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An Analysis of the Thunderstorm and Disturbance Lines Induced Rainstorm in Ibadan, Nigeria.

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Abstract

Rainstorms being the single most important physical environmental factor affecting agricultural activities in Nigeria has provoked many climatological studies. Analyses of rainstorms over Nigeria have however largely been confined to the rainstorm characteristics relevant to moisture availability for agricultural purposes in which the indices of seasonality and variability were mainly employed. The characteristics–the sequence of rainstorm events, duration of rainstorms, rainfall amount, rainfall intensity and the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines–which determine the exact amount of moisture available, have been relatively neglected. The present study, based on an analysis of 154 rainstorms recorded in Ibadan between 2013 and 2014, is an attempt to examine the effect of these characteristics–duration of rainstorms, rainfall amount and rainfall intensity on areal coverage of rainstorms in Ibadan, Nigeria. Daily rainstorms data, especially the sequence of rainstorm events (percentage), duration of rainstorms (minutes), rainfall amount (millimetre) and the rainfall intensity (millimeter/hour) were processed for 50 rain gauge stations. The areal coverage of rainstorms (square kilometre) was determined using the square method. Data collected were analysed using multiple regression at p≤0.05. The results indicated a close relationship between a number of rainstorm characteristics. In fact, the correlation coefficient produced between the rainstorms *characteristics, showed that a close relationship exist between the duration and rainfall amount, and between the rainfall amount and intensity due to thunderstorm and those due to disturbance lines, which were highly significant (.000 and .000). The results of the analysis showed among other things that the duration of rainstorms, rainfall amount and rainfall intensity were significantly contributed to the areal coverage of rainstorms, though the predictors did not significantly explained the areal coverage of rainstorms in Ibadan.*

Keywords: Thunderstorm, disturbance lines, Rainstorm, Dynamics, Nigeria

1. Background of the study

Water is an important element in any agricultural production system. Crops and animals are adapted to survive within given soil moisture and humidity levels. Moisture in soils aids the mobility of nutrients necessary for the growth of crops. Soil nutrient depletion in the processes of leaching and soil erosion is aided by the availability of excess water.

The tropical environment is blessed with abundant supplies of rainwater. Rainstorm is the prevalent precipitation received in the tropics in the form of rainfall. It is the single most important physical environmental factor affecting agricultural activities in Nigeria. The major source of water for all uses either in the form of surface runoff into rivers or underground storage is the rainstorm which results mainly from the atmospheric circulation over West Africa. According to Ayoade and Akintola (1986), rainstorms may contribute up to 95% of inland rainfall. Also, rainstorms are major generators of runoff and sediment yield, especially in areas without adequate vegetal cover. They also frequently occur in a random pattern temporally and spatially, and thus have an influence on the high variability of rainfall in the region.

However, although rainstorm characteristics are very important, it can pose problems if not taken into detailed account (Ayoade, 2012). An understanding of rainstorm characteristics is of immense benefit to man (Pal, 2009 and Kundzewicz, 2012). When storm characteristics such as amount and duration of storms occur in excess, they become a hazard to the people and farmers in particular. When storms occur in high intensity and longer duration, they cause havoc rather than good (Singh, 2002b) and extended periods of rainstorm could cause mass movements of earth in the form of mudslides and landslides which could lead to loss of life, damage to property and wholesale changes in land configuration. Continuous storm events can produce more runoff than single and separated events with significantly higher precipitation depths (Pal, 2009; Jin, 2009; Kundzewicz, 2012; Ayala, et al., 2017 and Ali, 2018).

Rainstorms vary in amount, duration, intensity and areal coverage (Jin, 2009). This variability leads to a subsequent variability in the amount of rainfall received over Ibadan (Olaniran, 2002; Gbobaniyi, et al., 2013; Dao and Hoang, 2016). Different rainstorm events can lead to different impacts and hazards (Pal, 2009 and Kaixi, et al., 2016). Flooding and rainstorms, apart from causing destruction to lives and property, often cause significant damage to the livelihood systems of the victims. These incidents generally cause disruption of electricity, affect transportation, destroy social amenities and lead to the washing away of crops and livestock. Economic activities among traders and artisans in particular are severely hampered. These disasters are often associated with a fair number of health problems including bodily injuries and the attendant physical and psychological trauma (Mufiraya and Muchuru, 2016 and Shi, et al., 2013).

An analysis of the incidence of rainstorm characteristics such as duration, rainfall amount, intensity relating to areal coverage of rainstorms is now of absolute necessity. A detailed understanding of duration, rainfall amount, intensity and areal coverage of rainstorms variations is necessary for infiltration of rainstorm water into soils. Rainstorm energy, soil erosion rates and nutrient recycling all relate to the time distribution of storm duration, rainfall amount, intensity and areal coverage variations. Against this background, the study aimed to explain the temporal variations of characteristics of rainstorms due to thunderstorm and those due to disturbance lines in Ibadan, Nigeria. Results are expected to be used to inform urban planners on the best way to assigning appropriate zoning types for precipitation-enhanced regions as well as used in establishing guidelines for the use of rainwater in agriculture.

2. Aim and objectives of the study

The paper focuses on the temporal analysis of rainstorm characteristics–frequency, duration, amount, intensity and areal coverage of rainstorms due to thunderstorm and those due to disturbance lines in Ibadan. In other to be able to investigate this, a two year datasets were studied. The analysis included rainstorms data recorded between 2013 and 2014 during the thunderstorm and disturbance lines events. The specific objectives can be summarized as follows:

a. To analyse the temporal patterns of the frequency, duration, amount, intensity and areal coverage of rainstorms due to thunderstorm and disturbance lines in Ibadan; and
b. To determine the relationship between the duration, rainfall amount, intensity and areal coverage of rainstorms due to thunderstorm and disturbance lines in Ibadan.

3. Materials and Methods

3.1 Study area

Ibadan is located approximately on latitude 7^0 22' N and longitude 30 58' E. Nevertheless, the expanse of land normally referred to as the metropolitan area lies between latitudes 7^0 15' and 7^0 30' North and longitudes 3^0 50' and 3^0 00' East about 450 km^2 (fig 1).

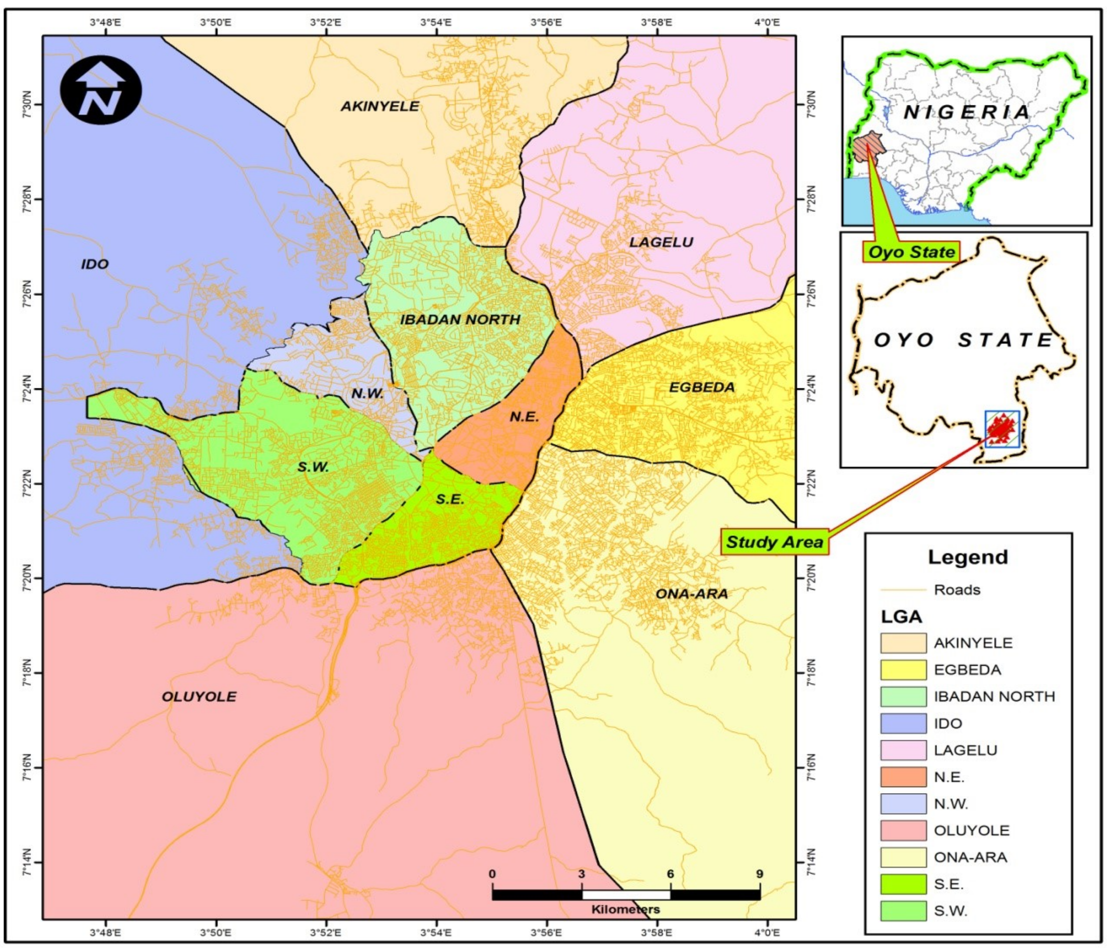

Figure 1: The Study area (Shuttle Radar Topographical Mapping (SRTM), 2013)

The area is in the vegetation transitional zone between the forest and savannah. The area experiences two seasons, the dry and the wet. The onset of the wet season is estimated at 15 March within a two week variation period and 15 November as the tentative end of the wet season with the same level of variation (Oguntoyinbo and Akintola, 1983; Ayode, 2012). The area also experiences the double maxima rainfall regime with the characteristic break in August known as the "little dry season" (Ayoade and Akintola, 1986; Ayoade, 2012; Zhihe et al., 2016 and Sikortu and Seibert, 2018). The mean annual rainfall over the study area is about 1500 mm. According to Ayoade and Akintola (1986), there are four seasons of rainfall events in Ibadan. These include, the dry, early, rainy and late rainy seasons. The onset of the dry is about the start of November to February; the early rainy is about the middle of March to April; the onset of the rainy is about the beginning of May to October and; late rainy is about the onset of September to October. More than 30 per cent of annual rainfall is received during early rainy season. The study area experiences the double maxima rainfall regime characterized by two peaks, one in June and the other in September/October with a period of relatively lower rainfall in between. This period is often referred to as the ‘little dry season’.

3.2 Data base and analysis

Archival meteorological (higher resolution precipitation) data from five synoptic stations (A1-A5) and 45 rainfall stations (B1-B45) (Appendix 1) in Ibadan established in the field in the metropolis (fig 2). Similarly, a 3x3 km grid was superimposed on the map of Ibadan metropolis and one rain gauge was installed in each of the 50 resultant grids. Data on rainstorms such as frequency of occurrence, duration, rainfall amount, intensity were recorded hourly from the 50 weather stations. The areal coverage of rainstorms was measured using square method. The rainstorms data for the period of the study were screened, aggregated, examined and analysed. This was done to determine the temporal variations of rainstorm characteristics due to thunderstorm and those due to disturbance lines in Ibadan metropolis.

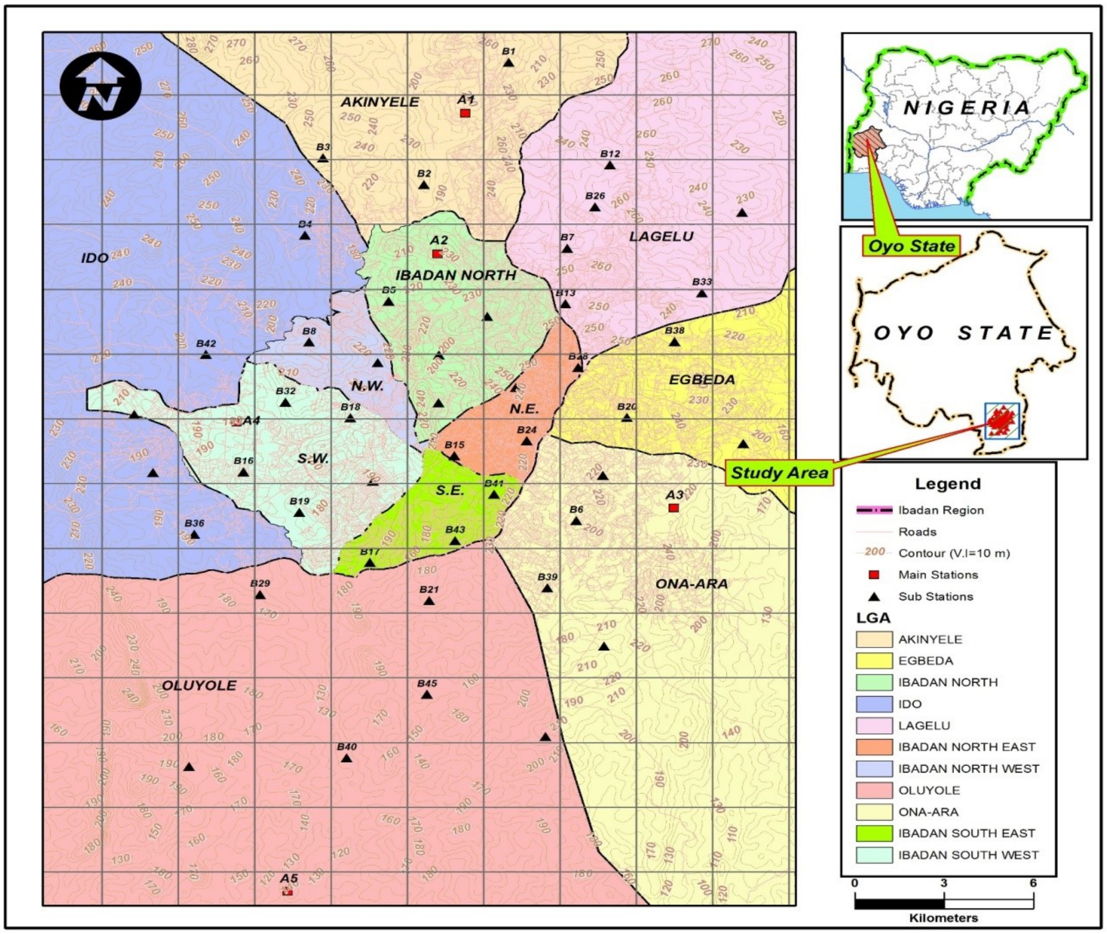

Figure 2: Location of rain gauge stations in Ibadan

The statistical methods employed for this study were both descriptive and inferential statistical tools such as tables, bar charts, mean, standard deviation, multiple regression analysis and Pearson correlation coefficients, respectively. The descriptive statistical method was used to summarize the observed rainstorm characteristics data collected, while the analytical method was used to draw inferences within a known degree of accuracy regarding the weather data under analysis and the distribution of each of the rainstorm characteristics. The interpretation of the result of the descriptive statistics was done based on percentages as well as absolute values. Data collected were analysed using multiple regression at $p \leq 0.05$. The regression equation, expressed as:

$$Y = a + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n + e \quad (1)$$

where (Y) represents the dependent variable, (a) represents constant term, (β_1 $\beta_2 \ldots$ β_n) represents beta coefficients, (X_1 $X_2 \ldots X_n$) represents a set of independent variables and (e) represents error term. The relationship between the dependent variable (Y = areal coverage of rainstorms due to thunderstorm and those due to disturbance lines) and the independent variables (X_1= duration, X_2 = rainfall amount and X_3 = intensity of rainfall due to thunderstorm and those due to disturbance lines) was studied using the correlation coefficient produced between the dependent variable and the independent variables (Sumner, 1988; Benesty, et al., 2009). The aim of doing this is to depict the interrelationship between the four variables. The duration of rainstorm equals to the difference between the times of onset and times of cessation of rainstorm events. The values obtained were expressed in minutes. The rainfall amount equals to the volume of rain water obtained from the rain gauges after the rainstorm events. The values obtained were expressed in millimetre. Similarly, the intensity of rainfall is the rainfall amount divided by storm duration in hours or minutes. The areal coverage of rainstorms equals to the distance covered by the rainstorm events. This was calculated using measurement of area of irregular shapes (square method). The values obtained were expressed in square kilometre.

4. Results

4.1. Temporal pattern of rainstorm events due to thunderstorm and those due to disturbance lines

The total frequencies of rainstorms due to thunderstorm and those due to disturbance lines events were recorded as 125 and 29, respectively (Table 1). In the two data sets, it was found that there was a variation in the frequency of occurrence of rainfall events. The frequency of occurrence of rainstorm events due to thunderstorm was higher than the frequency of occurrence of rainstorm events due to disturbance lines.

Table 1: Frequencies of rainstorms due to thunderstorm and those due to disturbance lines

S/N	Thunderstorm	Disturbance lines
1.	125	29

The rainstorm events showed an average duration of 102 minutes and 119 minutes, respectively. The maximum durations of rainstorm events were 286 minutes and 240 minutes, while 20 minutes and 10 minutes were the minimum. The standard deviations were 51.8 and 75.9. In the two data sets, it was found that there was a variation in the durations of rainstorms. About 24% and 21% of rainstorm events lasted less than 1 hour, 48% and 45% between 1 and 2 hours, while 28% and 34% lasted for as long as 2 hours or more (fig 3a).

Furthermore, the data showed an average amount of rainfall due to thunderstorm and those due to disturbance lines of 13.6 mm and 12.8 mm, respectively. The maximum amounts of rainfall were 45.2 mm and 38.5 mm, while 0.30 mm and 1.30 mm were the minimum. The standard deviations were 9.6 and 8.7, respectively. In the two data sets, it was found that there was a variation in the amounts of rainfall. The maximum amount of rainfall due to thunderstorm was higher than the maximum amount of rainfall due to disturbance lines. This was also revealed in the standard deviation values. Figure 3b shows the frequency distribution of rainfall amount. From the total data, 23% and 21% of rainfall amounts measured less than 5.0 mm, 20% and 21% between 5.0 mm and 10.0 mm, while 71% and 58% measured above 10.0 mm.

The average intensities of rainfall were 0.13 mm h^{-1} and 0.23 mm h^{-1}. The maximum intensities were 0.41 mm h^{-1} and 2.56 mm h^{-1}, while 0.01 mm h^{-1} were the minimum. The standard deviations were 0.08 and 0.47, respectively. In the two data sets, it was found that there was a variation in the average intensities of rainfall. The average intensity of rainfall due to thunderstorm was lower than the average intensity of rainfall due to disturbance lines. Figure 3c shows the frequency distribution of rainfall intensity. From the total data, 19% and 17% of rainfall intensity measured less than 0.05 mm h^{-1}, while 18% and 35% measured between 0.05 and 0.10 mm h^{-1}, 48% and 28% between 0.10 and 0.20 mm h^{-1}, 9% and 10% between 0.20 and 0.30 mm h^{-1} and 6% and 10% measured above 0.30 mm h^{-1}.

The average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were 172.0 km2 and 170.0 km^2, respectively. The maximum areal coverage of rainstorms were 426.4 km2 and 435.0 km2, while 16.6 km^2 and 22.5 km^2 were the minimum. The standard deviations were 105 and 131. Figure 3d depicts the frequency distribution of the areal coverage of rainstorms. As evident in the total data, 9% and 21% of rainstorms measured less than 50.0 km^2, 26% and 17% measured between 50.0 and 100.0 km^2, 31% measured between 100.0 and 200.0 km^2, while 34% and 31% measured between 200.0 km^2 and above.

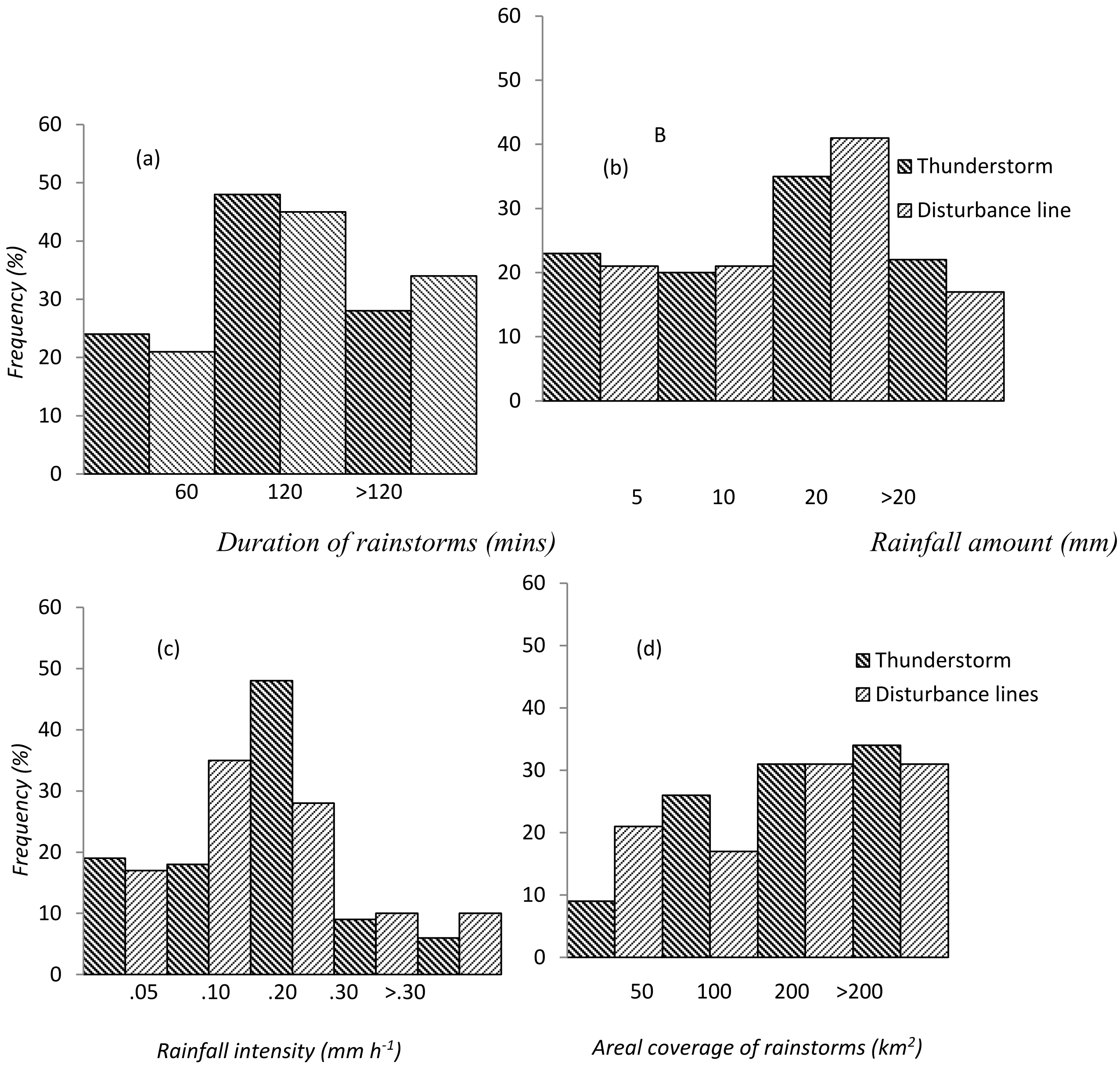

Figure 3: Rainstorm events due to thunderstorm and those due to disturbance lines in Ibadan (a) Duration of rainstorms (b) Rainfall amount (c) Rainfall intensity (d) Areal coverage of rainstorms

4.2 Effect of duration, rainfall amount and intensity of rainfall due to thunderstorm and those due to disturbance lines on the areal coverage of rainstorms

The effect of duration, rainfall amount and intensity of rainfall due to thunderstorm and those due to disturbance lines on the areal coverage of rainstorms was examined. In this analysis, the regression model for all the variables was produced. The correlation coefficient of areal coverage, duration, rainfall amount and intensity of rainfall due to thunderstorm revealed that, duration (.054) and rainfall amount (.195) and rainfall intensity (.182) related directly with the areal coverage of rainstorms. The correlation coefficient further revealed that there is significant correlation between the duration and rainfall amount and between the rainfall amount and rainfall intensity due to thunderstorm (Table 2a). But only rainfall amount (.000) due to disturbance lines related directly with the areal coverage of rainstorms. Other variables compared related inversely with the areal coverage of rainstorms (Table 2b).

Table 2a: Correlation coefficient of duration, rainfall amount and intensity of rainfall due to thunderstorm on areal coverage of rainstorms

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Intensity (mmh^{-1})
Areal coverage (km^2)	1.00	0.054	0.195*	0.182*
Duration (mins)		1.00	0.613**	-0.069
Rainfall amount (mm)			1.00	0.665**
Intensity (mmh^{-1})				1.00

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Table 2b: Correlation coefficient of duration, rainfall amount and intensity of rainfall due to disturbance lines on areal coverage of rainstorms

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Intensity (mmh^{-1})
Areal coverage (km^2)	1.00	-0.004	0.000	-0.104
Duration (mins)		1.00	0.384*	-0.293
Rainfall amount (mm)			1.00	0.353*
Intensity (mmh^{-1})				1.00

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

As shown in Table 3a, an R value of .212, R^2 value of .045 and coefficient of determination value of 4.5%, mean that, jointly, the duration, rainfall amount and intensity of rainfall due to thunderstorm accounted for 4.5% variation in the areal coverage of rainstorms. However, an R value of .131, R^2 value of .017 and coefficient of determination value of 1.7%, mean that, jointly, the duration, rainfall amount and intensity of rainfall due to disturbance lines accounted for 4.5% variation in the areal coverage of rainstorms (Table 3b).

Table 3a. Model summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.212[a]	.045	.021	104.29886

Table 3b. Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.131[a]	.017	-.101	137.97626

The p-value, (in Tables 4a and b), revealed that the independent variables, when taken together, were not significant predictors (.314) and (.932), explaining the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines.

Table 4a: ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	61927.516	3	20642.505	1.898	.134[a]
	Residual	1316268.404	121	10878.251		
	Total	1378195.920	124			

Table 4b. ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8302.406	3	2767.469	.145	32[a]
	Residual	475936.232	25	19037.449		
	Total	484238.638	28			

However, the variable that contributed most to predicting the areal coverage of rainstorms was rainfall amount (.245) and (.090), which means that rainfall amount was the one that gave the highest explanation on areal coverage of rainstorms due to thunderstorm and those due to disturbance lines, respectively (Tables 5a and b). However, the three independent variables were not significant at 0.05 level (that is, .616mins; .337 mm; .951 mm h^{-1}) and (.733mins; .726 mm; .515 mm h^{-1}) (Tables 5a and b).

Table 5a Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	153.262	38.198		4.012	.000
	Duration of rainstorms	-.195	.387	-.096	-.503	.616
	Amount of rainfall	2.685	2.782	.245	.965	.337
	Intensity of rainfall	15.437	249.165	.012	.062	.951

Table 5b. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	181.193	56.356		3.215	.004
	Duration of rainstorms	-.148	.428	-.085	-.345	.733
	Amount of rainfall	1.350	3.804	.090	.355	.726
	Intensity of rainfall	-45.228	68.521	-.161	-.660	.515

5. Discussion

The frequency of occurrence of rainstorms due to thunderstorm and those due to disturbance lines over 2013 - 2014 period showed a total of 125 and 29, respectively (Table 1.) There was an uneven distribution of rainstorms of varying duration in Ibadan (fig 3a). This again contrasts with Ibadan where about 25 per cent of the rainstorms due to thunderstorm were less than one hour in duration and close to 50 per cent lasted less than two hours and 28 per cent more than two hours. In Ibadan, only about 20 per cent of the rainstorms due to disturbance lines were less than one hour duration, 45 per cent lasted less than two hours and 34 per cent more than two hours. The amounts of rainfall accompanying the rainstorms in Ibadan varied a great deal (fig 3b). About 42 per cent of rainstorms due to thunderstorm and those due to disturbance lines gave less than 10.0 mm of rainfall and 71 and 58 per cents yielded rainfall amounts of 10.0 mm and above (fig 3c). About 19 and 17 per cents of rainstorms due to thunderstorm and those due to disturbance lines measured less than 0.05 mm h^{-1} of rainfall intensity and 18 and 35 per cents measured between 0.05 and 0.10 mm h^{-1}, 57 and 38 per cents measured between 0.10 and 0.30 mm h^{-1} and 6 and 10 per cents measured above 0.30 mm and above. The areal coverage of rainfall accompanying the rainstorms in Ibadan varied a great deal (fig 3d). About 38 per cent of rainstorms measured less than 100.0 km^2, 31% measured between 100.0 and 200.0 km^2, while 31 per cents measured between 100.0 and 200.0 km^2 and 200.0 km^2 and above, respectively.

The study revealed a good relationship between areal coverage, duration, rainfall amount and intensity of rainfall in Ibadan. The Pearson correlation coefficient produced revealed that there appeared to be some relationship between duration and amount of rainfall per storm and between intensity and amount of rainfall. The duration, amount and intensity of rainfall related directly with the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines. This is, however, confirmed by statistical test. P-value results obtained revealed that the independent variables, when taken together, were not significant predictors (.314) and (.932), explaining the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines (Tables 4a and b). However, the variable that contributed most to predicting the areal coverage of rainstorms was rainfall amount (.245) and (.090), which means that rainfall amount was the one that gave the highest explanation on areal coverage of rainstorms due to thunderstorm and those due to disturbance lines, respectively (Tables 5a and b).

6. Conclusion

There was a close relationship between duration and amount of rainfall and between intensity and amount of rainfall due to thunderstorm and those due to disturbance lines. There were many rainstorms of short durations as there were medium or long durations. Most of the rainstorms in Ibadan were rather small in size as they yielded less than 10.0 mm of rainfall. The rains that accompanied the rainstorms at the beginning and towards the end of the rainy season tend to be more intense than the rains that accompanied the rainstorms that occurred at the height of the rainy season (Ayoade and Akintola, 1986).

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Appendix 1

Rainfall stations used in the study

Network Stations A1-A5 & B1-B45	Station Name	Coordinates		Altitude (Metres)
		Latitude (North)	Longitude (East)	
A1	IITA	7.495477	3.908723	231
A2	University of Ibadan	7.445375	3.900265	222
A3	Airport	7.354977	3.971782	224
A4	Moor Plantation	7.385400	3.839579	180
A5	Cocoa Research Institute	7.230673	3.872243	128
B1	Papa Malu	7.529777	3.936333	221
B2	Ojoo	7.470122	3.896154	213
B3	Ajibode	7.479579	3.865643	233

B4	Apete	7.452077	3.860232	205
B5	Ijokodo	7.428616	3.885589	194
B6	Olunloyo	7.350432	3.942314	201
B7	Agbowo	7.447424	3.939554	225
B8	Eleyele	7.414007	3.861477	191
B9	Oke-Itunnu	7.406685	3.882293	204
B10	Total Garden	7.392422	3.900603	211
B11	Mokola	7.409386	3.900718	204
B12	Ashi	7.477170	3.952424	211
B13	Basorun	7.427600	3.939007	245
B14	Akobo	7.460189	3.992403	217
B15	Mapo	7.373511	3.905399	184
B16	Molete	7.367786	3.841649	167
B17	Challenge	7.335505	3.879863	172
B18	Onireke	7.386987	3.873982	202
B19	Oluyole	7.353390	3.858567	160
B20	Idi-Ape	7.387128	3.957547	221
B21	Soka	7.313623	3.903531	171
B22	New Gbagi	7.377876	3.992755	200
B23	Babanla	7.366465	3.950292	219
B24	Bodija	7.378872	3.927265	217
B25	Gate	7.423096	3.915373	216

B26	Gospel	7.462193	3.947888	259
B27	Omi Adio	7.393287	3.793832	197
B28	Iwo Road	7.404987	3.942794	225
B29	Podo	7.311917	3.842823	149
B30	Oke Ado	7.364481	3.880834	189
B31	Adegbayi	7.397808	3.924010	229
B32	Jericho	7.395499	3.856307	187
B33	Olodo	7.431515	3.980282	208
B34	Sanyo	7.305661	3.950687	192
B35	Ring-Road	7.367584	3.814270	188
B36	Odo Ona	7.345571	3.826758	187
B37	Arapaja	7.276297	3.825242	192
B38	Monotan	7.414157	3.971989	221
B39	Academy	7.326408	3.933497	192
B40	Alomaja	7.265915	3.872811	128
B41	Aperin	7.359810	3.917474	216
B42	Ologuneru	7.409602	3.830258	187
B43	Odinjo	7.343279	3.905635	193
B44	Ogbere	7.273541	3.932988	197
B45	Idi-Osan	7.294338	3.884303	171