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CONTENTS

Editorial Board ii

Contents iii

Environmental Conditions of Wells and their Sustainability for Domestic Water Consumption in Gbagyi Villa, Kaduna State, Nigeria 1
G.I. Danjuma, B.R. Atiyong, J. Birga, I. Istifanus

Some Features of Diurnal Rainstorms Over Ibadan Metropolis, Nigeria 11
A. Adediran and T. O. Jaiyeola

In-situ Surface Temperature and Thermal Infrared Satellite Data Collection for Heat Island Evaluation and Data Comparison in an Urban Area in Southwest Nigeria 21
O.O. Tope-Ajayi, O. H. Adedeji, C. O. Adeofun and A. O. Akingbade

GIS-based Suitable Site Selection for Internally Displaced Persons' Camps in Abuja, Nigeria 30
J. Oloukoi, A. O. Akingbade, O. G. Atureta and G. O. Enaruvbe

Spatio-temporal Analysis of Igbo Traders and their Socio-economic Activities in Ilorin Metropolis 45
D. Ogunfolaji and A. Adeniyi

Residents' Perception of Crime in Osogbo, Osun State, Nigeria 53
M.B. Gasu and A.O. Ezekiel

Urban Densification and Land Surface Temperature in Kano Metropolis, Nigeria 63
H. A. Idris and A. I. Tanko

Awareness and Perceptions on Registration of Births and Deaths in Sokoto State, Nigeria 75
L. Barau, M. Sani, H. Dangaladima and H. S. Muhammad

Sustainable Cooking Energy Use among Low-income Urban Households of Abeokuta Metropolis, Ogun State Nigeria 87
A. S. Aguda and O. O. Adu

Monitoring Spatial Variation of Ambient Air Pollutants in Alimosho Local Government Area of Lagos State 99
O. S. Adejobi

Geospatial Monitoring of Vegetation Vigour in Kuyambana Game Reserve, Zamfara State, Northwestern Nigeria 113
A. M. Jibrillah and I. Hamisu

Mobilizing the Community-based Organizations for Sustainable National Development in Ondo Senatorial District, Ondo State, Nigeria **121**
T. A. Omolade and O. S. Eludoyin

Quantification of Fuelwood Supply to Kano Metropolis, Nigeria **131**
U. K. Mohammed

Influence of Climate Change on Adoption of Agricultural Technologies by Farmers in Katsina State, Nigeria **141**
T. Ibrahim and I. B. Abaje

Internally Displaced Persons and the Achievement of Sustainable Development Goals in Nigeria **153**
M. M. Sackflame, B. Omitola, A. A. Omitola

Irrigation Water Quality Assessment of River Wupa, Abuja North Central Nigeria **163**
A. J. Adano, N. D. Marcus, J. I. Magaji and O. D. Opaluwa

Impact of Urban Sprawl on Land Use Dynamics In Suleja, Niger State, Nigeria **174**
K. A. Mohammed, A.S. Abubakar, M. Muhammed and M. Dalil

An Exploratory Analysis of the Impacts of Landuse Transition on Nigeria's National Economic Development **183**
O. O. Fabiyi

Assessment of the Impact of Urban Growth on Agricultural Lands in Zaria and its Environs **194**
R. E. Agbo, E. Ikpe and A. Mayowa

Note to Contributors **204**

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SOME FEATURES OF DIURNAL RAINSTORMS OVER IBADAN METROPOLIS, NIGERIA

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Abstract

The seasonal characteristics-sequence, amount, duration and intensity of rainstorms during various periods of the day, which determine the exact amount of moisture available have received little attention. This study investigated the diurnal cycles of rainstorms over Ibadan, Nigeria. A two-year hourly data on the characteristics of rainstorms for 50 stations were processed to generate statistics on the amplitude and phases of diurnal cycles of rainstorms in Ibadan. Their temporal variations were analysed using descriptive statistics. Of the 154 rainstorms studied, 14.3%, 30.7%, 21.7% and 33.9% occurred during dry, early, late and rainy seasons. The highest frequency of rainstorms during the dry season was recorded in February and November, in the late afternoon and early evening between 1500 h and 1800 h, with values of 22.2 % and 33.4%, respectively. Over 50% of the frequency of rainstorms was recorded in the midnight and early morning between 0000 h and 0600 h during the early rainy season, especially in April. The highest frequency was recorded at midnight between 0000 h and 0300 h, with a value of 27.2%. During rainy season months, the highest frequency of rainstorms was recorded in June, in the afternoon between 1200 h and 1500 h, with a value of 17.7%, and 29.5% of the total frequency of rainstorms was recorded as the highest in the afternoon between 1200 h and 1500 h during late rainy season months, other rainstorms characteristics studied showed a similar pattern. There was a general tendency for rainstorms to decrease from midnight to late morning between 0000 h to 0900 h. Most water in rainstorms occurring late in the afternoon is available for soil moisture replenishment since little evaporation happens at night.

Keywords: Diurnal cycles; Rainstorm characteristics; Temporal variations, Seasonal variations

Introduction

Documentation of the diurnal variability of rainfall has been the topic of well over a hundred published articles, some of which date back to the middle of the 19th century (Schmidt, 1952; Mejía et al., 1999; Adediran, 2017). Hann (1901) attempted to synthesise the results of a large number of early investigations in terms of the following interpretation, based upon a simple geographical classification scheme: a) In regions with continental climates, most precipitation events fall in convective showers during the afternoons while over the open oceans and in coastal regions with marine climates maximum rainfall occurs at night or during the early morning; b) In some regions there are pronounced seasonal differences in the character of the diurnal variability. Over much of Western Europe, winter precipitation exhibits a nocturnal rainfall maximum, while during summer, the maximum occurs during the afternoon. Over parts of the monsoon areas of the tropics, there is a shift toward morning maximum during the wet season c) The first comprehensive study of the diurnal variability of precipitation over the United States was carried out by Kincer (1916) using summer rainfall data at 175 stations. His results brought to light the existence of two broad regions that did not fit Hann's classification scheme: i) At many stations in the central and north-central United States more rainfalls at night than during the day; b) Coastal stations in the southeastern United States show a pronounced afternoon rainfall maximum. In a subsequent study by Means (1944), it was shown

that summer thunderstorms exhibit a diurnal variability similar to that found by Kincer for precipitation. Means' study provided much more detailed information concerning the phase of the diurnal cycle as a function of geographical location. The overall qualitative similarity between Kincer's and Means' results indicates that the diurnal variability of summer precipitation largely reflects the diurnal cycle in convective activity.

Six-hourly thunderstorm and precipitation probability statistics published by the U.S. Weather Bureau (1941) and Jorgensen (1967) show little evidence of any pronounced diurnal variability. The purpose of the study is to provide comprehensive and consistent documentation of the diurnal variation of rainstorm activity and precipitation at various intensity levels over the United States during both the summer and winter seasons. By displaying amplitudes and phases in a vectorial format, it is possible to demonstrate the high degree of spatial consistency of the diurnal cycle over broad areas of the country. This display technique also proves to be convenient for comparing the diurnal variability of different parameters. Despite some ambiguities in interpreting these amplitude and phase differences, it is possible to glean from them several valuable insights regarding the nature of the environmental controls upon a convective activity (Schmit, 2017). However, temporal and seasonal variations of the diurnal cycles in tropical rainstorm characteristics have received little or no attention. Yet an analysis of diurnal variations in rainstorm frequencies, durations, amounts, and intensities is essential to understanding moisture exchanges between the terrestrial and atmospheric systems. Solar radiation is the main energy source for evaporation and evapotranspiration processes which take place only during the daytime. So, if the rains come during the night, most of their moisture would end up as soil moisture. Based on the preceding discussion, the need to undertake a detailed analysis of the temporal and seasonal variations of the diurnal cycles of rainstorm characteristics over the Ibadan metropolis becomes evident as this will provide a better understanding of the complex and character of the diurnal cycles in tropical rainstorms over urban areas.

Literature Review

The existing literature suggests that rainstorm characteristics are critical, although they can pose problems if not seriously considered (Ayoade, 2012). When rainstorm characteristics, such as rainfall amount and storm duration, occur in excess, they become a hazard to people and farmers. When rainstorms occur in high intensity and long duration, they cause havoc rather than good (Kaixi et al., 2016). Rainstorms which exceed 25 mm in amount will most likely lead to severe disaster (Akintola et al., 2009; Mario et al., 2016; Hongyan et al., 2016). Rainfall intensities during extreme rainstorms usually exceed soil infiltration rates significantly (Akintola, 1974). Since the soil cannot absorb water at the same rate the rain falls, a significant amount of run-off can be generated. This run-off will erode and carry soil particles. Continuous rainstorm events can produce more run-off than single and separated events with significantly higher precipitation depths (Keggenhoff et al., 2014; Zhihe et al., 2015). A detailed understanding of diurnal cycles of rainstorm characteristic variations is necessary for infiltrating rainstorm water into soils. The diurnal variations in rainstorm characteristics have not received adequate scholarly attention. Yet an analysis of diurnal variations in rainstorm characteristics is fundamental to understanding moisture exchanges between the terrestrial and atmospheric systems. Solar radiation is the main energy source for evaporation and evapotranspiration processes, which only occur during the daytime. So, if the rains come during the night, most of their moisture would end up as soil moisture. Studying the diurnal variability of rainstorm characteristics is essential for several reasons. First, it will provide a baseline for future investigations of the dynamics of diurnal rainstorms. Second, such analyses could potentially inform urban planners in considerations, such as assigning appropriate zoning types for precipitation-enhanced regions and establishing guidelines for using rainwater in agriculture.

Aim and Objectives

This study evaluated temporal distributions of diurnal rainstorm characteristics during dry, early, rainy, and late rainy periods over Ibadan. The specific objectives are to:

1. examine the temporal variations of the diurnal (24 h) cycles of rainstorm characteristic over Ibadan and;
2. determine the seasonal variations of the diurnal cycles of rainstorms during dry, early, rainy and late rainy periods in the study area

Materials and Methods

The study's data set consists of hourly precipitation records covering the period from 2013 to 2014 at 50 rain gauges located across Ibadan territorial boundaries (Figure 1). The data set was extracted from daily weather registers kept by the research and academic institutions in Ibadan. These included the Nigerian Meteorological Agency (NIMET) Office in Ibadan; National Cereals Research Institute (NCRI), Ibadan; International Institute for Tropical Agriculture (IITA), Ibadan; Cocoa Research Institute (CRIN), Ibadan and University of Ibadan (main-stations). Data were also extracted from manual rain gauge stations (sub-stations), complementing autographic rain gauge data. These stations were coded "A1 - A5" and "B1 - B45", respectively (Figure 1).

The selected stations have rainfall gauges that log total rainfall every 15 minutes. The data were in the form of times of onset and cessation, day, month, frequency, duration (in minutes), amount (in millimetres) and intensity of rainstorms (mmh^{-1}). The fifty stations from which data were collected were chosen in such a way as to have a uniform (even) spatial distribution and also to reflect the varied land use and surface roughness of the area. Also, a 3x3 km grid was superimposed on the map of the Ibadan metropolis, and one rain gauge was installed in each of the 50 resultant grids. The statistical method employed for this study was descriptive statistics. The study measured rainstorm characteristics (such as frequency, duration, amount and rainfall intensity). To determine the temporal variations in the frequency, duration, rainfall amount and rainfall intensity of diurnal cycles of rainstorms, the observed daily frequencies, durations, amounts and intensities of rainstorm events across each station were recorded and analysed. This was done for each of the rainstorm events for the period under investigation.

In addition, to determine the seasonal variations in the occurrences of diurnal cycles of rainstorm characteristics, the observed daily frequencies, durations and rainfall amounts across each station were averaged during dry, early rainy. Late rainy periods give the relevant frequency, duration and rainfall amount for each period into which the day had been divided (Ayoade and Akintola, 1986). In this case, the rainstorm events could occur during any of the eight periods into which the day had been divided, namely: midnight (between 0000 h and 0300 h), early morning (between 0300 h and 0600 h), morning (between 0600 h and 0900 h), late morning (between 0900 h and 1200 h), afternoon (between 1200 h and 1500 h), late afternoon (between 1500 h and 1800 h), early evening (between 1800 h and 2100

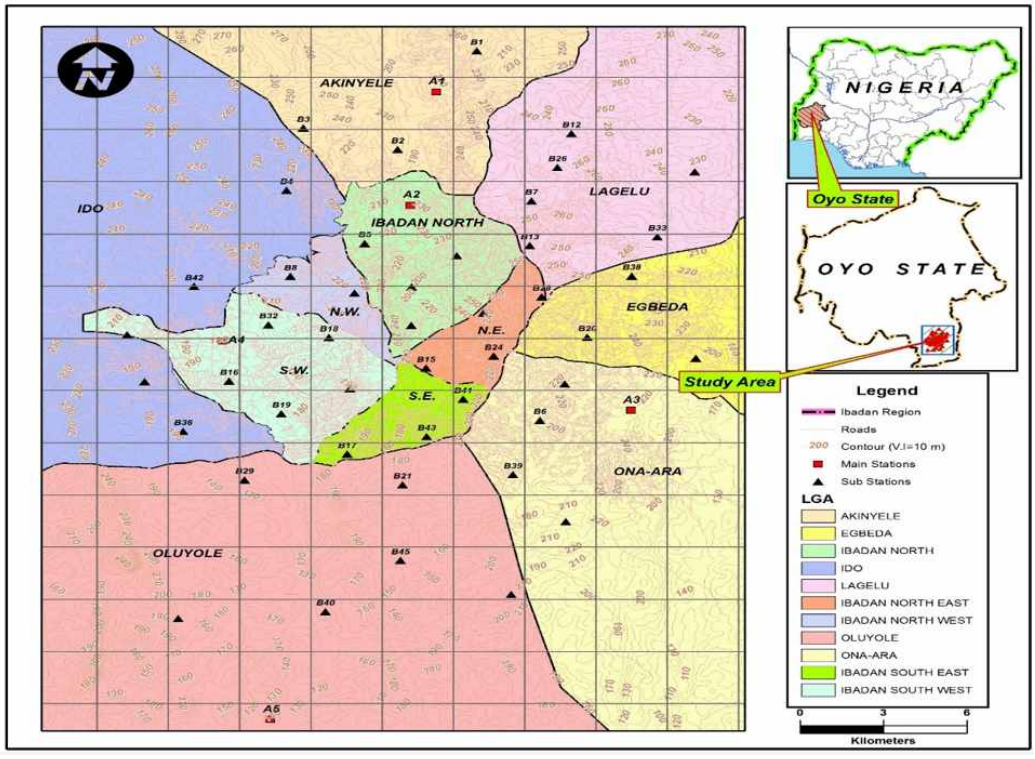


Figure1: Location Map of Autographic Rain gauge Stations and Manual Raingauge Stations in Ibadan (Shuttle Radar Topographical Mapping (SRTM), 2013)

h) and late evening (between 2100 h and 2400 h) (Ayoade and Akintola, 1986). Therefore, each rainstorm was recorded according to the periods of its occurrence.

Results and Discussion

There were notable variations in rainstorms over the day in the study area. The rainstorm characteristics - frequencies, durations, rainfall amounts and intensities occurring during various periods of the day varied over the study area.

Diurnal Variations in the Frequencies of Rainstorms

Dry Season

During the dry season months of November-February, there was a general tendency for the frequency of rainstorms to decrease from midnight to late morning between 0000 h to 0900 h (Table 1). However, the highest frequency of rainstorms during this season was recorded in February and November, in the late afternoon and early evening between 1500 h and 1800 h, with values of 22.2 % and 33.4%, respectively. However, no rainstorm event was recorded in Ibadan in December (Table 1).

Early Rainy Season

During the early rainy months of March and April, over 50% of the total frequency of rainstorms was recorded in the midnight and early morning between 0000 h and 0600 h, especially in April. The highest frequency was recorded at midnight between 0000 h and 0300 h, with a value of 27.2%, while the lowest frequency was recorded in the early morning and late evening between 0600 h and 0900 h, and 2100 h and 2400 h, with a value of 9.1%. However, March recorded no rainstorm event in the night and late afternoon between 0000 h and 1500 h. Towards the early and late evening, between 1800 h and 2400 h, values of 18.2% and 9.1% were recorded, respectively (Table 1).

Late Rainy Season

During the late rainy months of September and October, 29.5% of the total frequency of rainstorms was recorded as the highest in the afternoon, between 1200 h and 1500 h, in September. The lowest frequency was recorded in the early evening between 1800 h and 2100 h, with a value of 17.6%. Whereas in the month of October, the highest frequency of rainstorms was recorded in the early evening between 1800 h and 2100 h, with a value of 17.6%; while the lowest frequency was recorded in the afternoon and late afternoon between 1200 h and 1500 h, and 1500 h and 1800 h, with a value of 5.9%. During this season, no rainstorm event was recorded from midnight to late morning between 0000 h and 0900 h, respectively (Table 1).

Rainy Season

During the rainy months of May-August, there was a tendency for the frequency of rainstorms to decrease during any of the eight periods into which the day had been divided. Though during this season, few of the rainstorm events were still recorded in the late morning via the late afternoon. The highest frequency of rainstorms was recorded in June, in the afternoon between 1200 h and 1500 h, with a value of 17.7%. The lowest frequency of rainstorms was recorded during the rainy months of July-August,

Table 1: Diurnal Variations in the Frequency of Rainstorms

Frequency of Rainstorms during the Eight Periods of the Day										
Season	Month	0h-3h	3h-6h	6h-9h	9h-12h	12h-15h	15h-18h	18h-21h	21h-24h	Total
Dry	January	-	-	-	-	11.1	-	-	-	
	February	-	-	-	-	-	-	33.4	22.2	
	November	-	-	-	-	-	22.2	11.1	-	100%
	December	-	-	-	-	-	-	-	-	
Early	March	-	-	-	-	-	-	18.2	9.1	
	April	27.2	18.2	9.1	-	-	9.1	-	9.1	100%
Late	September	-	-	-	17.6	29.5	-	17.6	-	
	October	-	-	-	-	5.9	5.9	17.6	5.9	100%
Rainy	May	-	-	11.7	-	5.9	5.9	-	-	
	June	-	5.9	-	5.9	17.7	5.9	-	-	
	July	5.9	-	-	5.9	-	11.7	11.7	-	100%
	August	**-**	**-**	**-**	**-**	**-**	**5.9**	**-**	**-**	

Source: Author's Fieldwork, 2013

from midnight to late afternoon between 0000 h to 1500 h, with a value of 5.9%. August recorded nearly no rainstorm event during the eight periods into which the day was divided. However, 5.9% of the total frequency of rainstorms was recorded in the late afternoon between 1500 h and 1800 h (Table 1). This confirmed the usual occurrence of the little dry season phenomenon in the month of August (Ireland, 1962).

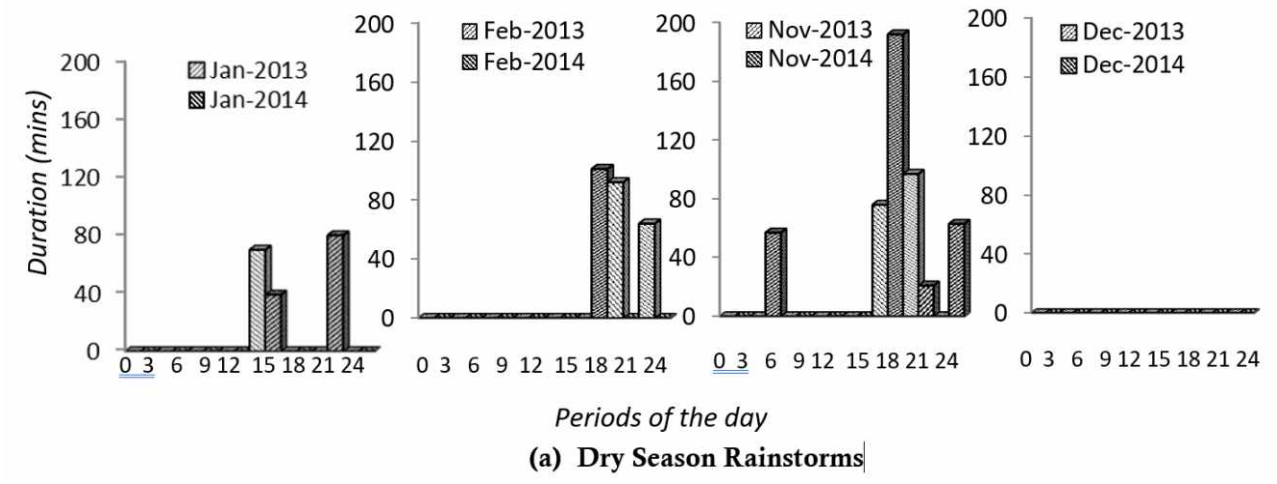
Diurnal Variations in the Duration of Rainstorms

Dry Season

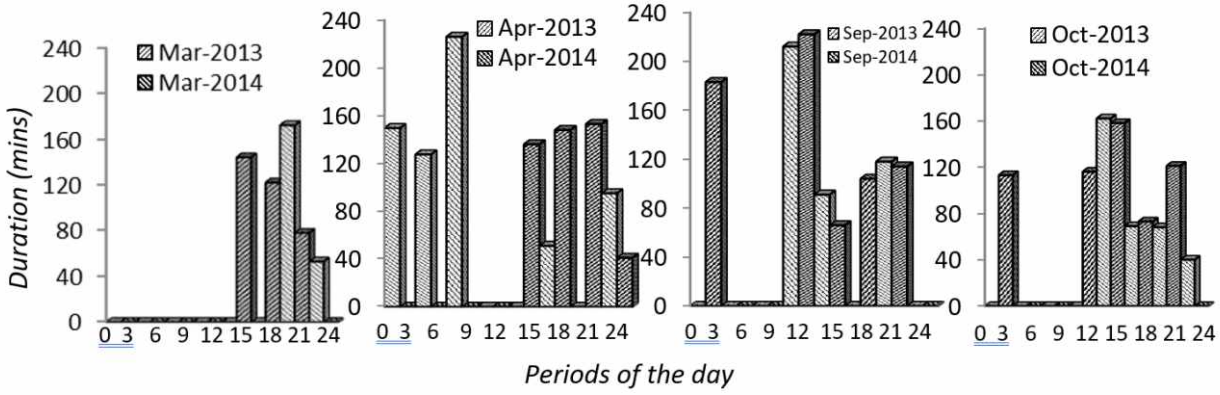
During the dry season months in 2013, close to 100% of the rainstorm events were of a short duration (Figure 2a), which occurred in the afternoon, early and late evening between 1200 h and 1500 h and 1800 h and 2100 h. The highest rainstorms duration was recorded in November, in the early evening between 1800 h to 2400 h, with a value of 97 minutes (Figure 2a); the lowest duration of rainstorms was recorded in February, in the late evening between 2100 h and 2400 h, with a value of 64 minutes. However, no rainstorm event due to thunderstorms was recorded in Ibadan in December.

Early Rainy Season

Similarly, during the early rainy season, most rainstorm events were of short and medium durations, which occurred during any of the eight periods into which the day has been divided. Rainstorm events of short duration mainly happened in the late afternoon via late evening between 1500 h and 1800 h, and 2100 h and 2400 h; the values ranged between 51 and 95 minutes in March and April (Figure 2b); medium duration mainly occurred in April, in the midnight via early morning between 0000 h and 0300 h, 0300 h and 0600 h, and 0600 h and 0900. During this period, the highest duration was recorded in April, in the early morning between 0600 h and 0900 h, with a value of 226 minutes. April also recorded the shortest duration of rainstorms in the late afternoon between 1500 h and 1800 h, with a value of 51 minutes (Figure 2b).



(a) Dry Season Rainstorms



(b) Early [March/April] and Late [September/October] Rainy Season Rainstorms

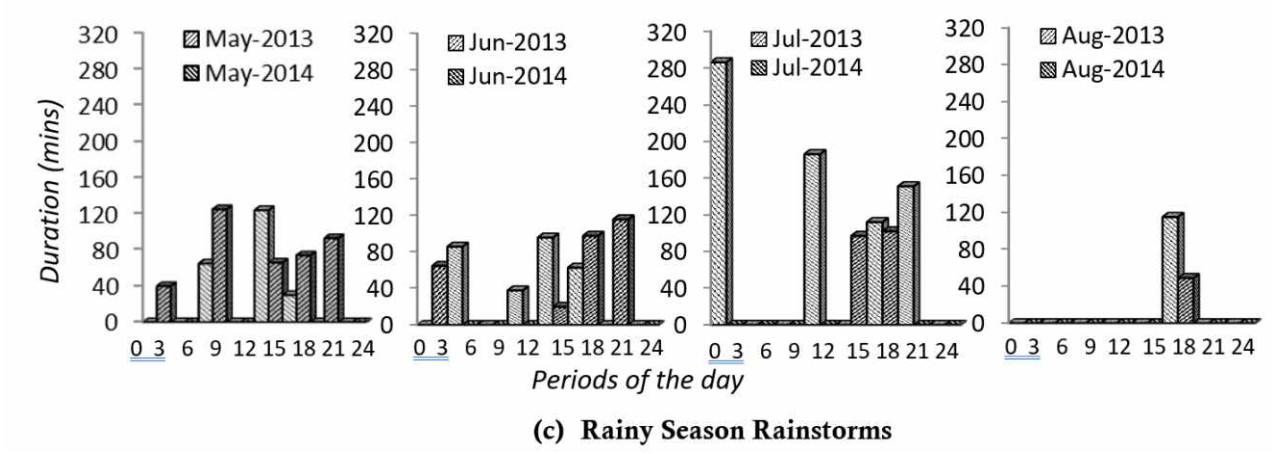


Figure 2: Mean Diurnal Variations in the Duration of Rainstorm Events

Late Rainy Season

Also, during the late rainy season, most rainstorm events were of short and medium durations, which occurred during any of the eight periods into which the day had been divided. Rainstorm events of short duration mainly occurred in October, in the late afternoon via late evening between 1500 h and 1800 h and 1800 h and 2100 h. The values of rainstorm duration during these periods of the day ranged between 40 and 69 minutes (Figure 2b). However, most of the rainstorm events with medium duration occurred in October, in the afternoon between 1200 h and 1500 h (Figure 2b). The highest duration of rainstorms was 212 minutes which was recorded in September, in the late morning between 0900 h and 1200 h (Figure 2b). The month of October recorded the lowest duration of rainstorms in the late evening between 2100 h and 2400 h, with a value of 40 minutes.

Rainy Season

During the rainy season, most of the rainstorm events were of short and medium durations. Most of the rainstorm events with short duration occurred in the months of May and June in the early morning via late evening between 0300 h and 0600 h, 0900 h and 1200 h, 1200 h and 1500 h, 1500 h and 1800 h, and 2100 h and 2400 h. Rainstorm events associated with medium duration occurred in the midnight and late morning between 0000 h and 0300 h and 0900 h and 1200 h. The highest duration of rainstorms was recorded in July, in the night between 0000 h and 0300 h, with a value of 286 minutes. The lowest duration of rainstorms was recorded in May, in the early afternoon between 1500 h and 1800 h, with a matter of 30 minutes (Figure 2c).

Diurnal Variations in the Amount of Rainfall

Dry Season

During the dry season months, the amounts of rainfall were generally low. About 8.8% (40.0 mm) of the total rainfall amount was recorded during this season in 2013, with the highest amount reaching about 46.3% (18.5 mm) of the rainfall amount, concentrated in the early evening between 1800 h and 2100 h. In this period, the month of November recorded the lowest amount of rainfall in the early evening between 1800 h and 2100 h, with a value of 2.7 mm. However, no rainfall due to thunderstorms was recorded in Ibadan in December 2013 (Figure 3a).

Early Rainy Season

During the early rainy season rainstorms in 2013, about 29.6% of the total rainfall amount was recorded, with an absolute value of about 134.5 mm. However, the rainfall amounts recorded in each period of the day during these seasons were relatively high. The early rainy season had the highest amount reaching up to 33.6% (45.2 mm) of the total rainfall amount, which occurred in April, in the morning, between 0600 h and 0900 h. The lowest amount of rainfall was recorded in March, in the late evening between 2100 h and 2400 h, with a value of 7.0 mm, representing 5.2% of the total rainfall (Figure 3b).

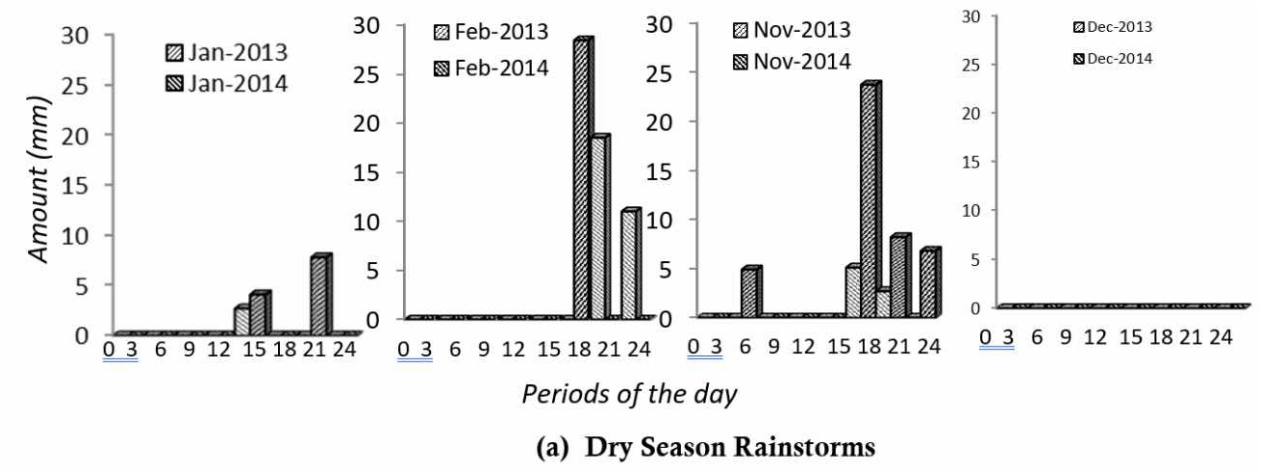
Late Rainy Season

Over 20% of the total rainfall amounts were recorded during this season, with an absolute value of about 111.0 mm. Also, the amounts recorded in each period of the day during these seasons were relatively high. The highest rainfall amount was recorded as 23.1 mm in October, in the late afternoon between

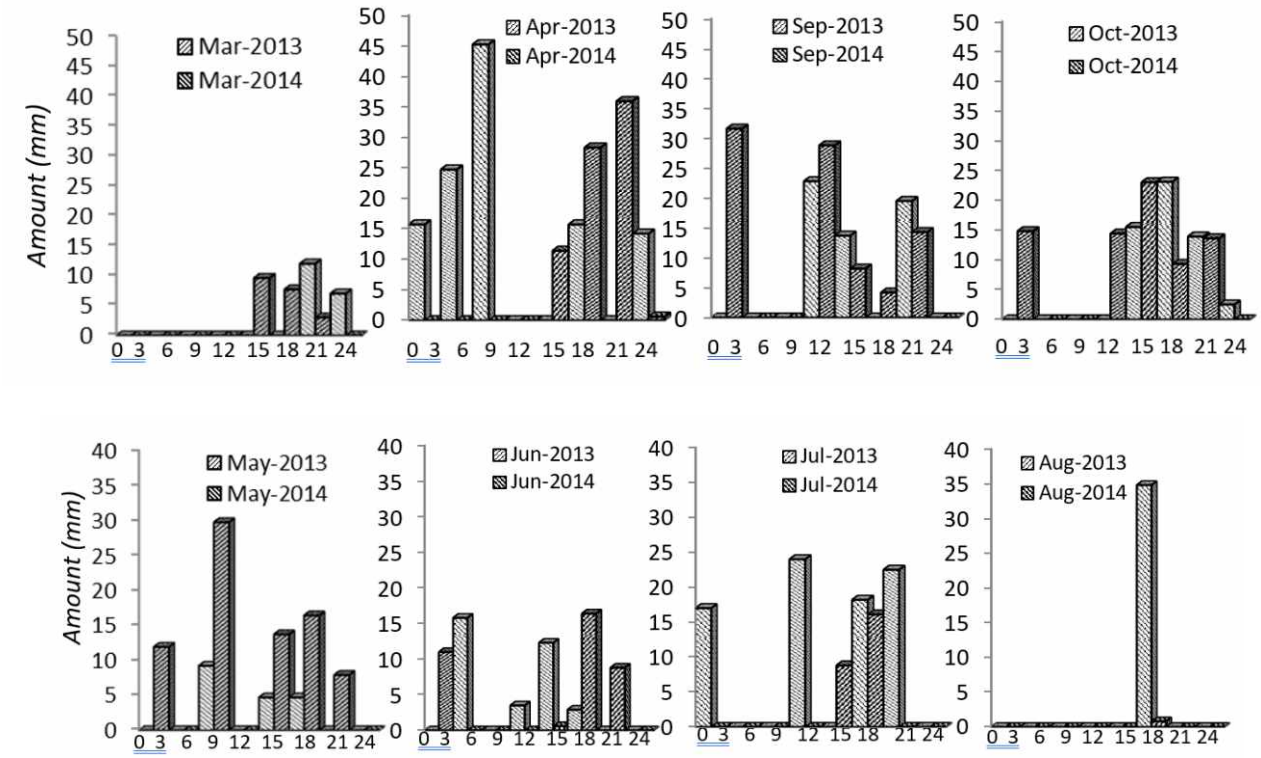
1500 h and 1800 h. October also recorded the lowest amount of rainfall, in the late evening, between 2100 h and 2400 h, with a value of 2.5 mm (Figure 3b).

Rainy Season

Besides, during the rainy season, the total percentage of rainfall amount was about 37.3%, with an absolute value of about 169.6 mm. In August, the highest rainfall amounts of aboutapproximately% (34.8 mm) were concentrated in the late afternoon between 1500 h and 1800 h (Figure 3c). At the same time, about 3.0 mm (1.7%) of the rainfall amount were recorded as the lowest rainfall amount in the late afternoon between 1500 h and 1800 h (Figure 3c).



(a) Dry Season Rainstorms



(c) Rainy Season Rainstorms

Figure 3: Mean Diurnal Variations in the Amount of Rainfall

Diurnal Variations in the Intensity of Rainfall

Dry Season

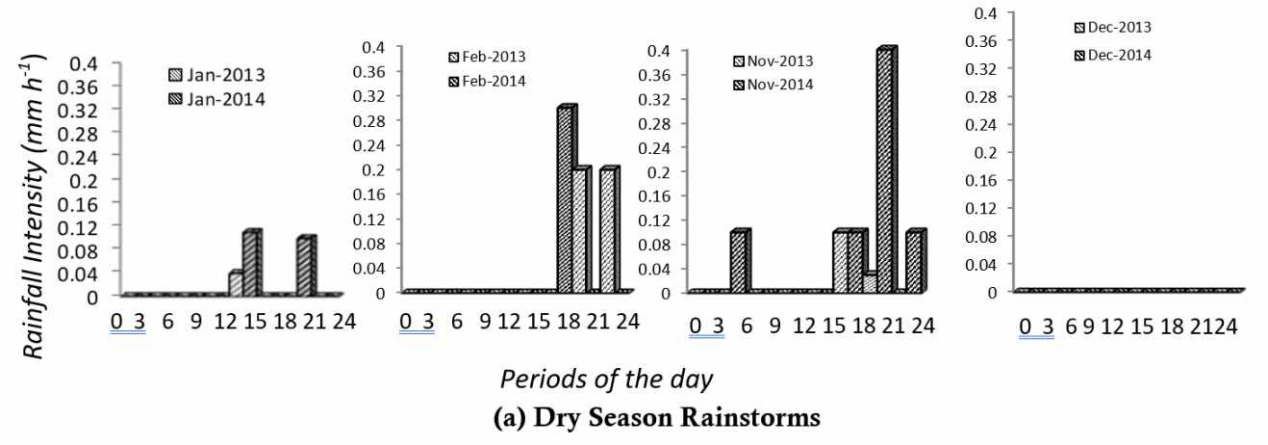
The intensities of rainfall during the dry season in 2013 were generally low. The highest rainfall intensities during the dry season, reaching about 0.20 mm h^{-1}, occurred in February, concentrated in the early and late evening, between 1800 h and 2100 h and 2100 h and 2400 h (Figure 4a). The lowest was recorded in January, reaching about 0.04 mm h^{-1}, concentrated in the afternoon, between 1200 h and 1500 h. However, no rainfall intensity was recorded at Ibadan in December. (Figure 4a).

Early Rainy Season

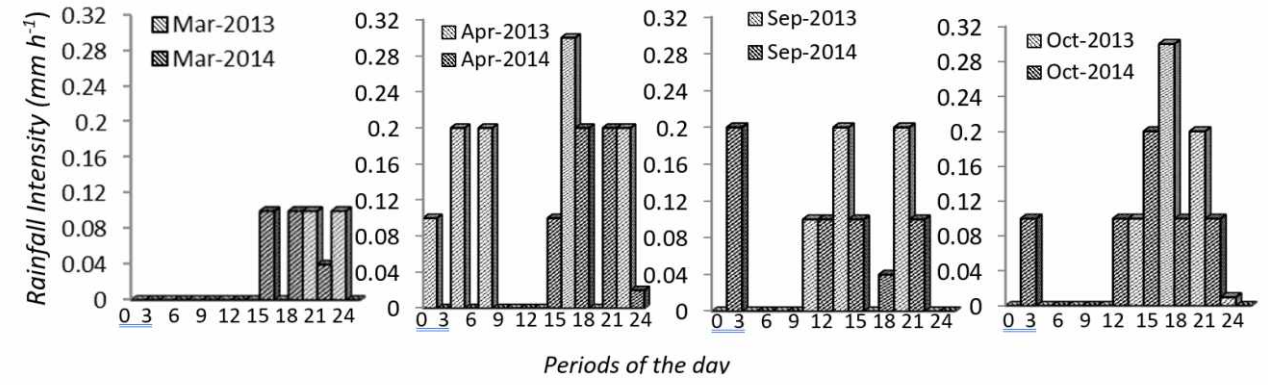
The rainfall intensities recorded in each period of the day during these seasons were relatively high. The early rainy season month (April) had the highest rainfall intensities reaching up to 0.30 mm h^{-1} and was concentrated in the late afternoon, between 1500 h and 1800 h (Figure 4b). Whereas the month of March recorded the lowest rainfall intensities of about 0.10 mm h^{-1} were concentrated in the early and late evening, between 1800 h and 2100 h and 2100 h and 2400 h (Figure 4b).

Late Rainy Season

The rainfall intensities recorded in each period of the day during these seasons were relatively high. The late rainy month (October) had the highest rainfall intensities reaching up to 0.30 mm h^{-1} and was concentrated in the late afternoon, between 1500 h and 1800 h, just like the early rainy season rainfall intensities in 2013. More so, the month of October recorded the lowest rainfall intensities of about 0.01 mm h^{-1} was concentrated in the late evening, between 2100 h and 2400 h (Figure 4b).



(a) Dry Season Rainstorms



(b) Early [March/April] and Late [September/October] Rainy Season Rainstorms

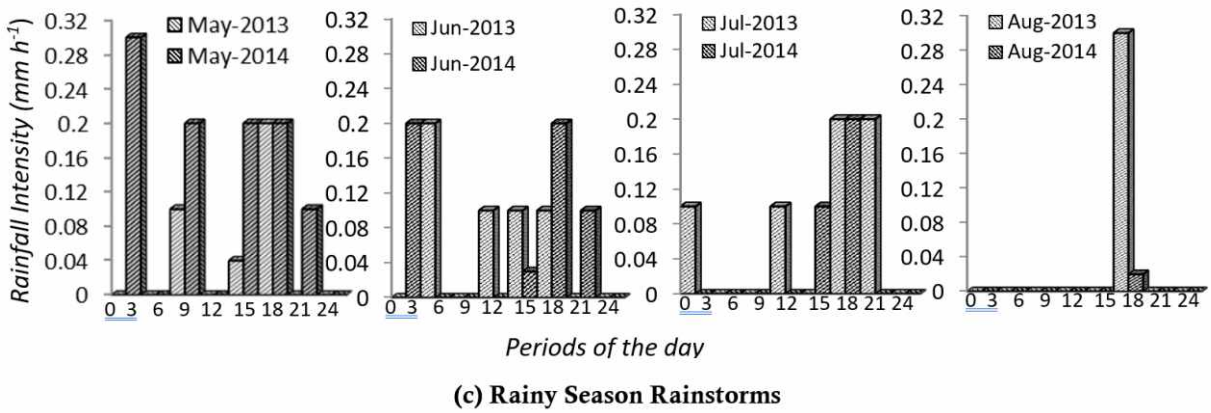


Figure 4: Mean Diurnal Variations in the Intensity of Rainfall

Rainy Season

During the rainy season, the highest rainfall intensities of about 0.30 mm h^{-1} were recorded in August, concentrated in the late afternoon, between 1500 h and 1800 h (Figure 4c). Similarly, during the primary rainy season, about 0.20 mm h^{-1} was recorded at the peak of the rainy season in June-July, concentrated in the early morning, late afternoon, and early evening between 0300 h and 0600 h, 1500 h and 1800 h and 1800 h and 2100 h. More so, during the primary rainy season, the lowest rainfall intensity of about 0.04 mm h^{-1} was recorded in May, concentrated in the afternoon, between 1200 h and 1500 h (Figure 4c).

Of the total rainstorm events studied, 42.6% and 63.4% occurred in the late afternoon via early evening between 1500 h and 1800 h and 1800 h and 2100 h in 2013 and 2014, respectively. This pattern implies that most rainwater in rainstorms occurring in the late afternoon is available for soil moisture replenishment since little evaporation occurs during the night. The results showed that rainstorms could occur during any of the eight periods into which the day has been divided in the study area. The results also showed that although rainstorms can occur during any of the eight periods into which the day has been divided, most of the rainstorms in Ibadan happen in the late afternoon and early evening. This general trend shows the conventional nature of rainstorms in Ibadan.

In addition, two things emerge from this Table 1. First is that the early and late rains were often associated with thundery activities; that is, rainstorms occurring between March and April and between September and October occurred in the afternoons and late afternoons. The other fact is that when the rainy season has been fully established, that is between June and August. However, most rainstorms due to thunderstorms were still concentrated in the afternoons and late afternoons; some took place in the early mornings and during the night. Figure 2 shows the seasonal distribution of rainstorm durations. Rainstorms of short duration occur during the dry season months of November, December, January and February. The duration per storm for all the other months was about 120 minutes. Figure 2 shows the frequencies of rainstorm durations set out at 40-min intervals. The distribution was skewed towards short and medium durations. Most rainstorms last between 30 and 120 min. Over 70% of all storms last for less than 2 hours in rainstorm events. The distribution also shows that Ibadan can have rainstorms with extremely long duration.

Figure 3 shows the rainstorm class distribution for Ibadan based on the rainfall amounts of each storm. About 40% and 65% had rainfall amounts of 12.5 mm or less, 50% and 30% with 25.0 mm or less and 10% and 5% with 50.0 mm or less in 2013 and 2014 rainstorm events, respectively. The early and late rainy season's rainstorm intensities were not higher than the soil infiltration capacities. These were the periods, especially the former when the soils were vulnerable to soil erosion due to the lack of the necessary protective cover of vegetation. Akintola (1974) has 17.8 mm h-1 as the mean infiltration capacity for all the landuse surfaces in the Ibadan region. When this figure is compared with Figure 4, no month exceeded this threshold of excess water generation. It is then postulated that soil erosion rates would be moderate in the early and late rainy seasons.

Conclusion

This study shows that most of the rainstorms at Ibadan compare favourably in their characteristics

with rainstorms from other parts of the tropics (Jorgehsen, 1964; Mejia et al., 1999; Schnidt, 2017). The rainstorms are short and of high intensities concentrated in the early portion of their duration. The storms will generally lead to excessively high water flow a few minutes after the start but for those that last long, intensities after about 30 min end up as soil moisture since they are lower than the infiltration capacities of the area. The implications of these findings, in relation to agriculture, are as follows: (a) The intensities of the diurnal cycles of rainstorms of the early and late months of the rainy season were higher than the soil infiltration capacities. These are the periods, especially the former when the soils are vulnerable to soil erosion processes due to the lack of the necessary protective cover of vegetation. It is then postulated that soil erosion rates would be very high early in the rainy season. This is, however, supported by the relatively higher concentrations of sediment in metropolitan rivers during the early period of the rainy season. (b) Most of the erosive work by excess rainfall is carried out in the early period of the rainstorm duration. Rainstorms will compound this problem with double peaks. These findings show the vulnerability of our soils to rainstorm attacks due to soil surface exposure. Exposure results from land preparation for cultivation and bush burning. Great care is then needed to protect our soils from the vagaries of the climate.

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