; while the data covered the period, 1981 to 2015 (35 years). The zone observes two distinct seasons namely, wet and dry seasons. The normal onset and cessation months of rains are April and October. The annual rainfall ranges between 1300mm–2200mm (Binbol, 1995; Abdulkadir, 2007; Odekunle *et al*., 2007; Yusuf & Yusuf, 2008; Yusuf, 2012); while mean annual temperature is about 28.03ºC.

The area consists of gently undulating plain with some hills, ridges and plateaux whose heights are between 300m-900m (Balogun, 2001 cited in Obateru, 2017). These highlands also influence the weather of the area especially rainfall and temperature. Two major rivers found in the zone are Rivers Niger and Benue which supply water for both onshore and offshore uses such as transportation, domestic, irrigation, fishing, generation of hydroelectricity, evaporation, tourism and recreation as well as inland drainage to some rivers. Figure 1 shows the study area.

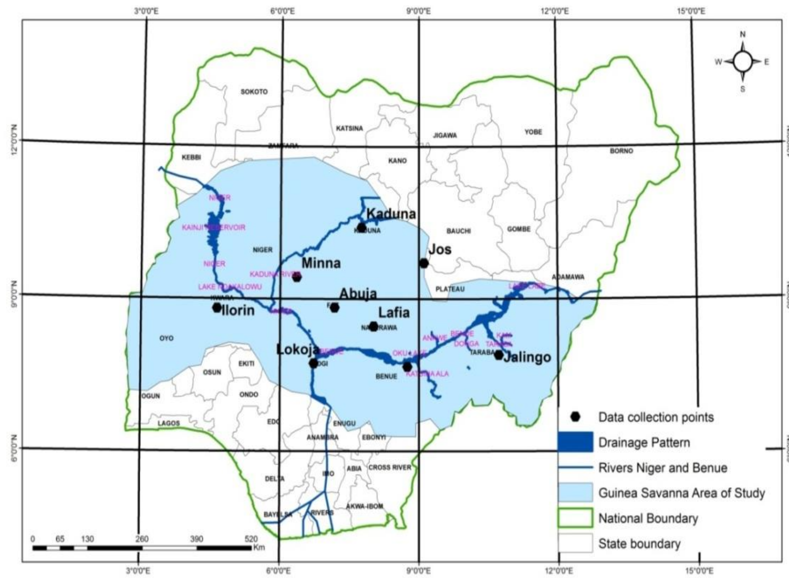

Figure 1: The Study Area
Source: National Research and Space Development Agency, Abuja (2021)

2.2 Types of Data

Secondary data which include daily relative humidity (RH) in percentage (%) as well as rainfall (mm), 1981-2015 (35 years) were used for this research. These data were in numerical forms.

2.3 Sources of Data

The secondary data used for this study were sourced from the Nigerian Meteorological Agency, Abuja which is in-charge of weather data in Nigeria.

2.4 Data Analysis

Before the analysis, heavy rainfall dates were extracted from the daily rainfall using micro soft excels package. Relative humidity (RH) on heavy rainfall days was also extracted using the same method following the dates for heavy rainfall as earlier extracted. Frequency count was used to establish the threshold, dominant and maximum relative humidity on heavy rainfall days. Number of occurrences of ranged Relative Humidity (RH) per station was calculated with eqn. 1.

$SF_{\gamma RH} =$ number of occurrences of ranged Relative Humidity (RH) per station 1

Where: $SF_{\gamma RH}$ = station frequency of RH.

Regional mean frequency relative humidity was calculated using eqn. 2.

$$\overline{GSZN} = \frac{\sum_{i=1}^{n} SF_{rRH}}{n} \qquad 2$$

Where:

$GSZN$= Guinea Savanna Zone, Nigeria (study area)

n= total number of stations in the GSZN

$i = 1,2, \ldots n$

In order to determine the ordinal relationship between mean RH and heavy rainfall over the study area, Kendall tau-b (T_b), Spearman rho (r_s) and Pearson moment correlation coefficients (r) were calculated. The T_b statistics, unlike Tau-a(T_a) make adjustments for ties. Values of T_b range from -1 (100% negative association or perfect inversion) to +1 (100% positive association or perfect agreement). A value of zero indicates the absence of association. The T_b coefficient is defined as:

$$T_b = \frac{n_c - n_d}{\sqrt{(n_0 - n_1)(n_0 - n_2)}} \qquad 3$$

Where: $n_0 = n(n-1)/2$;
$n_1 = \sum_i t_i (t_i - 1)/2$;
$n_2 = \sum_j u_j - 1)/2$
$n_c = Number\ of\ concordant\ pairs$
$n_d = Number\ of\ discordant\ pairs$
$t_i = Number\ of\ tied\ values\ in\ the\ i^{th}\ group\ of\ ties\ for\ the\ first\ quantity$
$u_j = Number\ of\ tied\ values\ in\ the\ i^{th}\ group\ of\ ties\ for\ the\ second\ quantity.$

Spearman rho (r_s) correlation coefficient assesses how well the relationship between two (2) variables can be described using a monotonic function. It was calculated with eqn. 4.

$$r_s = 1 - \frac{6\sum d_1^2}{n(n^2-1)} \qquad 4$$

Where:

r_s=Spearman's rank correlation coefficient

d_i = the difference between the ranks of corresponding values.

$i = 1,2, \ldots \ldots \ldots \ldots \ldots n$; n =number of observations

The Pearson moment correlation coefficient (r) is a measure of linear correlation between two (2) sets of data. It is a ratio between the covariance of two (2) variables and the product of their standard deviations, thus it is essentially a normalized measurement of the covariance, such that the result always has a value between -1 and 1. It was calculated as follows:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \qquad 5$$

Where: r = Pearson 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 calculated to determine how much relative humidity and heavy rainfall differ from their mean values. It was calculated using eqn. 6.

$$SD = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad 6$$

Where: $SD = Standard\ deviation$
$\sum = summation\ \ x = Set\ of\ numbers\ (35\ years)$

$in\ a\ data$

$\bar{x} = Mean\ of\ the\ set\ of\ numbers$

$(35\ years)\ in\ the\ data$

$n = number\ of\ data\ points\ (9)$

$under\ consideration$

3. Results and Discussion

Table 1 shows the frequency range of relative humidity (RH) on heavy rainfall days over the data collection points and the relative percentage (%) in the entire study area. The RH range of 1-24 was excluded from the table because no station recorded such value within the period. Jos observed the least range of RH of 25-29% on heavy rainfall days. Lafia had the 2nd least range of 50-54%, Lokoja, Ibi, Jos and Kaduna had 55-59% each; while all data collection points experienced the range of 60-64% except Makurdi. All stations had various frequencies of ranges between 65-99%. In the area of highest range of RH on heavy rainfall days, Makurdi, Lokoja, Ibi, Ilorin, Lafia, Minna and Jos observed 100%; while Abuja and Kaduna had the 2nd highest of 95-99%. The dominant range of RH on heavy rainfall days over Makurdi is 75-84%; Kaduna is 75-79%; Jos, Minna, Lafia, Ilorin, Ibi and Lokoja, 80-84%; while it was 85-89% over Abuja. Considering the dominant range, Lokoja had the highest frequency (38), while Jos had the least frequency (19).

At the regional level (GSZN), the lowest RH (%) on heavy rainfall days is 60-64% (threshold), highest is 100%; while the dominant is 80-84%. Ranges of between 25-59% are not considered as threshold at the regional level even though few stations observed it because their percentages are approximately zero (0) each (Table 1).

Table 1: Frequency range of relative humidity (RH)/percentage (%) on heavy rainfall days over the study area.

Station/Range	25-29	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
Abuja	0	0	0	02	04	07	14	20	24	21	08	0
Makurdi	0	0	0	0	04	13	39	39	21	08	09	02
Lokoja	0	0	01	04	08	28	28	38	18	12	11	01
Ibi	0	0	01	04	04	05	26	28	14	07	12	01
Ilorin	0	0	0	01	02	13	31	33	28	13	08	03
Lafia	0	01	0	03	01	02	12	22	07	08	05	01
Minna	0	0	0	01	03	09	11	29	19	10	17	03
Jos	01	0	01	01	01	06	09	19	11	05	04	02
Kaduna	0	0	01	03	03	17	25	24	05	01	05	0
GSZN (%)	0	0	0	02	03	11	21	28	16	09	09	01

Source: Authors' computation, 2021

In Table 2, there is disparity between lowest and dominant, whereas; parity exits between the maximum and dominant RH on heavy rainfall days. This can be substantiated by the fact that six (6) out of the seven (7) stations with 100% RH experienced 80-84% dominant RH on heavy rainfall days. Using the threshold range for GSZN, 60-64% is the normal lowest range, 80-84 is the dominant range; while 100 is the maximum. Hence, all data collection points had normal lowest range, while Makurdi had greater than (>) normal (65-69%). In dominant range, Makurdi and Kaduna had below (<) normal, Abuja observes >normal; while other stations had normal. In maximum RH, Abuja and Kaduna observed <normal (that is, they did not observe RH of 100% on heavy rainfall days), other stations observed normal. There are both intra and inter variations in ranges of RH on heavy rainfall days.

Table 2: Ranges of lowest, dominant, maximum and variations in relative humidity (%) on heavy rainfall days over GSZN.

Station/Range	Abuja	Makurdi	Lokoja	Ibi	Ilorin	Lafia	Minna	Jos	Kaduna	GSZN
Lowest	60-64	65-69	55-59	55-59	60-64	50-54	60-64	25-29	55-59	60-64
Dominant	85-89	75-84	80-84	80-84	80-84	80-84	80-84	80-84	75-79	80-84
Maximum	95-99	100	100	100	100	100	100	100	95-99	100

Note: Range of 25-59% is discarded because their % is about zero (0) each (see Table 1).
Source: Authors' computation, 2021

In Table 3, it is clear that; there exist a relationship between mean relative humidity and heavy rainfall days over the study area. Kendall tau-b (T_b), Pearson correlation (r) and Spearman rho statistics (r_s) used showed weak positive correlations. However, the T_b depicts weak positive relationship with corresponding correlation coefficient of 0.260, r is .348 while r_s is 0.346. This implies that an increase in daily mean relative humidity will increase the frequency of heavy rainfall over the study area.

Table 3: Correlations of mean relative humidity and mean heavy rainfall over the GSZN
Note: MeanRH= Mean relative humidity

			MeanRH	MeanHRR
Kendall's tau_b (T_b)	MeanRH	Correlation Coefficient	1.000	.260*
		Sig. (2-tailed)	.	.030
		N	35 years	35 years
Spearman's rho (r_s)	MeanRH	Correlation Coefficient	1.000	.346*
		Sig. (2-tailed)	.	.042
		N	35 years	35 years
Pearson correlation (r)	MeanRH	Correlation Coefficient	1	.348*
		Sig. (2-tailed)		.040
		N	35 years	35 years

*Correlation is significant at the 0.05 level (2-tailed)

Source: Author's computation, 2021

In Table 4 (regression), there is an observable positive relationship between mean relative humidity (RH) and mean heavy rainfall. Mean RH contributes 12.1% to mean heavy rainfall. By implication, there are other factors both meteorological and synoptic which also have positive relationship with heavy rainfall over the study area. Some of these factors may include amount and type of cloud cover as well as cloud top temperature (cloud micro physics), wind in terms of both direction and speed, thunderstorms (TSs), Tropical Maritime (mT) air mass, squall lines, atmospheric waves such the African Easterly Jet (AEJ) as well as the Equatorial Easterlies. The correlation (r) is 34.8%, while the adjusted R^2 was obtained as a result of the application of an inbuilt correctional factor. Table 4 does not require P value because hypotheses were not compared and no model testing of goodness of fit was done.

Table 4: Relationship between mean relative humidity and mean heavy rainfall in GSZN

Model Summary					
Model	r	R^2	Adjusted R^2	Std. Error of the Estimate	R^2 Change
1	.348[a]	.121	.095	3.8203	.121
a. Predictors: (constant), Mean Relative Humidity					

Source: Authors' computation, 2021

In Table 5, the mean relative humidity on heavy rainfall days is about 82% which is high, while the mean heavy rainfall is about 68.3 mm. The standard deviations for both mean relative humidity and mean heavy rainfall are 3 and 4 respectively.

Table 5: Descriptive Statistics of mean relative humidity and mean heavy rainfall in GSZN

	Mean	Std. Deviation	N
Mean relative humidity	82%	3	35
Mean heavy rainfall	68.3 mm	4	35

Source: Authors' computation, 2021

This study has revealed that, relative humidity (RH) must not be 100% for heavy rainfall to occur. For the period under study, Abuja and Kaduna did not experience 100% RH on heavy rainfall days. This result corroborated the study of Audu *et al*. (2013) which observed that over Lokoja, 64.5% mean RH occurs at wet season resulting in about 86.7% mean rainfall during the same period. The threshold RH (%) on heavy rainfall days which ranges from 60-64% in GSZN signifies that, it is sufficient to produce rain if other rain-bearing factors are favourable as there is no single factor that is superior over others (Oyewole *et al*., 2014). Below this level, the likelihood of heavy rainfall is uncertain. However, Jos Plateau, Nigeria; experienced RH (%) of between 25-29% and there was heavy rainfall. This can be attributed to the relief, temperate climate of the area as well as the presence of sufficient condensation nuclei especially, the hygroscopic nuclei. Likewise, Lokoja, Ibi, Lafi and Kaduna have RH of between 55-59% which was also discarded.

Further, the dominance of RH (%) range of 80-84% implies that this value is high enough to contribute to heavy rainfall. Ismail *et al*. (2015) observed that, air temperature and rainfall trends are similar to that of RH which indicates warm environment as well as wetness in terms of rainfall. Variation in RH may impact on rainfall directly and on surface water resources both directly and indirectly. This was expressed by Byrne & O'Gorman (2016) who stated that, the pattern of RH changes influences the projected response of the water cycle to climate change. The study of Nchom *et al*. (2021) over Kaduna State, Nigeria revealed a link between RH and rainfall which are at their peaks in August.

4. Conclusion

The analysis of mean relative humidity (RH) on heavy rainfall days in Guinea Savanna Zone, Nigeria (GSZN) was carried out in this study. Daily rainfall and RH data, 1981-2015 for nine (9) synoptic stations within the GSZN were collected from Nigerian Meteorological Agency, Abuja and used for this study. Various statistical methods were adopted and results revealed that, the regional threshold RH (%) range is 60-64 (2%), dominant is 80-84 (28%) and maximum is 100 (1%). Relative humidity contributes 12.1% to heavy rainfall. The correlation (r) is 0.348, while adjusted R^2 is 12%. The T_b correlation coefficient is 0.260, Pearson correlation is .348, while r_s correlation coefficient is 0.346. By implication, an increase in mean daily relative humidity would increase the frequency of heavy rainfall and vice versa. Standard deviation for both mean RH and mean heavy rainfall are 3 and 4 respectively.

5. Recommendations

Arising from this study therefore, the following recommendations are hereby advanced:

1. More studies should be conducted on the relationship between these two (2) weather variables on daily basis so as to establish if daily relative humidity has the same effect on daily rainfall the manner it does on heavy rainfall;
2. Relative humidity should be forecast across meteorological stations in Nigeria since it plays a key role in rainfall so as to determine its effect on heavy rainfall and also to serve as a guide to heavy rainfall forecast; and
3. Pearson correlation coefficient statistics should be adopted in studying the relationship between weather parameters since it produces higher values than the Kendall tau-b and Spearman’s statistics.

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