CHAPTER ONE

INTRODUCTION

1.1 Background and Statement of the Problem

Rainstorms account for most of the rainfall received in the tropics and the single most important physical environmental factor affecting agricultural activities in Nigeria (Ayoade and Akintola, 1986). The major source of water for all uses, either in the form of surface run-off into rivers or underground storage, is rainstorm. According to Ayoade and Akintola (1986), rainstorms may contribute up to 95% of the total annual rainfall in some inland areas. They yield rainfalls of moderate to high intensity which generates a lot of run-off and sediment yield, especially in areas without adequate vegetal cover. They also frequently occur in a random pattern both temporally and spatially, and thus contribute to the high variability both over time and space of rainfall in the tropics.

In spite of their predominance as a feature of tropical climate and the relevance of their characteristics to land conservation and water resources management, only a few studies of rainstorms exist (Ayoade and Akintola, 1982; Oguntoyinbo and Akintola, 1983). These few studies have concentrated on two rainstorm characteristics, seasonality and variability. Walter (1967), Ayoade (1970), Jackson (1977), Walsh and Lawler (1981), Oyebande (1982), Sekoni (1992), Chin (2007), Indrani (2009), Omogbai (2010), Kundzewicz (2012), Audu et al. (2013), Terranova and Gariano (2014), Oreste et al. (2015) and Zhang and Changhe (2016) made reasonable spatial comparisons of rainfall seasonality and some other aspects of rainfall regimes of different areas in the tropical environment. These studies have been helpful in determining the onsets and ends of the wet season useful for agricultural calendar planning and the expectancy of certain amounts of rainwater.

The existing literature suggests that rainstorm characteristics are very important, although they can pose problems if not seriously considered (Ayoade, 2012). When rainstorm characteristics, such as rainfall amount and duration of storms, occur in excess, they become a hazard to the people and farmers in particular. When rainstorms occur in high intensity and long duration, they cause havoc rather than good (Singh, 2002b; Kaixi et al., 2016). Rainstorms which exceed 25 mm in amount will most likely lead to severe disaster (Adefolalu, 2001; Akintola et al., 2009; Mario, et al., 2016; Hongyan et al., 2016). Severe rainstorm events may bring about disasters to the people or businesses in the areas concerned. Rainstorms could also create problems in traffic, transportation and other public services. The rainstorms which often accompany rainfall may also bring lightning to human dwellings, and airports threatening the safety of the operational staff on the ground and adversely affecting operations at airports (Adefolalu, 2001).

Rainfall intensities during extreme rainstorms usually exceed soil infiltration rates significantly (Akintola, 1974). Since the soil is unable to absorb water at the same rate at which the rain falls, a significant amount of run-off can be generated. This run-off will erode and carry soil particles. The erosive power of extreme rainstorm events is highly evident in most tropical countries. 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 rainstorm events can produce more run-off than single and separated events with significantly higher precipitation depths (Indrani, 2009; Jin, 2009; Kundzewicz, 2012; Audu et al., 2013; Keggenhoff et al., 2014; Zhihe et al., 2015). There are other specific problems posed by rainstorm characteristics for which some detailed understanding of other attributes of the rainstorm is needed. For example, many irrigation and water supply dams designed during the colonial days have now become obsolete owing to the previous inadequate understanding of the nature of rainstorms and because flooding has become much more frequent than before (Oguntoyinbo, 1982). A detailed understanding of rainstorm duration, rainfall amount, speed and areal coverage 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 rainstorm duration, rainfall amount, speed and areal coverage variations. Such knowledge will not only increase the understanding of the complex nature and character of rainstorms (the marked variation in its spatial distribution and concentration), it will also provide a reasonably sound physical basis for dynamic interpretation of causal relationships. Diurnal variations in rainstorm characteristics have not received adequate scholarly attention. Yet an analysis of diurnal variations in rainstorm characteristics is basic to understanding moisture exchanges between the terrestrial and atmospheric systems. Solar radiation is the main source of energy 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.

The present study therefore differs from existing studies on rainstorms in Nigeria and other West African countries in that an attempt is being made in this work to analyze the seasonal variations in rainstorms duration, rainfall amount and speed of rainstorms on areal coverage of rainstorms with a view to understanding factors that account for seasonal variations in Ibadan metropolis, Nigeria. This was done through careful analysis of rainfall chart and registers of rainstorm events at the selected locations over a two-year period. The rainstorms data has also been collected in such a manner as to allow spatial variations due to landuse to be observed. The topography of Ibadan can greatly impact the microclimate, possibly resulting in locally enhanced precipitation. These occur because topography alters energy, mass, and momentum fluxes between the surface and the atmosphere and in the urban mixed layer (Dabberdt et al., 2000). Urbanization can also alter local climate and form an urban heat island (UHI) (Bornstein and Lin, 2000). Altering landuse by creating impervious urban surfaces causes increased run-off, decreased evapotranspiration, increased solar radiation absorption, additional release of anthropogenic heat, and changes in surface friction, which result in changes in near-surface air temperature, humidity, wind speeds, low-level convergence/divergence, convection, and precipitation (Arnfield, 2003). When changes in landuse occur in a growing urban area, changes in the frequency, intensity, duration and amount of precipitation can occur (Shepherd, 2005). Based on the foregoing discussion, the need to undertake a detailed analysis of the spatio-temporal variations and the effect of duration, rainfall amount and speed of rainstorms on areal coverage of rainstorms over Ibadan metropolis become evident as this will provide a better understanding of the complex and character of tropical rainfall over urban areas.

1.2 Justification of the Study

The humid tropical environment is blessed with an abundant supply of rainstorms and rainwater (Oguntoyinbo and Akintola, 1983; Audu et al., 2013; Dao and Hoang, 2016). Rainstorms serve as an integral part of tropical rainfall, accounting for over 90 percent of the rainfall received (Oguntoyinbo, 1982). Apart from underground water, rainwater is a major source of water for any usage in the tropics. Rainstorms provide rainfall for a variety of natural and anthropogenic uses, from groundwater and stream recharge to water for domestic uses. Since rainfall is the easiest source of water availability in the tropics, the importance of rainstorms cannot be limited to rainfall distribution and occurrence alone. The abundant supply of rainwater can be useful if properly harnessed.

In the tropics, the distribution characteristics and variability of rainstorms are extremely vital. However, rainstorms are primary features of the climate over areas in the tropical sub-region of the world and they occur variably over space and time (Kane, 2000; Gbuyiro, 2002; Jin, 2009; Audu et al., 2013; Ivana et al., 2016). This contributes to the high variability of rainfall that is characteristic of tropical areas. A proper understanding of rainstorm dynamics and characteristics aids proper planning and physical development. A lack of understanding of rainstorms, in terms of rainstorms behaviour, could lead to several problems. Flooding, damage to infrastructure and amenities, water issues and agricultural difficulties could arise if a proper understanding of rainstorms is not achieved before man undertakes any endeavour. Rainstorms studies are extremely vital, especially in developing countries. The significant increases in precipitation and evaporation rates over the last half century has theoretically become a threat to the human population, given the increased frequency in extreme rainstorm events (Kundzewicz, 2012; Atsamon and Patama, 2016). The increasing rates of precipitation and evaporation pose a greater risk to the developing countries of the world, particularly Nigeria, as a result of lack of resources, technology and scientific know-how in the mitigation and control of extreme climatic events (Gbuyiro, 2002).

Unlike most developed countries, the inability to predict, avoid and control the problems of these climatic events owing to the lack of adaptation and control methods leave these

Third–World countries susceptible to great loss of life, infrastructure and socio-economic resources (Gbuyiro, 2002). The destructive effects of rainstorms are becoming increasingly frequent in developing countries. Damage to infrastructure and socio-economic amenities is complemented by the uprooting of trees and the destruction of plant life. Felled trees block roads and other transport routes, thus hindering the effectiveness and flow of transportation. Livestock and human property are also affected by heavy, intense rainstorms; these rainstorms have even resulted in loss of human life. From a geographical standpoint heavy erosion and flooding are the most serious with regard to the effects of intense rainstorms.

In general, several authors have written on rainstorm pattern, rainstorm characteristics, such as rainfall intensity, duration and rainfall amount, and their implications for human welfare (Walter, 1967; Ayoade, 1970; Jackson, 1977; Walsh and Lawler, 1981; Oguntoyinbo, 1982; Oguntoyinbo and Akintola, 1983, Ayoade and Akintola, 1986; Sumner, 1988; Sekoni, 1992; Adefolalu, 2001; Indrani, 2009; Kundzewicz, 2012; Ayoade, 2012; Audu et al., 2013; Keggenhoff et al., 2014; Zhihe et al., 2015 and Ivana et al., 2016). These studies did not consider the seasonal dynamics of rainstorms. Studying the seasonal dynamics and areal patterns of rainstorms is important for several reasons. First, it will provide a baseline for future investigations of dynamics of rainstorms, a topic which has been only minimally examined and characterized in a climatological context. Second, it can also aid forecasters in urban regions, both on the meteorological level as well as for local and regional climate modelling. Besides, results from such analyses could potentially be used to inform urban planners in considerations, such as assigning appropriate zoning types for precipitation-enhanced regions as well as used in establishing guidelines for the use of rainwater in agriculture.

1.3 Aim and Objectives

The aim of this work is to examine the seasonal dynamics and areal patterns of rainstorms over Ibadan metropolis, Nigeria. The objectives of the study are to:

1. analyse the spatial and temporal patterns of the frequency (%), duration (mins) and amount (mm) of rainstorms in Ibadan;
2. examine the diurnal and seasonal variations in the occurrences of rainstorms;
3. analyse the lifetime and speed (m^{-1}) of rainstorms in Ibadan;
4. determine the relationship between the duration (mins), rainfall amount (mm), speed (m^{-1}) and areal coverage (km^2) of rainstorms in Ibadan; and
5. examine the difference in the durations (mins), rainfall amounts (mm), speeds (m^{-1}) and areal coverage (km^2) of rainstorms due to thunderstorm and those due to disturbance lines in Ibadan.

1.4 Research Hypotheses

The following hypotheses were tested:

1. The areal coverage of rainstorms during the early rainy season is not a function of the duration, rainfall amount and speed of rainstorms;
2. The areal coverage of rainstorms during the late rainy season is not a function of the duration, rainfall amount and speed of rainstorms;
3. There are no significant differences in the speed of rainstorms during the early and the late rainy seasons;
4. There are no significant differences in the areal coverage of rainstorms during the early and the late rainy seasons; and
5. There are no significant differences in the durations, rainfall amounts, speeds and areal coverage of rainstorms due to thunderstorm and those due to disturbance lines.

1.5 The Study Area

1.5.1 Location and Extent

The study area is Ibadan, the capital city of Oyo State in southwestern Nigeria. Ibadan is located approximately on latitude 7° 22'N and longitude 3° 58'E of the Greenwich Meridian. Nevertheless, the expanse of land normally referred to as the metropolitan area lies in the portion lying between latitudes 7° $15^{'}$ and 7° $30^{'}$North of the Equator; and longitudes 3° $50^{'}$ and 4° $00^{'}$East of the Greenwich Meridian. It covers an area about 450 km^2 (Figures 1.1). It is 145 km northeast of Lagos. The city is directly connected to many towns in Nigeria, by a system of roads, railways and air routes. The area is in the vegetational transitional zone between the forest and savanna. 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). The area also experiences the double maxima rainfall regime with the characteristic break in August known as the "little dry season" (Ireland, 1962). Three major rivers drain the city. These are Ogunpa, Ogbere and Ona Rivers, with many tributaries (Akintola, 1994).

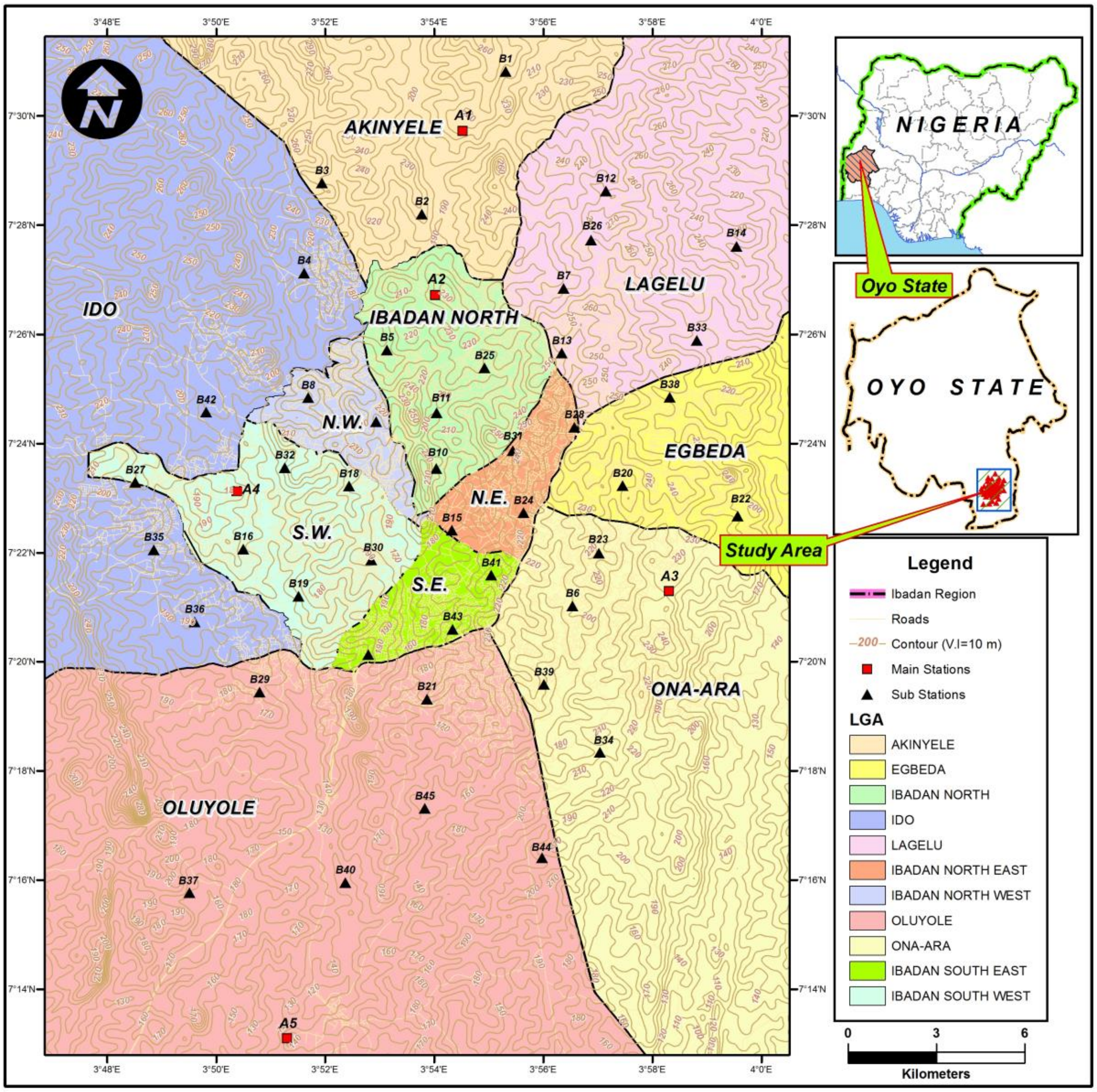


Figure 1.1: The Study Area. Inset: Map of Nigeria showing Oyo State (Shuttle Radar Topographical Mapping (SRTM), 2013)

1.5.2 Population of Ibadan

The growth of the population of Ibadan has also been equally remarkable. From a war camp consisting in 1829 of a motley collection of soldiers, the population rose from the estimated 100,000 in 1851 to 175,000 in 1911 (Tomori, 2012). Between 1911 and 1921 it increased at about 3.1% per annum to 238,075. The rate of increase between 1921 and 1931 was 0.5% per annum while it was only 0.8% per annum for the period between 1931 and 1952 when the population rose from 387,133 to 459,196. In 1952, the less city was counted and it was 286,252 (Tomori, 2012; Adelekan, 2016). From then on, the population of Ibadan metropolitan area increased at a growth rate of 3.95% per annum from 1952 and 1963 when the population rose to 1,258,625 (Afolayan, 1994; Tomori, 2012). According to Afolayan (1994), the total population size of the wider Ibadan region was 1,258,625, according to the 1963 census. For Ibadan urban and rural, the population sizes were 627,379 and 631,246, respectively in 1963. On the other hand, the villages within the circumference of the smaller Ibadan region had a total population of 97,821 in 1963. The city proper has engulfed many of these villages (Afolayan, 1994). As a result, any projection of the population of Ibadan urban should be based on a total size of 725,200, that is, the figure obtained by adding the population sizes of Ibadan urban with those for the for the former villages in the smaller Ibadan region (Afolayan, 1994). The populations of the city proper and of Ibadan urban were 1,222,570 and 1,829,187, respectively in 1991 (Afolayan, 1994). The population rose to 1,829,300 in 1999 at a growth rate of 1.65% from 1963 and increased to 1,338,659 in 2006 at a growth rate of 2.35% (Tomori, 2012). However, the population growth is gradually shifting to the less city with a growth rate of 4.8% per annum between 1991 and 2006 according to the provisional census figure released by the Federal Republic Nigeria (2007) (Adelekan, 2016). According to Ayeni (1994), "the population of Ibadan has continuously been on the increase and these low rates of growth are due to implementations and inaccuracies of census estimates".

1.5.3 Industrial activities of Ibadan

The scattered nature of modern industries in Ibadan is due to the location of the industrial estates namely: Oluyole, old Lagos road, Olubadan Industrial Estate near express Toll Gate, Olubadan Estate along New Ibadan/Ife express road, Ajoda New Town and Eleyele

Light Industrial Estate (Tomori, 2012; AEO, 2015). The Nigerian Breweries PLC has a modern brewery located next to Olubadan Estate with some industries located round the place. The traditional craft (e.g. blacksmith industry is organized on cottage or compound basis, so that industrial and residential spaces are practically in one and the same place while factory production, especially of the large scale types is generally in buildings or premises separate from dwelling houses e.g. Sanyo Nigeria limited along Ibadan Lagos express road, Odo-Oba and Askar Paints Nigeria limited at Eleyele (Tomori, 2012). What also constituted the periphery or fringe of Ibadan has been changing in line with urban development some industries are now located in those areas such as Gas Cylinders limited located at Ejioku, Leyland Nigeria Limited at Iyana – Church, the Nigeria Wire and Cable limited along Ibadan-Abeokuta Road Owode, the Standard Breweries at Alegongo Village, Eagle Flower Mills, Toll-Gate, The British-American Tobacco Company on Lagos-Ibadan express road new Toll-Gate Ibadan etc (Tomori, 2012; AEO, 2015).

1.5.4 Relief and Drainage of Ibadan

One of the features of the geography of Ibadan is the variation in the relief features found within its territorial boundaries (Figure 1.2). Relief regions based on land units in Ibadan include the hills, plains and river valleys–which dominate the scenery of Ibadan region (Faniran, 1994). The hills are the most striking features around Ibadan, although they constitute less than 5 per cent of the total area. The hills can be classified into three types namely the quartzite, ridges and gneissic inselbergs (including tors, kopjes, ruwares, sugar-1 loaves, whalebacks). Of these, the quartzite ridges are by far the most impressive, widespread and best known. Not only do they occur in the immediate vicinity of the city (of, the “seven” famous hills of historic Ibadan) but they also occur widely within the region.

The inselbergs are restricted mainly to the north-eastern corner, along Ibadan-Oyo Road. Many of these rock outcrops are currently being quarried for civil constructions in and outside the city. Another important feature of the hills in this area is the hillside slope. Generally, the inselbergs attain domical shape, some symmetrical and others asymmetrical (Faniran, 1994). The ridges can have width to length ratio of up to 1:20 or more.

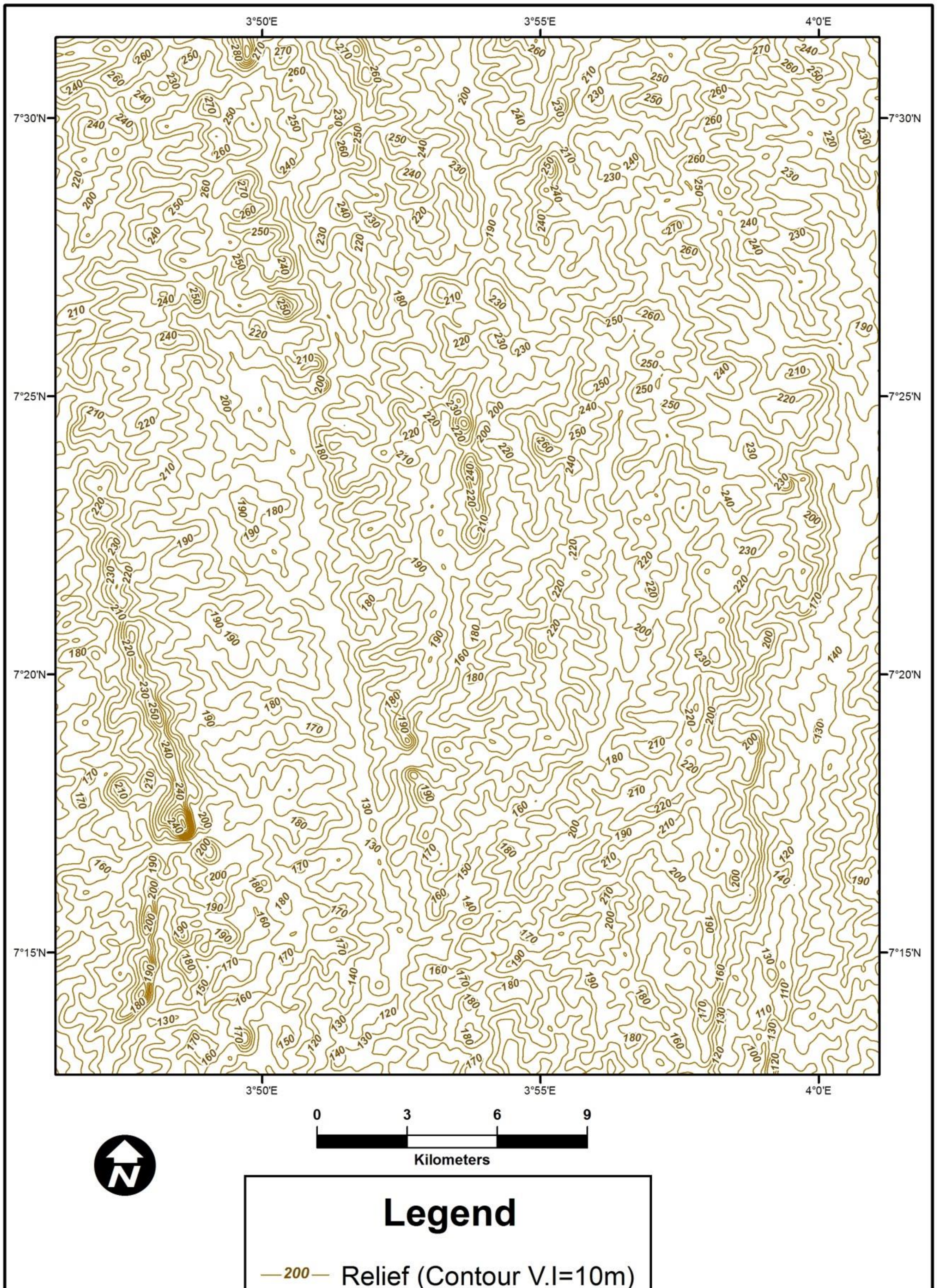


Figure 1.2: Relief Map of the Study Area (Shuttle Radar Topographical Mapping (SRTM), 2013)

The quartzite ridges are generally well vegetated, particularly where they have not been cleared, partly because of the existence of pockets of thick soils in the well-jointed rock, and partly because of the generally steep slopes which limit the intensity of human interference. The hills are commonly broken up by passes or gaps, for example the pass utilized by Elizabeth Road, between Mokola and the University College Hospital.

The inselbergs are mostly fresh rock surfaces covered with thin to skeletal soils and sparse vegetation. In fact, they are mostly bare rock surfaces except along joints and in depressions where skeletal soils support some plant life. Even then, the plant life here is mostly low plants, varying from algae to grasses and xerophilous tree species. The fresh rock outcrops around Ibadan also have some interesting surface phenomena in common with similar features in other parts of Nigeria. The most common of these are rock pits quartz veins, corestones and exfoliation blocks (Faniran and High, 1971). These pits in the area occur exclusively on the fresh rock (gneissic) outcrops, that is, on inselbergs, ruwares, whalebacks, tor and so on. Corestones and exfoliation blocks are perched on many inselbergs, especially in the case of tors, while quartz veins can be observed at a number of sites, for instance near the disused aerodome, the Ojoo quarry and the Gbanda Hill. Unlike the ridges which tend to occur close together, the inselbergs are mostly small features, and are more widely spaced.

The hill-land topography consists of a number of recognizable land facets, two of which can be summarized as follows: The plains form by far the most extensive landform system in the area. The general elevation is between 180 m and 210 m above sea level. From estimates by Burke (1967), and Burke and Durotoye (1971), among others, this landform makes up about 80 per cent of the total surface area of the region, overlapping with the hill-land facets described earlier, especially with the hill-foot slope facets. It covers essentially the areas between the hill bases and the usually intrenched valley bottoms. Although generally smooth and rolling, with convexo-concave slopes, some geomorphologists have described it as pediment surface, apparently relating it to some arid/semi-arid processes described by King (1953; 1962), among others.

In the gneissic rock areas, the depth of weathering varies from nothing (fresh rock outcrops, e.g. ruwares) to over 30m. Although this phenomenon has not been studied extensively in this area, studies in other parts of the country suggest that the basal surface in many parts of Nigeria, especially in granitic rock areas, is characterised by irregular (dome- and basin) pattern and that inselbergs do not generally occur according to any defined pattern, say, in the interfluve regions (Faniran, 1974: Faniran and Jeje, 1983).

Rather, their distribution seems to depend more on the occurrence of suitable rock types, especially granites and gneisses; while ridges occur in the quartzite areas (Faniran, 1974). The slopes vary widely from 1° to 10° while ironstone concretions (duricrusts) have been observed at many locations, including on top of the low interfluves, as well as in certain positions along the valley-side slope, notably at breaks of slope.

Some aspects of the geomorphology of the plains in these areas have been studied in slightly more detail. Among the finest exposures was a section of the University of Ibadan swimming pool, at the time of its construction.Second, a number of land facets have been studied, including: (a) Ruwares and Turtle back Topography (b) Crest of Interfluves Facet (c) Long-connecting Slopes (d) Wide River Channels and Floodplains.

The third and final landform system is the river valleys which are the narrowest, though not necessarily the least extensive landforms in the area. The most important feature of this landform system is perhaps the conspicuous incision of the rivers into the flood plain or river bed. In almost every case, even in small streams, such as the Orogun stream which flows through the Ibadan University Botanical Garden, the river has cut into its bed to reach the bed rock in places, the cutting appears to still be in progress and has been attributed to a recent drop in the sea level, following a major change of climate (Burke, et al., 1971).

The general layout in Ibadan conforms to the dendritic pattern, showing irregular branching in all directions, with tributaries joining at all possible angles. However, in detail, trellised patterns occur, especially in the area where quarzitic and gneissic bands are interposed. Both rocks have suffered periods of dastropism and are consequently marked by faults, joints and displacements, which have influenced the drainage pattern (Burke, et al., 1971). Streams have utilized such weak areas, resulting in features which appear to illustrate classical river capture phenomena. Many of such features are described by Burke (1967), for the study area and by Wilson (1962) and Jeje (1982) for other parts of Nigeria.

Gullying is a common phenomenon, especially in the settled parts. The most spectacular example of gully yet observed by the author is around Eleyele Water Reservoir where a gully has developed, strangely enough, within the forest reserve (Faniran and Areola, 1974).

Finally, a number of typical river features have been observed. Riffles – and pools have been observed along the north of the University of Ibadan campus, and although these have not been mapped, the correspondence between their locations and those of meanders agrees with reported cases elsewhere. Moreover, river meanders are not restricted to big streams; lakes, e.g. along Orogun stream in the Teak Plantation area of the University's Botanical Garden; meanders and braids have been studied along the Ogunpa and Kudeti (Faniran, 1975 a, b) streams. The drainage network of Ibadan was analysed for order, number, length, drainage/density, stream frequency, drainage intensity, and bifurcation ratio. Some of these indices were calculated for the entire area and others for the 30 selected samples. Analysis of stream order shows that the highest order stream is the 5th-order stream, represented by the lower reaches of the Omi and Ona rivers. River Ona at the Eleyele reservoir is a 5th-order stream, while Ogunpa and Kudeti within the built-up area are both 3rd-order streams. The Ona enters the region as a 4th-order stream and so has been found large enough to be dammed at two sites-within the International Institute for Tropical Agriculture (IITA) and at Eleyele. By contrast, the Omi starts virtually within the region. Apart from the Ogunpa/Kudeti system, the Ona has another important tributary the Ogbere – which joins it just before it leaves the map area. None of these rivers is howver, found large enough to satisfy Ibadan's water need; hence the damming of the Osun River at Asejire, to provide the bulk of Ibadan's water supply. The Eleyele and other smaller schemes are used to supplement this major source. However, the selected samples have been grouped into three main categories. Category I smple come from areas with low drainage intensity mainly in the northern high-relief areas; categories II and III are from medium and high drainage intensity areas, respectively. These are equivalent, respectively, to coarse, medium and fine-textured topographies. It is important to note that the Ogunpa stream falls within category II and that both its drainage intensity index and its bifurcation ratio are lower than the mean for the entire area. The Ogunpa and the Kudeti are only third-river streams their frequent flooding will therefore have to be explained mainly in terms of the effect of human activities, especially urbanisation (Akintola, 1974).

1.5.5 Climate of Ibadan

Ibadan is a tropical city and has a tropical wet and dry climate and shares virtually all the climatic conditions that operate in Nigeria. In discussing the climate of Ibadan, this study will be limited to the climatic elements which affect rainfall and its characteristics. These elements include insolation, prevailing air mass and disturbance lines. The conditions of these elements depend on the apparent movement of the Inter-tropical Discontinuity (I.T.D), the fluctuating boundary zone between the prevalent air masses which determines the weather type experienced in a place at a particular time of year.

Ibadan enjoys a tropical climate which is influenced by two air masses. These are, the warm, rain-bearing Southwest monsoon wind which is generated from the Atlantic Ocean, and the cold, dry, continental air mass which blows from the Sahara Desert. The boundary between these two air masses (the I.T.D) moves across the country as one air mass takes prevalence over the other.

The I.T.D in Ibadan has an approximate WNW-ESE surface orientation (Ayoade, 1974) and the climate of Ibadan is controlled by the North-South movement of the I.T.D. From April onwards, the Southwest monsoon winds which are moisture laden begin to advance inland in response to the insolation and decreasing pressure in the continent's interior. Thus, the location of the I.T.D shifts northward correspondingly. As the depth of the moisture laden maritime air mass increases, it brings clouds and rain which begin at the coast and advance inland.

This arrival of the maritime air mass in Ibadan is characterised by rainfall and is often called the "wet" season. It starts in March and prevails until October when it comes under the influence of the dry continental air mass from the Sahara which moves southward from the North, bringing on the “dry” season. The dry season spans from November to late February, sometimes early March (Oguntoyinbo, 1978). There is usually a lull in precipitation received by the metropolis during the month of August. This cessation of rainfall is referred to as the “Little dry season”.

Other causes of rainfall in Ibadan include the existence of disturbance lines which usually begin about 3.5° south of the surface location of the I.T.D. they travel as an arc-shaped entity, convex from East to West with a speed of about 20-50km per hour. They are associated mainly with troughs of low pressure at the surface causing a major build-up of tropical cumulus clouds. The resultant rainfall may be grouped into those associated with the frontal activities of the I.T.D which dominates the beginning and the end of rainy seasons, and those that occur once the I.T.D is fully established. The former is short in duration and usually sporadic and of high intensity while the latter produces rainfall of much lower intensity and longer duration. Mean climatic figures for the Ibadan metropolis are somewhat standard since Ibadan isn’t supremely elevated. Annual temperature over the Ibadan metropolis averages at with mean temperature extremes usually around 31°C and 23°C, respectively. Mean annual rainfall is about 1, 121 mm and percentage humidity is about 81% (Oguntoyinbo, 1978).

1.5.6 Landuse/Landcover of Ibadan

The city of Ibadan consists of 11 local government councils, with five in the inner city and six in the outer areas. Since its foundation in the 1800s, the city has had rapid growth; in fact, it was regarded as one of the pre-colonial urban centres in Nigeria. Developed land increased from only 100 ha in 1830 to 12 km^2 in 1931, 30 km^2 in 1963, 112 km^2 in 1973, 136 km^2 in 1981, and 214 km^2 in 1988. Ibadan, the capital city of Oyo State, is reputed to be the most urbanized state in Nigeria, after Lagos (Fabiyi, 2006).

The landuse pattern in Ibadan metropolis is broadly categorized into educational/institutional, vegetation, bush fallow, industrial, water body, open space, recreational and residential (Figure 1.3) (Fabiyi, 2006). The landuse change, referred to as change detection, and the growth of urban centres have gained prominence in recent years. This is partly due to the fact that there is an increasing need for proper land use planning to control haphazard developments that characterized the city systems in most developing countries. Land cover within the Ibadan metropolis has transformed significantly in over the last four decades and especially since the 1970s consequent upon rapid national economic development during the oil boom years. In 1972, vegetation was the dominant land cover, occupying about 92 percent of the total area followed by peri-urban development, which covered about 25.43 km^2 (3.66%) of the study area. The urban core, which represents the pre-colonial parts of the city, occupied about 20.70 km^2 (2.98%). The peri-urban developments that came at this period were principally residential zones. A noteworthy feature of the city before 1972 was the absence of high-density areas within the metropolis. However, by 1984, 11.42 km^2 of the urban area was classified as high-density urban development, increasing significantly to 64.8 km^2 in 2003. Urban development reduced significantly the vegetal cover to 63.12% of the total land area of the city by 1984. By implication, 205.73 km^2 of vegetal cover disappeared for urban development in a period of twelve years and, by 2003, it reduced to about 38.9% of the total land area (Fabiyi, 2006).

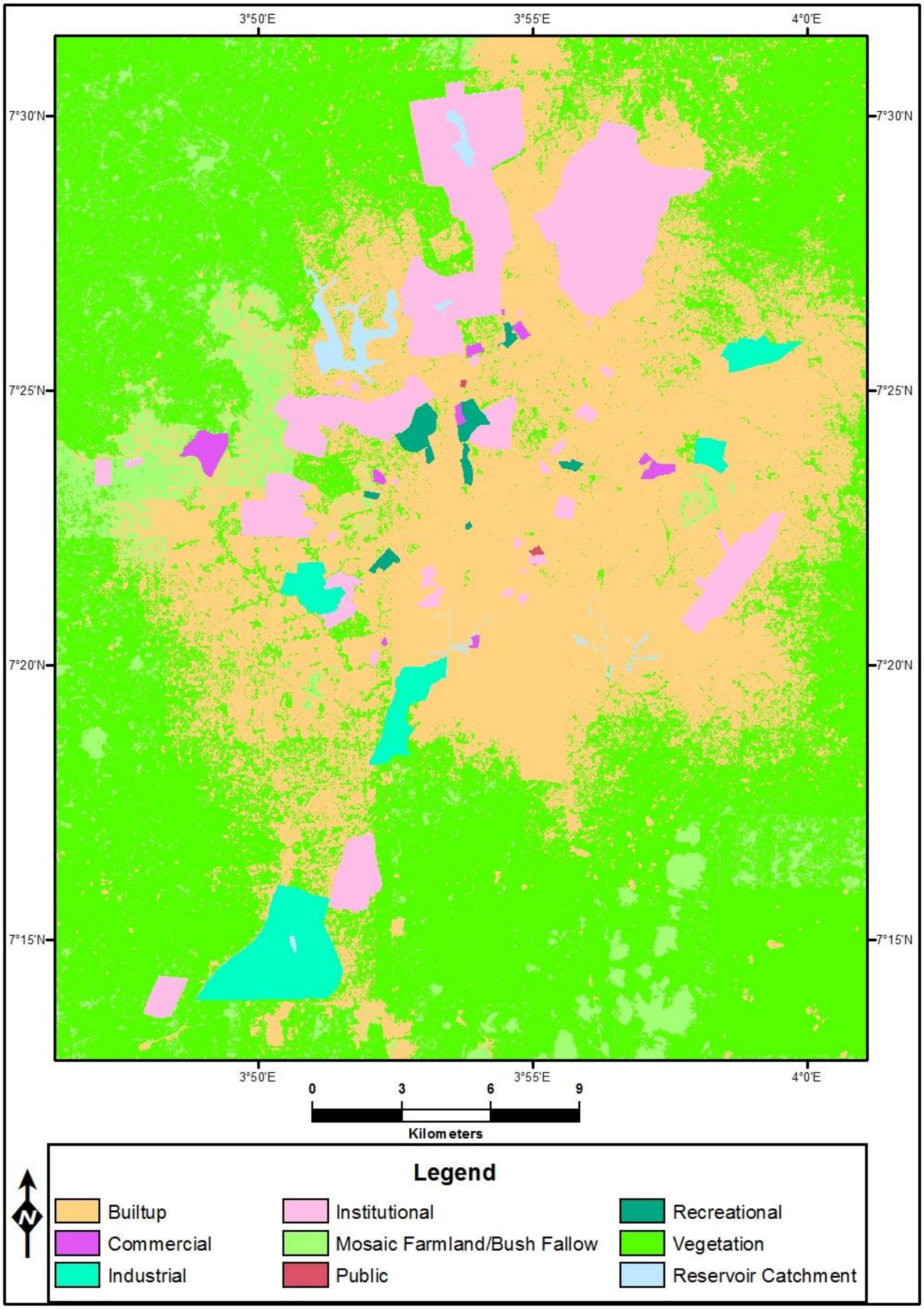


Figure 1.3: Landuse Map of the Study Area (Shuttle Radar Topographical Mapping (SRTM), 2013)

1.5.7 Building Density of Ibadan

The development of Ibadan has been influenced by the traditional and colonial forms of urbanization. It was founded in 1829 and occupied by immigrants who moved into the city in search of security from inter-tribal wars. It is now the largest indigenous city in tropical Africa and the capital of Oyo State. Since its founding, the city has had rapid growth both in area and in population. Developed land increased from only 100 hectares in 1830 to 12.5 km^2 in 1931, and 38.85 km^2 in 1935. In 1955 and 1965, the figures were 46.40 km^2 and 77.70 km^2, respectively. The city extended to 112 km^2 in 1973, 152.8 km^2 in 1977, 214 km^2 in 1987, 323.3 km^2 in 1990 and 463.33 km^2 in 2011 (Bankole and Bakare, 2011). The spatial and demographic figures above demonstrate the high incidence of landuse development in Ibadan, with residential developments intensified over the years (Figure 1.4).

The city can be classified into 4 morphological regions, varying in their housing densities, types and levels of infrastructural facilities. These are the core area, the older suburb, the newer eastern suburb, the newer western suburb, the post–1952 suburb, the Government Reserved Areas (GRAs) and the government–planned residential estates (at Bodija, Oluyole and Akobo) (Onibokun, 2006). Furthermore, the residential areas in Ibadan can be classified into high-, medium- and low-density areas. The high-density zones comprised the pre–industrial traditional housing areas of Ibadan. This is characterized by narrow streets and physical planlessness (Fadare, 1997) (Figure 1.6). The medium-density zone is a hybrid of the traditional and modern lifestyles. The buildings are usually blocks of flats or tall buildings built in the modern form (at residential and central business districts of Ibadan). The low-density areas vary from the high- and medium-density areas. Most of the buildings are mostly single family units (Fadare, 1997).

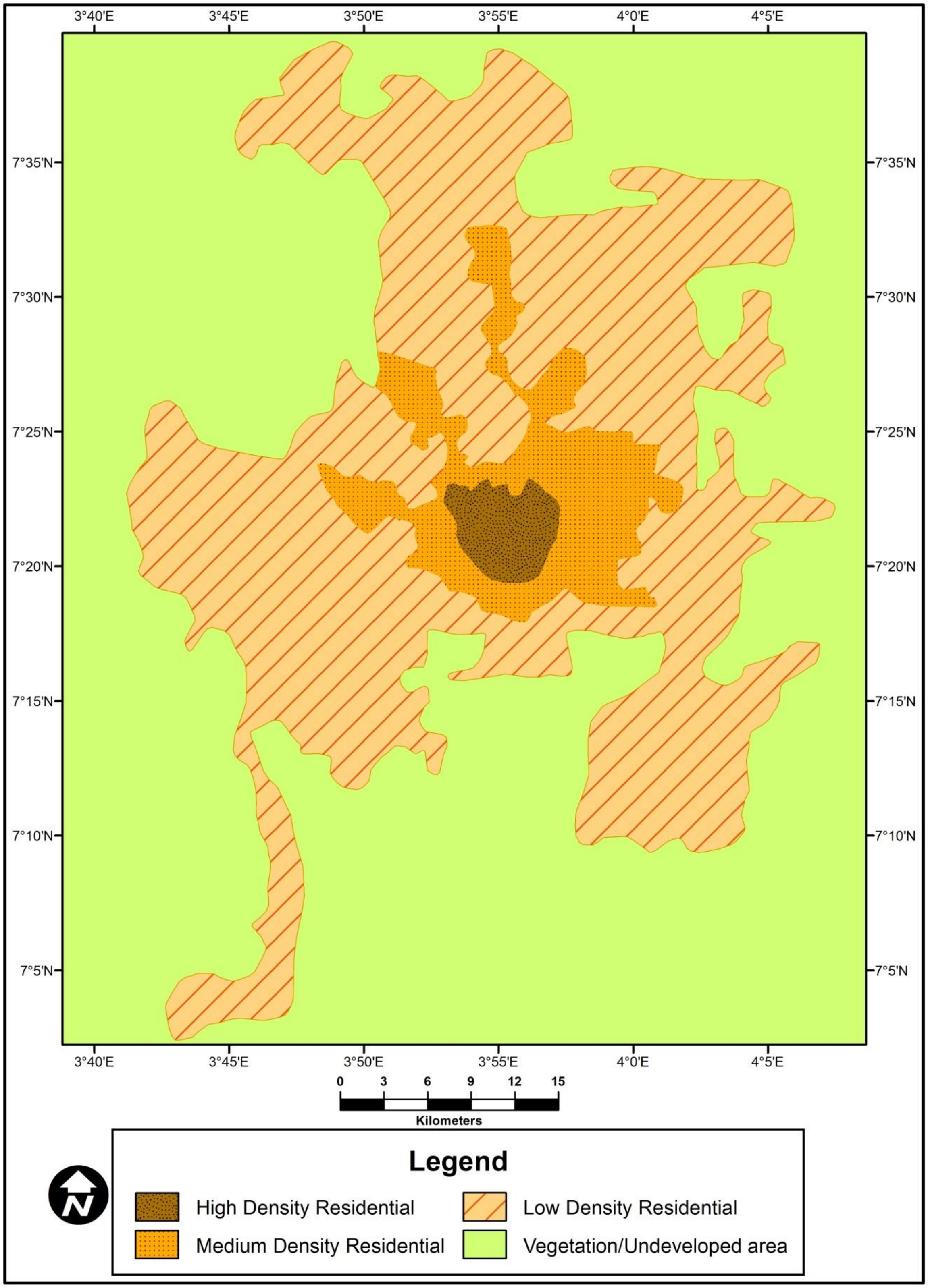


Figure 1.4: Building Density of the Study Area (Shuttle Radar Topographical Mapping (SRTM), 2013)

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 The Circulation Systems and Rainfall Producing Mechanisms in West Africa

A basic feature of the lower atmosphere over West Africa during the rainy season (April-October) is the thermal-induced low pressure cell over the Sahara, with its axis located between latitudes 18°N and 22°N. Simultaneously, the subtropical high over the South Atlantic intensifies and extends equator-wards. The resulting gradient between the two pressure systems induces a southwesterly airstream (southwest monsoon) from the South Atlantic. This warm, moist and convectively unstable airmass penetrates deep into West Africa, reaching latitudes 20° - 22°N in August. During the Northern Hemispheric winter, most of the West African area is under the influence of the dry continental air originating in the Sahara as the north easterly trades and only the Guinea coastlands experience some rain. In summer months, the monsoonal air penetrates far into the African continent, supplying a large portion of water vapour necessary for the formation of rains farther inland.

The boundary zone separating the two contrasting air masses is known as the Inter-tropical Discontinuity (ITD) particularly on land; while on the ocean surface, where convergence between the two air streams is evident, Intertropical Convergence Zone (ITCZ) is more appropriate. There is no particular weather activity associated with the position of the ITD over West Africa as such (Ayoade, 1983).

Its climatological significance lies in the fact that it provides a framework for following the south-north motion of the rain-producing southwest monsoon winds whose depth and motion influence rainfall amount, duration and distribution. Several authors, for example Hamilton and Archbold (1945) and Adejokun (1985), have identified different weather zones with reference to the Inter-tropical Discontinuity. As the surface position of the ITD shifts northwards or southwards, the West African region comes under different zones. The average depth of the moist layer has to be greater than about 1,500 m for the formation of rains (Tetzlaff and Peters, 1988). In the summer months, this depth is found only south of 15°N that is the entire area of Nigeria. At the peak of the rainy season, the maximum rainfall occurs at about latitude 11°N.

The formation of rains cannot be fully explained solely considering the average summer flow conditions mentioned above as the horizontal transport of moist air alone is not sufficient to organize the rains. There has to be both a moisture convergence as well as vertical motions. The relatively cool monsoonal air in the south and the hot Saharan air in the north cause a reversed meridional temperature gradient with surface temperatures increasing polewards. This temperature structure leads to the formation of a strong easterly thermal wind which increases with height and reaches a peak at midtropospheric levels (Peters and Tetzlaff, 1986; Adefolalu, 1988; Keggenhoff et al., 2014) resulting in the African Easterly Jet (AEJ). The AEJ which consists of narrow bands of jet streams located at a height of about 3 km (700 hpa) above the south-west monsoon is situated at latitude of 12^0N in June and has a northernmost position of 16^0N in August. This jet often becomes barotropically and baroclinically unstable and develops into the wavelike pattern of the easterly waves (Burpee, 1972).

According to Krishnamurti and Kanamitsu (1981) and Reed et al. (1977), the rain-producing West African disturbances are maintained by the combined barotropic and baroclinic instability mechanism. They propagate to the west with an average velocity of 8 m sec^{-1} (Reed et al., 1977). Due to their structure, they cause convergence ahead of the wavetrough. However, this convergence is generally not large enough to produce vertical motions for the initiation of rains. A large enough convergence is found in the squall lines travelling most frequently in the latitudinal belt of $10^\circ - 15^\circ$N (Riehl, 1954). The squall lines are most frequently situated ahead of the trough of the easterly waves (Riehl, 1954).

Figure 2.1 is a schematic representation of the zones and the associated cloud pattern. Zone A lies north of the ITD and it is completely devoid of most convective activity. Surface winds are northeasterly and the relative humidity is low, measuring about 40% in some places. Rainfall is practically nil in this zone and the sky is generally cloudless. Zones B, C, D and E lie south of the ITD and organization of the convection within the ITD circulation varies from the deep little convection (cumulus, cumulonimbus) to linesqaulls and bigger systems consisting of cloud clusters. The ITD band of rain results from these systems and precipitation in West Africa, especially Sahelian stations, is highly ITD-controlled while a decline takes place as one goes further south (Adedokun, 1978).

Weather zone B extends from the surface position of the ITD southward for about 350 km. In this zone, the surface winds are southwesterly with hot days and only moderately cool nights. The little amount of rainfall of between 25 and 50 mm per month experienced is derived from occasional isolated thunderstorms and the relative humidity varies from about 90% at night to 60% during the day.

Weather zone C_1 extends from about 350 km to 1, 250 km south of the ITD. This is the zone of lines of thunderstorms known as linesqaulls. Cumulus and cumulo-nimbus clouds in this zone give fairly heavy and thundery rains. Relative humidity varies from 95% in the mornings to 65% in the afternoons. Zone C_2 lies roughly between 1, 250 km and 1, 600 km south of the surface position of the I.T.D. Surface winds in this zone are southwesterly or southerly; clouds are abundant but are usually non-convective. There are periods of steady and prolonged rains though the rains are not as intense as those of weather zone C_1. Such rains are called ‘monsoon’ rains and this zone can be described as the monsoon zone.

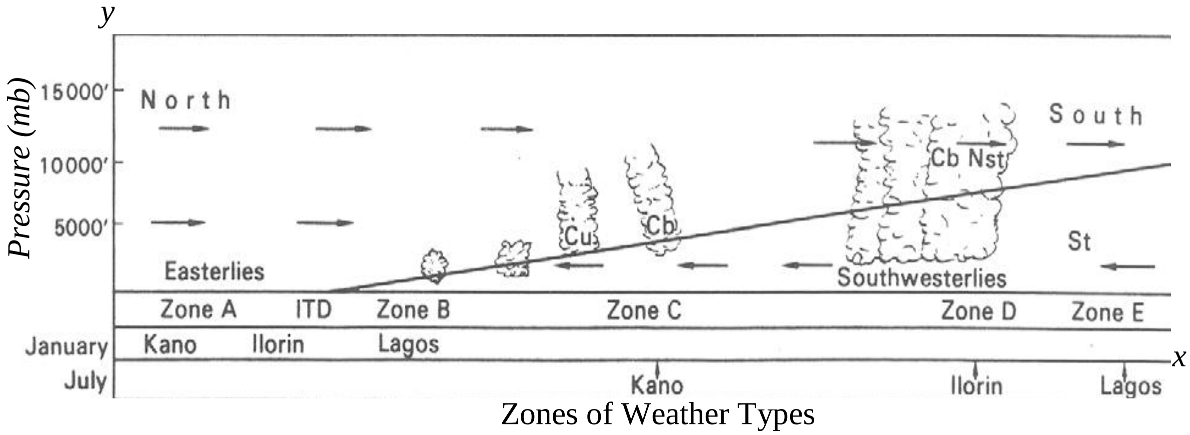


Figure 2.1: The I.T.D and the Weather Zones in an Idealized Atmospheric Cross-Section from South to North over Nigeria (see Ojo, 1977)

Zone D is the most southerly weather zone and is characterized by an inversion layer within the moist southwest monsoon at a height of about 2, 000 metres. This zone is able to penetrate the coastal areas for only a short period in July/August, giving rise to the ‘little dry season’ phenomenon.

The usual cloud types are stratus and strato-cumulus. Convective type clouds, like the altocumulus and altostratus, are rare because of the inversion layer within the southwesterlies and rainfall is, therefore, low compared to weather zone C_1. Rainfall occurs in the mornings in the zone as light rains or drizzle from stratiform clouds, the weather being generally cool and cloudy.

Figure 2.2 shows the average monthly position of the ITD estimated along longitude 7°E based on available data for the years 1959-1971 (Balogun, 1981). In this figure, zones D and E are equivalent to zones C_2 and D in Figure 2.2, while zones A, B and C are the same for both figures. The weather conditions associated with each zone are, therefore, experienced in the different areas covered by the curves.

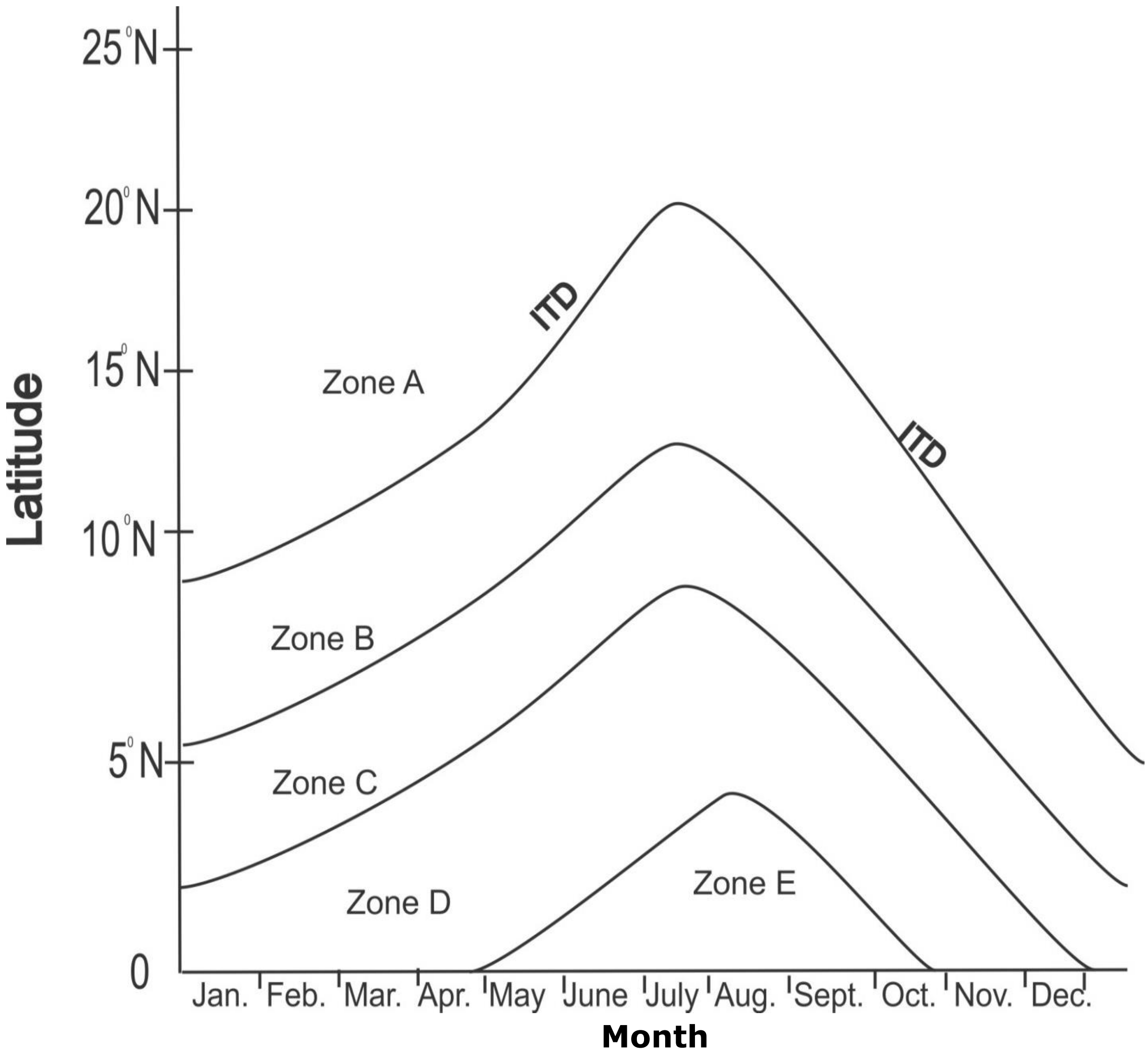


Figure 2.2: Meridional Variation of the ITD Position at about Longitude 7°E and the Weather Zones over Nigeria (Balogun, 1981)

2.1.1 Thunderstorms as Rain-producing Weather Systems

Thunderstorms, which can be considered as manifestations of large-scale conditions rather than factors which make for the change in them, are of considerable climatological importance in the tropics. They are an elementary unit of the larger tropical disturbances and produce a large proportion of the rainfall in most tropical areas. Thunderstorms are highly localized and largely stationary weather systems affecting a limited area of about 20-50 km^2, depending on the size of the cumulus-tower. They are shower clouds or aggregations of shower clouds in which electrical discharges can be seen as lightning and heard as thunder by a person on the ground. Since thunderstorms are showers that attained a stage of producing lightning, they represent an advanced stage in the development of convection in moist air. If the rainfall produced by a thunderstorm is considered with respect to the moving cell, it is found that the duration of moderate or heavy rain from a single cell may vary from a few minutes in the case of a weak, short-lived cell to almost an hour in a large active one. At a fixed point on the ground, the duration of the rain depends upon such factors as the number, size and longevity of the cells passing over the point. The most intense rain occurs under the core of the cell within two or three minutes after the first measurable rain from that cell reaches the ground and rain usually remains heavy for a period of five to fifteen minutes (Byers, 1951; Sekoni, 1992). The rainfall rate then decreases but much more slowly than it first increased. Around the edges of the cell, less rainfall occurs but outside that area, no rainfall is received.

It is generally estimated that a thunderstorm will develop when the instability reaches levels around 8,000 m (Landsberg, 1964). For this condition to be met, a great deal depends on the local conditions which trigger off the process by causing an initial upward air movement. The most common factor is convection, resulting in widely scattered thunderstorms developing over places where surface heating is most intense. Night-time convection over water bodies and advection of cold air aloft are other factors which can cause thunderstorms show frequencies of occurrence which are closely related to the properties of the prevailing airmasses. They are, therefore, generally rare during seasons when stable or dry airmasses prevail over an area.

The thunderstorm process can be divided into three stages, each lasting about 40 minutes determined by the magnitude and direction of the predominating vertical motions (Figure 2.3). In the beginning stage, strong updraughts prevail in the thunderstorm cell and the cumulus cloud rapidly upwards reaching levels around 8, 000 metres. In this stage, little or no precipitation takes place and lightning is rare. Converging air feeds the updraughts from the surface and also from the unsaturated environment at all levels penetrated by the cloud. Air is, therefore, entrained into the cloud and is accommodated by the evaporation of some of the liquid water carried in the updraughts. This entraining continues throughout all the stages. The cloud temperatures in a strongly developing cell are higher than those of the environment at corresponding altitudes, with the greatest differences occurring in regions of strongest updraughts, which are in the upper parts of the cloud. These are especially well developed at the end of the stage. At this initial stage of a thunderstorm, there appears to be a considerable concentration of hydrometeors at or slightly above the freezing level in the form of liquid or solid or the mixture of the two. Although rain or snow in the clouds may be observed towards the end of this stage, these condensation products are suspended by the updraught since no precipitation is observed at the ground. The end of the first stage and the beginning of the mature stage can be signaled by the occurrence of precipitation at the ground.

In the mature stage, the thunderstorm reaches its highest intensity. This stage begins when rain first falls distinctly out of the bottom of the cloud. This is because the size and concentration of the raindrops become so great that they cannot be supported by the updraught and they begin to fall relative to the earth. The frictional drag exerted by the precipitation helps to change the updraught into a downdraught which, once started, can continue without this frictional drag. The mature stage represents the most increased period of the thunderstorm in all its aspects. At the ground, heavy precipitation is rather intense and strongly localized. Strong winds gusting up to 20 knots are also observed. In the clouds, severe turbulence also occurs. In this stage, the cumulonimbus cloud frequently reaches levels up to 1, 800 m and it often develops an anvil head caused by upper tropospheric winds.

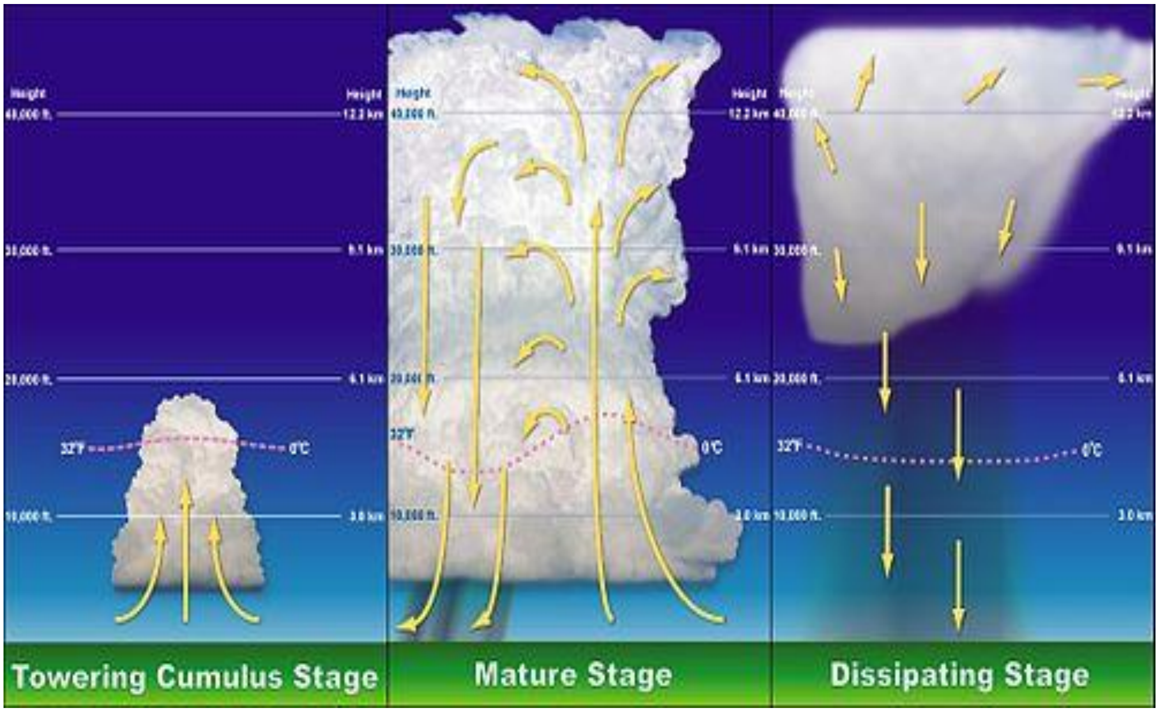


Fig. 2.3a**:** Vertical Cross Section in Cumulus Stage showing Vertical Motions, Inflow, Hydrometeors and Temperature Distribution

Fig. 2.3b: Vertical Cross Section in Mature Stage showing Vertical Motions, Inflow, Hydrometeors and Temperature Distribution

Fig. 2.3c: Vertical Cross Section in Dissipating Stage showing Vertical Motions, Inflow, Hydrometeors and Temperature Distribution

Figure 2.3: Life Cycle of a Thunderstorm Cell (National Weather Service (NWS), 2005)

In the last stage when dissipation occurs, down draughts prevail in most of the cell and lighter precipitation falls over most of the area covered by the cell. The climatological importance of thunderstorms is, therefore, mainly related to the precipitation which they bring. Since most of this falls during the second stage of the process, it is usually characterized by high intensity, short duration and strong localization. The total amount of precipitation caused by one thunderstorm depends not only on its size and intensity, but also on its movement during its most active stage.

2.1.2 Disturbance Lines as Rain-producing Weather Systems

Linesqualls have been identified as a major form of organization of convective rains over West Africa and theories relate them to the African low level easterly jet (for example Rennick, 1976; Simmon, 1977; Bolton, 1981). Linesqualls consist of lines of thunderstorms, 300-500 km length, and oriented roughly north-south. They move westward against the low level monsoon flow with a speed of about 25 knots, gusting at times to 30-40 knots near the coast and up to 60 knots in the northern part of West Africa in late summer. Figures 2.4 capture idealized cross-sections through the lower troposphere of West Africa during the process of initiation of squall lines.

Initially, there is the perfect state of an undisturbed atmospheric structure with the north easterlies aloft and oppositely directed to southwesterlies. As a result of the setting in a wavelike disturbance along the surface of discontinuity (ITD) between the airmasses, probably due to a mode of the African easterly waves, there is a perturbation (Fig. 2.4b). This perturbation intensifies to the extent of blocking the 650mb tropospheric jet which progressively sinks as it travels westwards across West Africa as a result of the low temperature of the jet core. On encountering the undulating surface of discontinuity, the jet further distorts it and this distortion forces the monsoon south-westerlies to ascend even more. As a result of forced ascent, rising parcels of the convectively unstable south westerlies may precipitate. The latent heat of vapourization being supplied by the dry jet causes some of the precipitation to be evaporated in the jet. This evaporative loss of heat cools the jet and it, therefore, sinks further. While sinking, the jet may reach the surface of the earth, especially if the whole process occurs over a high flat terrain. The relative

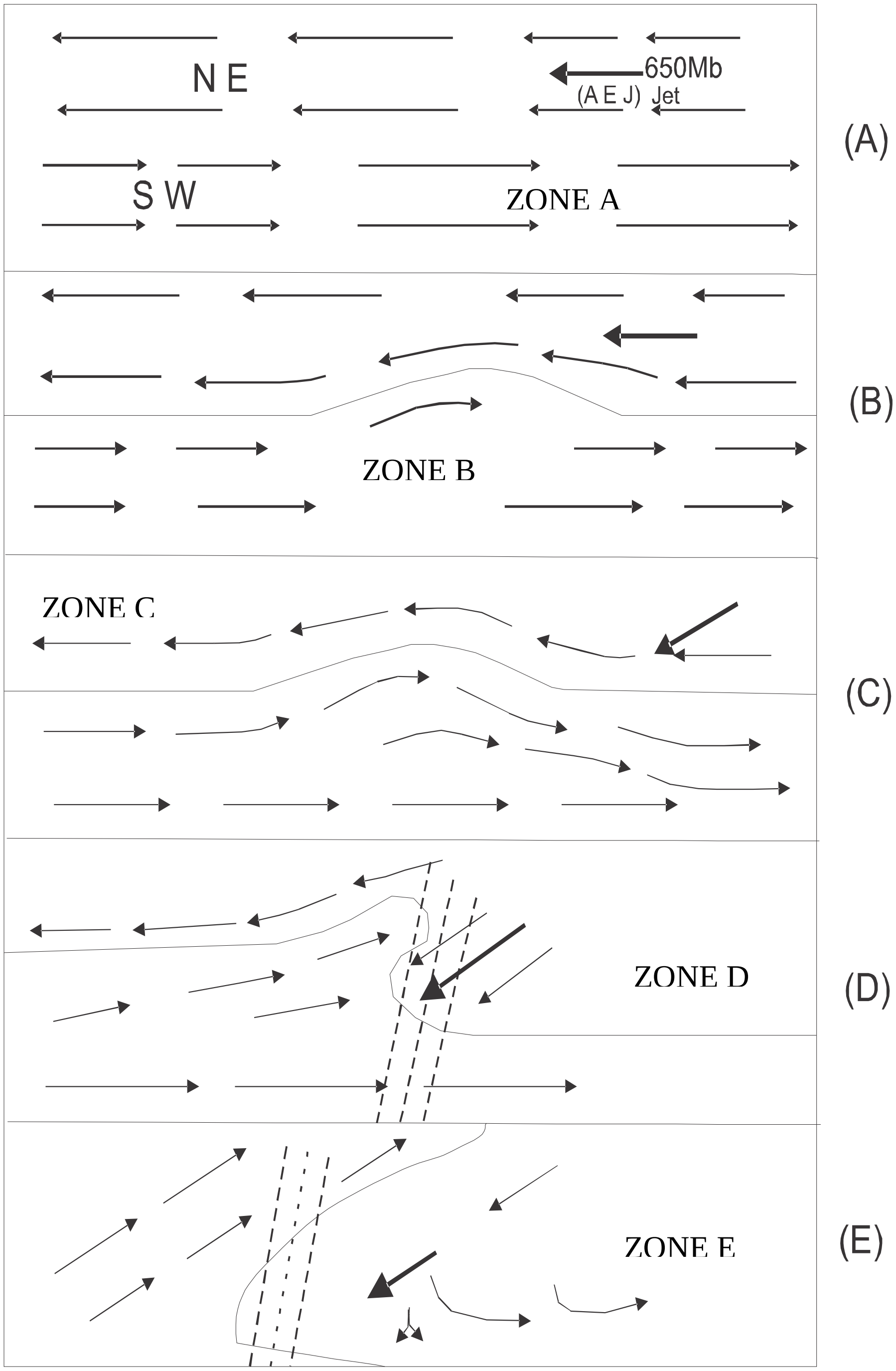


Figure 2.4: An idealized Cross Section through the Lower Troposphere of West Africa during the Process of formation of Linesqualls (Adedoyin, 1989)

Key

Zone A: The Perfect State of an undisturbed atmospheric Structure with the North Easterlies aloft and oppositely directed to Southwesterlies
Zone B: The Perturbation Stage
Zone C: The active phase in the evolution of squall lines
Zone D: The zone of convective activity
Zone E: The Squall lines Stage

ease with which the jet touches down over highlands explains the preference of elevated areas as the source region of squall lines. Otherwise, the jet continues its motion over the earth's surface.

The active phase in the evolution of squall lines starts as soon as the jet reaches the surface. Forced ascents cause large precipitation clouds (cumulonimbus) to develop since the depth of the southwesterlies within the active squall zone (Zone C) is enough to support the development of cumulonimbus cells. Squall lines often propagate as a series of cumulonimbus cells. Sekoni (1992) notes that it is possible that this zone of convective activity is between the cyclonic shear side of the African easterly jet and the anticyclonic shear side of the upper tropical easterly jet.

The horizontal extent of propagation of linesqualls depends on how far the jet travels over the surface as well as the atmospheric conditions ahead of the storm. In the case of an environment where considerable convective activity has occurred before the arrival of a linesquall, precipitation is usually light and linesqualls usually dissipate completely due to lack of energy for release in areas where thunderstorms have just occurred (Peters and Tetzlaff, 1986; Adedoyin, 1989). Some linesqualls regenerate after passing such areas. Moisture supply could also be cut off from linesqualls through the existence of a layer of temperature inversion in the lower troposphere (Balogun, 1978). Such capping may prevent rising columns of moist air from reaching the lifting condensation level and situations like this occur in Zone D in West Africa. This is why linesqualls have been frequently observed to dissipate around coastal areas in the subregion.

2.1.3 Rainfall due to Large Scale Convergence

Between July and September, most areas of West Africa south of 15°N experience widespread and prolonged 'monsoon' rains. The question of what causes the massive uplift of air that produces this widespread rainfall has baffled meteorologists for a long time (Kamara, 1986). It is, however, legitimate to rule out convection as an underlying cause because convective processes are localized and cannot, therefore, cause widespread cloudiness and rainfall; neither can it be ascribed to orographic uplifting because mountain masses are isolated and their influence is localized.

A large part of the humidity over West Africa comes from the South Tropical Atlantic and is transported in the surface layer by the African monsoon flux induced by the trade winds' equator-ward deviation. The strength of these trade winds is itself dependent on the strength and position of the subtropical anticyclones of both hemisphere, the Azores and the Southern Atlantic (Desbois et al., 1988). The position and strength of the large-scale ascendances and subsidences also influence the precipitation mechanisms associated with large-scale convergence. The main ascendance zone is associated with the Inter-tropical convergence zone, where the convergence of the water vapour flux in the low layers is likely for convection development. Precipitation anomalies have also been related to changes in the strength of the Hadley cell ascending and descending branches, an enhanced subsidence enhancing the airmass stability (Nieuwolt, 1977; Nicholson, 1981). The influence of the zonal cell circulation is also stressed by Krishnamurti and Kanamitsu (1981) and Stoeckenius (1981). The African easterly jet and the tropical easterly jet can be considered the upper branch of a zonal cell, the lower branch of this cell is created by the monsoon flux. The modulation of this "African Walker Cell" influences large-scale subsidences and ascendances because of the meridional circulation (Desbois et al., 1988).

Recent advances in dynamic climatology suggest the influence of the tropical easterly jet (TEJ). The TEJ occurs above the southwest monsoon at a height of about 12 km (200 hpa) where the upper easterly winds concentrate into narrow bands of jet streams. Large scale surface convergence below the jet axis counterbalanced by high level divergence promotes widespread instability within the moist maritime tropical airmass which results in the development of thick and medium-level altostratus and altocumulus clouds and low- level stratus and stratocumulus decks over very wide areas.

Periods of maximum convergence rainfall coincide with minimal thunderstorm activity which tends to suggest differences in the mechanism that organize the thunderstorm and the massive uplift of monsoon air. Apart from affecting wide areas at a time, another characteristic of monsoon rains is that they occur in light continuous downpours with occasional spells lasting from a few hours to several days.

2.1.4 Mechanisms of Urban Influence on Precipitation

Urban areas have been shown to influence climate on a variety of spatial scales (Lamptey, 2010; McCarthy et al., 2010). It is important to improve our understanding of their impacts on climate because of the rapid growth rate of cities worldwide. Changes in land use/land cover and increases in surface roughness, building density and aerosol concentrations continuously alter energy, moisture, and momentum fields as well as circulation patterns above urban environments. Expansion of Urban Heat Islands (UHIs) that result from these changes increase the convection and convergence that occur over and downwind of the city centre. Pollution has been shown to increase the number of cloud condensation nuclei over urban regions, with a complex series of feedbacks to cloud formation and precipitation. Surface roughness has been shown to affect locations of enhanced convergence.

A robust understanding of precipitation processes over urban regions, driven primarily in the warm season by convergence and convection (Diem and Mote, 2005), is essential for understanding a range of environmental and socioeconomic implications. It is particularly important to understand the coupling between the urban area and the local synoptic regime to improve forecasts (Dabberdt et al., 2000) and enhance the efficiency of urban planning for a variety of human benefits (Vanos et al., 2010). This is especially true in the study area, with rapid urbanization, abundant and variable precipitation totals, and numerous precipitation-generating mechanisms, each of which may have a different degree of coupling to the ever-changing urban surface.

Many studies have identified the mechanisms responsible for the urban influence on precipitation (Ntelekos et al., 2007; Lacke et al., 2009; Shem and Shepherd 2009). Collectively, studies such as these suggest that the three primary mechanisms are (1) UHI-induced convection zones which decrease static stability (Lacke et al., 2009); (2) enhanced aerosol concentrations (Shem and Shepherd 2009), which can either suppress precipitation by producing many small droplets which are too small to fall, or enhance precipitation by increasing the efficiency of the collision-coalescence process; and (3) increased surface roughness which creates areas of convergence at the surface (Diem and Mote 2005). Below are the Mechanisms contributing to urban influence on precipitation.

2.1.4.1 Urban Heat Island (UHI)

The most widely studied element of urban climate is the UHI (Souch and Grimmond, 2006). It is important to understand the UHI effect when examining urban precipitation because it has been shown that the temperature gradient between an urban area and its rural surroundings is partly responsible for precipitation initiation (Dixon and Mote, 2003). A UHI is defined as an urban area where temperatures exceed those of the surrounding (non-urbanized) areas, with the gradient between these regions generally strongest on calm, clear nights. A UHI alters air temperature in the lower layers of the atmosphere, but certainly deeper UHI layers can exist (Voogt and Oke, 2003). The general characteristics of a UHI may vary by city due to differences in albedo, anthropogenic heat, emissivity, sky view factor, and thermal inertia (Arnfield, 2003). While all of these factors were considered important, a modelled UHI with geographic and climatological characteristics similar to London showed that lack of surface evaporation was the dominant factor producing the UHI (Atkinson, 2003).

Regardless of the primary reason for the increased temperatures in the city, differential surface heating between urban and rural areas leads to horizontal temperature gradients and the creation of an urban-breeze circulation (Hidalgo et al., 2008). Hidalgo et al. (2008) simulated the urban-breeze circulation for Toulouse in southwestern France. In part due to the high static stability during the experiment, a daytime July UHI of 1 C° easily formed over the centre of the city (detected up to a vertical height of 1100 m), and was advected leeward of the city. These results were expected to be typical for that time of the year. The urban-breeze was observed soon after the temperature gradients formed. An area of convergence near the city was compensated by divergent winds in the upper levels of the planetary boundary layer, with increased intensity of this circulation in early evening, when it dominated the local wind flow (Hidalgo et al., 2008). Basara et al.

(2008) used points along transects through Oklahoma City to show that temperatures vary within the horizontal gradients as a result of proximity to the central business district, sky view factor, and nearby buildings. A dominant southerly flow advected the centre of the UHI north of the central business district (Basara et al., 2008). Cheng and Byun (2008) modelled the effects of land cover on the local circulation for the Houston-Galveston metropolitan area and found that large continuous impervious surface areas produced an unrealistically modelled UHI and caused stronger bay breeze flows than using an area broken down into grass, trees, as well as residential and impervious surfaces. As a result, by better representing the local wind and heat patterns within the area using detailed land cover representation, the modelled bay breeze more realistically penetrated farther into the city (Cheng and Byun, 2008). Such circulations caused by the UHI are responsible for the genesis and/or enhancement of convective storms' downwind of the urban area (Dixon and Mote, 2003).

Several studies showed that vegetation reduces the magnitude of the UHI by increasing the contribution of latent heating at the expense of sensible heating in the local energy balance (Hamada and Ohta, 2010). Vegetation also shades and changes the albedo of the surface, absorbs solar radiation before it can reach the ground, and increases surface humidity through transpiration. "Green zones" (Hirano et al., 2004) are regions within a city consisting of high tree or green vegetative density that lowers the air and surface temperature. Green zones have been shown to modify microclimatic conditions through the regulation of temperature changes, with the influence of green zones dependent on site characteristics (Gomez et al., 2004). Cheng and Byun (2008) showed different land use simulations for the Houston-Galveston metropolitan area where the UHI was responsible for changing the location and strength of the dominant local circulation (sea-breeze). They stated that land cover changes allowed for the influence of local circulation during weak synoptic conditions.

With the long growing season and abundant sunshine and moisture, the Southeastern U.S. appears to have good opportunity to mitigate UHI effects via reforestation and strategic landscaping. The surface albedo of the built environment is another component of urban areas having a direct impact on the UHI effect, which, in turn, affects urban precipitation.

Alterations in small-scale, local heat fluxes of an urban region caused by differing surface albedos can influence the local surface energy budget. The albedo of a surface is greatly dependent on the colour and type of surface; therefore, heat storage directly depends on the albedo of the land cover (Asaeda and Wake, 1996). Because the study area is growing very quickly, changing surface characteristics may play an important role in the urban climate of many cities.

Numerous studies have been conducted to determine the specific UHI effect for various cities across the United States, especially in the Sunbelt. Comrie (2000) studied the UHI of Tucson, Arizona, one of the rapidly-growing metropolises in the United States. Other contributing factors, such as upward surface heat fluxes and entrainment of warm air aloft, were considered (Zhang et al., 2009). Many studies have also examined the UHI of cities in the southeastern United States. Using MODIS technology, Xie et al. (2006) found a nocturnal UHI of 4 - 5 C° compared to the average temperature of San Antonio. Zhou and Shepherd (2009) found the mean UHI of Atlanta-Athens to be 1.31 C° and that of Atlanta-Monticello to be 1.71 C° (Zhou and Shepherd, 2009). These studies claimed that cities of the Southeast display UHI characteristics despite the prevalence of many types of broader-scale circulation features, including frontal passages, tropical storm systems, and land-sea breeze circulations.

2.1.4.2 Increases in Aerosols

The local climatic effects of urban-enhanced air pollution are believed to depend on the concentration and size of solid aerosols serving as Cloud Condensation Nuclei (CCN). Aerosols larger than 1 μm in diameter tend to cause a net increase in precipitation by increasing the efficiency of the collision-coalescence process of converting cloud droplets to raindrops (Rosenfeld et al., 2008a). This conversion efficiency increases because larger cloud droplets are more likely to collide with other cloud droplets (Rosenfeld et al. 2008a). Aerosols smaller than 0.1 μm tend to suppress precipitation because smaller CCNs increase the time required for cloud droplets to coalesce with other droplets (Givati and Rosenfeld, 2004; Rosenfeld et al., 2008a). Aerosols also suppress precipitation by attenuating solar radiation, thereby stabilizing the near surface atmosphere and destabilizing the layer between the height of significant absorption and several metres above it, with the net effect often suppressing convective activity (Rosenfeld et al., 2008b). The effects of aerosols have not been described in the climatological literature, especially in the area of urban climatology.

Anthropogenically-produced CCN have been found to increase precipitation in western Washington, with the magnitude of the effect depending on aerosol size (Hobbs et al., 1970). Van den Heever and Cotton (2007) noted that the influence of aerosols on storms in St. Louis was exceeded by the influence of convergence caused by urban heating. The “Eight Cities Study” (Huff and Changnon, 1973) consisted of an analysis of precipitation for St. Louis, Chicago, Cleveland, Washington, Indianapolis, Tulsa, Houston, and New Orleans. It was concluded that larger concentrations of industrial aerosols, along with increased condensation, were the causes of the increase in precipitation (Huff and Changnon, 1973). Even though aerosols affected the microphysical processes involving precipitation produced by these storms, their influence did not play a large role in the precipitation characteristics of the storm until after development. Simulations of increased urban aerosol concentrations resulted in more intensity increases than with rural aerosols alone (Van den Heever and Cotton, 2007).

Other studies have found that the net effect of urban-produced aerosols is to decrease precipitation totals. Givati and Rosenfeld (2004) state that regions with clouds that have warm tops and short lifetimes experience the greatest precipitation suppression, due to pollution contribution by small aerosols. Jirak and Cotton (2006) aver that the decrease in orographic precipitation since 1950 west of urban areas along the Front Range of the Rocky Mountains may be attributable to anthropogenically-produced pollution. In studying the effects of pollution on orographic winter precipitation across the western U.S., Rosenfeld and Givati (2006) found a decrease in their precipitation factor (Ro) of 24 percent over the last century, which was attributed to the increase in smaller aerosols. In a simulation of various aerosol concentrations associated with a squall line over the south plains of the U.S., Li et al., (2009) assert that increasing the number of aerosols increases the concentration of CCNs, reducing cloud droplet size. Although a variety of aerosol sizes was simulated, the size responsible for the reduction in cloud droplets was not specified. In the various simulations of the squall line, aerosol concentration was found to influence precipitation intensity but not the spatial pattern. Deep convective clouds were found to be intensified with increases in aerosols, while small cumulus clouds distant to the squall line decreased in intensity (Li et al., 2009). Regardless of whether the net effect of solid aerosol contribution is toward increasing or decreasing precipitation, indications are that, as urban areas continue to grow, so will the transportation, industrial, and/or domestic needs of the city, causing the UHI effect to intensify and increase the number of aerosols emitted (Rosenfeld et al., 1995).

The net effect of aerosols on precipitation variation in time and space has been examined more thoroughly in the Southeast than in most other regions. Using Tropical Rainfall Measuring Mission (TRMM) estimated precipitation, Bell et al. (2008) found a statistically significant weekly signal in precipitation during the summer over the southeastern U.S., where the intensity of precipitation and area covered by rain increased during the middle of the week (and with a minimum on Sunday), very similar to the flux in anthropogenic aerosols, possibly indicating an anthropogenic influence. Over the Atlantic, the signal was very strong but reversed in sign. It was concluded that sea salt - larger aerosols possibly serving as CCNs - weakened the effects of anthropogenic pollution by enhancing rainfall (Bell et al., 2008).

Lacke et al. (2009) examined radar-derived precipitation for Atlanta to determine the role of aerosols in enhancing or initiating precipitation under maritime tropical air mass conditions (Kalkstein et al. 1996). They found a statistically significant increase in precipitation on Thursdays compared with other days of the week and precipitation maxima in northwestern and eastern metropolitan Atlanta on days with greater aerosol concentrations, while maxima occurred in southeastern Atlanta on low aerosol days (Lacke et al., 2009).

The relationship between aerosols and convective thunderstorms in the U.S. Southeast has been analyzed recently. In a follow-up study focused partially on the U.S. Southeast (Bell et al., 2009), lightning data from the National Lightning Detection Network (NLDN) was used to confirm the results of Bell et al. (2008). The authors claimed that the presence of lightning is an indicator of the effects of aerosols on storm development due to its dependence on ice aloft. Lightning activity peaked over the southeastern U.S. during the middle of the week and over the Atlantic Ocean and Gulf of Mexico on the weekends. Compared to the strength of the signal found in Bell et al. (2008), the signal was weaker, especially over the urban areas, and more widespread. The authors posit that this result may suggest that the aerosol-influenced growth of the storms has already reached a maximum. When compared to the weekly cycle of lightning, the cycle in pollution was less visible. The UHI may have invigorated the storms so much that any influence caused by aerosols was difficult to distinguish (Bell et al., 2009).

Carrio et al. (2010) modelled the effect of aerosols on two convective events in Houston using the Town Energy Budget Urban Model within the Regional Atmospheric Modeling System (RAMS) from Colorado State University. The first group of storms, not influenced by urban-simulated CCNs as a result of "cleaner" air from the incoming sea-breeze, occurred southwest of the city, while the second group was influenced by the CCNs and occurred downwind of the city. High aerosol concentrations prevented growth of ice particles, reducing precipitation efficiency (Carrio et al., 2010).

2.1.4.3 Surface Roughness

The topography of the urban environment can greatly impact the microclimate, possibly resulting in local changes in precipitation. These changes occur because surface roughness alters energy, mass, and momentum fluxes between the surface and the atmosphere and in the urban mixed layer (Dabberdt et al., 2000). While the direct influence of surface roughness on precipitation has not been widely explored in the literature, its influence has been shown to impact storm movement and dynamics (Dixon and Mote, 2003).

Many aspects of urban design regarding roughness elements, such as density of urbanization, street orientation, building height and location, and size of green areas, impact the local circulation regimes. Givoni (1994) presents ways that an urban area can be developed to influence local winds which can lead to convergence. For instance, enhancement of ventilation of the city core can occur by designing streets parallel to the direction of prevailing winds; once these winds are set up, they can affect local storm motion by creating areas of convergence (Kishtawal et al., 2010). Also, constructing buildings of different heights perpendicular to the prevailing wind and orienting buildings of similar height parallel to the prevailing wind will increase ventilation and perhaps alter precipitation patterns (Givoni, 1994). Grimmond et al. (1998) assert that the heights of the upwind roughness elements influence winds at a greater distance compared to shorter roughness elements. They found that roughness length in the winter was 82-87% of the length for the summer, noting that the land cover of an urban area becomes more uniform with increasing height. The importance of adding green zones, including on rooftops (Dvorak and Volder, 2010), with varying heights to provide shade, encourage ventilation, and save irrigation costs by increasing humidity is also stressed (Givoni, 1994).

Thielen et al. (2000) developed a surface model by testing the sensitivity of parameters within an urban area to find the influence of the surface roughness on developing convective precipitation. Roughness length significantly influences downwind precipitation (Oke, 1987). If the roughness elements are small, simulated UHIs were the dominant surface forcing (Thielen et al., 2000). Childs and Raman (2005), when studying the interaction between the UHI of NYC with the sea-breeze, found that events occurring at night under a strong regional flow were subjected to a roughness-induced cyclonic turning over the core of the city, enhancing the chance of precipitation (Childs and Raman, 2005). Carraca and Collier (2007) note that that either the upwind rural-urban discontinuity or the presence of buildings (affecting upward vertical velocities) may be responsible for initiating convective cloud cover and precipitation in Manchester, UK, with closely-built tall buildings impacting the initiation of convection and sensible heat fluxes similar to that of widely-spaced medium-sized buildings. If the atmospheric boundary layer is unstable, then convection may be initiated by the increase in sensible heat flux.

2.1.4.4 Changes in Landuse and Landcover

In rural areas, vegetation and open land typically dominate the landscape. Trees and vegetation provide shade, which helps lower surface temperatures. They also help reduce air temperatures through a process called evapotranspiration, in which plants release water to the surrounding air, dissipating ambient heat. In contrast, urban areas are characterized by dry, impervious surfaces, such as conventional roofs, sidewalks, roads, and parking lots. As cities develop, more vegetation is lost, and more surfaces are paved or covered with buildings. The change in ground cover results in less shade and moisture to keep urban areas cool. Urbanization can alter local climate and form an urban heat island (UHI) (Bornstein and Lin, 2000).

When changes in landuse and land cover (LULC) occur in a growing urban area, changes in the frequency, intensity, and amount of precipitation can occur (Shepherd, 2005), but this anthropogenic alteration is generally strongest in the warm season although its effects have been seen year-round (Changnon, 2003; Gero et al., 2006; Svoma and Balling, 2009). The strongest evidence for urban influences occurred on days with heavy rainfall during the warm season, although increases in thunder-day frequencies were also observed in other seasons (Huff and Changnon, 1973). A convective sequence (increase in convective activity over the city resulting in thunderstorm formation, and further evolution into hailstorms downwind of the urban centre) initiated by urban areas is the cause for these downwind patterns (Huff and Changnon, 1973).

Urban areas have been shown to influence the frequency, intensity, and amount of precipitation through changes in LULC (Shepherd, 2005). Project METROMEX (Illinois State Water Survey 1974) established that afternoon precipitation is enhanced in urban areas (Changnon et al., 1971). Huff and Changnon (1973) conducted the first multiple-city analysis of urban influence on precipitation and found possible evidence of urban-enhanced increases in average daily and seasonal precipitation at many of their study sites.

Subsequent studies have revealed that while influences occur year-round, the signal is usually strongest in the warm season (Changnon et al., 1991; Changnon 2003; Gero et al., 2006). Recent studies (Bell et al., 2008; Svoma and Balling, 2009) have advanced knowledge of the urban climate using the increased data availability and technology, allowing for improved hypothesis testing regarding mechanisms responsible for precipitation enhancement. Among the earliest comprehensive investigations of urban-precipitation relationships was Project METROMEX (Illinois State Water Survey, 1974), a field study of St. Louis intended to analyze the effects of weather modification by urbanized areas. It was found that not only did afternoon precipitation increase after urbanization, but clouds over urban areas were more likely to merge with developing storm systems, resulting in stronger storm units (Changnon et al., 1971).

Urban-enhanced increases in average daily and seasonal precipitation, particularly in June through August, were found in St. Louis, Chicago, and Cleveland, while Washington showed most enhancement in September through November, and Houston and New Orleans only experienced enhancement in May through September and May through October, respectively. No significant evidence of increased precipitation in Indianapolis and Tulsa was found. While the scope of the conclusions was limited by the data and technology available at the time, it was asserted that destabilization of the atmosphere caused by the UHI, along with additional condensation linked to increases in industrial aerosols, were responsible for the observed precipitation enhancement (Huff and Changnon, 1973). Collectively, these studies showed urban influences on “heavy"-precipitation days during the warm season (Huff and Changnon, 1973) and enhanced precipitation downwind of the urban area (Hand and Shepherd, 2009). Further understanding of storm dynamics over urban areas is needed, as storm movement is linked directly to hazards, such as lightning strikes and flash flooding.

Urban areas have many effects on their local environment. While numerous studies show that downwind enhancement of total precipitation, propagation of individual storm cells, or the slowing of storm systems in and around an urban area can occur, it has been very difficult to conclude that urban features are the sole cause of such influences. Therefore, it is important to continue to study urban effects on precipitation to obtain a better understanding of this complex and dynamic relationship. If urban influence on rainfall can be predicted successfully, then urban infrastructure can be zoned for green space or reservoirs to maximize rainfall capture. Finally, a broader understanding of rainstorms variability across major sections in Ibadan will provide potential benefit to a range of stakeholders, like city planners and emergency managers, whose work is informed by climatological information.

2.2 Literature Review

Many researches have been carried out on rainstorms, in Nigeria as well as other parts of the world. However, the available literature shows the existence of spatial differences in the nature of rainstorms dynamism and variability experienced in Nigeria. It is important to note the dynamics and areal pattern of rainstorms so that predictions can be made about the distribution of the storm water embedded within the periods of the day and the different seasons of the year, and the areas vulnerable to soil erosion, massive run-off and flood disasters, which are prevalent in virtually all states in Nigeria. This necessitated the focus of this study on the dynamics and areal patterns of rainstorms over Ibadan, southwest Nigeria. Several authors have written on rainstorm pattern characteristics, such as amount, intensity and duration and their implications for human welfare. However, most of these studies have been written for application in the areas of physical and urban planning. This is because most Third World countries are ill-prepared for the occurrence of heavy rainstorms and lack the required tools to mitigate the adverse effects of heavy rainstorm events. Among the studies on rainstorm in Nigeria as well as other parts of the world are Ayoade (1970), Walsh and Lawler (1981), Adefolalu (1986), Adebayo (1999), Sekoni (1992), Kane (2000), Chin (2007), Omogbai (2010), Kundzewicz (2012), Audu et al. (2013); Zhihe et al. (2015) and Ivana et al. (2016). They made reasonable spatial comparisons on rainfall seasonality and some other aspects of rainfall regimes in several parts of the tropics. Despite the volume of studies done on rainstorm characteristics, a gap still exists in that the rainstorm characteristics, like duration, rainfall amount, speed and areal coverage of rainstorms and their interrelationship have not been addressed in the previous studies in trying to understand and explain their spatial-temporal variations in atmospheric circulation over West Africa.

Several in-depth studies on tropical rainstorms have also been conducted, with a view to applying inferences and results obtained to a specific need at a specific time. The nature of tropical rainstorm in the Southwestern region of Nigeria has been studied over the years. Ayoade and Akintola (1986) carried out a study on the rainstorms in Lagos.

Available data on the number of rainstorms, amount and duration of rainstorm, and annual and monthly means of rainstorm amount from 1960 to 1980 were taken and analyzed. Oguntoyinbo and Akintola (1983) studied rainstorm characteristics affecting water availability for agriculture in Ibadan. In their study, temporal variations of diurnal, monthly and annual rainstorm characteristics were analyzed. It was observed that the rainstorms in Ibadan were short in duration, and episodes of relatively high intensities were usually concentrated in the earlier part of the storms.

The first painstaking document of West African linesquall was by Hamilton and Archbold (1945). Their study of the monthly frequency of linesqualls was restricted to five Nigerian stations–Kano, Maiduguri, Minna, Lagos and Calabar, and for a period of three years. However, the study was not related, to rainfall and many of the finding were based on fragmentary aircraft reports, a few pilot balloon ascents and theoretical considerations (Obasi, 1965). Eldridge (1957) also carried out a synoptic study of West African linesqualls in which the statistics of their monthly distribution, length and distance transversed were computed. Results of Eldridge's study showed that linesqualls contributed as much as 55% of the total early and late summer rainfall in Ghana. The study was, however, limited to the year 1955.

Similarly, Obasi (1975) showed that about 62% of the March and April rainfall of 1962 in Lagos was deposited by linesquall alone, their importance diminishing dramatically to only 14% for May and June in the same year when the southwest monsoon flow is very deep. Bolton (1981), in his study of linesqualls that affected Minna, Nigeria, identified sixty-six linesqualls over a two-year period using the following criteria:

(i) Maximum squall speed of at least 12m/sec;
(ii) Rainfall of at least 5 mm;
(iii) Storm duration of at least 3 hours; and
(iv) Pressure jump of at least 0.5 mb.

Studies on thunderstorm have also been carried out. Oladipo and Mornu (1985) looked at the characteristics of thunderstorms in Zaria, Nigeria for the period 1969-1982. Salau (1986) also carried out a temporal and comparative analysis of thunderstorms and some related phenomena (hail, squall and lightning) for three northern stations in Nigeria

(Kaduna, Jos and Zaria). The study was mainly based on data for the year 1969. Mulero (1973), in his study on seasonal distribution of thunderstorm days in Nigeria gave a climatological background of occurrence of thunderstorms in Nigeria, for the period 1962-1971. Balogun (1981) explained total rainfall distribution in Nigeria in relation to thunderstorm activity for the period 1959-1976. The study showed a marked minimum in thunderstorm activity in the month of August in parts of the Nigerian coast; and although both thunderstorm and rainfall were found to exhibit a double maximum, the first maximum in rainfall lagged that of thunderstorm by months.

Acheampong (1982), using daily rainfall data for a 10-year period (1961-1970) for five Ghanaian coastal stations, classified rainfall types into four based on their synoptic origin: local thunderstorm, monsoon, disturbance lines (linesqualls) and wave or vortex. The results of his work showed that, although the nature of the coast might have some influence on rainfall distribution in space, it is the meteorological factors that have to be studied closely in order to fully explain the rainfall anomaly along the coast. For the five stations, percentage contribution of linesqualls to the annual total ranged from 2.09% to 32.15%, local thunderstorm accounted for 23.57-44.10%, monsoon rains, and 43.28-52.60%, wave or vortex accounted for less than 2% of the annual rainfall in all the stations.

Omotosho (1985), using thunderstorms and rainfall information from five Nigerian stations (Sokoto, Minna, Maiduguri, Yola and Port-Harcourt) for a five-year period (1972-1976) investigated the separate contributions of linesqualls, thunderstorm and ordinary monsoons to the total rainfall. His criteria for classification were based mainly on the time of start of a rain episode in relation to the time of arrival of a linesquall/thunderstorm. If the time of start of a rain episode was less than about 30 minutes before or after the arrival time of a linesquall/thunderstorm, the recorded rainfall amount was put against linesquall/thunderstorm. Where the associated thunderstorms changed to ordinary rain, the rain was still put against linesquall/thunderstorm provided the time was not more than six hours; any further precipitation was recorded as monsoon rain. Results of Omotosho’s study indicated that the percentage contribution of linesquall to total rainfall increased from south to north while that for thunderstorm and monsoon rains decreased from south to north.

Kamara (1986) observes that although rainstorms tend to follow a trend during the rainy season, some often deviate from the norm. Some storms even occur during the dry season, for example, the unusual rainstorm that occurred during the Christmas week of 1960 in Nigeria and the “Christmas rain” in Sierra Leone. These are tropical weather associated with extra tropical disturbances that affect West Africa during the northern winter (winter in the Northern Hemisphere). Adebayo (1999) maintains that the distribution of rainstorms is affected by topography, which the aftermath of the formation is of eddies on the lee sides of hills. The formation of eddies depends on the nature of the rainstorm, especially its capacity for transformation by air currents.

Sekoni (1992) determined the temporal and spatial variations in the separate contribution of the different rain-producing weather systems to total rainfall within the monsoon circulation framework using rainfall data and associated weather information over a 30-year period (1960-1989) for nineteen synoptic stations in Nigeria. The results of the study indicated that the percentage contribution of each of the rain-producing weather systems contradicted that of the Omotosho’s study.

Several studies have also been conducted on the duration and rainfall amount received during these events. Most studies on duration and rainfall amounts are conducted primarily to predict or explain flooding events and to put forward ideas regarding prevention or mitigation of the malevolent effects of flooding. For instance, Akintola (1994), in his study on urbanization processes and problems, notes that the 1969 flood which occurred in Ibadan was caused by rainfall which measured just less than 25 mm. For a rainfall event of moderate magnitude, the corresponding effects on life and property were undeniably colossal. In the case of the flooding event which occurred in Ibadan on the 30th of August, 1980, 270 mm of rainfall occurred within only 9 hours and resulted in flooding. In essence, while duration and rainfall amounts are of extreme importance, speed and areal pattern of rainstorms carry even greater importance in better understanding the behaviour of rainstorms (Akintola, 1994).

Several methods based on multi-scaling and self-similarity ideas have been proposed in recent years. A multi-component decomposition of spatial rainfall fields are given by Friesen (2002) who used the coefficients of variation to determine the spatio-temporal rainstorm patterns in Northern Region in Ghana. Using the gauge network which was organized as a nested grid consisting of three levels – A, B and C, he was able to determine the spatial variability of rainstorm events. Felgate and Read (1975) demonstrated the potential for correlation techniques to accurately describe the small-scale structure of rainstorms in quantitative terms. Employing a network of 16 gauges at 1 km^2 spacing, they were able to determine the spatial scale, and velocity of rainfall cells. Drufuca and Zawasdski (1975) evaluated 10 years of rain gauge data from a single site for numerous statistical measures, including the autocorrelation function and the probabilities of various rainfall rates. A cross-correlation analysis by Messaoud and Pointin (1990) was used to determine the minimum time interval and spatial gauge resolution for which statistically significant results can be obtained. Their study included a comparison of data from both a gauge network and weather radar for the same event. They found that the cross-correlation coefficient between pairs of station decreased as the gauge separation distance increased.

However, in the recent past, in Africa, Nigeria, in particular, the emphasis of many scholars in the study of tropical climatology has been the consideration of rainstorm characteristics, such as rainfall intensity, duration and rainfall amount. The various rainstorm characteristics have been studied in terms of their distributions over space and time, trends, periodicities, onset, retreat, probabilities (Ayoade, 1974; Ayoade and Akintola, 1982; Oguntoyinbo and Akintola, 1983; Adefolalu, 1986; Sumner, 1988; Sekoni, 1992; Akintola, 1994; Adebayo, 1999; Olaniran et al., 2001; Friesen, 2002; Ologunorisa, 2006; Omogbai, 2010 and Kundzewicz, 2012; Audu et al., 2013; Terranova and Gariano, 2014; Zhihe et al., 2015 and Dao and Hoang, 2016). A critical look at these studies showed that most of these studies focused on an aspect of rainstorm characteristics. There has been no research on the seasonal dynamics and areal patterns of rainstorms. As a result, the study is considered the seasonal dynamics and areal patterns of rainstorms over Ibadan metropolis, Nigeria.

CHAPTER THREE

METHODOLOGY

3.1 Types and Sources of Data

The data used for this study was extracted from daily weather registers kept by the research and academic institutions in Ibadan. These included Nigerian Meteorological (NIMET) Agency Office Ibadan, National Cereals Research Institute (NCRI) Ibadan, International Institute for Tropical Agriculture (IITA) Ibadan, Cocoa Research Institute (CRIN) Ibadan and University of Ibadan. Data were also extracted from daily weather registers from forty-five manual rain gauge stations (sub-stations). Daily rainstorm data were processed for fifty stations consisting of five autographic rain gauge stations (main stations) and forty-five manual rain gauge stations (Table 3.1 and Plate 3.1) over a two-year period (2013 to 2014). 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 landuse and surface roughness, such as relief and building density of the area.

3.2 Data Types

This research employed both primary and secondary data.

3.2.1 Primary Data

The primary data included rainstorm data, such as rainstorm characteristics. This data was generated through the autographic and the manual rain gauges during the dry, early, late and rainy season rainstorms in the selected stations in the study area. In addition, Global Positioning System (GPS) 76S eTrex Venture Garmin was used on the field to determine the elevation, X and Y geographical coordinates of each of the selected stations. The X, Y coordinates and the elevation (Z) data were used to describe the attribute data of each of the selected stations captured on the field. They also aided in determining the spatial pattern of duration, rainfall amount, speed and areal coverage of rainstorm events across the study area.

3.2.2 Secondary Data

The secondary data for the study included:

Information about the location and extent, the climatic history, relief, landuse/land cover and building density features of the study area; maps, such as map showing the study area (Figures 1.1), maps to show the relief and drainage (Figure 1.2), landuse areas (Figure 1.3), building density of the study area (Figure 1.4) and map showing the selected rain gauges stations in the selected locations in the study area (Figure 3.1); photographs, such as photographs of the selected autographic and non-recording rain gauges for the study (see Plate 3.1); data attesting to rainstorms over the study area: sourced from Nigeria Meteorological (NIMET) Agency, Ibadan, Federal Environmental Protection Agency (FEPA), Oyo State Ministry of Housing and Development, National Emergency Management Agency (NEMA), National Bureau of Statistics, Ibadan, Federal Research Institute of Nigeria (FRIN) Ibadan, National Cereals Research Institute (NCIR) Ibadan, International Institute of Tropical Agriculture (IITA) Ibadan, Cocoa Research Institute (CRIN) Ibadan, Meteorological Department, Federal University of Technology, Akure (FUTA), and the Department of Geography Weather Stations, University of Ibadan.

Similarly, information was obtained from libraries, such as Kenneth Dike Library, University of Ibadan, Nigeria Institute of Social and Economic Research (NISER). Other secondary data were obtained from published and unpublished texts, such as books, journal articles, theses, and the Internet.

Table 3.1: Rainfall Stations used in the Study

Network Stations A1-A5 & B1-B45	Station Name	Coordinates		Altitude (Metres)
		Latitude (North)	Longitude (East)	
A1	IITA-Moniya	7.495477	3.908723	231
A2	University of Ibadan	7.445375	3.900265	222
A3	Airport, Alakia	7.354977	3.971782	224
A4	NCRI-Moor Plantation	7.385400	3.839579	180
A5	CRIN-Idi Ayunre	7.230673	3.872243	128
B1	Papa Malu-Akingbile	7.529777	3.936333	221
B2	Ojoo-Distinct Jubilee Sec. Sch	7.470122	3.896154	213
B3	Ajibode Gram. Schl	7.479579	3.865643	233
B4	Apete Neighbourhood	7.452077	3.860232	205
B5	Ijokodo-United Sec. Sch	7.428616	3.885589	194
B6	Olunloyo Neighbourhood	7.350432	3.942314	201
B7	Agbowo Express	7.447424	3.939554	225
B8	Eleyele-Anwarul Islamic Sec. Sch	7.414007	3.861477	191
B9	Oke-Itunnu-St. Louis Gram. Sch	7.406685	3.882293	204
B10	Total Garden-Orita Mefa Baptist Sch	7.392422	3.900603	211
B11	Mokola-Moret Comprehensive Coll.	7.409386	3.900718	204
B12	Ashi Neighbourhood	7.477170	3.952424	211
B13	Basorun-Islamic High Sch.	7.427600	3.939007	245
B14	Akobo Neighbourhood	7.460189	3.992403	217
B15	Mapo-Bishop Akinyele Gram Sch.	7.373511	3.905399	184
B16	Molete-St. Anne's Sch.	7.367786	3.841649	167
B17	Challenge-Methodist High Sch.	7.335505	3.879863	172
B18	Onireke-Seed of Life College	7.386987	3.873982	202
B19	Oluyole Ext. High Sch	7.353390	3.858567	160
B20	Idi-Ape-St. Patrick Gram. Sch.	7.387128	3.957547	221
B21	Soka-Lagelu Industrial Estate	7.313623	3.903531	171
B22	New Gbagi Neighbourhood	7.377876	3.992755	200
B23	Babanla-Ogbere Community High Sch	7.366465	3.950292	219
B24	Bodija-Mt. Olivet Gram. Sch.	7.378872	3.927265	217
B25	Gate-Ikolaba Sec. Sch.	7.423096	3.915373	216
B26	Gospel-Idi Omo Neighbourhood	7.462193	3.947888	259
B27	Omi Adio-United Christian Sec. Sch.	7.393287	3.793832	197
B28	Iwo Road Neighbourhood	7.404987	3.942794	225
B29	Podo-High Class Sch. of Science	7.311917	3.842823	149
B30	Oke Ado-Ibadan Boys High Sch.	7.364481	3.880834	189
B31	Adegbayi Neighbourhood	7.397808	3.924010	229
B32	Jericho-FRIN	7.395499	3.856307	187
B33	Olodo Gram. Sch.	7.431515	3.980282	208
B34	Sanyo-Fountain Intl. Private Sch.	7.305661	3.950687	192

Table 3.1 contd				
B35	Ring-Road-Kambridge Compr. Coll.	7.367584	3.814270	188
B36	Odo Ona Neighbourhood	7.345571	3.826758	187
B37	Arapaja-Sydney Model College	7.276297	3.825242	192
B38	Monota-TL Oyesina Model College	7.414157	3.971989	221
B39	Academy-Olomi Neighbourhood	7.326408	3.933497	192
B40	Alomaja-CTY Model College	7.265915	3.872811	128
B41	Aperin-Ibadan Christ Gram Sch	7.359810	3.917474	216
B42	Ologuneru-Community High Sch.	7.409602	3.830258	187
B43	Odinjo Neighbourhood	7.343279	3.905635	193
B44	Ogbere Community High Sch	7.273541	3.932988	197
B45	Idi-Osan-Solution Group of Schs.	7.294338	3.884303	171

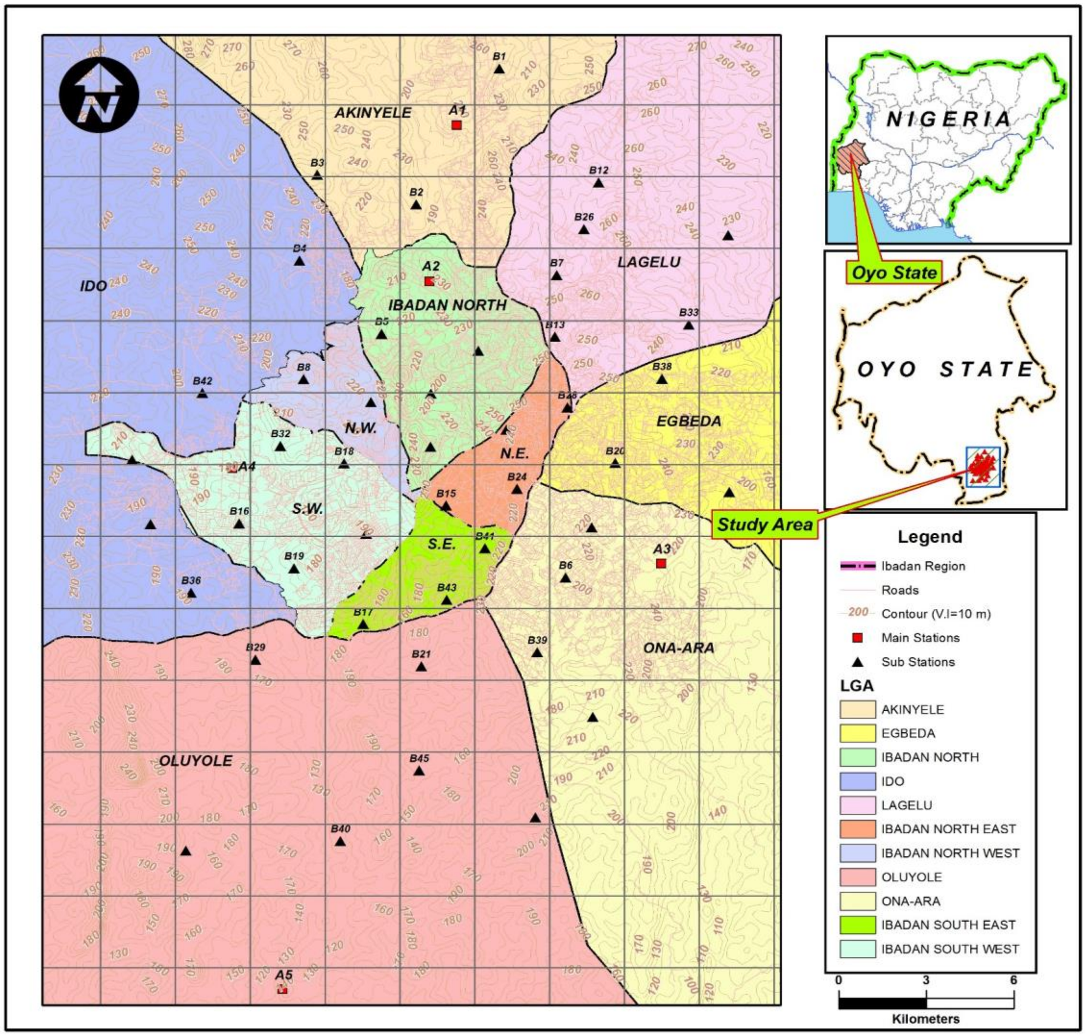


Figure 3.1: Location Map of Autographic Rain gauge Stations (Main stations-A1-5) and Manual Rain gauge Stations (Sub-stations-B1-45) in Ibadan. (Shuttle Radar Topographical Mapping (SRTM), 2013)

3.3 Climatic Data Network

There are four types of weather stations from which climatic records can be obtained in Ibadan. These are rainfall stations, climatological stations, synoptic stations and agro-meteorological stations. These stations differ on the basis of type of observations made.

The rainfall stations measure rainfall alone. They are usually made up of isolated rain gauges which may be manual or the automatic self-recording types. Climatological stations are installed to monitor only the basic climatic phenomena of rainfall, air-temperature and humidity. In the case of synoptic stations, instantaneous observation of the weather is made for prediction purposes. In most cases, observations are made hourly by full-time professional observers. The meteorological phenomena monitored include rainfall (using both automatic and manual rain gauges), temperature, cloud type and cover, wind speed and direction, humidity, soil temperature at different depths, solar radiation, sunshine and evaporation. Agro-meteorological stations observe and monitor climatic phenomena for agricultural purposes. The same parameters monitored by the synoptic stations are observed here. The hours of observation are, however, less frequent.

For the period employed, there were 5 autographic stations of different categories and 45 manual rainfall stations in Ibadan. The autographic stations were established and monitored by many agencies but all records are taken to Nigeria Meteorological Services, Lagos where the various data are coordinated and synthesized for climatological study and forecasting purposes. These stations are distributed and established in time and space. There are 1 climatological station, 3 agro-meteorological stations and 1 synoptic station; others are manual/improvised rainfall stations in Ibadan. This work dealt more with the rainfall stations, climatological station, agro-meteorological stations and synoptic station. They are discussed below.

3.3.1 Rainfall Stations

These are stations manned by part-time observers who take daily readings of rainfall only. This type of station is found at the old Airport, Ibadan.

3.3.2 Climatological Stations

These are stations manned by part-time observers making only once or twice daily instrumental observations of temperature, humidity, rainfall, and wind. This station is found at the University of Ibadan, Ibadan.

3.3.3 Agro-Meteorological Stations

These are stations manned by part-time observers making at least twice daily instrumental observation of the major weather elements. Evaporation, grass and soil temperatures, and solar radiation are also usually measured in view of their obvious importance in agriculture. This type of station can be found at the International Institute for Tropical Agriculture (IITA) station and Cocoa Research Institute of Nigeria (CRIN), all in Ibadan

3.3.4 Synoptic Stations

These are stations manned by full-time professional observers who maintain continuous weather watch and make hourly instrumental observations of the weather elements on which information is required for the compilation of the synoptic charts or weather maps used in weather forecasting. The sole agency responsible for the establishment and monitoring of the synoptic stations in Nigeria is the Meteorological Department of the Federal Ministry of Aviation, with technical, finance and personnel assistance from the World Meteorological Organization (WMO). This type of station is found at the Alakia Airport, Ibadan.

3.4 The Criteria used to determine the Thunderstorm and Disturbance Lines

The criteria used to determine whether the rain is thunderstorm or disturbance lines have been documented in the literature (Sekoni, 1992). For instance, rainstorms due to thunderstorm are characterised by the following:

(i) Main storm duration of usually not more than 1 hour;

(ii) Wind gusts less than 23 knots; and

(iii) A record in the daily weather register of thunder not later than 15 minutes before or after the start of rain.

On the other hand, rainstorms due to disturbance lines are characterised by the following:

(i) Disturbance lines speed of at least 23 knots. This lower limit is chosen to meet the WMO observation criterion of 23 knots for a disturbance lines. Thunder may also accompany the disturbance lines;

(ii) A record in the description of summary of daily weather of disturbance lines. This precludes a record of pressure jump of at least 0.5mb;

(iii) No lower limit is given to rainstorm amount associated with disturbance lines because the rainstorm associated with this system is known to be erratic (Tepper, 1950); and

(iv) The storm duration at any particular location is dependent on how far the jet had travelled before reaching that point as well as the atmospheric conditions in that particular environment. As a result, no lower limit was given for the duration of a rainstorm due to disturbance lines. However, where the duration lasts for up to or more than 3 hours, it is not considered to be as a result of disturbance lines activity since the disturbance lines are a mode of the easterly growth rates. The largest growth rate has a period of 35 hours (Adedoyin, 1989).

3.5 Data Screening

For rain gauge stations, the daily weather registers were screened for the following information for each rain day:

(i) Time of commencement and cessation of rainstorm;

(ii) Amount of rain associated with the rainstorm;

(iii) Occurrence or non-occurrence of thunder;

(iv) Time thunder was heard, if any;

(v) Wind gust and time of occurrence, if any;

(vi) The summary of daily weather containing the synoptic weather situation for the day.

3.6 Sources of Rainstorms Data

Rainstorm data were sourced from the spatially fixed self-recording (autographic) rain gauges and the non-recording rain gauges (manual rain gauges) across the study area. Rainstorm data from autographic rain gauges were in the form of logger format/EXCEL spreadsheet (autographic data) (Appendix I). Also, rainstorm data from non-recording rain gauges were in the form of manual field measurement notebooks kept by the field assistant. The data needed for the study were measured on the field over a two-year period (2013 to 2014). The field measurements involved the direct measurement of rainstorms characteristics, such as date, time of onset, time of cessation, duration, amount, speed and areal coverage embedded within diurnal and seasonal rainstorm events during the dry, early, late and rainy seasons.

A B

Plate 3.1: A-IITA Autographic Rain gauge Station (Main Station) and B-FRIN and Mapo Manual Rain gauge Stations (Sub-Stations) used in the Study

3.7 Methods of Data Collection

The rainstorms in Ibadan were monitored at five autographic rain gauge stations. There are five autographic rain gauge stations (spatially fixed raingauges) across the study area monitoring climatic variables, namely: International Institute of Tropical Agriculture (IITA), University of Ibadan (UI), Nigeria Meteorological (NIMET) Agency Office, Alakia Airport Ibadan, National Cereals Research Institute (NCRI) and Cocoa Research Institute of Nigeria (CRIN). These stations were coded "A_1 - A_5", respectively (Figure 3.1). The selected stations have rainfall gauges that logged total rainfall every 15 minutes. The data were in the form of times of onset and cessation, day, month, frequency, duration (in minutes) of rainstorms and amount (in millimeters) of rainstorms.

Data were also obtained from 45 non-recording (improvised) rainfall gauges in the selected sub-stations which were coded "B_1 - B_{45}", complementing autographic rain gauges data (Figure 3.1). A 3x3 km grid was superimposed on the map of Ibadan metropolis and one raingauge was installed in each of the 50 resultant grids. Data on rainstorms duration (mins) and rainfall amount (mm) were recorded daily from the 50 weather stations (Figure 3.1). The speed of the storm (ms^{-1}) is calculated from the perpendicular distance between the two stations and the difference between their time values. The areal coverage of rainstorm (km^2) is area covered by the rainstorm events. However, the rainstorm events due to thunderstorm and those due to disturbance lines embedded within diurnal and seasonal rainstorms were processed for 50 stations for two years (2013 to 2014) to determine the spatio-temporal and seasonal variations in frequency of rainstorms, rainstorms duration, rainfall amount, speed and areal coverage of rainstorm events across the study area.

The guidelines for installing rainfall stations were strictly followed. In addition, each recording rain gauge in the selected stations was positioned on masonry with the standard height of 300 mm above the ground (Ayoade, 1988). This rain gauge was usually read at 1000 hours local time and the amount of rainfall measured from each rainstorm events credited to the proceeding 24-hour period (Ayoade, 1988).

3.8 Techniques of Data Analysis

The statistical methods employed for this study were both descriptive and inferential statistical tools. The study involved the measurement of rainstorm characteristics (such as frequency, duration, rainfall amount, rainfall intensity, speed and areal coverage of rainstorms). 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 (mins). 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 millimetres (mm). The rainfall intensity equals to the rainfall amount divided by storm duration in hours or minutes. Similarly, the speed of rainstorms was determined by carefully observing the movement of rainstorm patterns as observed by the recording rain gauges. Different arrival times of some features of the rainstorms, such as time of start of rainstorms recorded at a number of measuring stations, were taken as an indication of a moving storm. Since the arrival times of rainstorms at different stations are not identical, the easily identified feature of the rainstorms data logger is the time of start of rainstorm (Diskin, 1987). The speed of movement can be calculated using the value obtained from the distance covered by the rainstorms (d) (in metre) which can be estimated as the interval between two or more points of time of start of rainstorms as observed by recording rain gauges divided by the value obtained from the arrival times of rainstorms (t) (in seconds) from data sets comprising the coordinates of the stations and the arrival times. The values obtained were expressed in metre per second (ms^{-1}). The areal coverage of rainstorms equals to the area covered by the rainstorms. This was calculated using measurement of area of irregular shapes (square method). The values obtained were expressed in square kilometre (km^2).

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 rainstorms characteristics. Data on rainstorms, such as frequency, rainfall intensity, speed and areal coverage of rainstorms, were illustrated with the aid of tables, bar and line graphs, and histograms. Climatological maps, such as

Isopleth maps, were analyzed and produced using ArcGIS 10.3 software to show the spatial pattern of frequency, duration and rainfall amount on monthly and seasonal bases. Temporal analysis was attempted for each year. The descriptive statistics included percentages and means, while the graphical illustrations comprised bar and line graphs. Standard deviation was used to find the deviations within a data set. Frequencies were deployed to depict the monthly and seasonal number of the occurrences of rainstorms due to thunderstorms and those due to disturbance lines in each year. The interpretation of the result of the descriptive statistics was done based on percentages as well as absolute values.

To determine the spatial and temporal patterns in the frequency, duration, rainfall amount, rainfall intensity and speed of rainstorms, the observed daily frequencies, durations, amounts, intensities and speeds of rainstorm events across each station were recorded and analysed. This was done for each of the rainstorm events for the period under investigation. Therefore, the relevant monthly rainstorm frequency, duration, rainfall amount, rainfall intensity and speed values were used to depict the spatial and temporal patterns. In addition, to determine the diurnal and seasonal variations in the occurrences of rainstorm characteristics, the observed daily frequencies, durations and rainfall amounts across each station were averaged to give the relevant frequency, duration and rainfall amount for each of the periods into which the day had been divided. 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 h) and late evening (between 2100 h and 2400 h). Therefore, each rainstorm was recorded according to the periods of its occurrence.

To achieve the stated hypotheses of this study, different statistical techniques were employed, using the Statistical Package for Social Sciences (SPSS) version 17.0 software, which contains multiple regression analysis. The first and second hypotheses of the study, on the effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms during the early rainy season; and the effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms during the late rainy season, were studied using Multiple Regression Analysis. The relationship between the dependent variable (Y = areal coverage of rainstorms) and the independent variables (X_1= duration, X_2 = rainfall amount and X_3 = speed of rainstorms during the early and the late rainy seasons) was studied using the correlation matrix produced between the dependent variable and the independent variables, a method which has been used in several studies on rainstorms (for example Longley, 1974; Sharon, 1981; Sumner, 1988; Sekoni, 1992). The aim of doing this is to depict the interrelationship between the four variables.

In the case of rainstorms due to disturbance lines, as a result of few occurrences in 2014 especially, the two-year data were collapsed together to form a data set. This was done in order to give a robust explanation on the temporal patterns of the rain-producing weather system over the city of Ibadan. In this analysis, the early rainy season (between March and April) and the late rainy season (between September and October) rainstorm characteristics were used. These were months with the greatest absolute occurrence of rainstorm events (Oguntoyinbo and Akintola, 1982; Ayoade and Akintola, 1986). The linear regression model table was produced which estimates the coefficients of the linear equation, involving independent variables (that is, the duration, rainfall amount and speed of rainstorms) that best predict the value of the dependent variable (that is, the areal coverage of rainstorms). The coefficient table showed the coefficients of the regression line. The unstandardized coefficients are the coefficients of the estimated regression model.

The independent variables were measured in different units. The standardized coefficients or betas were an attempt to make the regression coefficients more comparable. If the data is transformed to z scores prior to the regression analysis, this would give the beta coefficients as the unstandardized coefficients. The p-value tests the acceptability of the model from a statistical perspective. The regression row displays information about the variation accounted for by the model. The residual row displays information about the variation that is not accounted for by the model. If the significance value of the F statistic is less than 0.05, the variation explained by the model is not due to chance. While the p-value is a useful test of the model's ability to explain any variation in the dependent variable, it does not directly address the strength of that relationship.

The model summary table reports the strength of the relationship between the model and the dependent variable. R value, the multiple correlation coefficients, is the linear correlation between the observed and the model-predicted values of the dependent variable. Its large value indicates a strong relationship. The R Square (R^2) value, the coefficient of determination, is the squared value of the multiple correlation coefficients. It shows that the level of the variation of the predators in dependent variable is explained by the model. As a further measure of the strength of the model fit, compare the standard error of the estimate in the model summary table to the standard deviation of time reported in the descriptive statistics table.

In this study, the R^2 value (coefficient of determination) determined the direction and significant level of relations between the variables in the mathematical model and showed how much the areal coverage of rainstorms in the mathematical model was affected by the duration, rainfall amount and speed of rainstorms. The interpretation of the result of the regression was done based on early and late rainy seasons. The multiple regression technique is of the form.

$$Y = a + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n + e \qquad 3.1$$

where:

Y is dependent variable

a is constant term

$\beta_1 \beta_2 \ldots \beta_n$ is beta coefficients

$X_1 X_2 \ldots X_n$ is independent variables

e is error term

Another statistical technique employed to test the formulated hypotheses in this study was Paired Samples T-test Statistics. The paired-samples t-test procedure compares the means of two variables for a single group. The paired samples t-test statistics was used to test if there is significant difference between the speed and areal coverage of rainstorms between the early and late rainy seasons.

The paired-samples t-test table displays the mean, sample size, standard deviation, and standard error for both groups. The Pearson Correlation table shows the sample size, the correlation and significance levels. The Paired Test table shows the mean, standard deviation, standard error mean, 95% confidence interval of the difference, t statistic, degree of freedom (df) and significance value (2-tailed). The mean column in the paired-samples t test table displays the average difference between values of the two variables. The standard deviation column displays the standard deviation of the average difference score. The standard error mean column provides an index of the variability one can expect in repeated random samples of the sample size of the two variables similar to the ones in this study. The 95% confidence interval of the difference provides an estimate of the boundaries between which the true mean difference lies in 95% of all possible random samples of the sample size of the two variables similar to the ones in this study. If the confidence interval for the mean difference does not contain zero, the difference is significant. If the significance value is high and the confidence interval for the mean difference contains zero, then we cannot conclude that there is a significant difference between the means for the two variables. The t statistic is obtained by dividing the mean difference by its standard error. Significance (2-tailed) column displays the probability of obtaining a t statistic whose absolute value is equal to or greater than the obtained t statistic. A low significance value for the t-test (typically less than 0.05) indicates that there is a significant difference between the two variables. However, if the computed value of the t-test statistics is greater than or equals to or less than table value, we reject the null hypothesis.

The third and fourth hypotheses, on the seasonal variation in the speed of rainstorms during the early and the late rainy seasons; and the seasonal variation in the areal coverage of rainstorms during the early and the late rainy seasons, were tested using paired samples t-test statistics. This is because the data were normally distributed and the sample that was selected from this population was independent. The critical table of the t-distribution of the percentage points was used. The values of the test statistics falls within the rejection or critical region and the acceptance region. If the computed value of t test statistics falls between the critical region, we will reject the null hypothesis (H_0). Otherwise, we do not reject it. The reject region is on one or either side of the distribution if the test is one-tail or two-tail tests. For a two-tail test, the critical region lies on both sides of the distribution. The paired samples t-test statistics, therefore, enabled us to see whether there were significant differences between the speed of rainstorms during the early and the late rainy season and between the areal coverage of rainstorms during the early and the late rainy seasons. In short, the hypotheses are concerned with whether the speed and the areal coverage of rainstorms vary with those seasons identified. The formula for the paired samples t-test statistics is expressed as:

$$t = \frac{|\bar{a} - \bar{b}|}{\sqrt{\frac{\sigma a^2}{n_a} + \frac{\sigma b^2}{n_b}}} \qquad 3.2$$

where:

a is mean of the speed/mean of the areal coverage of rainstorms during the early rainy season

b is mean of the speed/mean of the areal coverage of rainstorms during the late rainy season

σ is standard deviation

n is number of observations

3.9 The Generation of Relief, Landuse and Building Density Maps

3.9.1 Geo Spatial Data Processing and Analysis

Landsat Enhanced Thematic Mapper Plus (ETM+) image of 2012, covering the eleven LGAs in the Ibadan metropolis (Ibadan North, Ibadan North East, Ibadan North West, Ibadan South East, Ibadan South West, Egbeda, Oluyole, Ido, Akinyele, Lagelu, Ona

Ara), was obtained for the study. The Landsat ETM+ satellite data was processed using ERDAS IMAGINE 9.2 image processing software. The image was imported into ERDAS using ERDAS native file format GEOTIFF. Since the images were in single bands, they were stacked together using ERDAS layer stack module to form a floating scene and to group the bands together. The 2012 image was co-registered with other images and later geo-liked to allow for the subset of the image to the study area. This was followed by performing further geometric corrections of the 2012 image to remove few scattered clouds in the image. The image was projected to the Universal Traverse Mercator (UTM) coordinates zones 32. The spheroid and datum was also referenced to WSG84. Enhancement of the images using histogram equalization techniques was later performed on the image and subset to an area to cover the eleven LGAs and environs. The image was later displayed as false-colour composites with band combination of red as bound 4, green as band 3, and blue as band 2. All the images were later categorized using the supervised classification technique to identify land cover and building density features within the study area.

The supervised classification was done by defining the number of classes to be 10, depending on the number of possible classes that can be readily identified by the software. Names were later assigned to the classes based on the patterns that could be identified. The classified map was later imported into ArcGIS 10.3 software for preparation and production.

3.9.2 Contour Creation and Data Preparation

The following steps were taken to prepare the data.

1. The XY data, that is, the selected points obtained from the field, was prepared in Excel Spread Sheet and saved in a format recognized by ArcGIS.
2. The points were plotted in ArcGIS by the use of the ADD XY data module found in the Tool Menu of ArcGIS 10.3 software.
3. An attribute database was created for the selected points during which all the values obtained from the field were keyed into their respective selected stations field or Row and Columns.

3.9.3 Data Analysis

The Spatial Analyst Tool in the Arc Toolbox was used to analyze the data obtained from the field after its preparation so as to meet the necessary conditions that permit its analysis in ArcGIS. Two tools were used, one is the SPLINE tool for data interpolation found in the Spatial Analyst and the second is the CONTOUR tool present in the Surface Analysis Box for carrying out surface analysis, such as contours and slope. The contour maps were created from the spline data generated from the selected point's data and the different variables, such as relief map of the study area, frequency, duration and amount of rainstorms, for the different seasons. The produced contour maps were later superimposed on the landuse map generated earlier. Labeling of the contour values and the selected stations were done and the map was taken to layout view for preparation and production. The produced maps were finally exported and saved in jpegs for easy accessibility to Word document.

3.10 Limitations of the Data

The main limitation in the data collected was the problem of missing data in some of the stations, especially during the industrial actions year (2013) and malfunctioning of equipment owned by the educational institution, such as UI. Some manual rain gauges kept by the field assistants were also taken away by the pupils of the selected schools who thought that the equipment was kept on their geographical gardens for fun. However, in order to avoid the problem of missing data, there was always a swift response to any reported cases like this, by replacing the stolen ones with manual rain gauges. Moreover, owing to environmental obstacles, such as clustered trees or agricultural plots, the gauges could not always be positioned at the calculated spacing cells, as seen in the map (Figure 3.1).

CHAPTER FOUR

RAINSTORMS DUE TO THUNDERSTORMS IN IBADAN

4.1 Characteristics of Rainstorms due to Thunderstorm

The total frequencies of rainstorms due to thunderstorm events recorded from January to December were 54 and 71 during the 2013 and 2014 rainstorm events, respectively. The total was 125 rainstorm events. A total of 54 rainstorm events in 2013 showed an average duration of 107 minutes. Also, 286 minutes was the maximum duration of rainstorm events in this data, while 30 minutes was the minimum. The standard deviation for duration of rainstorm events was 56. A total of 71 rainstorm events in 2014 showed an average duration of 98 minutes. 222 minutes was the maximum duration of rainstorm events in this data, 20 minutes was the minimum. The standard deviation for rainstorm events was 47.

In the two data sets, it was found that there was a variation in the durations of rainstorms. About 18% and 25% of rainstorm events lasted less than 1 hour, 50% and 48% between 1 and 2 hours, while 30% and 27% lasted for as long as 2 hours or more in 2013 and 2014, respectively (Figure 4.1).

The average amount of rainfall events due to thunderstorm over the selected stations in 2013 was found to be 15.1 mm. Besides, 45.2 mm was the maximum amount of rainfall events in this data, while 2.3 mm was the minimum. The standard deviation was 9.8. However, the average amount of rainfall due to this system over the study area in 2014 was found to be 12.5 mm. While 35.9 mm was the maximum amount of rainfall in this data, 0.3 mm was the minimum. The standard deviation was 9.3.

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 rainfall events due to this system in 2014 was higher than the frequency of occurrence of rainfall events in 2013. In spite of this, during the rainstorm events in 2013, the daily rainfall amounts were high and the maximum and the minimum amounts of rainfall due to this system were also higher than the daily rainfall amounts and the maximum and minimum amounts of rainfall events in

2014. This was also revealed in the standard deviation values. Figure 4.2 shows the frequency distribution of rainfall amount. From the total data, 19% and 27% of rainfall amount measured less than 5.0 mm, while 2% and less than 1% measured above 40.0 mm in 2013 and 2014, respectively.

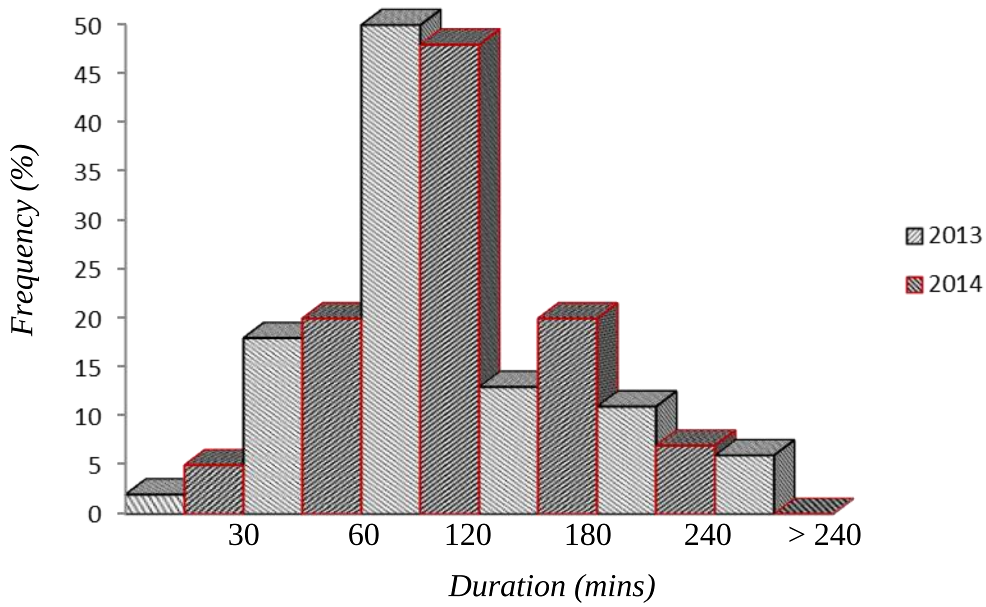


Figure 4.1: Duration of Rainstorms due to Thunderstorm

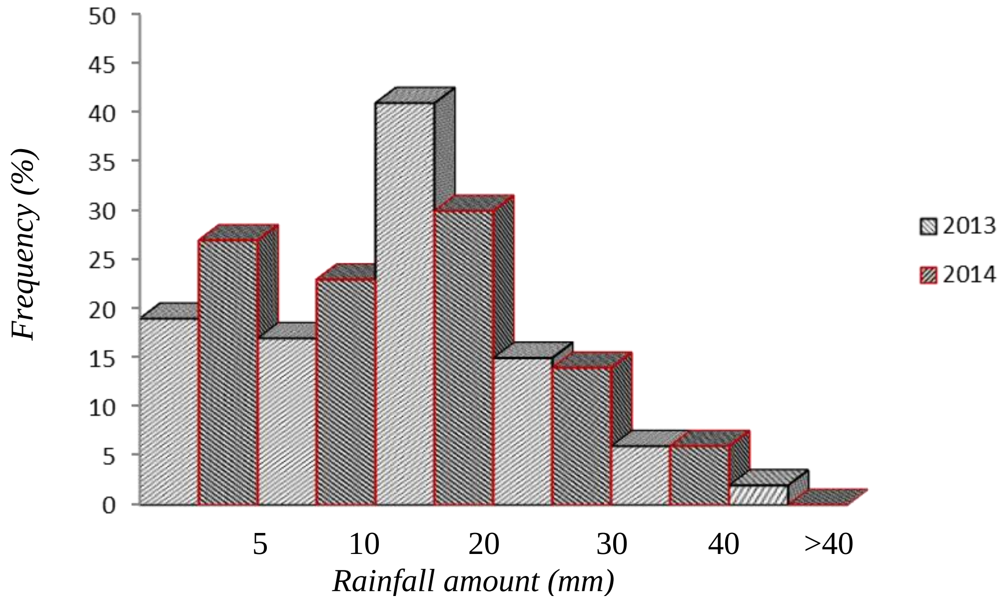


Figure 4.2: Rainfall Amount due to Thunderstorm

In addition, a total of 54 rainstorm events in 2013 showed an average rainfall intensity of 0.15 mm h^{-1}. Also, 0.37 mm h^{-1} was the maximum rainfall intensity in 2013 rainstorm events, while 0.30 mm h^{-1} was the minimum. The standard deviation was 0.08. A total of 71 rainstorm events in 2014 showed an average rainfall intensity of 0.13 mm h^{-1}. 0.41 mm h^{-1} was the maximum rainfall intensity of rainstorm events in 2014, 0.01 mm h^{-1} was the minimum. The standard deviation was 0.09.

In the two data sets, it was found that there was a variation in the average rainfall intensity. The average rainfall intensity due to this system in 2014 was higher than the average rainfall intensity of rainstorm events in 2013. Figure 4.3 shows the frequency distribution of rainfall intensity. From the total data, 11% and 17% of rainfall intensity measured less than 0.05 mm h^{-1}, while 17% and 28% measured between 0.05 and 0.10 mm h^{-1}, 56% and 41% between 0.10 and 0.20 mm h^{-1}, 9% and 9% between 0.20 and 0.30 mm h^{-1} and 7% and 5% measured above 0.30 mm h^{-1} in 2013 and 2014, respectively.

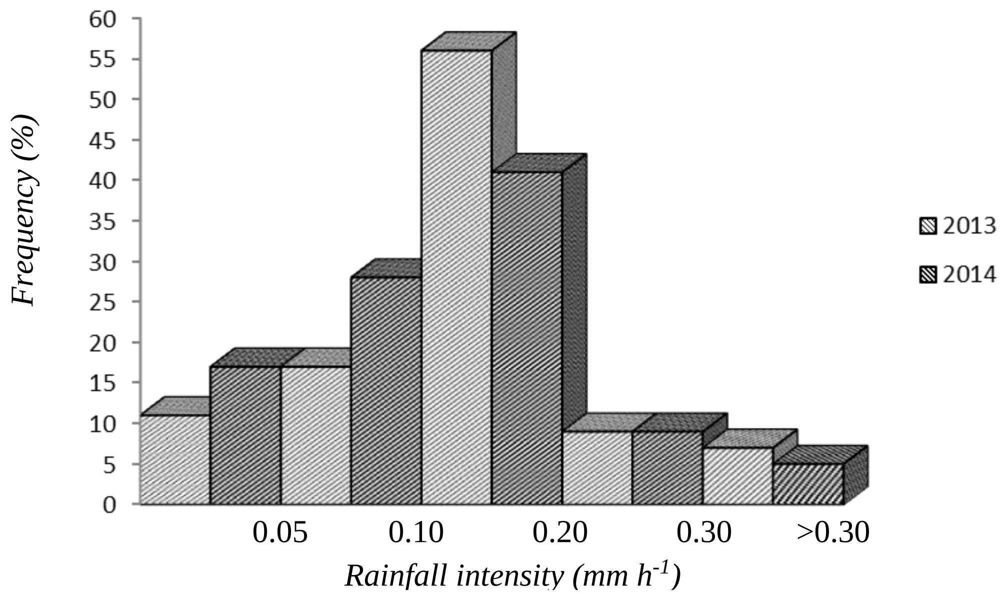


Figure 4.3: Rainfall Intensity due to Thunderstorm

4.2 Diurnal Variations of Rainstorms due to Thunderstorm

There were notable variations in rainstorms due to thunderstorm incidence in the course of a day over the study area. However, on a seasonal basis, frequencies of rainstorms, rainfall amounts and intensities of rainfall due to thunderstorm occurring during various periods of the day in 2013 and 2014 rainstorm events are shown in the section below.

4.2.1 Diurnal Variations in the Occurrences of Rainstorms due to Thunderstorm in 2013 and 2014

The diurnal variations in the frequency (%) of occurrences of rainstorms on a seasonal basis in 2013 and 2014 rainstorm events are shown in Tables 4.1 and 4.2.

4.2.1.1 Diurnal Variations in the Occurrences of Rainstorms due to Thunderstorm in 2013

The diurnal variations in the frequency (%) of occurrences of rainstorms on a seasonal basis in 2013 rainstorm events are presented in this section.

4.2.1.1a Dry Season

During the dry season months of November-February, there was a general tendency of frequency of rainstorms to decrease from midnight to late morning between 0000 h to 0900 h (Tables 4.1). However, the highest frequency (%) of rainstorms during this season, were recorded in February and November, in the late afternoon and early evening between 1500 h and 1800 h, with the values of 22.2 % and 33.4%, respectively. However, no rainstorm event was recorded at Ibadan in December 2013 (Tables 4.1).

4.2.1.1b Early Rainy Season

During the early rainy season 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 in the midnight between 0000 h and 0300 h, with the 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% (Tables 4.1). However, the month of March recorded no rainstorm event in the night and late afternoon between 0000 h and

Table 4.1: Diurnal Variations in the Frequency (%) of Rainstorms due to Thunderstorm during the Dry, Early, Late and Rainy Seasons in 2013 Rainstorm Events

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

Table 4.2: Diurnal Variations in the Frequency (%) of Rainstorms due to Thunderstorm during the Dry, Early, Late and Rainy Seasons in 2014 Rainstorm Events

		Frequency (%) of Rainstorms due to Thunderstorm during the Eight Periods of the Day								
Season	Month	0 h-3 h	3 h-6 h	6 h-9 h	9 h-12 h	12 h-15 h	15 h-18 h	18 h-21 h	21 h-24 h	Total
Dry	January	-	-	-	-	12.5	-	12.5	-	100%
	February	-	-	-	-	-	12.5	-	-	
	November	-	12.5	-	-	-	12.5	25.0	12.5	
	December	-	-	-	-	-	-	-	-	
Early	March	-	-	-	-	23.0	30.8	15.4	-	100%
	April	-	-	-	-	7.7	7.7	7.7	7.7	
Late	September	4.0	-	-	4.0	8.0	8.0	16.0	-	100%
	October	8.0	-	-	4.0	4.0	32.0	12.0	-	
Rainy	May	4.0	-	4.0	-	16.0	12.0	8.0	-	100%
	June	4.0	-	-	-	4.0	20.0	4.0	-	
	July	-	-	-	-	8.0	12.0	-	-	
	August	-	-	-	-	-	4.0	-	-	

1500 h (Tables 4.1). Though towards the early and late evening between 1800 h and 2400 h, values of 18.2% and 9.1%, were recorded, respectively (Tables 4.1).

4.2.1.1c Late Rainy Season

During the late rainy season 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 (percentage) was recorded in the early evening between 1800 h and 2100 h, with a value of 17.6% (Tables 4.1). 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% (Tables 4.1); while the lowest frequency (percentage) 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% (Tables 4.1). During this season, no rainstorm event was recorded from midnight to late morning between 0000 h and 0900 h, respectively (Tables 4.1).

4.2.1.1d Rainy Season

During the rainy season months of May-August, there was a tendency of frequency (%) of rainstorms to decrease during any of the eight periods into which the day has been divided. Though during this season, few of the rainstorm events were still recorded in the late morning via late afternoon (Tables 4.1). The highest frequency (%) of rainstorms was recorded in June, in the afternoon between 1200 h and 1500 h, with a value of 17.7% (Tables 4.1). The lowest frequency (%) of rainstorms was recorded during the rainy season months of July-August, from the midnight to late afternoon between 0000 h to 1500 h, with a value of 5.9% (Tables 4.1). The month of August recorded nearly no rainstorm event during any of the eight periods into which the day has been divided, though a value of 5.9% of the total frequency (%) of rainstorms was recorded in the late afternoon between 1500 h and 1800 h (Tables 4.1). This confirmed the usual occurrence of the little dry season phenomenon in the month of August (Ireland, 1962).

4.2.1.2 Diurnal Variations in the Occurrences of Rainstorms due to Thunderstorm in 2014

The diurnal variations in the frequency (%) of occurrences of rainstorms on a seasonal basis in 2014 rainstorm events are presented in this section.

4.2.1.2a Dry Season

During the dry season months of November-February, there was a general tendency of frequency of rainstorms to decrease from midnight to late morning between 0000 h to 0900 h (Table 4.2). However, the highest frequency (%) of rainstorms during this season in November was recorded in the late evening between 1800 h and 2100 h, with a value of 25% of the total frequency (%) of rainstorms (Table 4.2); the lowest frequency (percentage) of rainstorms was concentrated in the afternoon, late afternoon, and late evening between 1200 h and 1500 h, 1500 h and 1800 h, and 2100 h and 2400 h, in the months of January, February and November, with a value of 12.5% (Table 4.2). However, no rainstorm event was recorded at Ibadan in December 2014 (Table 4.2).

4.2.1.2b Early Rainy Season

Besides, during the early rainy season months of March and April, over 60.0% of the total frequency (%) of rainstorms was recorded in March from afternoon to late evening between 1200 h and 1500 h, 1500 h and 1800 h, and 1800 h and 2100 h (Table 4.2). The highest frequency (%) of the rainstorms occurred in the late afternoon between 1500 h and 1800 h, with a value of 30.8% (Table 4.2), while the lowest frequency (percentage) of the rainstorms were recorded in the late evening between 1800 h and 2100 h, with a value of 15.4% (Table 4.2). However, over 30% of the total frequency (%) of rainstorms was recorded in April from afternoon to late evening between 1200 h and 1500 h, 1500 h and 1800 h, and 1800 h and 2100 h, with a value of 7.7% recorded in this periods of the day (Table 4.2). The highest and lowest frequency (percentage) of the rainstorms was 7.7% of the total frequency (%) of rainstorms recorded in April (Table 4.2).

4.2.1.2c Late Rainy Season

Moreover, during the late rainy season months of September and October, over 35% and 52% of the total frequency (%) of rainstorms were recorded in September and October, from late morning to late evening between 0900 h and 1200 h to 1800 h and 2100 h, respectively (Table 4.2). Furthermore, in September, the highest frequency (percentage) of the rainstorms was recorded as 16%, in the late evening between 1800 h and 2100 h (Table 4.2); the lowest was recorded in the midnight, and late morning between 0000 h and 0300 h, and 0900 h and 1200 h, with a value of 4% (Table 4.2). However, in October, the highest frequency (%) of the rainstorms was 32% of the total frequency which was recorded in the late afternoon between 1500 h and 1800 h. More so, during this month, the lowest was recorded as 4% of the total frequency (%) of rainstorms (Table 4.2).

4.2.1.2d Rainy Season

During the rainy season months of May-August, there was also a tendency of the frequency (%) of rainstorms to decrease during any of the eight periods into which the day has been divided. Though during this season, much of the rainstorm events were concentrated in the afternoon via late evening between 1200 h and 1500 h, 1500 h and 1800 h, and 1800 h and 2100 h (Table 4.2). Besides, few of the rainstorm events were still concentrated in the midnight via early morning between 0000 h and 0300 h, and 0600 h and 0900 h (Table 4.2). During this season, especially in June, the highest frequency (%) of rainstorms was recorded, in the late afternoon between 1500 h and 1800 h, with a value of 20% (Table 4.2). The lowest value of rainstorm events, during this season was 4%, which was recorded in May, June and August. Similarly, a value of 4% of the frequency (%) of rainstorms was recorded in the late afternoon between 1500 h and 1800 h (Table 4.2); other periods of the day recorded no rainstorm event.

4.2.1.3 Deduction from the Diurnal Variations in the Occurrences of Rainstorms due to Thunderstorm in 2013 and 2014

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. The implication of this pattern is that most of the rainwater in rainstorms occurring in the late afternoon is available for soil moisture replenishment since little evaporation takes place during the night. The results showed that rainstorms can 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 occur in the late afternoon and early evening. This general trend shows the convectional nature of the rainstorms in Ibadan.

In addition, two things clearly emerge from these tables (4.1 and 4.2). First is that the early rains and the 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, though most rainstorms due to thunderstorm were still concentrated in the afternoons and late afternoons, some definitely took place in the early mornings and during the night.

4.2.2 Diurnal Variations in the Duration of Rainstorms due to Thunderstorm

Figure 4.4 captures the diurnal variations in the duration of rainstorms due to thunderstorm. Rainstorms due to thunderstorms are generally of short duration. The results obtained were not so different from what were expected. There was evidence of rainstorm events associated with the medium and longer durations.

4.2.2.1 Diurnal Variations in the Duration of Rainstorms due to Thunderstorm in 2013

The diurnal variations in the duration of rainstorms on a seasonal basis in 2013 rainstorm events are presented in this section.

4.2.2.1a Dry Season

During the dry season months in 2013, close to 100% of the rainstorm events were of the short duration (Figure 4.4), which occurred in the afternoon, early and late evening between 1200 h and 1500 h, and 1800 h and 2100 h (Figure 4.4). The highest rainstorms duration was recorded November, in the early evening between 1800 h to 2400 h, with a value of 97 minutes (Figure 4.4); the lowest durations of rainstorms was recorded in February, in the late evening between 2100 h and 2400 h, with a value of 64 minutes (Figure 4.4). However, no rainstorm event due to thunderstorm was recorded at Ibadan in December 2013 (Figure 4.4).

4.2.2.1b Early Rainy Season

Similarly, during the early rainy season months in 2013, most of the 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 occurred mostly 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 4.4); medium duration occurred mostly in April, in the midnight via early morning between 0000 h and 0300 h, 0300 h and 0600 h, and 0600 h and 0900 h (Figure 4.4). 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. The month of April also recorded the lowest duration of rainstorms in the late afternoon between 1500 h and 1800 h, with a value of 51 minutes was recorded (Figure 4.4).

4.2.2.1c Late Rainy Season

Also, during the late rainy season months in 2013, most of the 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 occurred mostly in October, in the late afternoon via late evening between 1500 h and 1800 h and 1800 h and 2100 h. The values of rainstorms duration during these periods of the day ranged between 40 minutes and 69 minutes (Figure 4.4). However, most of the rainstorm events with medium duration occurred in October, in the afternoon between 1200 h and 1500 h (Figure 4.4). The highest duration of rainstorms was 212 minutes which was recorded in September, in the late morning between 0900 h and 1200 h (Figure 4.4). 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.

4.2.2.1d Rainy Season

Besides, during the rainy season months in 2013, the majority 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 (Figure 4.4). 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 (Figure 4.4). The highest duration of rainstorms was recorded in July, in the night between 0000 h and 0300 h, with a value 286 minutes. The lowest duration of rainstorms was recorded in May, in the early afternoon between 1500 h and 1800 h, with a value of 30 minutes (Figure 4.4).

4.2.2.2 Diurnal Variations in the Duration of Rainstorms due to Thunderstorm in 2014

The diurnal variations in the duration of rainstorms on a seasonal basis in 2014 rainstorm events are presented in this section.

4.2.2.2a Dry Season

During the dry season months 2014, about 85% of the rainstorm events were of the short duration, which occurred in the early morning, early evening via late evening between 0300 h and 0600 h, 1800 h and 2100 h, and 2100 h and 2400 h (Figure 4.4); the remaining 15% of the duration of rainstorms were of the medium duration which occurred in November, in the late afternoon between 1500 h and 1800 h, with a value of 192 minutes (Figure 4.4). Also, during this period, the month of November recorded the lowest duration of rainstorms, in the early evening between 1800 h and 2100 h, with a value less than 30 minutes (Figure 4.4). However, no rainstorm event due to thunderstorm was recorded at Ibadan in December 2014.

4.2.2.2b Early Rainy Season

During the early rainy 2014, most of the rainstorm events were of medium durations which occurred in March and April, in the afternoon via early evening between 1200 h and 1500 h, 1500 h and 1800 h, and 1800 h and 2100 h, here the values ranged between 122 and 153 minutes. However, few of the short duration of the rainstorm events were still occurred in these months, especially in the late evening between 2100 h and 2400 h, with a value of 41 minutes (Figure 4.4). The highest duration of rainstorm events was recorded in April, in the early evening between 1800 h and 2100 h, with a value of 153 minutes. The month of April also recorded the lowest duration of rainstorm events, with a value less than 50 minutes (Figure 4.4).

4.2.2.2c Late Rainy Season

Moreover, during the late rainy season months in 2014, about 80% and 20% of the rainstorm events were of short and medium durations respectively, which occurred during any of the eight periods into which the day has been divided. Rainstorm events of short duration occurred mostly in October, in the midnight, late morning via early evening between 0000 h and 0300 h, 0900 h and 1200 h, 1200 h and 1500 h, 1500 h and 1800 h and 1800 h and 2100 h. Here, the values ranged between 66 and 121 minutes (Figure 4.4). Rainstorm events of medium duration occurred mostly in September, in the midnight and late morning between 0000 h and 0300 h, and 0900 h and 1200 h; during these periods of the day, the of duration of rainstorms ranged between 183 and 222 minutes. During this season, 222 minutes was recorded in September as the highest duration of rainstorms, while 66 minutes was the lowest (Figure 4.4).

4.2.2.2d Rainy Season

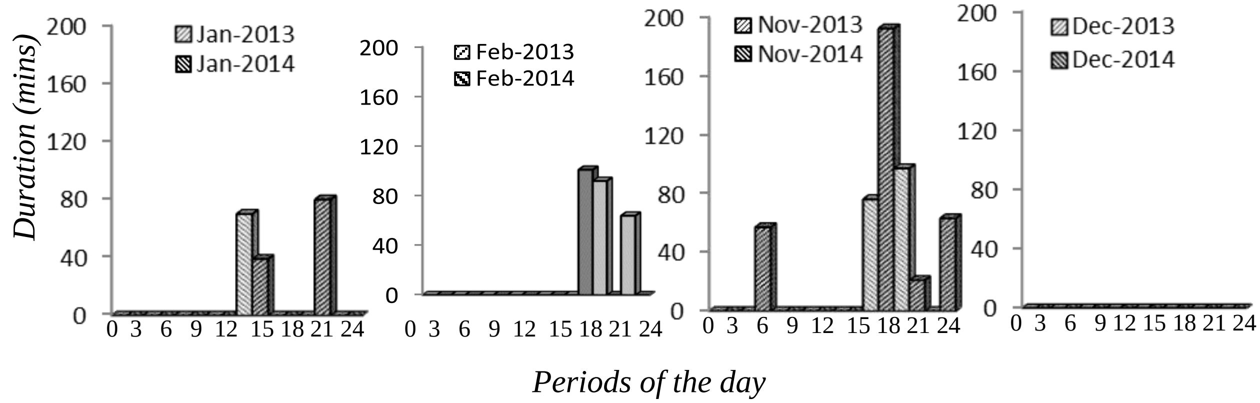
During the rainy season months in 2014, about 100% of the rainstorm events were of short duration which occurred during any of the eight periods into which the day has been divided with the exception of the late morning period which recorded no rainstorm events (Figure 4.4). The duration of rainstorms ranged between 20 and 125 minutes. The highest value was recorded in May, in the morning between 0600 h and 0900h, with a value of 125 minutes; the month of June recorded the lowest, in the afternoon, between 1200 h and 1500 h, with a value of 20 minutes (Figure 4.4).

4.2.2.3 Deduction from the Diurnal Variations in the Duration of Rainstorms due to Thunderstorm in 2013 and 2014

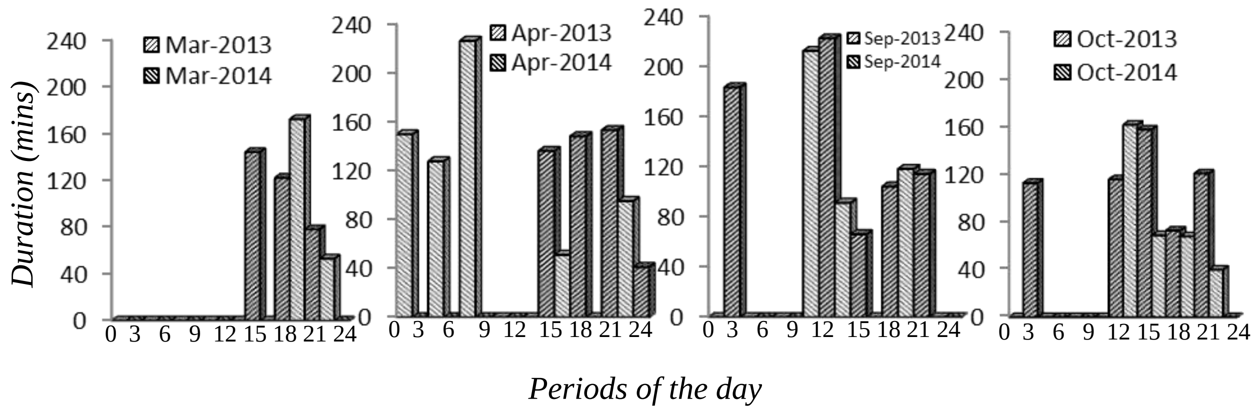
Figure 4.4 shows the seasonal distribution of rainstorm durations. Rainstorms of short duration occur during the dry season months of November, December, January and February. The duration per storm for all the other months was about 120 minutes. Figure 4.4 shows the frequencies of rainstorm durations set out at 40-min intervals. The distribution was skewed towards short and medium durations. Most of the rainstorms last between 30 and 120 min. In fact, over 70% of all the storms last for less than 2 hours in

2013 and 2014 rainstorm events. The distribution also shows that Ibadan can have rainstorms of extremely long.

Dry Season Rainstorms



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



Rainy Season Rainstorms

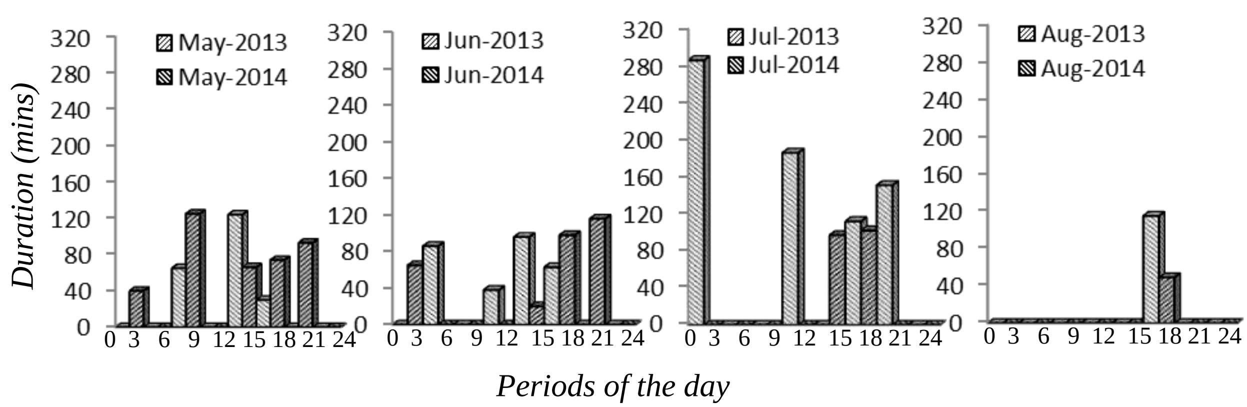


Figure 4.4: Mean Diurnal Variations in the Duration of Rainstorms due to Thunderstorm

4.2.3 Diurnal Variations in the Amount of Rainfall due to Thunderstorm

Figure 4.5 shows the diurnal variations in the amount of rainfall for Ibadan based on amounts of each storm due to thunderstorm. The rainfall amount in Ibadan is found to be highly seasonal. The amounts of rainfall in Ibadan vary a great deal.

4.2.3.1 Diurnal Variations in the Amount of Rainfall due to Thunderstorm in 2013

The diurnal variations in the amount of rainstorms on a seasonal basis in 2013 rainstorm events are presented in this section.

4.2.3.1a 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 (Figure 4.5). 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 (Figure 4.5). However, no rainfall amount due to thunderstorm was recorded at Ibadan in December 2013 (Figure 4.5).

4.2.3.1b Early Rainy Season

During the early rainy season rainstorms in 2013, about 29.6% of the total rainfall amount was recorded, with the 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 months had the highest amount reaching up to 33.6% (45.2 mm) of the total rainfall amount, which occurred April, in the morning, between 0600 h and 0900 h (Figure 4.5). 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 4.5).

4.2.3.1c Late Rainy Season

In 2013, over 20% of the total amounts of rainfall were recorded during this season, with the 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 (Figure 4.5). The month of 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 4.5).

4.2.3.1d Rainy Season

Besides, during the rainy season months in 2013, the total percentage of the rainfall amount was about 37.3% with the absolute value of about 169.6 mm. In this period, the highest rainfall amounts of about 20.5% (34.8 mm) were concentrated in the late afternoon between 1500 h and 1800 h in August (Figure 4.5). Whereas 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 4.5).

4.2.3.2 Diurnal Variations in the Amount of Rainfall due to Thunderstorm in 2014

The diurnal variations in the amount of rainstorms on a seasonal basis in 2014 rainstorm events are presented in this section.

4.2.3.2a Dry Season

During the dry season months of 2014, the amounts of rainfall were generally low. About 17.3% (83.9 mm) of the total rainfall amount was recorded, with the highest rainfall amount reaching about 33.8% (28.4 mm) in February, concentrated in the late afternoon, between 1500 h and 1800 h; the lowest rainfall amount was recorded in January, in the afternoon between 1200 h and 15 h, with a value of 4.9% (4.1 mm). However, no rainfall amount due to thunderstorm was recorded at Ibadan in December 2014, just like that of the December, 2013 (Figure 4.5).

4.2.3.2b Early Rainy Season

Furthermore, during the early rainy season rainstorms in 2014, about 20% of the total amounts of rainfall were recorded, with the absolute value of about 96.5 mm. However, the amounts recorded in each period of the day during these seasons were relatively high. The month of April had the highest amount reaching up to 37.2% (35.9 mm) of the rainfall amount, which occurred in the early evening, between 1800 h and 2100 h (Figure

4.5). The month of April also recorded the lowest amount of rainfall, in the late evening between 2100 h and 2400 h, with a value of 0.6% (0.6 mm) (Figure 4.5).

4.2.3.2c Late Rainy Season

However, about 33.5% (162.2 mm) of the total rainfall amount were recorded during the late rainy season in 2014. The highest rainfall amounts of about 19.5% (31.6 mm) were recorded in September, concentrated in the night, between 0000 h and 0300 h (Figure 4.5); the lowest value of rainfall amount was recorded in September, in the late afternoon between 1500 h and 1800 h. The rainfall amounts in these seasons are characteristic of weather zone B. The showers at the beginning and the end of the rainy season are sporadic in occurrence since they are due to the isolated thunderstorms.

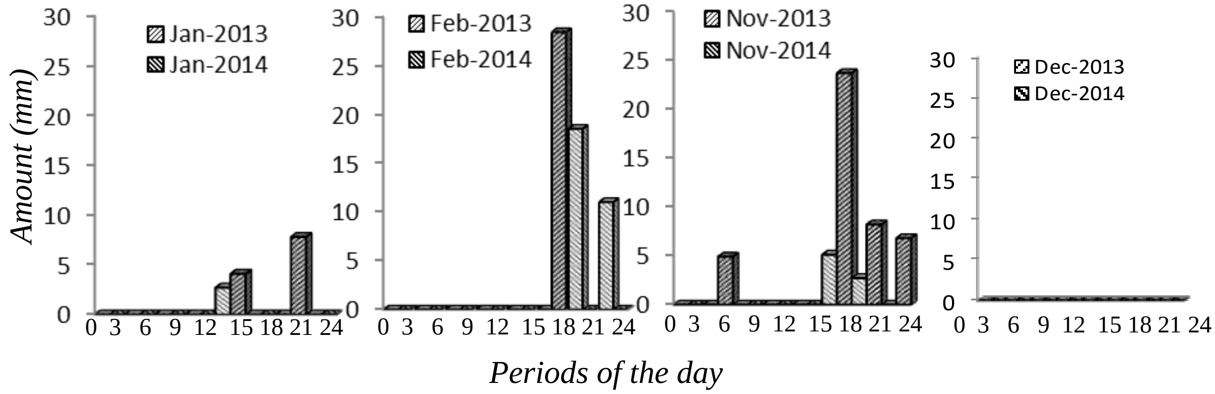
4.2.3.2d Rainy Season

Besides, during the rainy season months in 2013, the total percentage of the total rainfall amount was about 29.3% with the absolute value of about 142.1 mm. The highest rainfall amounts of about 20.9% (29.7 mm) were recorded in May, concentrated in the morning, between 0600 h and 0900 h (Figure 4.5). The lowest rainfall amounts were recorded in August, in the late afternoon between 1500 h and 1800 h, with a value of 0.6% (0.8 mm) (Figure 4.5).

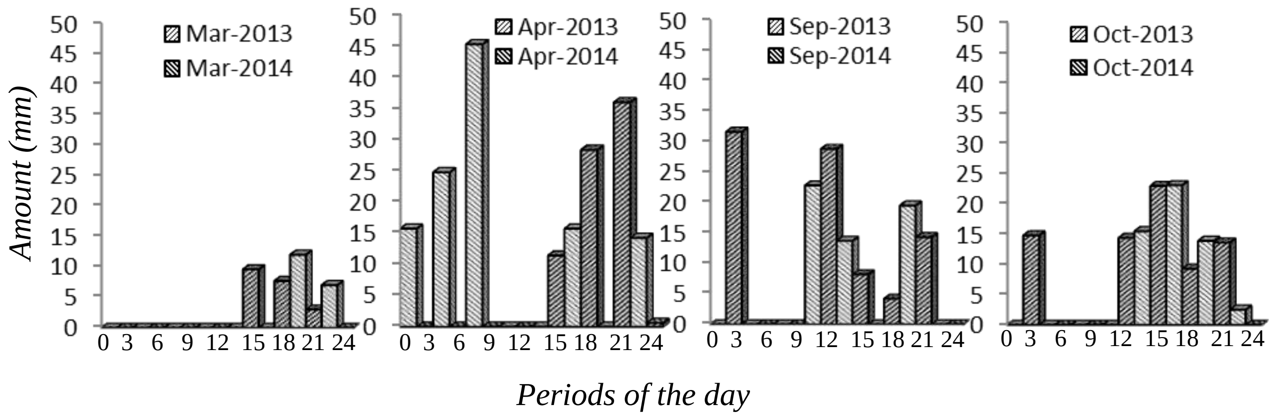
4.2.3.3 Deduction from the Diurnal Variations in the Amount of Rainfall due to Thunderstorm in 2013 and 2014

Figure 4.5 shows the rainstorms class distribution for Ibadan based on rainfall amounts of each storm. About 40% and 65% have rainfall amounts with 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.

Dry Season Rainstorms



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



Rainy Season Rainstorms

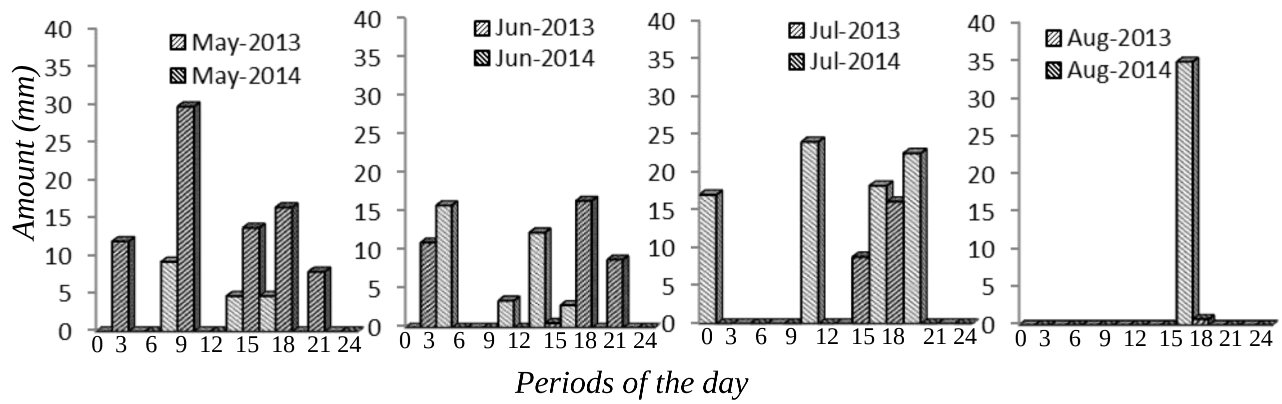


Figure 4.5: Mean Diurnal Variations in the Amount of Rainfall due to Thunderstorm

4.2.4 Diurnal Variations in the Intensity of Rainfall due to Thunderstorm

The diurnal variations in the intensity of rainfall for Ibadan based on average intensities of each storm due to thunderstorm. However, the rainfall intensity in Ibadan is highly seasonal. The intensities of rainfall in Ibadan vary a great deal (Figure 4.6).

4.2.4.1 Diurnal Variations in the Intensity of Rainfall due to Thunderstorm in 2013

The diurnal variations in the intensities of rainstorms on a seasonal basis in 2013 rainstorm events are presented in this section.

4.2.4.1a Dry Season

The intensities of rainfall during dry season in 2013 were generally low. The highest rainfall intensities during dry season reaching about 0.20 mm h^{-1} were occurred in February, concentrated in the early and late evening, between 1800 h and 2100 h and 2100 h and 2400 h (Figure 4.6). The lowest was recorded in January; reaching about 0.04 mm h^{-1} was concentrated in the afternoon, between 1200 h and 1500 h (Figure 4.6). However, no rainfall intensity was recorded at Ibadan in December 2013 (Figure 4.6).

4.2.4.1b Early Rainy Season

During the early rainy season in 2013, 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 4.6). 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 4.6).

4.2.4.1c Late Rainy Season

In 2013, the rainfall intensities recorded in each period of the day during these seasons were relatively high during this season. The late rainy season 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 that of the early rainy season rainfall intensities in 2013 (Figure 4.6). 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 4.6).

4.2.4.1d Rainy Season

During the rainy season months in 2013, 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 4.6). Similarly, during main rainy season, about 0.20 mm h^{-1} were recorded in 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 (Figure 4.6). More so, during main 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 4.6).

4.2.4.2 Diurnal Variations in the Intensity of Rainfall due to Thunderstorm in 2014

The diurnal variations in the intensities of rainstorms on a seasonal basis in 2014 rainstorm events are presented in this section.

4.2.4.2a Dry Season

The intensities of rainfall during dry season in 2014 were relatively high. The highest rainfall intensities during dry season reaching about 0.40 mm h^{-1} were recorded in November, concentrated in the early evening, between 1800 h and 2100 h (Figure 4.6). The lowest intensity of rainfall was recorded in January; reaching about 0.1 mm h^{-1} was concentrated in the afternoon, and early evening between 1200 h and 1500 h, and 1800 h and 2100 h (Figure 4.6). However, no rainfall intensity was recorded at Ibadan in December 2014 (Figure 4.6).

4.2.4.2b Early Rainy Season

In 2014, the rainfall intensities recorded in each period of the day during these seasons were generally low during this period. The early rainy season month (April) had the highest rainfall intensities reaching up to 0.20 mm h^{-1}, and was concentrated in the late afternoon and early evening between 1500 h and 1800 h and 1800 h and 2100 h (Figure

4.6). Also, the month of April recorded the lowest rainfall intensities of about 0.02 mm h^{-1} was concentrated in the late evening, between 2100 h and 2400 h (Figure 4.6).

4.2.4.2c Late Rainy Season

During this season in 2014, the rainfall intensities recorded in each period of the day during these seasons were generally low. The late rainy season months (September and October) had the highest rainfall intensities reaching up to 0.20 mm h^{-1}, and were concentrated in the night and afternoon, between 0000 h and 0300 h and 1200 h and 1500 h, respectively (Figure 4.6). However, the month of September recorded the lowest rainfall intensities of about 0.04 mm h^{-1} was concentrated in the late afternoon, between 1500 h and 1800 h (Figure 4.6).

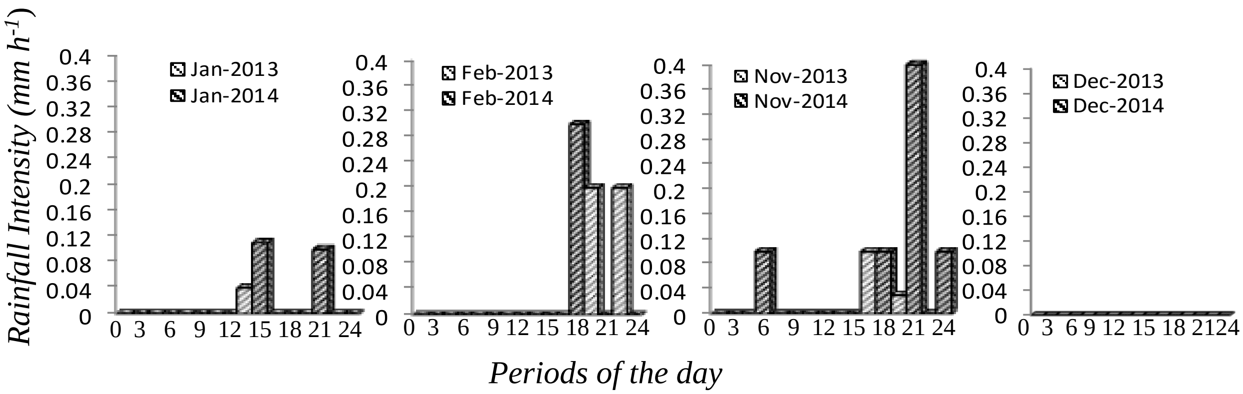
4.2.4.2d Rainy Season

In 2014, the highest rainfall intensities of about 0.30 mm h^{-1} were recorded in May, concentrated in the night, between 0000 h and 0300 h (Figure 4.6). Similarly, during this period, about 0.20 mm h^{-1} were recorded in at the peak of the rainy season in June-July, concentrated in the night, and late afternoon between 0000 h and 0300 h, 1500 h and 1800 h (Figure 4.6). More so, during this season, the lowest rainfall intensity of about 0.02 mm h^{-1} was recorded in August, concentrated in the late afternoon, between 1500 h and 1800 h (Figure 4.6).

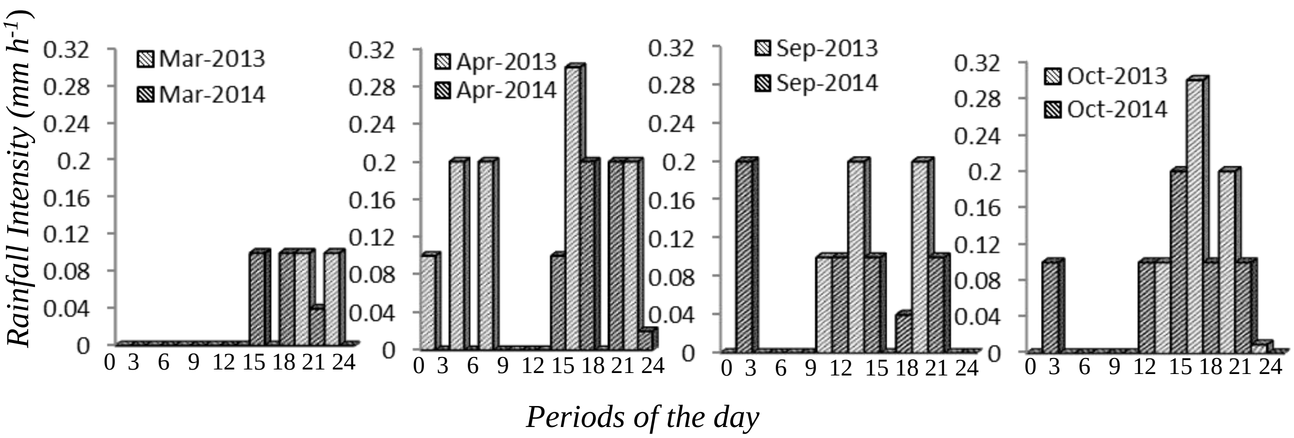
4.2.4.3 Deduction from the Diurnal Variations in the Intensities of Rainfall due to Thunderstorm in 2013 and 2014

Figure 4.6 shows the mean intensity per storm on a seasonal basis. For the Ibadan region, Akintola (1974) has 17.8 mm h^{-1} as the mean infiltration capacity for all the landuse surfaces. When this figure is compared with those in Table 4.6 no month exceeded this threshold of excess water generation. The intensities of the rainstorms of the early and late rainy season months were not higher than the soil infiltration capacities. These were 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 moderate in the early and late rainy seasons.

Dry Season Rainstorms



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



Rainy Season Rainstorms

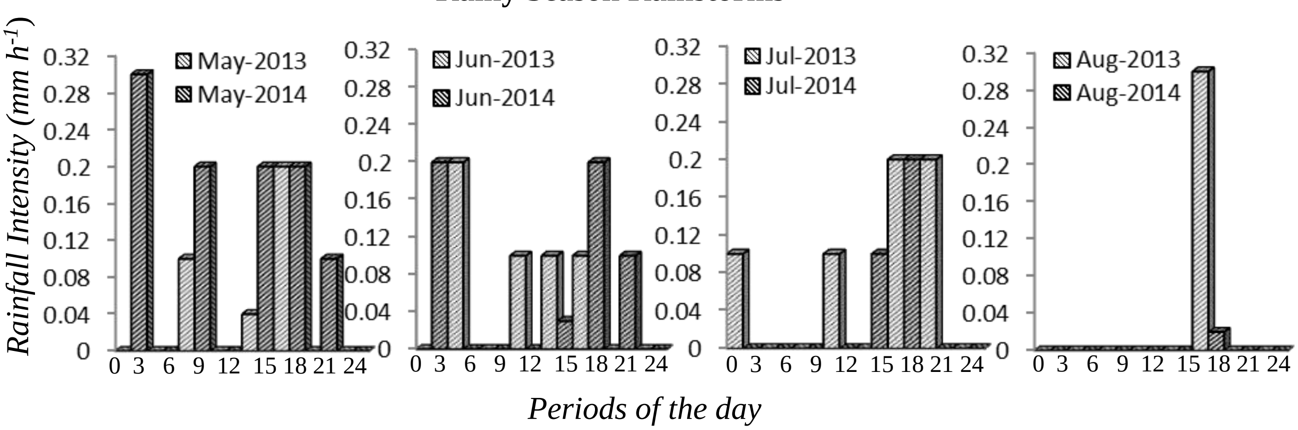


Figure 4.6: Mean Diurnal Variations in the Intensity of Rainfall due to Thunderstorm

4.3 Seasonal Variations in the Frequency of Rainstorms due to Thunderstorm in Ibadan

The seasonal variations in the frequency of rainstorms in Ibadan are illustrated below. Comparison of the seasonal variations in the frequency of rainstorms of two years-2013 and 2014, as shown in Figure 4.7, has been included in the discussion because it presents different patterns of frequency of rainstorms over Ibadan.

4.3.1 Seasonal Variations in the Frequency of Rainstorms due to Thunderstorm in 2013

The highest frequency of rainstorms during the dry season in 2013 was recorded in February, with a value of five. The frequencies of rainstorms went low to three in November. Other months, such as January recorded a total value of one of rainstorm event. No rainstorm event due to thunderstorm was recorded at Ibadan in December (Figure 4.7).

Moreover, during the early rainy season in 2013, the frequency of rainstorms varied between three (the lowest in March) and eight in April which had the highest value (Figure 4.7). During the late rainy season in 2013, rainstorm events due to thunderstorm varied between six (the lowest in October) and 11, with September having the highest value (Figure 4.7).

The highest rainstorm events observed during the rainy season in 2013 was at the peak of the rainy season-June and July, with a value of six rainstorm events. The month of May had a value of four rainstorm events. The lowest rainstorm event was recorded in August, with a value of one rainstorm event (Figure 4.7).

4.3.2 Seasonal Variations in the Frequency of Rainstorms due to Thunderstorm in 2014

The highest frequency of rainstorms during the dry season in 2014 was recorded at Ibadan in November, was five rainstorm events. The frequencies of rainstorms went low to two in January. February recorded a value of one rainstorm event. December recorded no rainstorm event, just like December 2013 (Figure 4.7). Furthermore, during the early rainy season in 2014, the frequency of rainstorms varied between 4 (the lowest in March) to nine in April with the highest value (Figure 4.7). More so, during the late rainy season in 2014, rainstorm events varied between 10 (the lowest in September) and 15, with October having the highest value of rainstorm events (Figure 4.7).

Besides, the highest rainstorm events observed during the rainy season in 2014 was in May, with a value of rainstorm events of 11. In addition, the month of June had value of eight. July followed with a value of five rainstorm events. However, in August, the rainy season rainstorm event was one (Figure 4.7). This was as a result of the little dry season phenomenon experienced during the month.

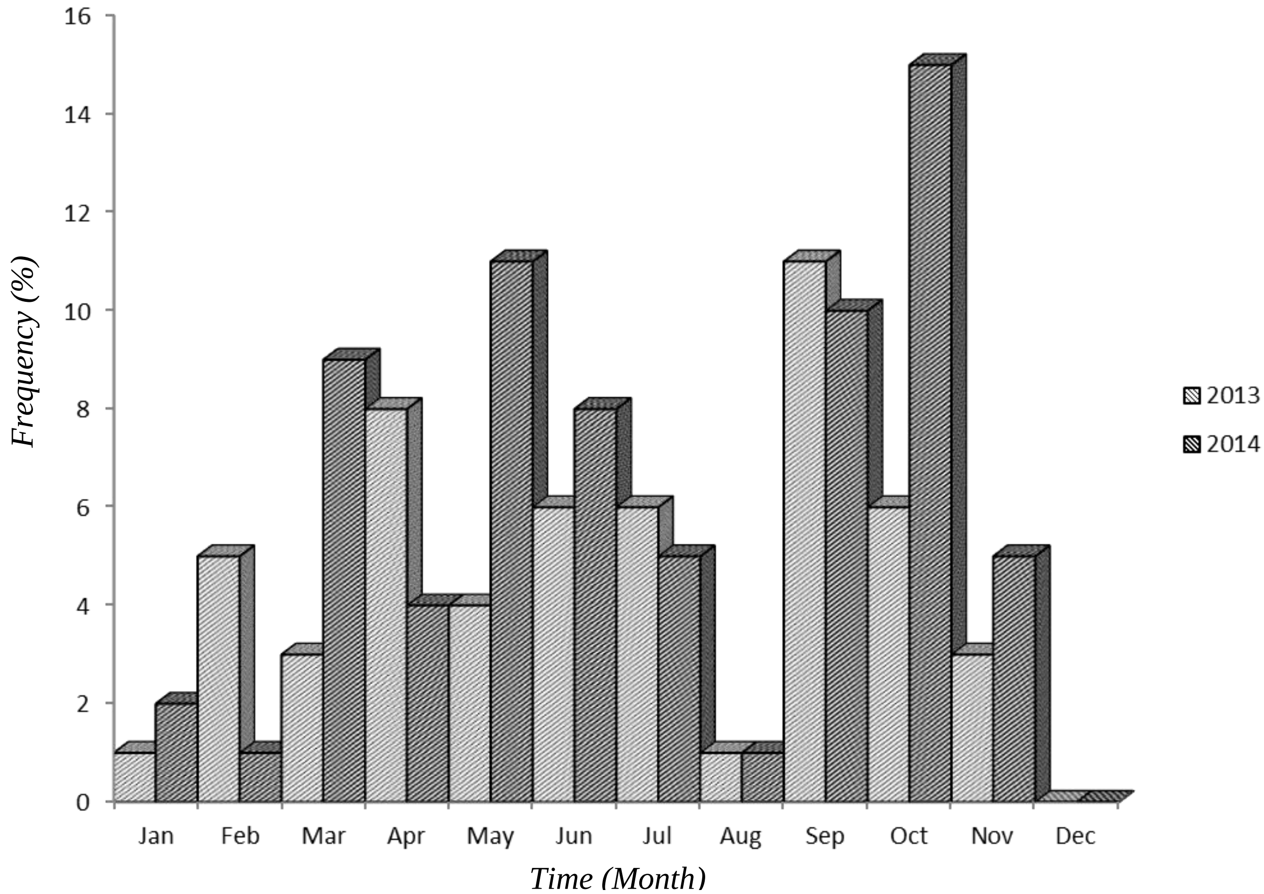


Figure 4.7: Seasonal Variations of Rainstorms due to Thunderstorm

4.4 Spatial Pattern of Rainstorms due to Thunderstorm in Ibadan

The spatial pattern of frequency of rainstorms, duration and rainfall amount due to thunderstorm in Ibadan are illustrated in this section.

4.4.1 Spatial Pattern of Frequency of Rainstorms due to Thunderstorm in Ibadan

Comparison of the spatial pattern of frequency of rainstorms due to thunderstorm of two years-2013 and 2014, shown in Figures 4.8, 4.10, 4.12 and 4.9, 4.11, 4.13, respectively, has been included in the discussion because it presents different spatial patterns of rainstorms over Ibadan. Generally, the rains from the rainstorms are spotty in areal distribution and the pattern of occurrence of the rains tends to be random (Sekoni, 1992; Ayoade, 2012). From the Figures 4.8, 4.10, 4.12 and 4.9, 4.11, 4.13, below, frequency of rainstorms varied seasonally at every section of the city of Ibadan and the overall thunderstorm events followed a seasonal distribution. During the dry season in 2013, the highest frequency of rainstorms was recorded at Alakia institutional and medium-density landuse area, with a value of nine rainstorm events. It decreased to six at UI and IITA educational and institutional and low-density landuse areas, respectively. Other areas in the city of Ibadan, such as commercial and medium-density landuse area of Gbagi and vegetative and medium-density landuse area of Omi-Adio recorded a total value of two rainstorm events (Figure 4.8).

The highest frequency of rainstorms during the dry season in 2014 was recorded at Alakia institutional and medium-density landuse area and vegetative and low-density residential landuse areas of Arapaja and Ologuneru with a value of eight. It decreased to seven rainstorm events at CRIN institutional and low-density landuse area and Apete medium-density residential landuse area. Mokola, Gate, and Mapo, Babanla and Odinjo medium-and high-density residential landuse areas recorded a value of rainstorm events of six. Other landuse areas, such as water body and medium-density residential landuse area of Eleyele and industrial areas of Oluyole and Lagelu, recorded five rainstorm events (Figure 4.9). However, as seen in the Figure 4.9 below, the “dry season rains” did not appear in all sections of the study area. Generally, the rainy phases during the “dry season rains” began in February and ended in November. On the western part, the rains set in slightly earlier, to the east, in the upper lying zone in the area around Alakia institutional and medium-density landuse area, a bit later, which means about the first week of February. The same held true for the northeastern part of the city.

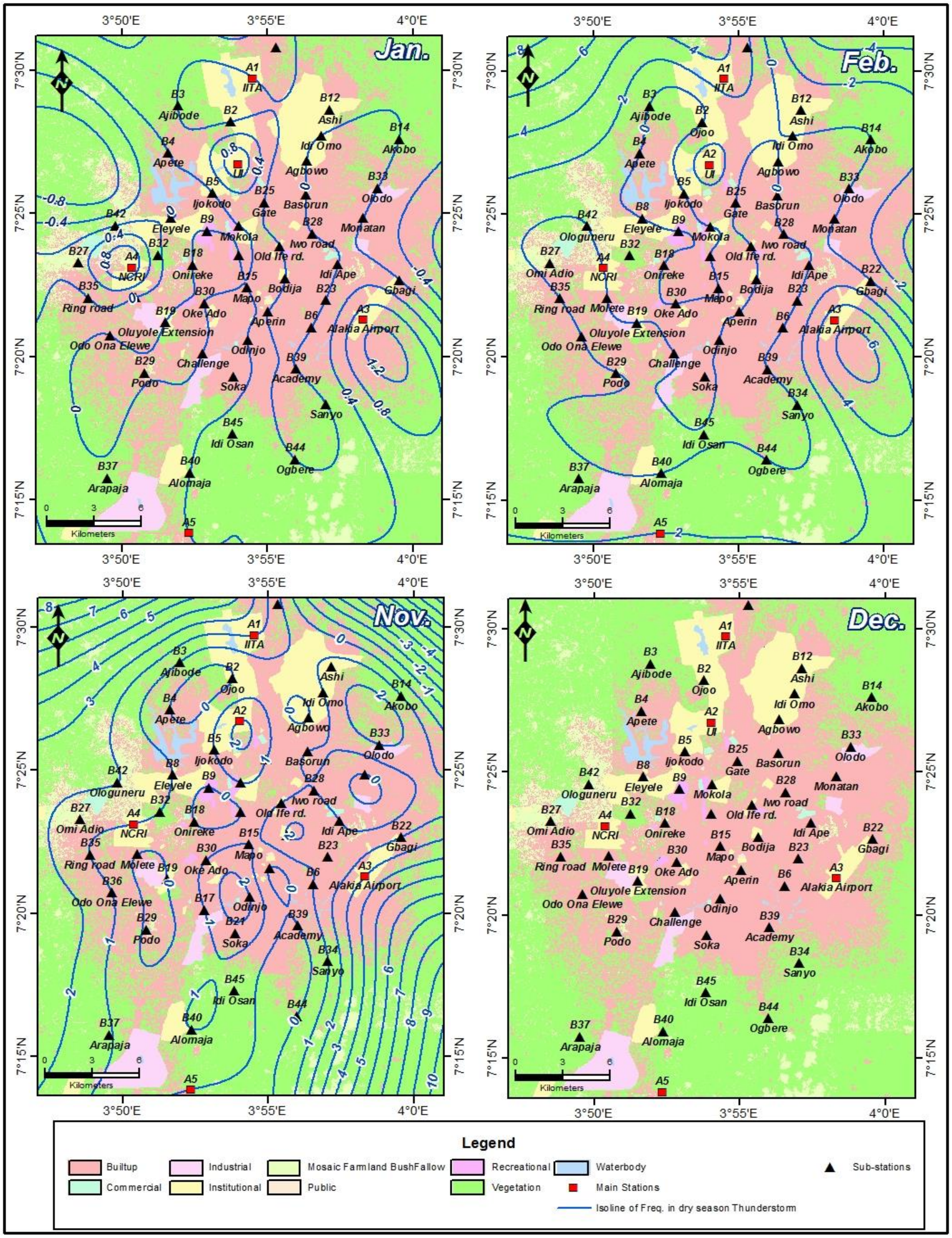


Figure 4.8: Spatial Pattern of Frequency of Rainstorms due to Thunderstorm during the Dry Season in 2013

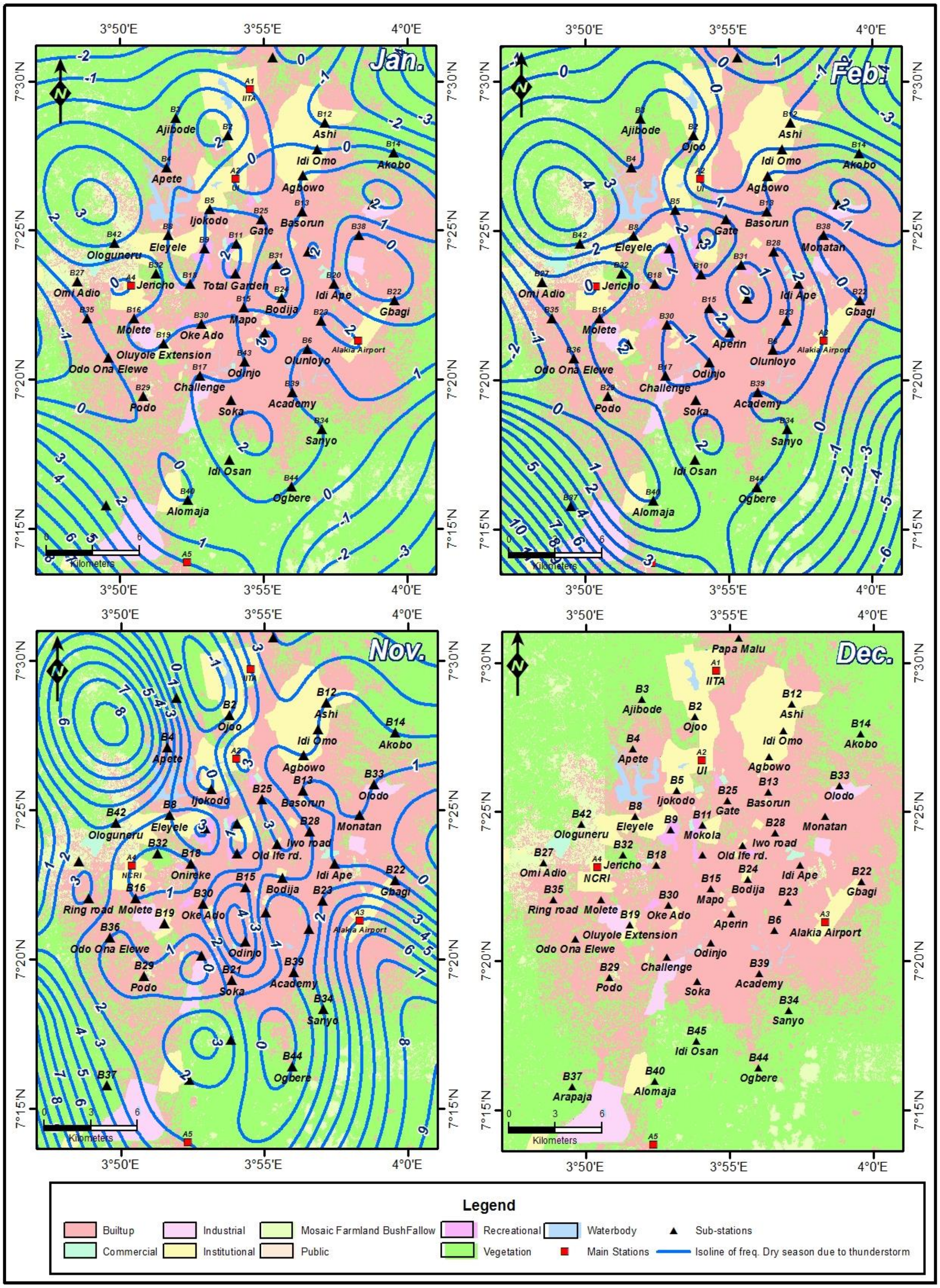


Figure 4.9: Spatial Pattern of Frequency of Rainstorms due to Thunderstorm during the Dry Season in 2014

The frequency of rainstorms during the early rainy season in 2013 varied between one (the lowest at Onireke–a medium-density residential landuse area) and 11 at the institutional and low-and medium-density landuse areas of IITA and Alakia which had the highest values (Figure 4.10). However, during this season in 2013, there was a general decrease of rainstorm events over the city especially in March. Some areas of the city stood out as sections of high frequency of rainstorms and among these areas were found towards the upper lying zone on the northern section of the city in the areas around UI educational and low-density landuse area–IITA institutional and low-density landuse area-Idi-Omo vegetative and low-density landuse area axis. The same held true for the eastern section of the city in the area around Alakia institutional and medium-density landuse area and towards the lower lying zone on the southeastern section of the city in the areas around Lagelu industrial area-CRIN institutional and low-density landuse area axis. Generally, the rainstorm events during the early rainy season began in the middle of March. There was an increase in the occurrence of rainstorms in April which appeared all over the sections of the city.

Besides, during the early rainy season in 2014, the frequency of rainstorms varied between one (the lowest at Ajibode vegetative and low-density area) to 13 at the institutional and medium-density area of Alakia (Figure 4.11). However, during the early rainy season in 2014, there was a general decrease of rainstorm events over the city especially in March. Some areas of the city stood out as sections of high frequency of rainstorms and among these areas were found towards the upper lying zone on the northern section of the city in the areas around UI educational and low-density landuse area–IITA institutional and low-density landuse area-Idi-Omo vegetative and low-density landuse area axis. The same held true for the eastern section of the city in the area around Alakia institutional and medium-density landuse area and towards the lower lying zone on the southeastern section of the city in the areas around Lagelu industrial area-CRIN institutional and low-density landuse area axis. Generally, the rainstorm events during the early rainy season began in the middle of March. There was an increase in the occurrence of rainstorms in April which appeared all over the sections of the city, just like the spatial patterns of rainstorm events experienced during the early rainy season in 2013.

In addition, during the late rainy season in 2013, rainstorm events varied between one (the lowest at Omi-Adio vegetative and medium-density landuse area) and 17, with institutional and medium-density landuse area of Alakia having the highest value (Figure 4.10). Nevertheless, during this season in 2013, there was a tremendous increase in the frequency of rainstorms over the city. About twenty areas in the five parts of the city stood out as sections of high frequency of rainstorms and among these areas were found on the northern section of the city in the areas around UI educational and low-density landuse area-IITA institutional and low-density landuse area-Idi-Omo vegetative and low-density landuse area axis, on the eastern section of the city in the area around Alakia institutional and medium-density landuse area, on the southeastern section of the city in the area around Lagelu industrial area and on the central section of the city in the area around Mapo. However, the rainstorm events increased northeastwards to southeastwards axis of the city. The western and southwestern range showed low frequency around Eleyele water body and medium-density residential area-Oke-Ado medium-density residential landuse area axis.

The rainstorm events during the late rainy season in 2014 varied between four (the lowest at Podo low-density landuse area) and 25, with institutional and medium-density landuse area of Alakia having the highest value (Figure 4.11). There was a similar pattern in the frequency of rainstorms during the late rainy season in 2014, where there was also a tremendous increase in the frequency of rainstorms on all the sections of the city including the northwestern axis in the area around Onireke medium-density residential landuse area-Jericho low-density residential landuse area axis and the southwestern section in the area around Ring Road commercial and low-density landuse area-Alomaja vegetative and low-density landuse area-CRIN institutional and low-density landuse area axis. Generally, during this period, the rainstorm events increased southwards.

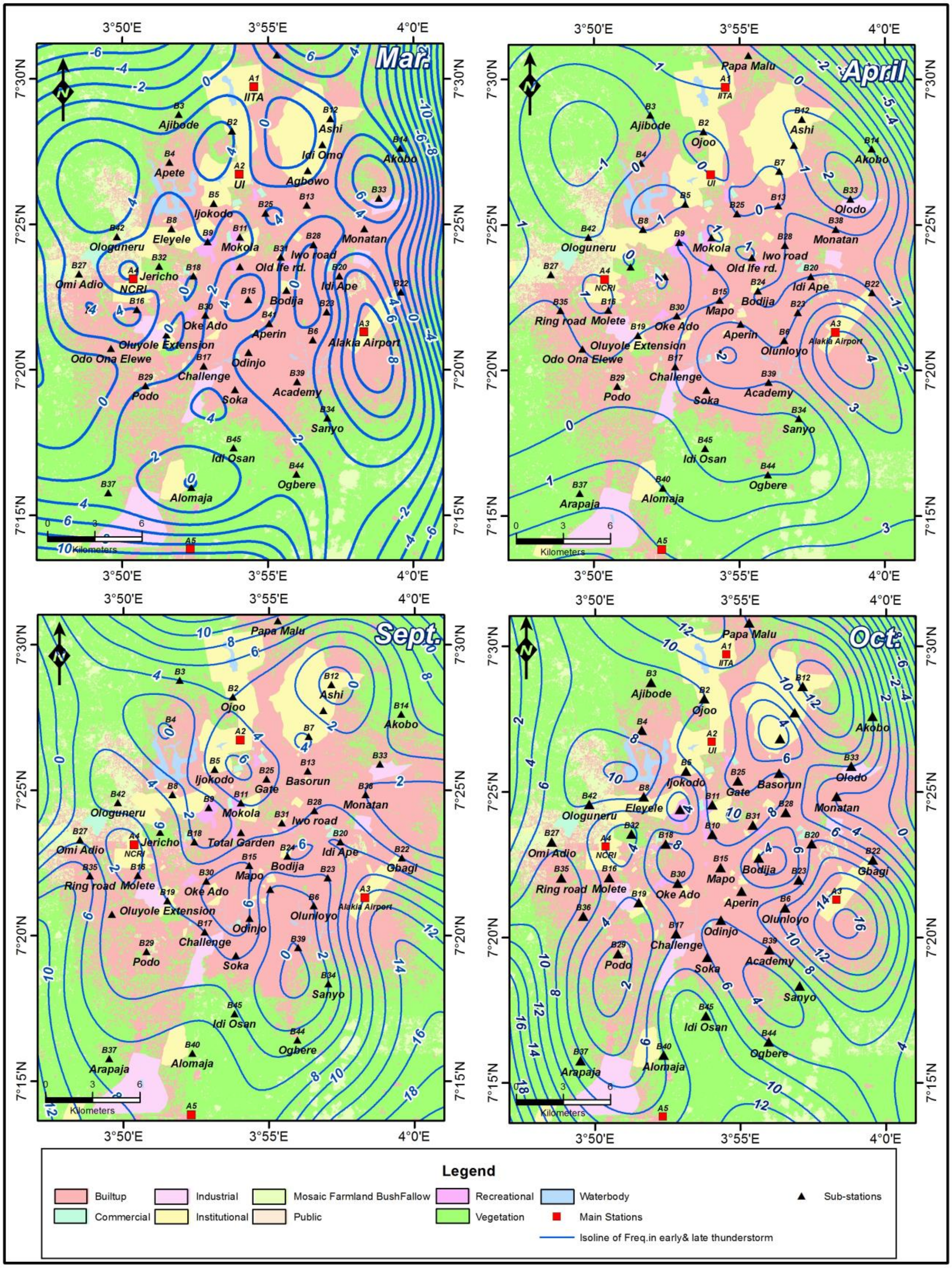


Figure 4.10: Spatial Pattern of Frequency of Rainstorms due to Thunderstorm during the Early and Late Rainy Seasons in 2013

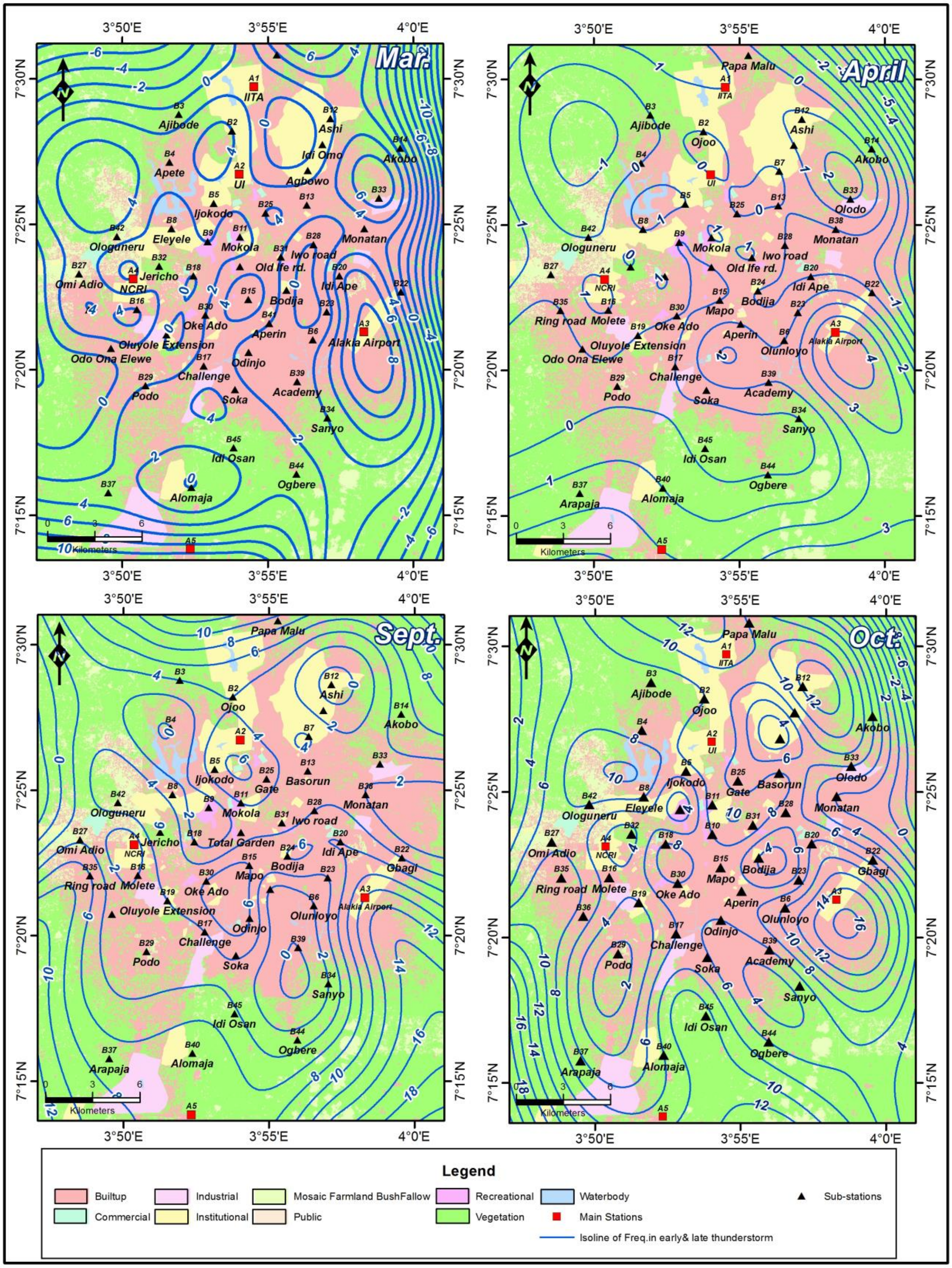


Figure 4.11: Spatial Pattern of Frequency of Rainstorms due to Thunderstorm during the Early and Late Rainy Seasons in 2014

The highest rainstorm events observed during the rainy season in 2013 was at Alakia institutional and medium-density landuse area, with a value of 17 rainstorm events. The low-density residential landuse area of Ikolaba had a value of 10. Medium-density residential landuse area of Agbowo followed with a value of nine rainstorm events. The rainstorm events however varied between the vegetative and low-density landuse area of Ajibode, with a value of eight rainstorm events and the industrial area of Oluyole, with a value of five rainstorm events. It decreased to four rainstorm events at other high-, medium-and low density residential landuse areas of Mapo, Basorun and Molete and Sanyo; and three rainstorm events at low-density residential landuse areas of Ashi, Akobo, and Jericho. At the vegetative and low-density landuse areas of Olodo and Alomaja, rainstorm events had a value of three rainstorm events. The lowest rainstorm event was recorded at Lagelu industrial area, with a value of one (Figure 4.12). Besides, during the rainy season in 2013, the frequency of rainstorms was highest in the area around Alakia institutional and medium-density landuse area and east of the city, here the figure stood at 17. Towards the south, west and north, rainstorm events decreased rapidly. The central axis showed rainstorm events about four.

The highest rainstorm events observed during the rainy season in 2014 was at Alakia institutional and medium-density landuse area, with a value of 25. The institutional and low-density landuse area of IITA had value of 18 rainstorm events. Vegetative and low-density area of Olodo followed with a value of 15 rainstorm events. It decreased to 10 at Ajibode vegetative and low-density residential area and high-density residential landuse area of Aperin. NCRI institutional and medium-density landuse area and Bodija and Idi-Ape medium-density residential landuse areas had seven rainstorm events. At Eleyele, water body and medium-density residential landuse area recorded a value of six rainstorm events. However, Oluyole industrial area recorded a value of five rainstorm events during rainy season. The lowest rainstorm event was recorded at Apete and Odo-Ona Elewe medium-and low-density residential landuse areas, with a value of one (Figure 4.13). However, during the rainy season in 2014, the frequency of rainstorms was highest in the area around Alakia institutional and medium-density landuse area and east of the city, here the figure stood at 25. Towards the south, west and north, rainstorm events decreased rapidly. The central axis showed rainstorm events about 10.

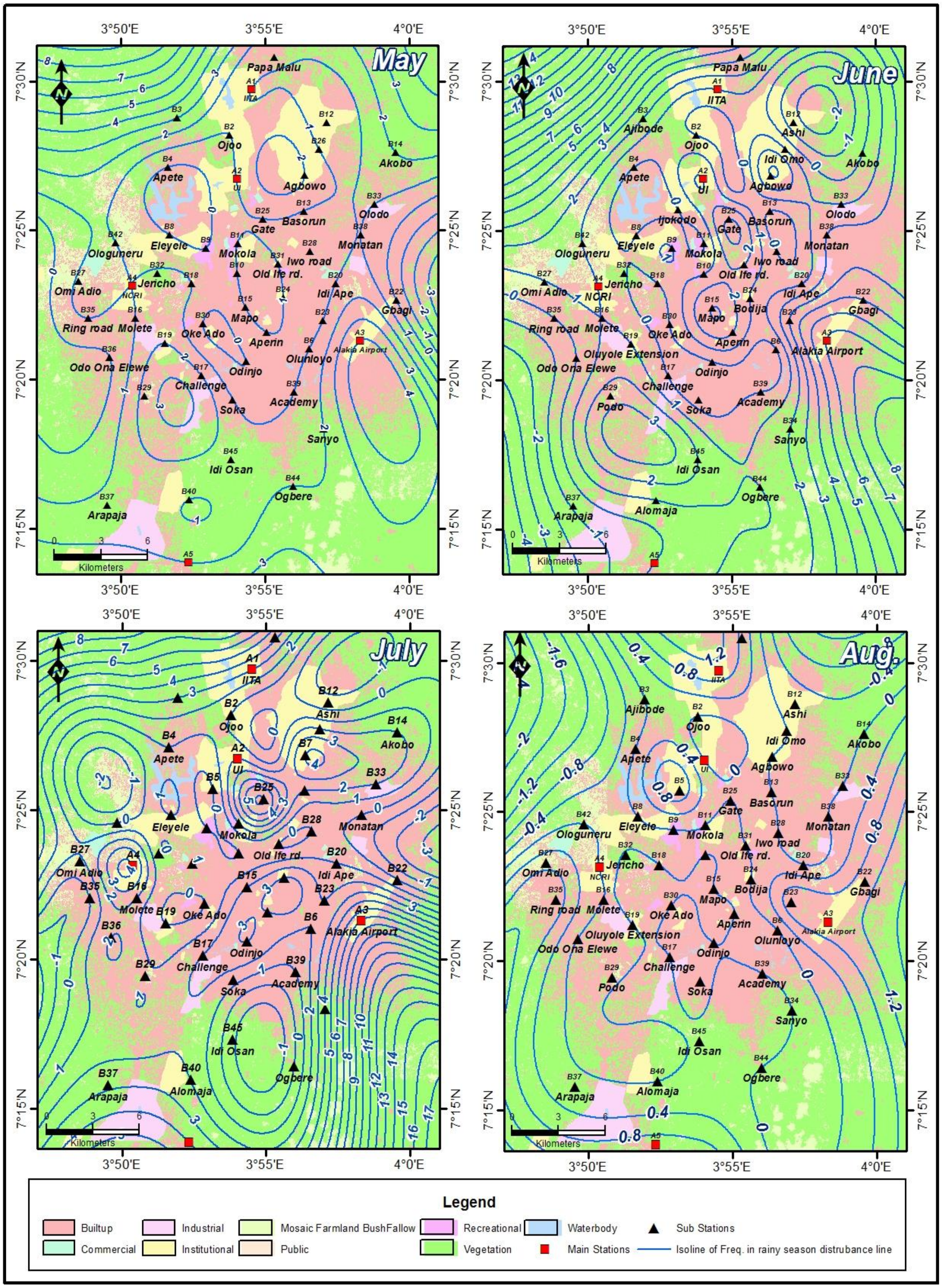


Figure 4.12: Spatial Pattern of Frequency of Rainstorms due to Thunderstorm during the Rainy Season in 2013

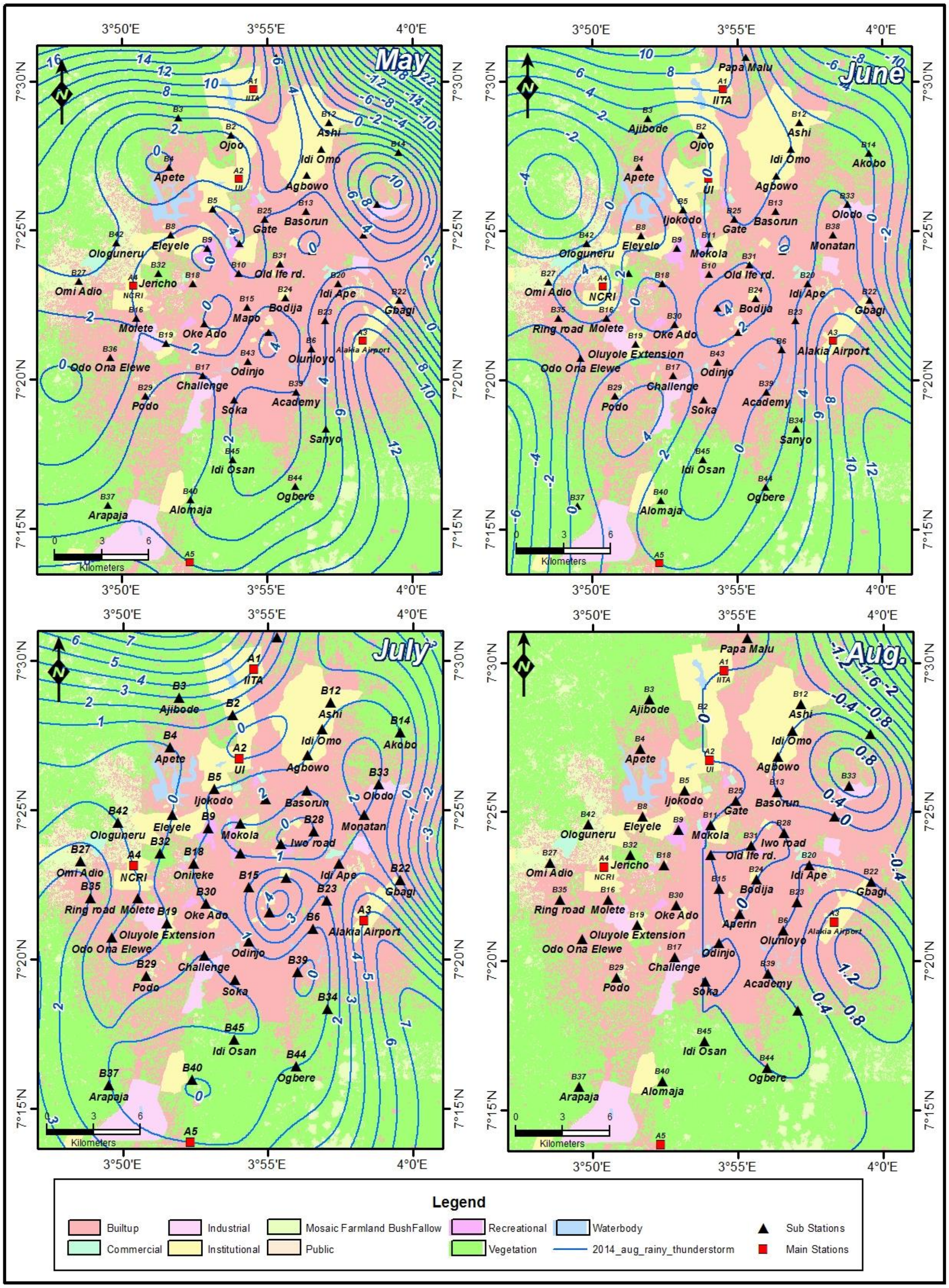


Figure 4.13: Spatial Pattern of Frequency of Rainstorms due to Thunderstorm during the Rainy Season in 2014

4.4.2 Spatial Pattern in the Duration of Rainstorms due to Thunderstorm in Ibadan

The spatial pattern of duration of rainstorms due to thunderstorm over the study area is illustrated in Figures 4.14, 4.16, 4.18 and 4.15, 4.17, 4.19, respectively. During the dry season in 2013, the highest duration of rainstorms was recorded at UI, a value of 210 minutes was recorded. It went low to 195 minutes at Alakia. At CRIN and Odinjo high-density residential landuse area, a value of 113 minutes was recorded. At Ologuneru low-density residential landuse area and NCRI institutional and medium-density landuse area, the dry season duration of rainstorms had values of 95 minutes and 75 minutes, respectively. At Omi-Adio and Gbagi commercial and medium-density residential landuse area, the values were 40 minutes and 39 minutes, respectively. Other landuse areas, such as Lagelu industrial area and Eleyele water body and medium-density area had 35 minutes and 33 minutes, respectively (Figure 4.14). However, during this period in 2013, the longest rainy phases, with duration of 210 minutes, was found on the northern section of upper lying zone of the city in the area around UI, the durations decreased, reaching 33 minutes and 30 minutes, were found on the northwestern and southwestern sections of the city in the around Eleyele water body and medium-density residential landuse area and Challenge.

The highest duration of rainstorms during the dry season in 2014 was recorded at Idi-Ape medium-density residential landuse area, with a value 225 minutes. It decreased to 210 minutes at Lagelu industrial area. At UI and Mokola, values of 195 minutes and 180 minutes were recorded, respectively. At Olunloyo high-density residential landuse area and CRIN, values of 165 minutes and 150 minutes were recorded, respectively. At Alakia, the value was 143 minutes. Other areas, such Babanla, Basorun and Ogbere high-, medium- and low-density residential landuse areas recorded value of 60 minutes. At NCRI and Challenge commercial and medium-density residential landuse area, the dry season rainstorms duration had a value of 30 minutes (Figure 4.15). However, during this period in 2014, the longest rainy phases, with durations of 225 minutes and 210 minutes, were found on the northern and southern sections of upper and lower lying zones of the city in the areas around Idi-Ape medium-density residential landuse area and Lagelu industrial area, the durations decreased, reaching 30 minutes and 25 minutes, were found on the northwestern and southwestern sections of the city in the around Eleyele and Challenge.

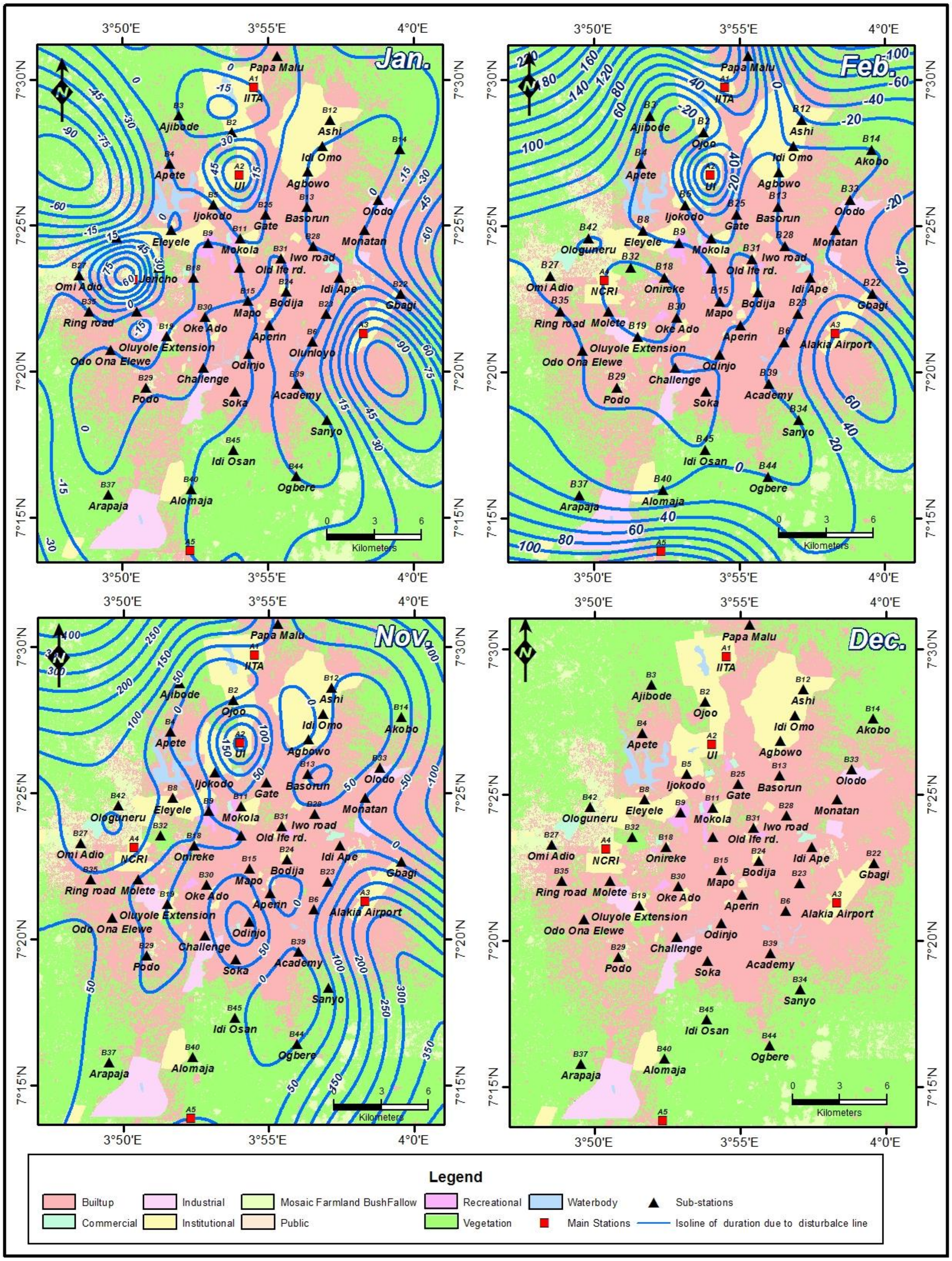


Figure 4.14: Spatial Pattern of Average Duration (mins) of Rainstorms due to Thunderstorm during the Dry Season in 2013

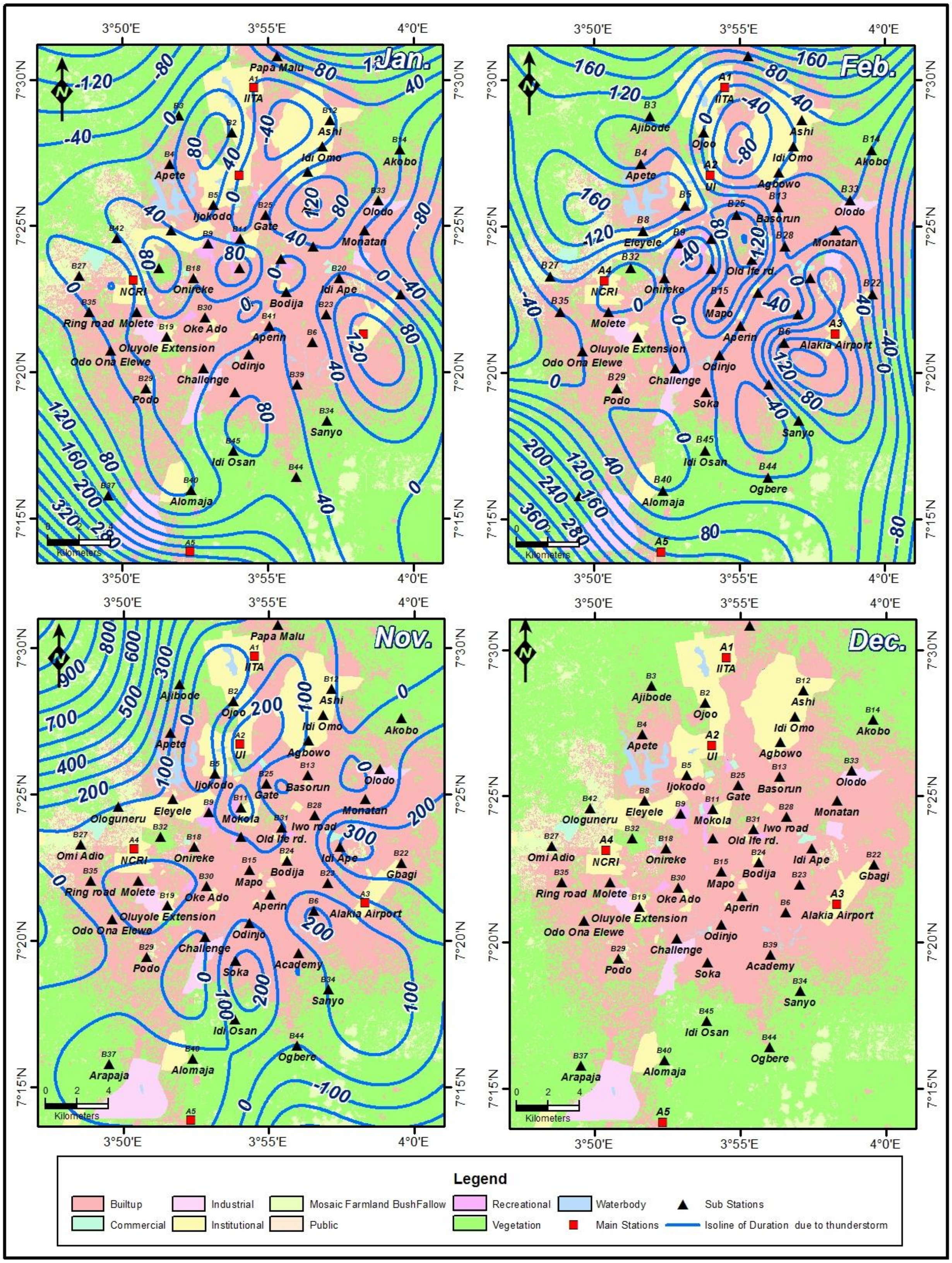


Figure 4.15: Spatial Pattern of Average Duration (mins) of Rainstorms due to Thunderstorm during the Dry Season in 2014

Furthermore, during the early rainy season in 2013, the duration of rainstorms varied between 38 minutes (the lowest at Eleyele) and 245 minutes at CRIN. It went low to 240 minutes and 235 minutes at low-density residential landuse areas of Ashi and Adegbayi, respectively. At Alakia, the value was of 233 minutes. At Odinjo and UI, values of 221 minutes and 203 minutes were recorded, respectively. The industrial areas of Oluyole and Lagelu, the values were 150 minutes and 111 minutes, respectively. At Mapo and Ijokodo, high-and medium-density residential landuse areas, the values in 2013 were 108 minutes and 90 minutes, respectively (Figure 4.16). However, during this period in 2013, the longest rainy phases were found in the areas around CRIN and Ashi, and lasted for 245 minutes and 240 minutes, respectively. The central axis of the city in the area around Mapo showed values between 108 minutes-99 minutes. The durations rose towards southern direction at the lower lying zone of the city.

Similarly, during the early rainy season in 2014, the duration of rainstorms varied between 10 minutes (the lowest at Olunloyo area and Idi-Omo) and 220 minutes at high-density residential landuse area of Academy. It was 210 minutes at Bodija high-density residential landuse area and Onireke, respectively. Molete medium-density residential landuse area and Olodo vegetative and low-density landuse area recorded 200 minutes and 180 minutes, respectively. UI and Alakia had values of 160 minutes and 134 minutes, respectively. CRIN and Babanla recorded 120 minutes. At Lagelu, the value was 110 minutes. Mapo and Ashi recorded 99 minutes and 70 minutes, respectively. Eleyele recorded a value of 45 minutes. No rainstorm duration was recorded at Oluyole and Iwo-Road commercial and medium-density landuse area during the early rainy season (Figure 4.17). However, during this period in 2014, the longest rainy phases were found in the areas around Academy and Bodija, and lasted for 220 minutes and 210 minutes, respectively. The central axis of the city in the area around Mapo high-density residential landuse area showed values between 98 minutes-90 minutes. The durations rose towards southern direction at the lower lying zone of the city.

In addition, during the late rainy season in 2013, the duration of rainstorms varied between 25 minutes (the lowest at Omi-Adio) and 227 minutes at Agbowo. It was 211 minutes and 192 minutes at Alakia and CRIN, respectively. At Eleyele, the value was

180 minutes. At Ologuneru, the value was 168 minutes. At Iwo-Road during the late rainy season, the duration was 116 minutes. At Ajibode vegetative and low-density residential landuse area, the value was 87 minutes. At Lagelu and Oluyole, the values were 59 minutes and 39 minutes, respectively (Figure 4.16). Besides, during this period in 2013, the longest rainy phases were found on the northern and southern sections of upper and lower lying zones with a maximum of 227 minutes and 211 minutes at Agbowo and Alakia, respectively. Conversely, the eastern section of the Gbagi and Adegbayi ranged showed short phases of 60 minutes-180 minutes, while the central section of the city in the area around Mapo and Ogbere, and Lagelu and Oluyole received rainfall for less than 60 minutes.

During the late rainy season in 2014, rainstorms duration varied between 20 minutes (the lowest at Basorun) and 233 minutes at low-density residential landuse area of Sanyo. It moved up to 180 minutes and 177 minutes at Olodo and Alakia, respectively. At Ajibode, the value was 90 minutes. It went low to 75 minutes at Challenge and 73 minutes and 45 minutes at Academy and Ogbere, respectively. At Lagelu and Oluyole, the values were 68 minutes and 55 minutes, respectively. At Eleyele, the value was 48 minutes (Figure 4.17). Besides, during this period in 2014, the longest rainy phases were found on the northern and southern sections of upper and lower lying zones with a maximum of 223 minutes and 180 minutes at Sanyo and Olodo, respectively. Conversely, the eastern section of the Alakia, and Gbagi and Adegbayi ranged showed short phases of 60 minutes-180 minutes, while the central section of the city in the area around Mapo and Ogbere, and Lagelu and Oluyole received rainfall for less than 60 minutes.

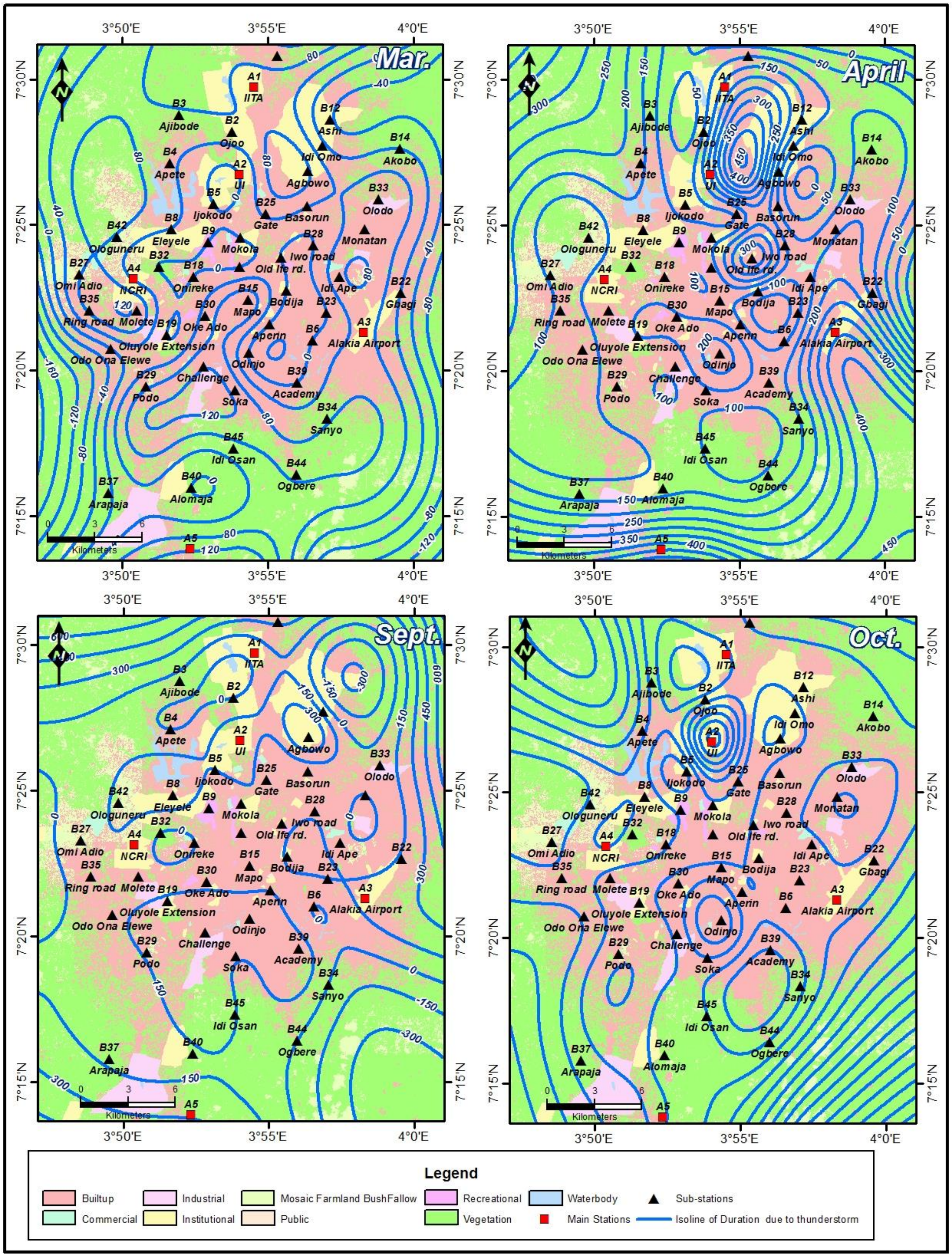


Figure 4.16: Spatial Pattern of Average Duration (mins) of Rainstorms due to Thunderstorm during the Early and Late Rainy Seasons in 2013

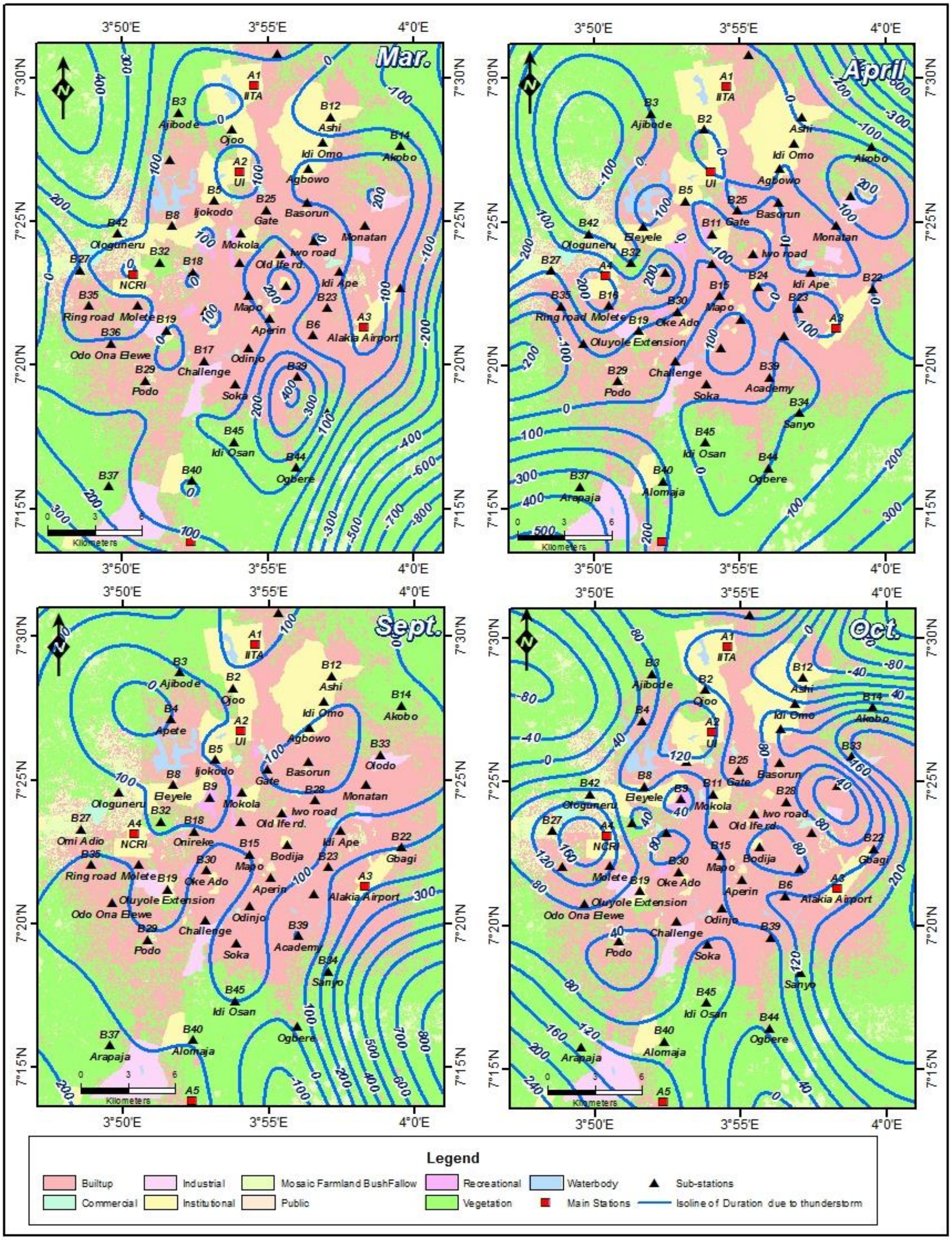


Figure 4.17: Spatial Pattern of Average Duration (mins) of Rainstorms due to Thunderstorm during the Early and Late Rainy Seasons in 2014

The highest rainstorm duration observed during the rainy season in 2013 was at the low-density residential landuse area of Idi-Osan, with a value of 240 minutes. UI had a value of 230 minutes. Ashi and Alakia followed, with values of 228 minutes and 224 minutes, respectively. The rainstorms duration, however, varied between Idi-Omo and Ajibode, with values of 223 minutes and 220 minutes, respectively and IITA, with a value of 215 minutes. At Eleyele, the value was 198 minutes. Both Molete and Monotan had values of 115 minutes and 90 minutes, respectively. NCRI had a value of 55 minutes. The values went low to 50 minutes and 20 minutes at Lagelu and Oluyole, respectively (Figure 4.18). Besides, during this period in 2013, the longest rainy phases, with durations of 240 minutes and 230 minutes, were found on the southern and northern sections of the city around Idi-Osan and UI, respectively. However, towards the western and southern sections in the areas around NCRI, Oluyole and Lagelu, the durations decreased, reaching 55 minutes, and 35 minutes and 30 minutes, respectively. A similar reduction appeared between Arapaja (less than 60 minutes) and Podo (less than 60 minutes).

The highest rainstorm duration observed during the rainy season in 2014 was at UI and CRIN, with values of 190 minutes and 180 minutes, respectively, and Alakia and Total Garden, with values of 175 minutes. Gbagi and Agbowo had a value of, 120 minutes. The rainstorms duration, however, varied between Ajibode, with a value of 93 minutes and Arapaja, with a value of 58 minutes. It went lower to 52 minutes at IITA. The lowest rainstorm duration due to thunderstorm was recorded at Bodija, with a value of 5 minutes. Both Oluyole and Lagelu had values of 35 minutes and 30 minutes, respectively (Figure 4.19). Moreover, during this period in 2014, the longest rainy phases, with durations of 190 minutes and 180 minutes, were found on the northern and southern sections of the city around UI and CRIN, respectively. However, towards the western and southern sections in the areas around NCRI and Oluyole and Lagelu, the durations decreased, reaching 55 minutes, and 35 minutes and 30 minutes, respectively. A similar reduction appeared between Arapaja (less than 60 minutes) and IITA (less than 60 minutes).

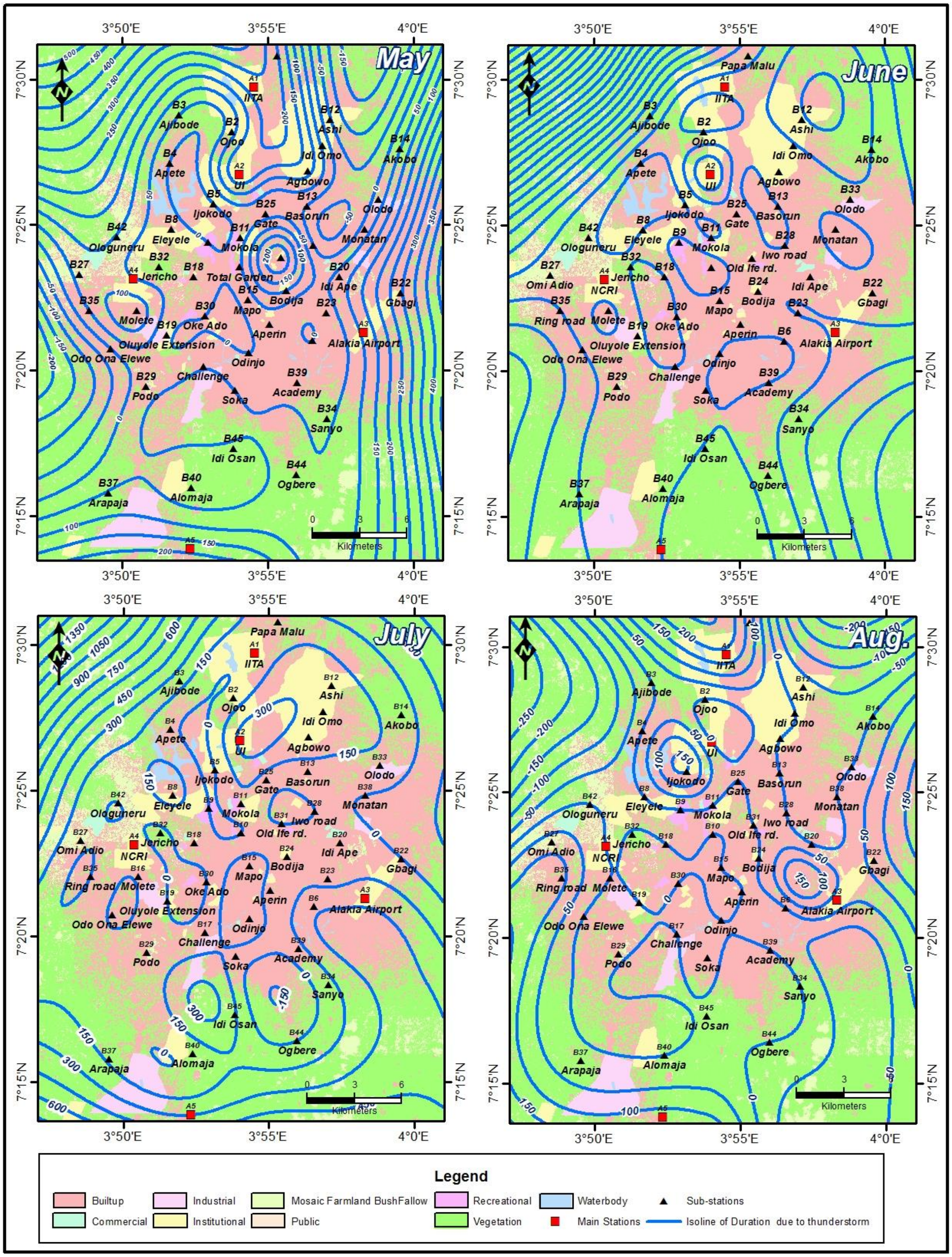


Figure 4.18: Spatial Pattern of Average Duration (mins) of Rainstorms due to Thunderstorm during the Rainy Season in 2013

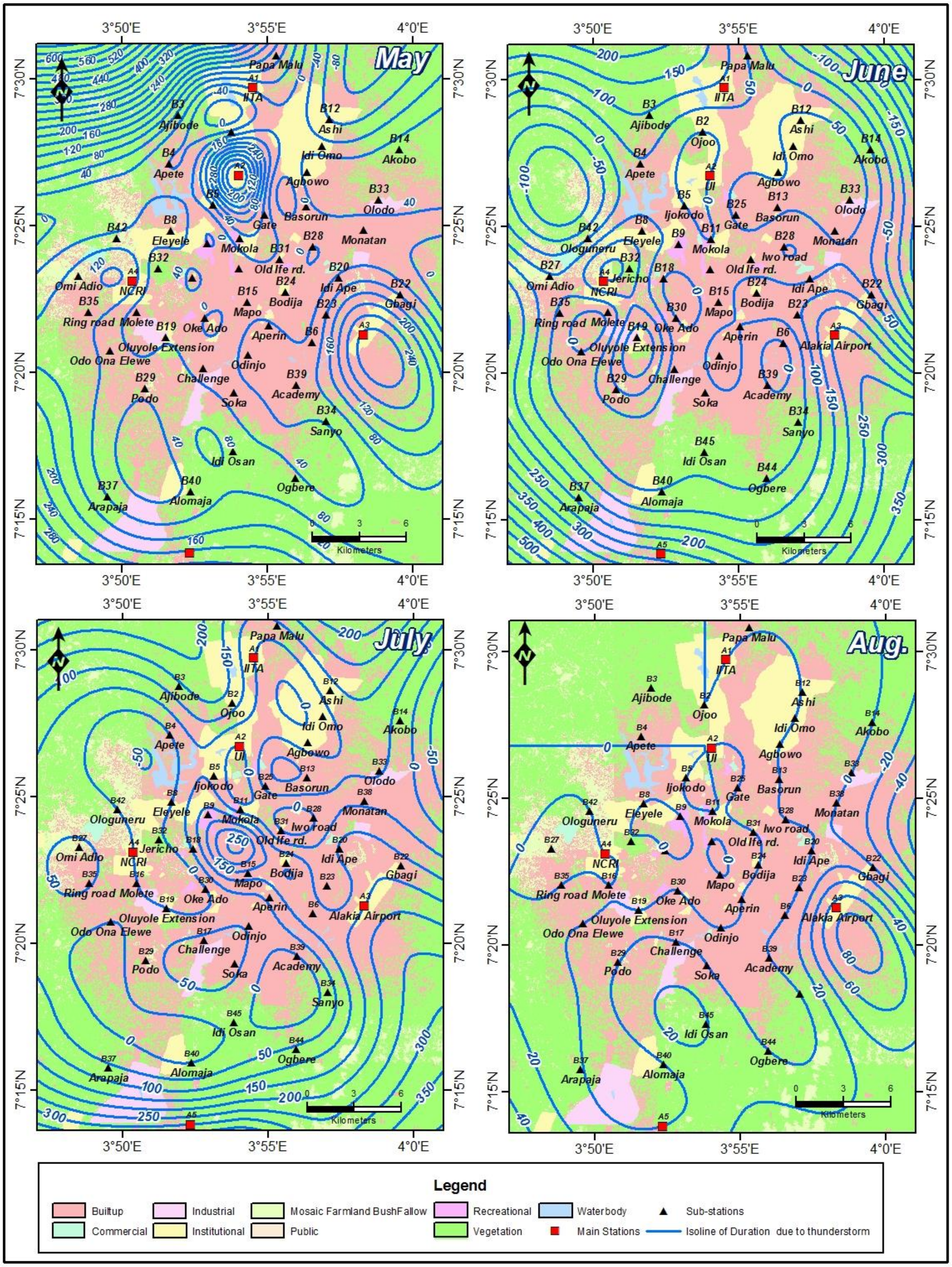


Figure 4.19: Spatial Pattern of Average Duration (mins) of Rainstorms due to Thunderstorm during the Rainy Season in 2014

4.4.3 Spatial Pattern in the Amount of Rainfall due to Thunderstorm in Ibadan

The spatial pattern of amount of rainfall due to thunderstorm over the study area is illustrated in Figures 4.20, 4.22, 4.24 and 4.21, 4.23, 4.25, respectively. Like overall thunderstorm events, rainfall amount followed a random distribution. The spatial patterns of rainfall amount due to thunderstorm were not in any way different from frequency of thunderstorm events patterns. During the dry season in 2013, the highest rainfall amount was recorded at CRIN, with a value of 24.7 mm. It went low to 24.3 mm at Alakia. At Ijokodo and Ologuneru, values of 22.0 mm and 14.0 mm were recorded, respectively. At Jericho and NCRI, 12.7 mm and 12.2 mm were recorded, respectively. At Ring-Road and IITA, 12.1 mm and 9.2 mm were recorded, respectively. Other landuse areas in Ibadan recorded a value between 7.8 mm and 1.0 mm (Figure 4.20). During the dry season in 2013, high rainfall amount was recorded in the southern section of the city in the area around CRIN; for this section, the “dry season rains” represent the most important period of rainfall in the course of the year. A relative minimum could be noticed on the northern section around IITA (9.2 mm).

During the dry season in 2014, the highest rainfall amount due was recorded at Mokola, with a value of 44.5 mm. It went low to 44.4 mm at Lagelu. At Arapaja, and Adegbayi and Ijokodo, 42.2 mm, 41.2 mm, and 40.4 mm were recorded, respectively. At Papa-Malu and Lagelu, 40.2 mm was recorded, respectively. At Alakia, the value was 37.2 mm. Other areas, such as Agbowo, Gbagi and Ojoo; Eleyele; Bodija and Mapo, and Challenge, and Ring-Road and Oke-Itunu, recorded a value of 10.0 mm (Figure 4.21). The same pattern held true for the dry season in 2014, just like that of the dry season in 2013 only that the northern axis around Mokola, had the highest rainfall amount, with a value of 44.5 mm.

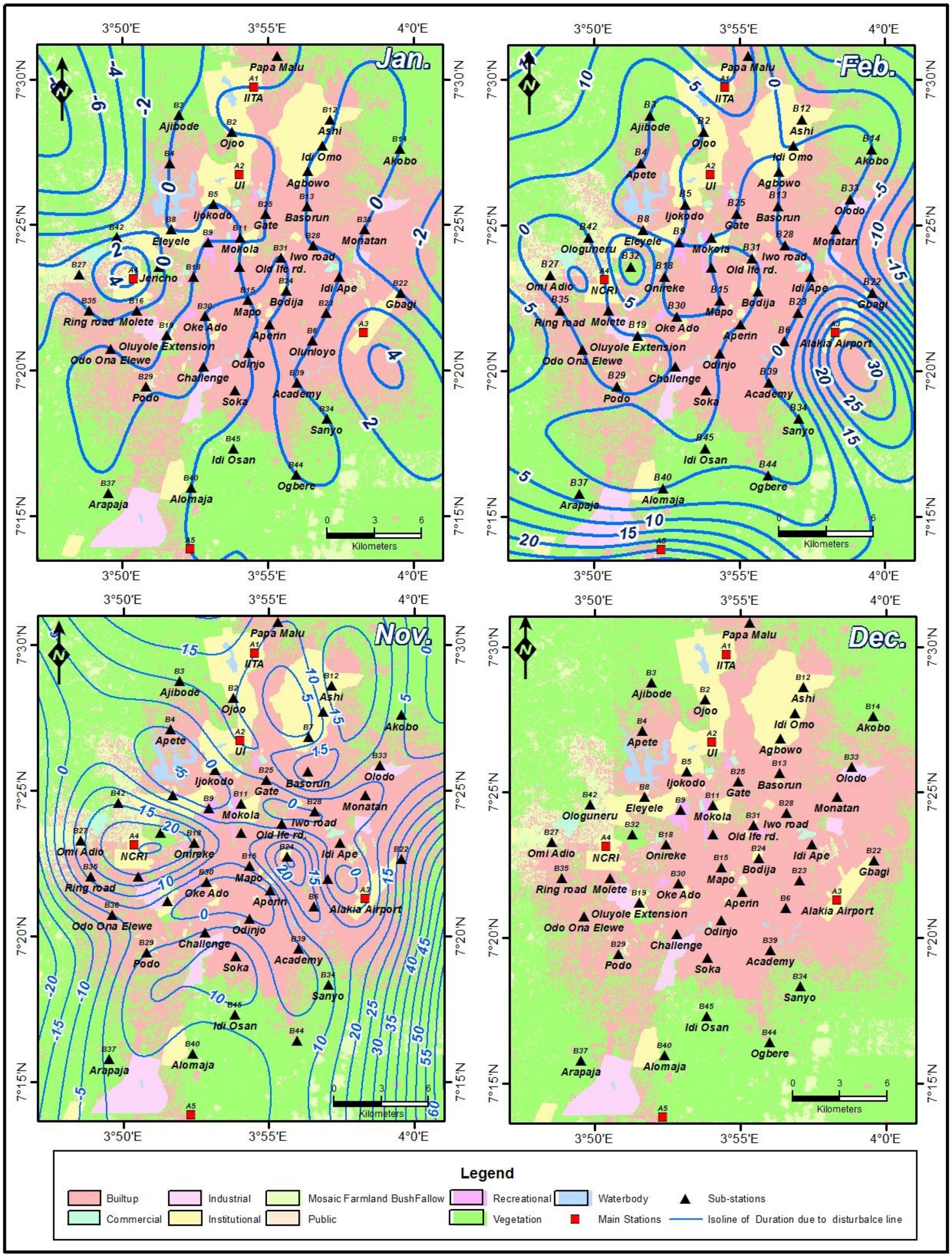


Figure 4.20: Spatial Pattern of Rainfall Amount (mm) due to Thunderstorm during the Dry Season in 2013

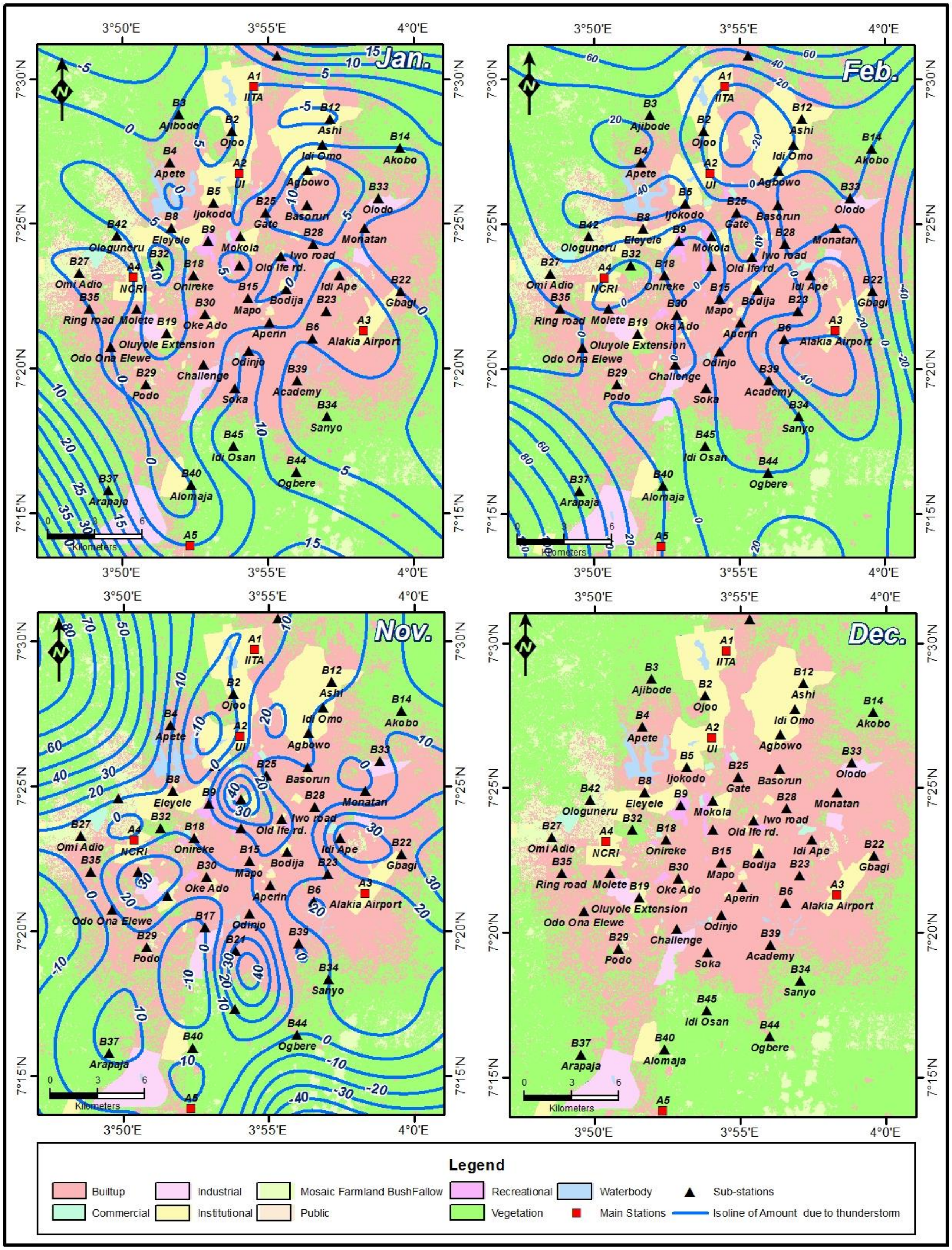


Figure 4.21: Spatial Pattern of Rainfall Amount (mm) due to Thunderstorm during the Dry Season in 2014

During the early rainy season in 2013, the rainfall amount varied between 3.1 mm (the lowest at NCRI) and 40.9 mm at Jericho (Figure 4.22). It was 32.4 mm at Aperin. At Onireke, the rainfall amount was recorded as 32.2 mm. Eleyele recorded a value of 31.2 mm. At Ashi, a value of 30.9 mm was recorded. Oluyole and Lagelu recorded values of 21.4 mm, and 20.9 mm, respectively. Alakia and IITA, and Ojoo, recorded values of 19.5 mm, 17.5 mm, and 17.4 mm, respectively. Agbowo, Idi-Osan and Sanyo; and Olodo, had values of, 16.0 mm, and 12.9 mm, respectively. Other areas in Ibadan, such as Ologuneru, UI, and Eleyele, recoded values of, 10.6 mm, 10.2 mm, and 7.4 mm, respectively (Figure 4.22). However, during the early season in 2013, there was an island of increased rainfall amount in the area around IITA-Olodo-Alakia-CRIN-NCRI-Mapo axis, reached at 27.1 mm – 46.8 mm. Although in every other section of the city, there was a reduction in the received rainfall amount due to this system.

Also, during the early rainy season in 2014, the rainfall amount varied between 0.2 mm (the lowest at IITA) and 57.8 mm at Odo-Ona Elewe. It was 57.6 mm, and 51.5 mm at NCRI, and Mokola, respectively. Eleyele, recorded a value of 48.7 mm. Molete and Onireke, had values of, 34.5 mm, and 30.8 mm, respectively. Other areas, such as Odinjo and Babanla, and Agbowo, recorded values of 29.7 mm, 29.4 mm, and 23.7 mm respectively (Figure 4.23). The same pattern held true during the early season in 2014, there was an island of increased rainfall amount in the area around IITA-Olodo-Alakia-CRIN-NCRI-Mapo axis, reached at 27.0 mm – 46.1 mm. Although in every other section of the city, there was a reduction in the received rainfall amount due to this system.

Further, during the late rainy season in 2013, rainfall amounts varied between 3.7 mm (the lowest at Challenge) and 112.7 mm at Eleyele. It was 40.0 mm at Agbowo. At Podo, the rainfall amount value during the late rainy season was put at 38.8 mm. At Ijokodo, the value of rainfall amounts was put at 35.8 mm. The rainfall amount values varied between 16.1 mm at UI, and 35.6 mm at CRIN and 30.4 mm at NCRI. At Idi-Omo, the late rainy season rainfall amount was 29.5 mm. However, at Lagelu and Oluyole, the rainfall amounts were recorded as 27.7 mm and 20.2 mm, respectively. Other areas, such as Basorun and Idi-Ape, Onireke and Apete and Idi-Osan, Ashi, Akobo and Ajibode and Olodo, recorded a value 12.5 mm (Figure 4.22). The pattern of rainfall amount during the late rainy season in 2013 is similar to that described in early rainy season, only that the received rainfall amount was relative high reached at 29.0 mm – 112.7 mm.

During the late rainy season in 2014, rainfall amount varied between 0.2 mm (the lowest at UI) and 38.3 mm at NCRI. It was 32.4 mm and 26.9 mm at Sanyo and Olodo, respectively. At Odinjo and Total Garden, the value of rainfall amount due to thunderstorm was 25.9 mm, and 25.7 mm, respectively. At Lagelu, the value of rainfall amount was 24.1 mm. It went low to 23.2 mm, 20.8 mm, and 19.1 mm at Arapaja, Ojoo, and Adegbayi and 18.9 mm and 18.0 mm at Ashi and Molete, respectively; 17.5 mm at Gbagi; 16.7 mm and 16.3 mm at Bodija, and Eleyele and 14.8 mm and 10.7 mm at IITA and Alakia, respectively. At CRIN, and UI, the value of rainfall amount was 8.7 mm, and 6.5 mm, respectively. Other areas, such as Ogbere, Monotan, and Basorun, recorded 5.8 mm, 4.5 mm, and 3.0 mm, respectively (Figure 4.23). The pattern of rainfall amount during the late rainy season in 2014 is similar to that described in early rainy season, only that the received rainfall amount was relative high reached at 31.0 mm – 110.2 mm.

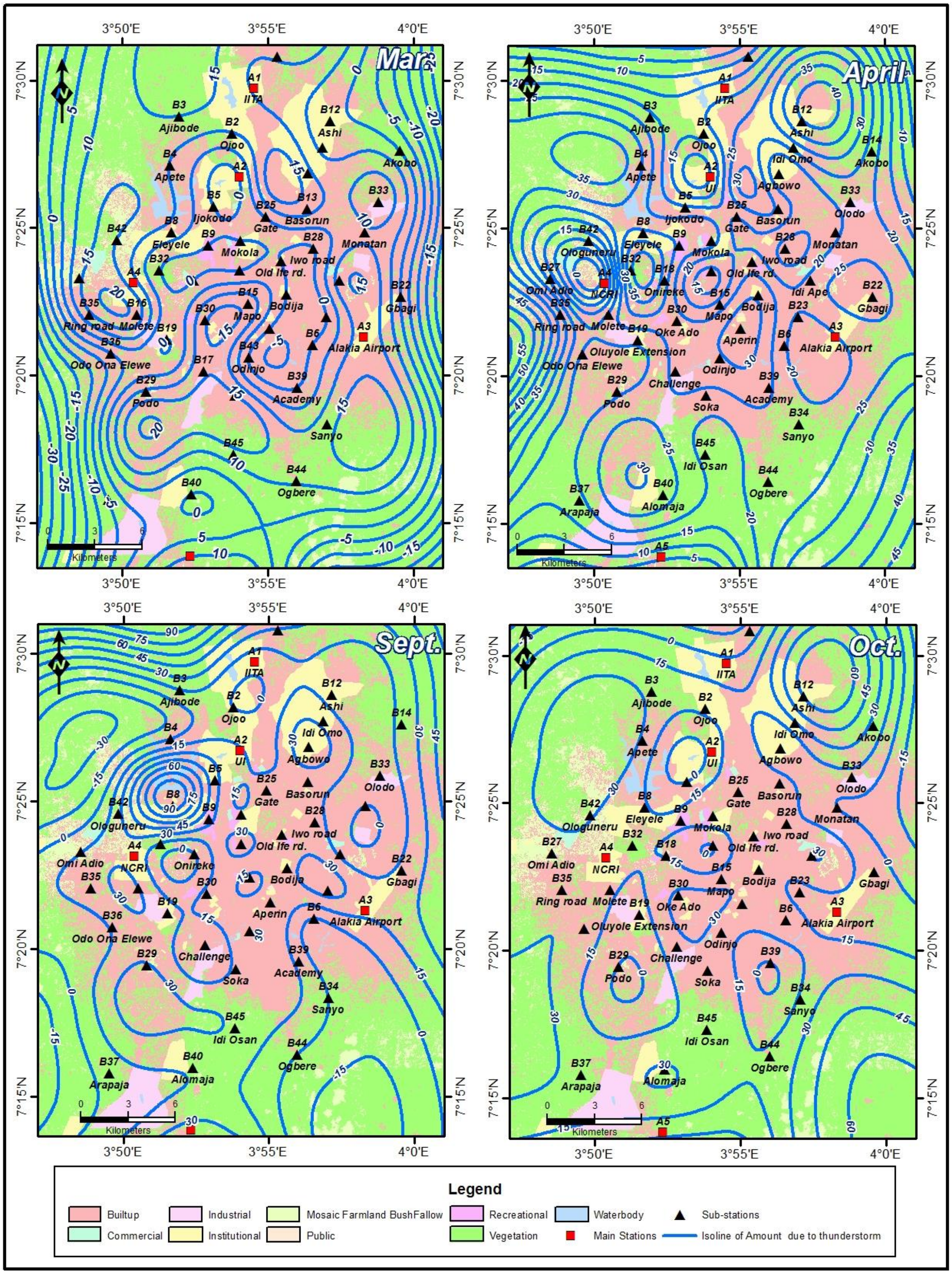


Figure 4.22: Spatial Pattern of Rainfall Amount (mm) due to Thunderstorm during the Early and Late Rainy Seasons in 2013

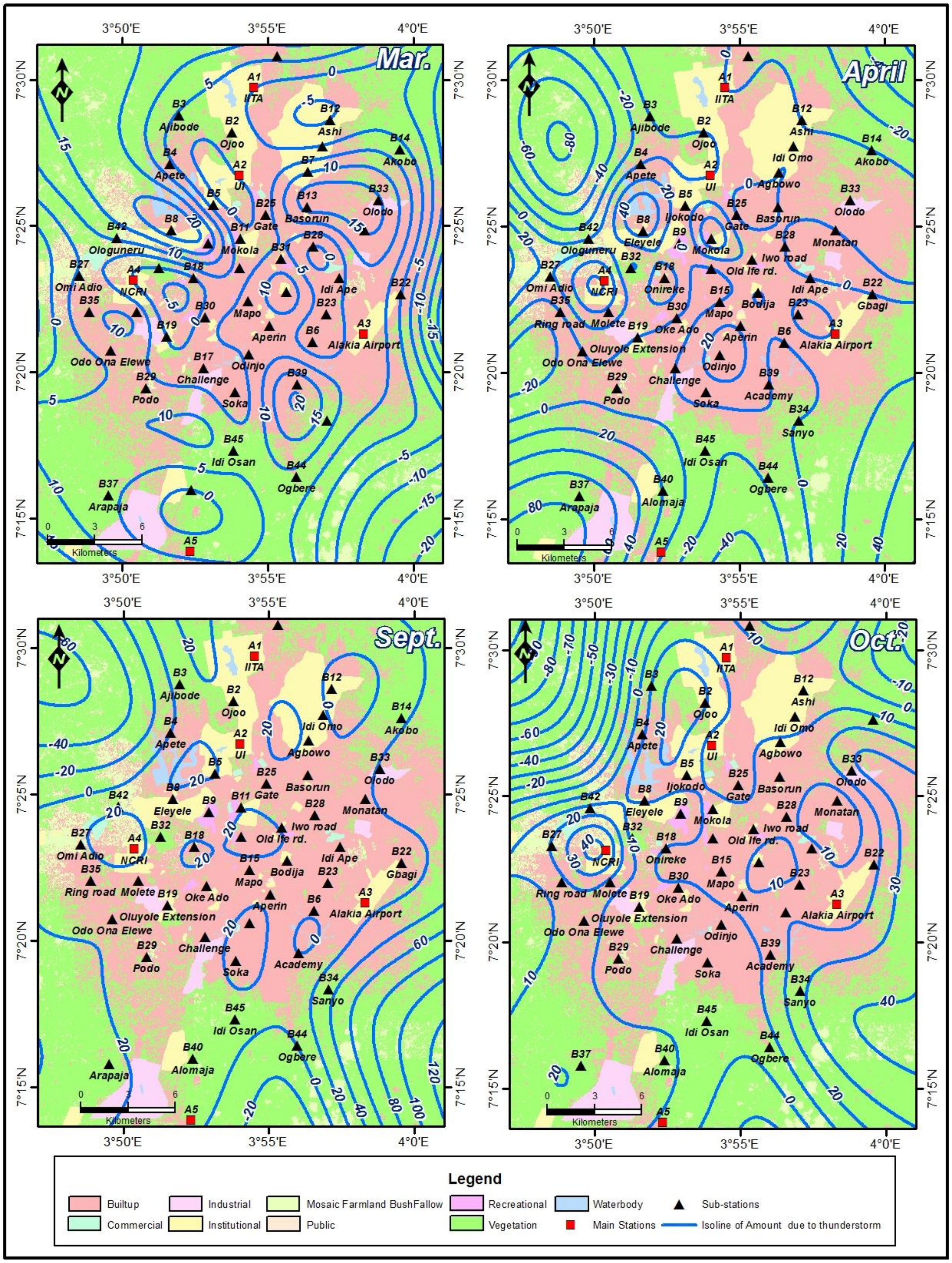


Figure 4.23: Spatial Pattern of Rainfall Amount (mm) due to Thunderstorm during the Early and Late Rainy Seasons in 2014

The highest rainfall amount observed during the rainy season in 2013 was at Ijokodo and Alakia, with 60.0 mm and 46.6 mm, respectively. Idi-Osan, and CRIN had 38.5 mm, and 37.0 mm, respectively; Monotan had 36.7 mm. Eleyele and Aperin had 36.0 mm and 29.9 mm, respectively. Babanla, and Gbagi, had 27.5 mm, and 27.0 mm, respectively. The rainfall amount during the rainy season went low, to 12.4 mm, at Lagelu. The lowest values of rainfall amount recorded were 2.3 mm and 2.0 mm at Oluyole and Adegbayi, respectively (Figure 4.24). As well, during the rainy season in 2013, rainfall amount was highest in the area around Ijokodo and northwest of the city, with 60.0 mm. Besides, towards the south, east and north, rainfall decreased rapidly. The central section showed total of about 29.9 mm.

Conversely, the highest rainfall amounts observed during the rainy season in 2014 were at Omi-Adio, and Oke-Itunu, with 50.2 mm, and 37.1 mm, respectively. Arapaja had a value of 34.9 mm; Odo-Ona Elewe followed, with 33.8 mm. Jericho, and Oke-Ado, had values of 32.5 mm, and 32.4 mm, respectively. The rainfall amount however varied between Papa-Malu, with 25.6 mm and Mokola, with 25.5 mm. It went lower, to 24.4 mm, at IITA. The lowest rainfall amount was recorded at UI, with 12.6 mm. Both Oluyole and Lagelu had values of 30.4 mm and 16.2 mm, respectively (Figure 4.25). During this period in 2014, rainfall amount was highest in the area around Omi-Adio and west of the city, with 50.2 mm. Besides, towards the south, east and north, rainfall decreased rapidly. The central section showed total of about 25.0 mm.

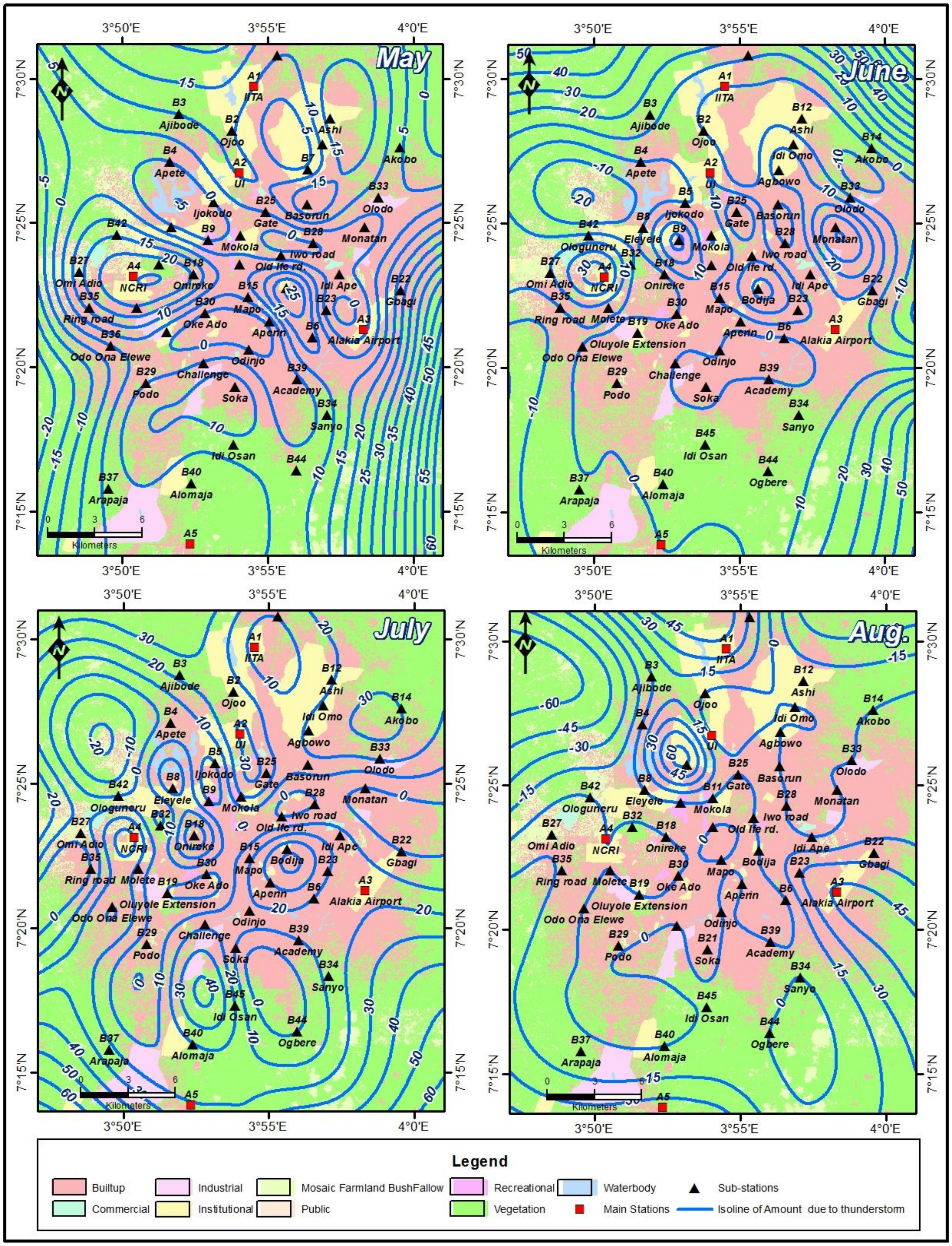


Figure 4.24: Spatial Pattern of Rainfall Amount (mm) due to Thunderstorm during the Rainy Season in 2013

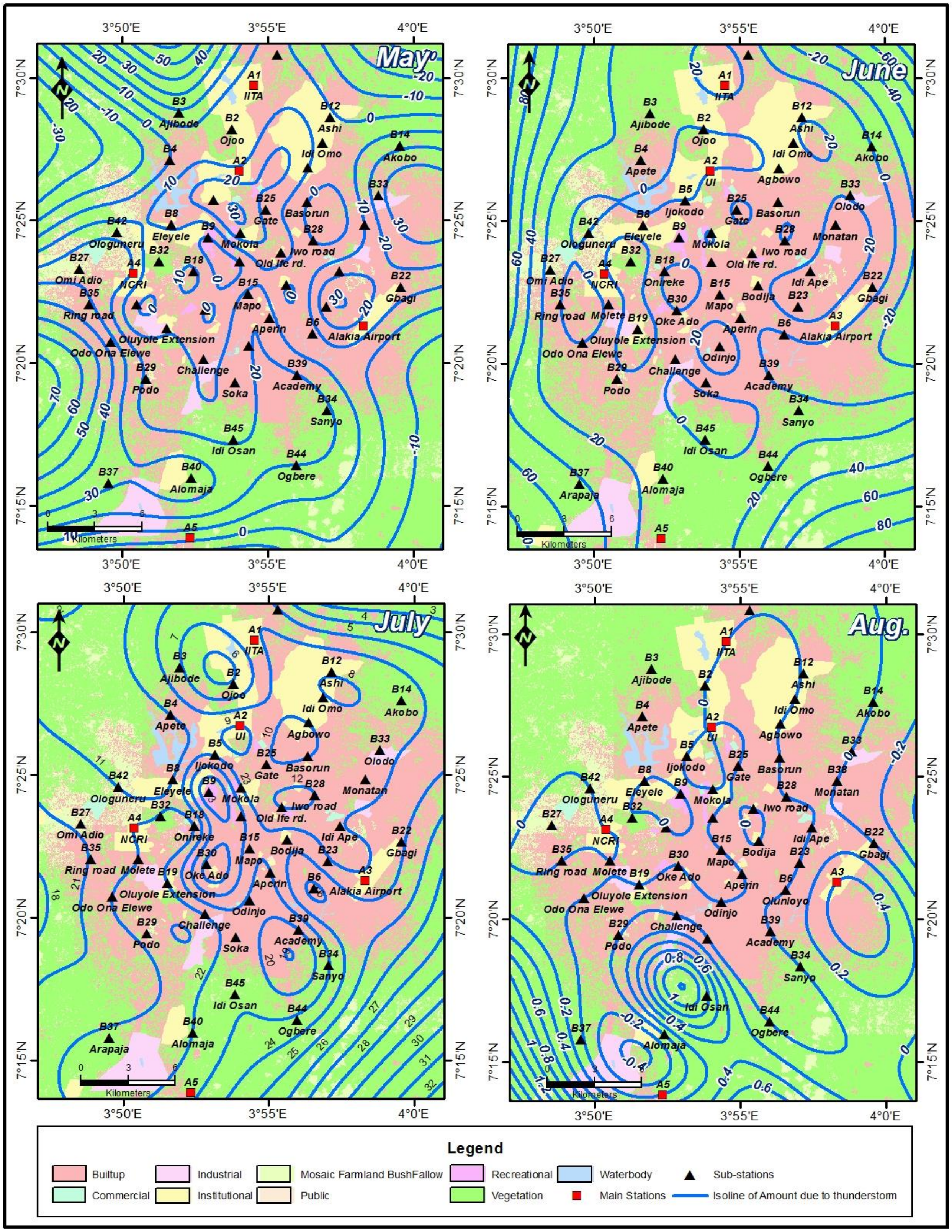


Figure 4.25: Spatial Pattern of Rainfall Amount (mm) due to Thunderstorm during the Rainy Season in 2014

4.5 Effect of Duration, Rainfall Amount and Speed of Rainstorms on the Areal Coverage of Rainstorms due to Thunderstorm during the Early and Late Rainy Seasons in Ibadan

This section examines the effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms due to thunderstorm during the early and late rainy seasons of 2013 and 2014 in Ibadan.

4.5.1 Effect of Duration, Rainfall Amount and Speed of Rainstorms on the Areal Coverage of Rainstorms due to Thunderstorm during the Early Rainy Season of 2013 and 2014

The effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms during the early rainy season of 2013 was examined. In this analysis, the regression model for all the variables was produced (as shown in Appendix II (a)). The correlation coefficient of areal coverage, duration, rainfall amount and speed of rainstorms revealed that during the early rainy season, duration (0.443) and rainfall amount (0.491) related directly with the areal coverage of rainstorms. But only speed of rainstorms (-0.419) related inversely with the areal coverage of rainstorms during the early rainy season of 2013. The correlation coefficient further revealed that there is significant correlation between the duration and rainfall amount during the early rainy season. The other variable compared with areal coverage of rainstorms as shown in Table 4.3, had no significant correlation.

As shown in Appendix II (a), an R value of 0.626, R^2 value of 0.392 and coefficient of determination value of 39.20%, mean that, jointly, the duration, rainfall amount and speed of rainstorms accounted for 39.20% variation in the areal coverage of rainstorms during the early rainy season. The p-value, (in Appendix II (a)), revealed that the independent variables, when taken together, were not significant predictors (0.295), explaining the areal coverage of rainstorms during the early rainy season of 2013. Therefore, the hypothesis one that states that areal coverage of rainstorms during the early rainy season is not a function of the duration, rainfall amount and speed of rainstorms was rejected.

The regression equation stating the relationship between the areal coverage of rainstorms and the duration, rainfall amount and speed of rainstorms during early rainy season is shown in Table 4.5. The R^2 statistics revealed that none of the predictor variables explaining the areal coverage of rainstorms during the early rainy season. However, the variable that contributed most to predicting the areal coverage of rainstorms during the early rainy season was rainfall amount (0.500), which means that X_2 was the one that gave the highest explanation on areal coverage of rainstorms during the early rainy season. However, the three independent variables were not significant at 0.05 level (that is, 0.928 mins; 0.323 mm; 0.244 ms^{-1}) (see Appendix II (a)). The predictive models of the independent variables are shown in Table 4.7.

The regression model for areal coverage of rainstorm and the duration, rainfall amount and speed of rainstorms was produced during the early rainy season in 2014. The correlation coefficient of areal coverage, duration, rainfall amount and speed of rainstorms during the early rainy season of 2014 revealed that during the early rainy season, duration (-0.171), rainfall amount (-0.252) and speed of rainstorms (-0.154) related inversely with the areal coverage of rainstorms. The correlation statistics further revealed that there is significant correlation between the duration and rainfall amount during the early rainy season. The other variable compared as shown in table 4.4 has no significant correlation.

As shown in Appendix II (b), an R value of 0.299, R^2 value of 0.90 and coefficient of determination value of 90.0%, means that jointly, the duration, rainfall amount and speed of rainstorms accounted for 90.0% variation in the areal coverage of rainstorms during the early rainy season of 2014. The p-value, (in Appendix II (b)), revealed that the independent variables, when taken together, were not significant predictors (0.828), explaining the areal coverage of rainstorms during the early rainy season of 2014. Therefore, the hypothesis one which states that areal coverage of rainstorms during the early rainy season is not a function of the duration, rainfall amount and speed of rainstorms was rejected.

The regression equation stating the relationship between the areal coverage of rainstorms and duration, rainfall amount and speed of rainstorms is shown in Table 4.7. The R^2 statistics revealed that none of the predictor variables explained the areal coverage of rainstorms during the early rainy season of 2014. However, the variable that contributed most to predicting the areal coverage of rainstorms during the early rainy season was duration of rainstorms (0.007), which means that X_1 was the one that gave the highest explanation on the areal coverage of rainstorms during the early rainy season. However, the three independent variables were not significant at 0.05 level (that is, 0.987 mins; 0.519 mm; 0.632 ms^{-1}) (see Appendix II (b)). The predictive models of the independent variables are shown in Table 4.7.

Table 4.3: Correlation Coefficient of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Thunderstorm during the Early Rainy Season of 2013

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Speed (ms^{-1})
Areal coverage (km^2)	1.00	0.443	0.491	-0.419
Duration (mins)		1.00	0.767**	-0.263
Rainfall amount (mm)			1.00	-0.65
Speed (ms^{-1})				1.00

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

Table 4.4: Correlation Coefficient of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Thunderstorm during the Early Rainy Season of 2014

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Speed (ms^{-1})
Areal coverage (km^2)	1.00	-0.171	-0.252	-0.154
Duration (mins)		1.00	0.556*	0.199
Rainfall amount (mm)			1.00	-0.033
Speed (ms^{-1})				1.00

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

4.5.2 Effect of Duration, Rainfall Amount and Speed of Rainstorms on the Areal Coverage of Rainstorms due to Thunderstorm during the Late Rainy Season of 2013 and 2014

The effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms during the late rainy season of 2013 and 2014 was examined. Regression result and model for the areal coverage, duration, rainfall amount and speed of rainstorms was produced for the late rainy season of 2013. The correlation coefficient between the areal coverage, duration, rainfall amount and speed of rainstorms during the late rainy season showed that, duration (0.075), rainfall amount (0.565), and speed (0.495) related directly with the areal coverage of rainstorms during the late rainy season of 2013 (as shown in Table 4.5). The correlation statistics further revealed that there was significant correlation between the duration and rainfall amount of rainstorms during the late rainy season of 2013.

As shown in Appendix II (c), an R value of 0.721, R^2 value of 0.521 and coefficient of determination value of 52.10%, means that, jointly, the duration, rainfall amount and speed of rainstorms accounted for 52.10% variation in the areal coverage of rainstorms during the late rainy season of 2013. The p-value of the model was 0.020, which was lower than 0.05. This implies that the model was significant at 0.05 level. Thus, the model was adequate for the prediction of variability in the areal coverage of rainstorms during the late rainy season. The p-value of the model also implies that the independent variables, when taken together, were significant predictors (0.020) at 0.05 level, explaining the areal coverage of rainstorms during the late rainy season in 2013. We, therefore, accept the alternative hypothesis, that there is a significant impact of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms during the late rainy season in 2013 (see Appendix II (c)).

The regression equation stating the relationship between the areal coverage of rainstorms and the duration, rainfall amount and speed of rainstorms is shown in Table 4.7. The variable that contributed most to predicting the areal coverage of rainstorms was rainfall amount (0.691), which means that X_2 was the one that gave the highest explanation on the areal coverage of rainstorms during the late rainy season. In addition, the rainfall amount was significant (0.023) at 0.05 level. The result means that the rainfall amount was significant and there was a strong relationship between the rainfall amount and the areal coverage of rainstorms during the late rainy season in 2013. However, the duration and speed were not significant at 0.05 level (that is, 0.285 mins; 0.172 ms^{-1}) (see Appendix II (c)). The predictive models of the independent variables are shown in Table 4.7.

The regression model for the areal coverage, duration, rainfall amount and speed of rainstorms was produced during the late rainy season of 2014. The correlation of coefficient of the areal coverage, duration, rainfall amount and speed of rainstorms revealed that, during the late rainy season, duration (-0.335) and rainfall amount (-0.197) related inversely with the areal coverage of rainstorms. But, only speed of rainstorms (0.215) related directly with the areal coverage of rainstorms during the late rainy season of 2014. The correlation table further revealed that there was significant correlation between the duration and rainfall amount during the late rainy season of 2014. The other variable compared, as shown in Table 4.6 had no significant correlation.

As shown in Appendix II (d), an R value of 0.380, R^2 value of 0.144 and coefficient of determination value of 14.40%, mean that, jointly, the duration, rainfall amount and speed of rainstorms accounted for 14.40% variation to the areal coverage of rainstorms during the late rainy season of 2014. The p-value of the model was 0.341, which was greater than 0.05. That is, the independent variables, when taken together, were not significant predictors. This implies that the model is inadequate for the prediction of variability in areal coverage of rainstorms during the late rainy season. Therefore, the hypothesis two which states that areal coverage of rainstorms during the late rainy season is not a function of the duration, amount and speed of rainstorms was rejected for the late rainy season of 2014.

The regression equation stating the relationship between the areal coverage of rainstorms and the duration, rainfall amount and speed of rainstorms is shown in Table 4.7. The R^2 statistics further revealed that none of the predictor variables explained the areal coverage of rainstorms during the late rainy season of 2014. However, the variable that contributed most to predicting the areal coverage of rainstorms was rainfall amount

(0.234) which means that X_2 was the one that gave highest explanation on the areal coverage of rainstorms during the late rainy season. However, the three independent variables were not significant at 0.05 level (that is, 0.206 mins; 0.536 mm; 0.623 ms^{-1}) (see Appendix II (d)). The predictive models of the independent variables are shown in Table 4.7.

Table 4.5: Correlation Coefficient of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Thunderstorm during the Late Rainy Season of 2013

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Speed (ms^{-1})
Areal coverage (km^2)	1.00	0.075	0.565*	0.495*
Duration (mins)		1.00	0.621**	-0.184
Rainfall amount (mm)			1.00	0.192
Speed (ms^{-1})				1.00

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

Table 4.6: Correlation Coefficient of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Thunderstorm during the Late Rainy Season of 2014

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Speed (ms^{-1})
Areal coverage (km^2)	1.00	-0.335	-0.197	0.215
Duration (mins)		1.00	0.833**	-0.278
Amount (mm)			1.00	-0.133
Speed (ms^{-1})				1.00

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

Table 4.7: Predictive Model Summary of Areal Coverage of Rainstorms due to Thunderstorm during the Early and Late Rainy Seasons of 2013 and 2014

Model S/N	Seasons	Prediction model
1	2013 early rainy season	Areal coverage $=265.850 - 0.046_{duration} + 0.500_{amount} - 0.398_{speed}$
2	2014 early rainy season	Areal coverage $=157.540 + 0.007_{duration} - 0.261_{amount} - 0.163_{speed}$
3	2013 late rainy season	Areal coverage $=59.114 - 0.297_{duration} + 0.691_{amount} + 0.307_{speed}$
4	2014 late rainy season	Areal coverage $=280.732 - 0.500_{duration} + 0.234_{amount} + 0.107_{speed}$

Model 1 can be expressed as:

$$y = 265.850 - 0.046X_1 + 0.500X_2 - 0.398X_3 \quad 4.1$$

Model 2 can be expressed as:

$$y = 157.540 + 0.007X_1 - 0.261X_2 - 0.163X_3 \quad 4.2$$

Model 3 can be expressed as:

$$y = 59.114 - 0.297X_1 + 0.691X_2 + 0.307X_3 \quad 4.3$$

Model 4 can be expressed as:

$$y = 280.732 - 0.500X_1 + 0.234X_2 + 0.107X_3 \quad 4.4$$

where:

X_1 is duration of rainstorms due to thunderstorm

X_2 is amount of rainfall due to thunderstorm

X_3 is speed of rainstorms due to thunderstorm

4.6 Comparison of the Duration of Rainstorms due to Thunderstorm between the Early and the Late Rainy Seasons of 2013 and 2014

This section is aimed at comparing the duration of rainstorms due to thunderstorm examined in this study between the early and the late rainy seasons in Ibadan. Paired Sample T-test was used to do this.

4.6.1 Comparison of the Duration of Rainstorms due to Thunderstorm between the Early and the Late Rainy Seasons of 2013

The comparison of the duration of rainstorms between the early rainy season and the late rainy season for 2013 is presented in this section. The analysis of two-independent sample comparison of means of duration of rainstorms between the early and the late rainy seasons was done using paired sample t-test method (see Appendix II (e)). The summary of the result is shown in Table 4.8. The results of the analysis of the differences between the mean of durations of rainstorms between the early and the late rainy seasons, (Table 4.8) revealed that there was no significant difference in the duration of rainstorms during the early and the late rainy seasons, with calculated T-value of 0.45, which was less than the T-critical value of 2.06 at 0.05 confidence level. This result means that the duration of rainstorms between both the early and the late rainy seasons did not vary significantly.

4.6.2 Comparison of the Duration of Rainstorms due to Thunderstorm between the Early and the Late Rainy Seasons of 2014

The comparison of the duration of rainstorms was examined between the early rainy season and the late rainy season of 2014 under the section. Table 4.8 shows the summary of the test of difference between the durations of rainstorms during the early and the late rainy seasons using paired sample t-test method (Appendix II (f)). The results of the analysis of the difference between the mean of durations of rainstorms between the early and the late rainy seasons, as seen in Table 4.8, revealed that there was no significant difference in the durations of rainstorms during the early and the late rainy seasons, with the calculated T-value of 0.83, which was less than the T-critical value of 2.04 at 0.05 confidence level. This result means that the duration of rainstorms between both the early and the late rainy seasons did not vary significantly. The implication of this result is that the durations of rainstorms in those two seasons did not differ.

4.7 Comparison of the Amount of Rainfall due to Thunderstorm between the Early and the Late Rainy Seasons of 2013 and 2014

This section is aimed at comparing the amount of rainfall due to thunderstorm examined in this study between the early and the late rainy seasons in Ibadan. Paired Sample T-test was used to do this.

4.7.1 Comparison of the Amount of Rainfall due to Thunderstorm between the Early and the late Rainy Seasons of 2013

The comparison of the amount of rainfall between the early rainy season and the late rainy season is presented in this section. The analysis of two-independent sample comparison of means of amount of rainfall between the early and the late rainy seasons was done using paired sample t-test method (see Appendix II (g)). The summary of the result is shown in Table 4.9. The results of the analysis of the differences between the mean of amounts of rainfall between the early and the late rainy seasons, (Table 4.9) revealed that there was no significant difference in the amount of rainfall during the early and the late rainy seasons, with calculated T-value of 0.58, which was less than the T-critical value of 2.06 at 0.05 confidence level. This result means that the amount of rainfall between both the early and the late rainy seasons did not vary significantly.

4.7.2 Comparison of the Amount of Rainfall due to Thunderstorm between the Early and the Late Rainy Seasons of 2014

The comparison of the amount of rainfall was examined between the early rainy season and the late rainy season of 2014 in this section. Table 4.9 shows the summary of the test of difference between the amounts of rainfall during the early and the late rainy seasons using paired sample t-test method (Appendix II (h)). The results of the analysis of the difference between the mean of amounts of rainfall between the early and the late rainy seasons, as seen in Table 4.9, revealed that there was no significant difference in the amount of rainfall during the early and the late rainy seasons, with the calculated T-value of 0.63, which was less than the T-critical value of 2.04 at 0.05 confidence level. This result means that the amount of rainfall between both the early and the late rainy seasons did not vary significantly. The implication of this result is that the amount of rainfall in those two seasons did not differ.

Table 4.8: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Duration of Rainfall due to Thunderstorm between the Early rainy season and the Late Rainy Season of 2013 and 2014

Season of duration of rainstorms	T-cal	T-critical	Level of significance	Year
Early and late rainy seasons	0.45	2.06	Not significant at 0.05 level	2013
Early and late rainy seasons	0.83	2.04	Not significant at 0.05 level	2014

Table 4.9: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Amount of Rainfall due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

Season of amount of rainfall	T-cal	T-critical	Level of significance	Year
Early and late rainy seasons	0.58	2.06	Not significant at 0.05 level	2013
Early and late rainy seasons	0.63	2.04	Not significant at 0.05 level	2014

CHAPTER FIVE

THE LIFETIME, SPEED AND AREAL COVERAGE OF RAINSTORMS DUE TO THUNDERSTORMS IN IBADAN

5.1 Characteristics of the Lifetime and Speed of Rainstorms due to Thunderstorm

This section is mainly based on the results obtained from the velocity of rainstorms due to thunderstorms observed over the city of Ibadan. The results obtained were analyzed and recorded over a two-year period (2013 to 2014). The patterns in the lifetime and speed of rainstorms were analyzed based on the Lafore and Moncrieff's (1989) classification of West African Mesoscale Convective System (MCS) trajectories based on duration and velocity. These include-the C1 class [Duration (D) < 9 hr; Velocity (V) < 10 $m.s^{-1}$] corresponds to short-lived slow-moving MCS. The C2 class [D > 9 hr; V < 10 $m.s^{-1}$] includes long-lived slow-moving MCS. The C3 class [D < 9 hr; V > 10 $m.s^{-1}$] corresponds to fast-moving short-lived systems; and the last C4 class [D > 9 hr; V > 10 $m.s^{-1}$] corresponds to fast-moving long-lived systems (see Appendix III).

A total of 54 and 71 speeds of rainstorm events were recorded during the 2013 and 2014 rainstorm events, respectively. The average speed of rainstorm events in 2013 was 6.5 ms^{-1} and the maximum speed was 79.4 ms^{-1}, while 0.2 ms^{-1} was the minimum. The standard deviation was 14.8. The year 2014 showed an average speed of rainstorms of 10.2 ms^{-1}. The maximum speed of rainstorms in this year was 174.2 ms^{-1}, while 0.2 ms^{-1} was the minimum with the standard deviation of 24.3 ms^{-1}. About 85% [D= 108 mins; V= 1.6 ms^{-1}] and 79% [D= 100 mins; V= 2.6 ms^{-1}] of the average speed of rainstorms in the study area was under the influence of the slow-moving systems, while the remaining 15% [D= 103 mins; V= 34.1 ms^{-1}] and 21% [D= 91 mins; V =38.5 ms^{-1}] was under the influence of the fast-moving systems in 2013 and 2014, respectively (Figure 5.1).

Majority of the rainstorms for the study period were influenced by slow-moving systems. In 2013, about 85% of the rainstorms lasted 108 minutes with velocity (average) 1.6 ms^{-1} were influenced by this slow-moving system. Similarly in 2014, about 79% of the rainstorms lasted 100 minutes with velocity (average) 2.6 ms^{-1} were influenced by this slow-moving system.

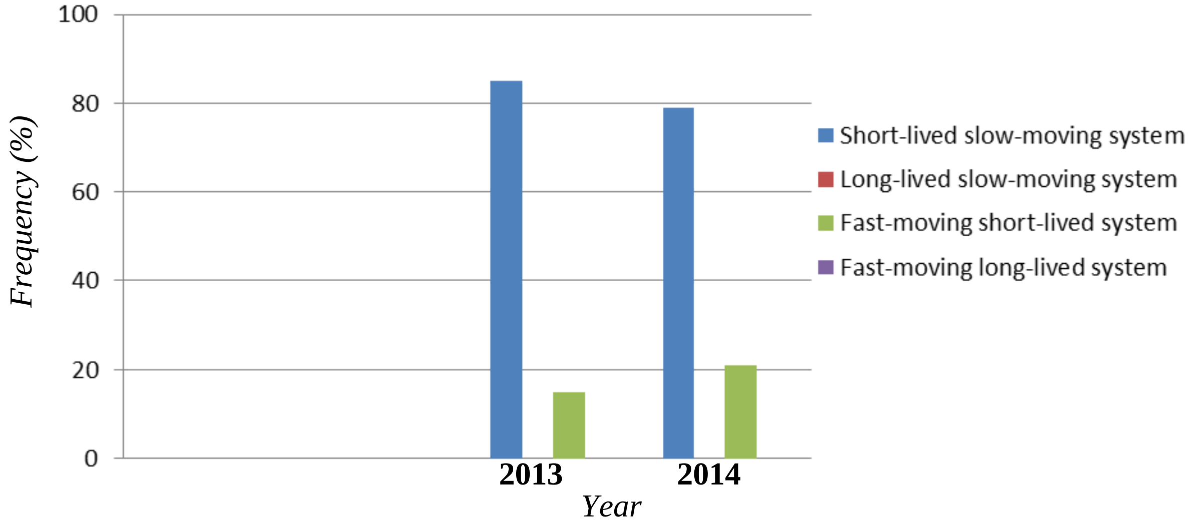


Figure 5.1: Pattern of the Lifetime and Speed of Rainstorms due to Thunderstorm in 2013 and 2014

5.2 Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Thunderstorm

The seasonal pattern in the lifetime and speed of rainstorms due to thunderstorm in 2013 and 2014 are illustrated in this section.

5.2.1 Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Thunderstorm in 2013

The seasonal pattern in the lifetime and speed of rainstorms due to thunderstorm in 2013 are illustrated in Figure 5.2. During the dry season months of November to February, about 100% [D= 80 mins; V= 0.5 ms^{-1}] of the average speed of rainstorms in the study area was under the influence of the slow-moving systems in 2013 (Figure 5.2).

The early rainy season of 2013 did not record any long-lived slow-moving system and fast-moving long-lived system in the study area. However, about 73% [D= 135 mins; V= 2.2 ms^{-1}] and 27% [D= 82 mins; V= 34.8 ms^{-1}] of the average speeds of rainstorms were recorded for the slow-moving systems and fast-moving systems, respectively (Figure 5.2).

During the late rainy season in 2013, slow-moving systems were the prevalent systems during the rainstorm events over the city of Ibadan in the two years (Figure 5.2). In 2013, about 88% [D= 112 mins; V= 2.4 ms^{-1}] and 12% [D= 100 mins; V= 28.7 ms^{-1}] of the average speeds of rainstorms were recorded for the slow-moving systems and the fast-moving systems, respectively (Figure 5.2).

During the rainy season in 2013 about 82% [D= 105 mins; V= 1.9 ms^{-1}] and 18% [D= 128 mins; V= 27.1 ms^{-1}] of the average speeds of rainstorms were recorded for the slow-moving systems and the fast-moving systems, respectively.

5.2.2 Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Thunderstorm in 2014

The seasonal pattern in the lifetime and speed of rainstorms due to thunderstorm in 2014 are illustrated in Figure 5.2. In 2014, about 75% [D= 88 mins; V= 2.2 ms^{-1}] of the average speed of the rainstorms during the dry season in the study area was under the influence of the slow-moving systems, while the remaining 25% [D= 65 mins; V= 58.7 ms^{-1}] was under the influence of the fast-moving systems around November (Figure 5.2).

The early rainy season 2014 did not record any long-lived slow-moving system and fast-moving long-lived system in the study area. However, about 85% [D= 113 mins; V= 1.9 ms^{-1}] and 15% [D= 157 mins; V= 57.5 ms^{-1}] were the slow-moving systems and fast-moving systems during the early rainy season in 2014, respectively (Figure 5.2).

During the late rainy season in 2014, about 84% [D= 109 mins; V= 2.5 ms^{-1}] and 16% [D= 90 mins; V= 17.4 ms^{-1}] of the average speeds of rainstorms were recorded for the slow-moving systems and the fast-moving systems. Other systems were completely absent during the late rainy seasons in 2014. In addition, the slow-moving systems and the fast-moving systems appeared to be the most prevalent systems over the city during the rainy seasons (Figure 5.2).

During the rainy season in 2014, about 72% [D= 85 mins; V= 3.1 ms^{-1}] of the average speeds of rainstorms were recorded for the slow-moving systems, while the remaining 28% [D= 82 mins; V= 39.5 ms^{-1}] accounted for the fast-moving systems (Figure 5.2).

It can be deduced from these results that there is seasonal variation in the pattern of the speed of rainstorms over the city during the 2013 and 2014 rainstorm events. The slow-moving systems accounted for the highest systems (100%, 75%, 73%, 85% and 88%, 84%, 82%, 72%) during the dry, the early, the late and the rainy seasons, respectively. The fast-moving systems followed with 25%, 27%, 15% and 12%, 16%, 18%, 28% next to the slow-moving systems, especially during the early and the late rainy seasons. Long-lived slow-moving systems and fast-moving long-lived systems were not recorded during the dry, the early, the late and the rainy seasons in 2013 and 2014 rainstorm events. The implication of these slow-and fast-moving systems over the study area during the dry, the early, the late and the rainy seasons in 2013 and 2014 is that the rainstorm event associated with the slow-moving systems may generate slow-onset floods. The floods usually last for a relatively longer period; it may last for one or more weeks, or even months. This can lead to loss of stock, damage to agricultural products, roads and rail links. The rainstorm events associated with fast-moving systems may generate rapid-onset floods. These lasts for a relatively shorter period; they usually last for one or two days only. Although this kind of flood lasts for a shorter period, it can cause more damage and pose a greater risk to life and property, as people usually have less time to take preventative actions during rapid-onset floods.

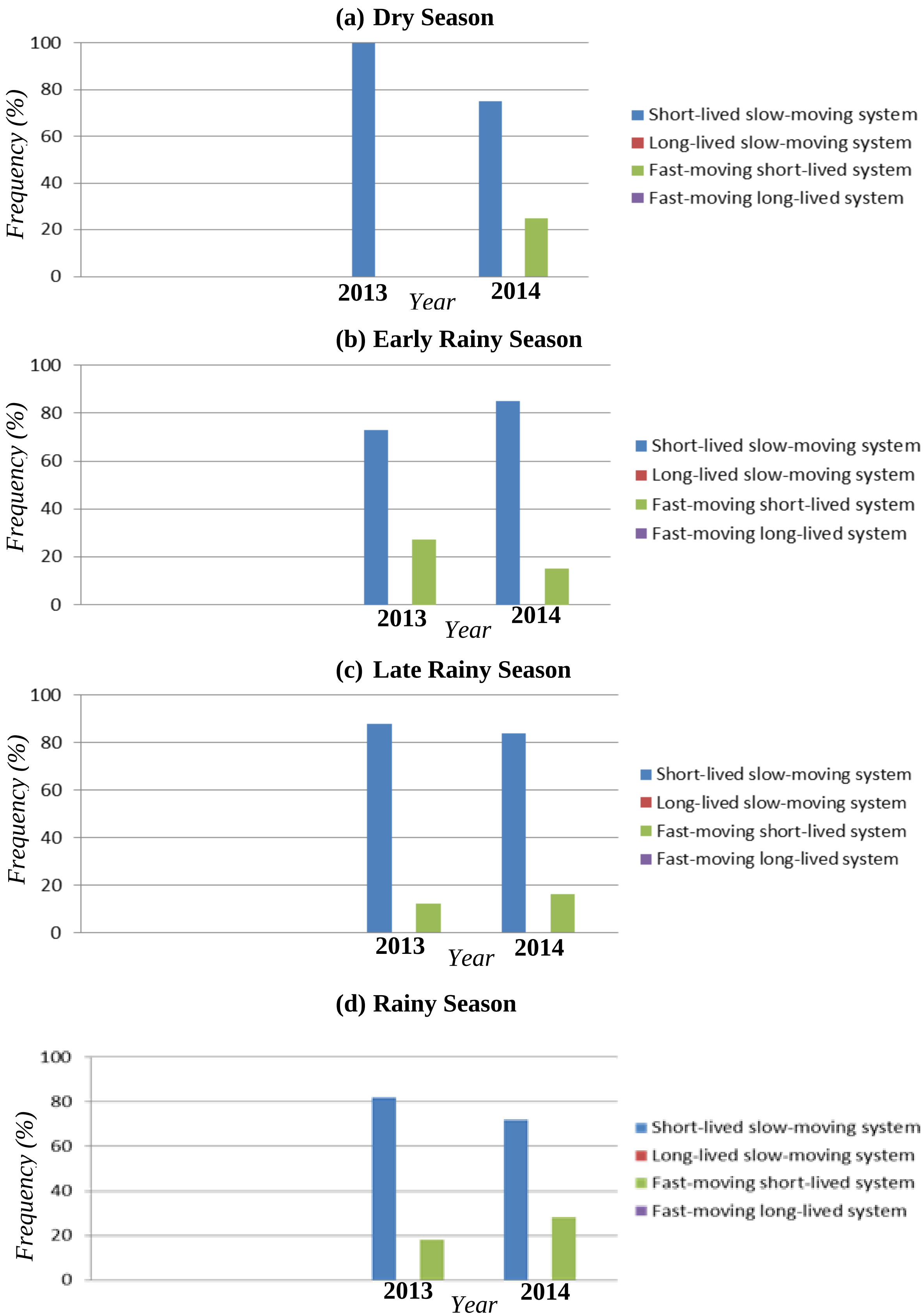


Figure 5.2: Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Thunderstorm at different Periods (a-d)

5.3 Speed of Rainstorms due to Thunderstorm between the Early rainy season and the Late Rainy Season

This section is aimed at comparing the speed of rainstorms due to thunderstorm examined in this study between the early and the late rainy seasons in Ibadan. Paired Sample T-test was used to do this.

5.3.1 Speed of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2013

The comparison of speed of rainstorms between the early rainy season and the late rainy season is presented under this section. The analysis of two-independent sample comparison of means of speed of rainstorms between the early and the late rainy seasons was done using paired sample t-test method (see Appendix IV (a)). The summary of the result is shown in Table 5.1. The results of the analysis of the differences between the mean of speeds of rainstorms between the early and the late rainy seasons (Table 5.1) revealed that there was no significant difference in the speed of rainstorms during the early and the late rainy seasons, with calculated T-value of 0.92, which was less than the T-critical value of 2.06 at 0.05 confidence level. Therefore, hypothesis three, which states that there are no significant differences in the speed of rainstorms during the early and the late rainy seasons, was rejected. This result means that the speed of rainstorms between both the early and the late rainy seasons did not vary significantly. The reason for this result is that during the early and late rainy seasons, the slow-moving and fast-moving systems were the prevailing speed systems and this might have made the speeds of rainstorms not to differ in those two seasons.

5.3.2 Speed of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2014

The comparison of the speed of rainstorms was examined between the early rainy season and the late rainy season of 2014 in this section. Table 5.1 shows the summary of the test of the difference between the speed of rainstorms during the early and the late rainy seasons using paired sample t-test method (Appendix IV (b)). The results of the analysis of the difference between the mean of speed of rainstorms between the early and the late rainy seasons, as seen in Table 5.1, revealed that there was no significant difference in the speed of rainstorms during the early and the late rainy seasons, with the calculated T-value of 0.89, which was less than the T-critical value of 2.04 at 0.05 confidence level.

Therefore, hypothesis three, which states that there are no significant differences in the speed of rainstorms during the early and the late rainy seasons, was rejected. This result means that the speed of rainstorms between both the early and the late rainy seasons did not vary significantly. The implication of this result is that the speed of rainstorms in those two seasons did not differ.

Table 5.1: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Speed of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

Season of speed of rainstorms	T-cal	T-critical	Level of significance	Year
Early and late rainy seasons	0.92	2.06	Not significant at 0.05 level	2013
Early and late rainy seasons	0.89	2.04	Not significant at 0.05 level	2014

5.4 Areal Coverage of Rainstorms due to Thunderstorm

The areal coverage of rainstorms due to thunderstorm during the period of the study, as observed from the data recorded in 2013 showed that the areal coverage of rainstorms ranged from 16.6 km^2 to as much as 426.4 km^2. The average areal coverage of rainstorms was 169.5 km^2, with standard deviation of 126.7. In 2014 the areal coverage of rainstorms, as observed from the total data recorded, showed that the areal coverage of rainstorms covered during this period ranged from 16.6 km^2 to as much as 355.2 km^2. The average areal coverage of rainstorms was 174.0 km^2. The standard deviation was 86.7. Figure 5.3 depicts the frequency distribution of the areal coverage of rainstorms in 2013 and 2014. As evident in the total data, 11% and 7% of rainstorms measured less than 50.0 km^2, 39% and 16% measured between 50.0 and 100.0 km^2, 13% and 45% measured between 100.0 and 200.0 km^2, while 37% and 32% measured between 200.0 km^2 and above in 2013 and 2014, respectively.

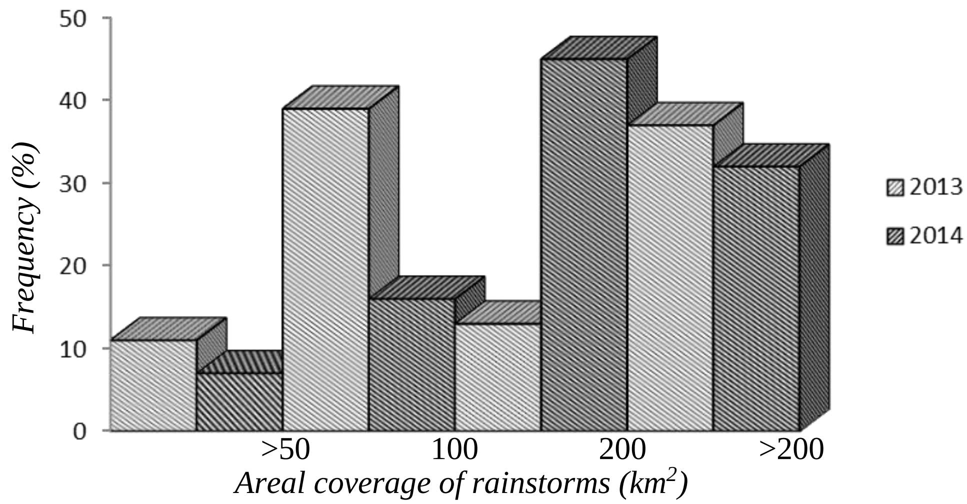


Figure 5.3: Areal Coverage of Rainstorms due to Thunderstorm

5.4.1 Distribution Pattern of the Areal Coverage of Rainstorms due to Thunderstorm

The pattern of the areal coverage of rainstorms due to thunderstorm events in 2013 and 2014 exhibited four distinct patterns: one each during the dry season months of November to February; the early rainy season months (March/April); the late rainy season months (September/October); and the main rainy season months of May to August (Figures 5.4).

5.4.1.1 Distribution Pattern of the Areal Coverage of Rainstorms due to Thunderstorm in 2013

The distribution patterns of the areal coverage of rainstorms due to thunderstorm in 2013 are illustrated in Figure 5.4. Generally, during the dry season of 2013, the highest areal coverage of rainstorms due to thunderstorm events was recorded in November as 326.6 km^2 (63.3% of the total area) followed by 61.6 km^2 (12.0%) in February; and 37.8 km^2 (7.3%) in January. The month of December recorded no rainstorm (Figure 5.4).

The pattern of the areal coverage of rainstorms relatively increased during the early rainy season, as a result of the moisture-laden maritime airmass; therefore, moisture was not a limiting factor for the areal coverage of rainstorm (Figure 5.4). Generally, during the early rainy season of 2013, the highest areal coverage of rainstorm events was recorded in April, as 426.4 km^2 (about 82.7% of the total area) followed by 313.4 km^2 (60.8%) in March.

By the late rainy season, the areal coverage of rainstorms changed and there was almost a northwest-and-southeast pattern. The areal coverage of rainstorms again decreased from the southern section to the northern section of the study area. Generally, during the late rainy season of 2013, the highest areal coverage of rainstorm events was recorded in October as 389.6 km^2 (about 75.6% of the total area) followed by 364.0 km^2 (70.6%) in September.

During the main rainy season, the pattern of the areal coverage changed, with the northern section and the area around the southeast section receiving higher coverage of rainstorms (Figure 5.4). At the peak of the rainy season (July), the northwest and the southeast sections of the city received the highest areal coverage of rainstorms due to thunderstorm. Generally, during the main rainy season of 2013, the highest areal coverage of rainstorm events was recorded in May as 327.4 km^2 (about 63.5% of the total area) followed by 280.2 km^2 (54.4%) in July; and 120.4 km^2 (23.4%) in June; and 88.4 km^2 (about 17.2%) in August.

5.4.1.2 Distribution Pattern of the Areal Coverage of Rainstorms due to Thunderstorm in 2014

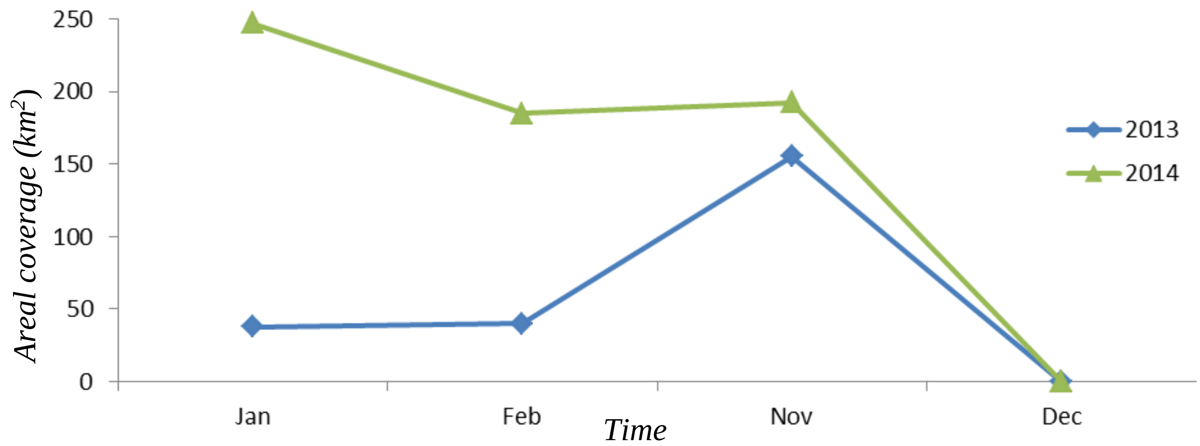
The distribution patterns of the areal coverage of rainstorms due to thunderstorm in 2014 are illustrated in Figure 5.4. During the dry season of 2014, the highest areal coverage of rainstorms due to thunderstorm events was recorded in November as 287.8 km^2 (55.8% of the total area) followed by 272.2 km^2 (52.8%) in January; and 185.2 km^2 (35.9%) in February; while the month of December recorded no rainstorm. This suggests that during the dry season, thunderstorm rainstorms coverage is dependent on the moisture content of the environment and not only on the local heating (Figure 5.4).

In 2014, the highest areal coverage of rainstorm events was recorded in April as 396.0 km^2 (about 82.7% of the total area) followed by 188.6 km^2 (36.6%) in March.

By the late rainy season of 2014, the highest areal coverage of rainstorm events was recorded in October as 355.2 km^2 (about 68.9% of the total area) followed by 314.6 km^2 (97.9%) in September (Figure 5.4).

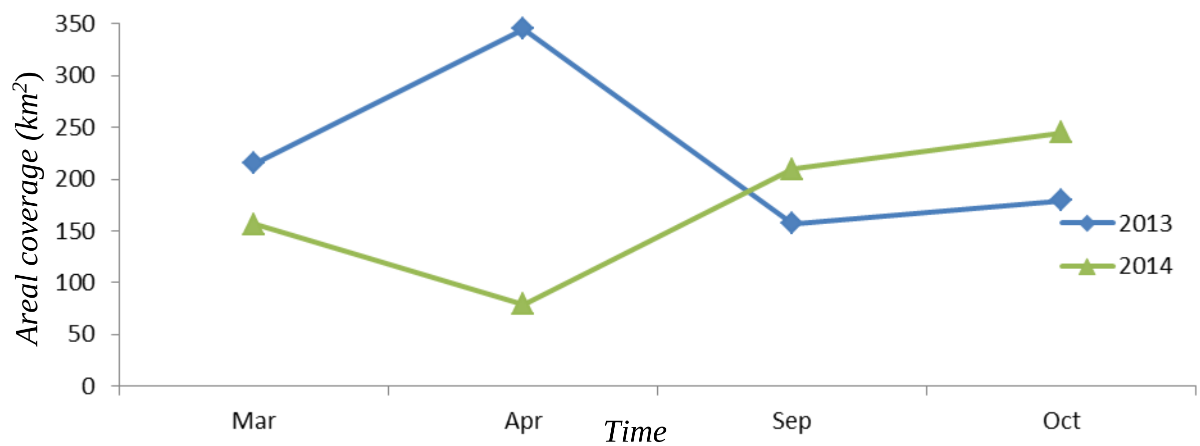
During the main rainy season in 2014, the highest areal coverage of rainstorm events was recorded in July as 268.8 km^2 (52.1% of the total area) followed by 241.4 km^2 (about 46.8%) in May; 197.4 km^2 (38.2%) in June; and 27.4 km^2 (5.3%) in August (Figure 5.4).

(a) Dry Period



(b) Early [March and April] and Late [September and October] Periods

(c)



(d) Rainy Period

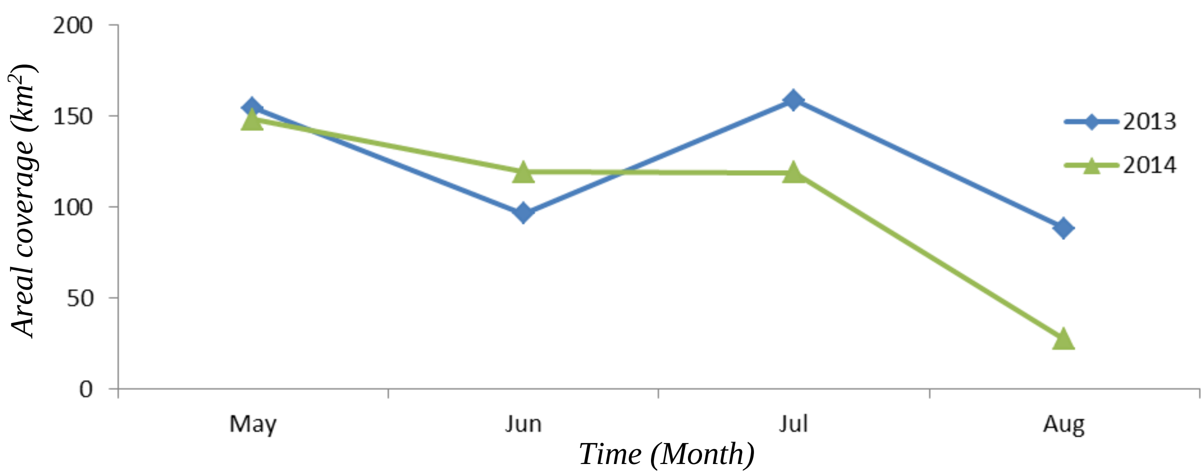


Figure 5.4: Areal Coverage of Rainstorms due to Thunderstorm at different Periods (a-c)

It can be deduced from these results that there is seasonal variation in the pattern of the areal coverage of rainstorms over the city during the dry season in 2013 and 2014 rainstorm events recorded the lowest areal coverage (about 63% and 55.8% in November, 12% and 52.8% in January, 7.3% and 35.9% in February, respectively) followed by areal coverage of rainstorms during the rainy season (about 63.5% and 46.8% in May, 23.4% and 38.2% in June, 54.4% and 52.1% in July and 17.2% and 5.3% in August next to the dry season areal coverage of rainstorms. The early rainy season areal coverage recorded about 60.8% and 36.6% in March and 82.7% and 82.7% in April of 2013 and 2014, respectively. The highest areal coverage of rainstorms was recorded during late rainy season month of October 2014, with a value of 97.9%. The implication of these variations in the pattern of the areal coverage of rainstorms over the city during 2013 and 2014 rainstorm events is that the rainstorm events associated with the highest areal coverage prevailed over the city in 2013 especially, while those with lowest areal coverage prevailed over the city in 2014. The rainstorm events associated with highest areal coverage covered a large area while those with lowest areal coverage covered only a small area. This phenomenon was observed during the dry season and towards the end of the rainy season in 2014. However, the seasonal variations in the areal coverage of rainstorms in 2013 and 2014 could be attributed to the climate change phenomenon.

5.5 Areal Coverage of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season

The section compares the areal coverage of rainstorms due to thunderstorm between the early and the late rainy seasons using paired sample t-test statistics.

5.5.1 Areal Coverage of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2013

The comparison of the areal coverage of rainstorms between the early rainy season and the late rainy season is captured in this section. The analysis of two-independent sample comparison of means of areal coverage of rainstorms between the early and the late rainy seasons was done using paired sample t-test method (Appendix IV (c)). The summary of the result is shown in Table 5.2. The analysis of the differences between the means of the areal coverage of rainstorms between the early and the late rainy seasons (Table 5.2) revealed that there was significant difference in the areal coverage of rainstorms during the early and the late rainy seasons, with calculated T-value of 3.36, which was greater than the T-critical value of 2.06 at 0.05 confidence level.

This result means that there was significant difference in the areal coverage of rainstorms during the early rainy season and the late rainy season. In other words, the result means that the areal coverage of rainstorms between the early rainy season and the late rainy season of 2013 varied significantly. Therefore, hypothesis four, which states that there are no significant differences in the areal coverage of rainstorms during the early and the late rainy seasons, was accepted. The implication of this result is that the rainstorms characteristics generating this areal coverage of rainstorms in both the early rainy season and the late rainy season differed.

5.5.2 Areal Coverage of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2014

The comparison of the areal coverage of rainstorms was examined between the early rainy season and the late rainy season of 2014 in this section. Table 5.2 shows the summary of the test of difference between the areal coverage of rainstorms during the early and the late rainy seasons using paired sample t-test method (Appendix IV (d)). The analysis of the difference between the means of areal coverage of rainstorms between the early and the late rainy seasons shown in Table 5.2, revealed that there was significant difference in the areal coverage of rainstorms during the early and the late rainy seasons, with the calculated T-value of 3.82, which was greater than the T-critical value of 2.04 at 0.05 confidence level.

This result means that the areal coverage of rainstorms between the early and the late rainy seasons varied significantly. Therefore, hypothesis four, which states that there are no significant differences in the areal coverage of rainstorms during the early and the late rainy seasons, was accepted. This result has shown that the areal coverage of rainstorms during the early and the late rainy seasons differed. These findings are in consonance with studies conducted by Huff and Changnon (1971), Grimmond et al. (1998) and Arnfield (2003).

Table 5.2: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Areal Coverage of Rainstorms due to Thunderstorm between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

Season of areal coverage of rainstorms	T-cal	T-critical	Level of significance	Year
Early and late rainy seasons	3.36	2.06	Significant at 0.05 level	2013
Early and late rainy seasons	3.82	2.04	Significant at 0.05 level	2014

CHAPTER SIX

RAINSTORMS DUE TO DISTURBANCE LINES IN IBADAN

6.1 Characteristics of Rainstorms due to Disturbance Lines

The total frequencies of rainstorms due to disturbance lines events recorded from January to December were 19 and 10 during the 2013 and 2014 rainstorm events, respectively. During the 2013 rainstorm events, the rainstorms lasted between 10 minutes and 185 minutes. In cases where the rainstorms extended for a long period of time, a greater proportion of the period was due to intermittent rainstorms and showers. The average duration was 90 minutes, with a standard deviation of 41. However, in 2014, the rainstorms lasted between 46 minutes and 240 minutes. The average duration was 175 minutes, with a standard deviation of 95. In the two data sets, the frequency distribution of duration indicated that only 5.3% and 50% lasted more than 180 minutes, while 94.7% lasted between 30 and 180 minutes in 2013 and 2014, respectively (Figure 6.1).

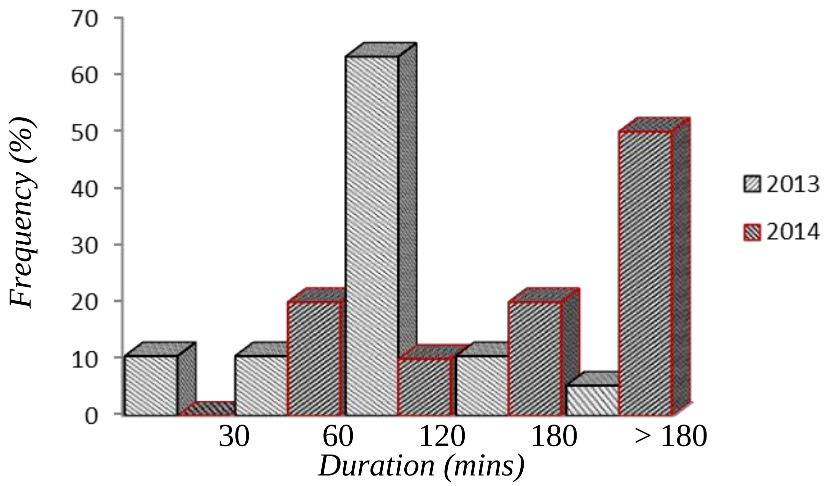


Figure 6.1: Duration of rainstorms due to Disturbance Lines

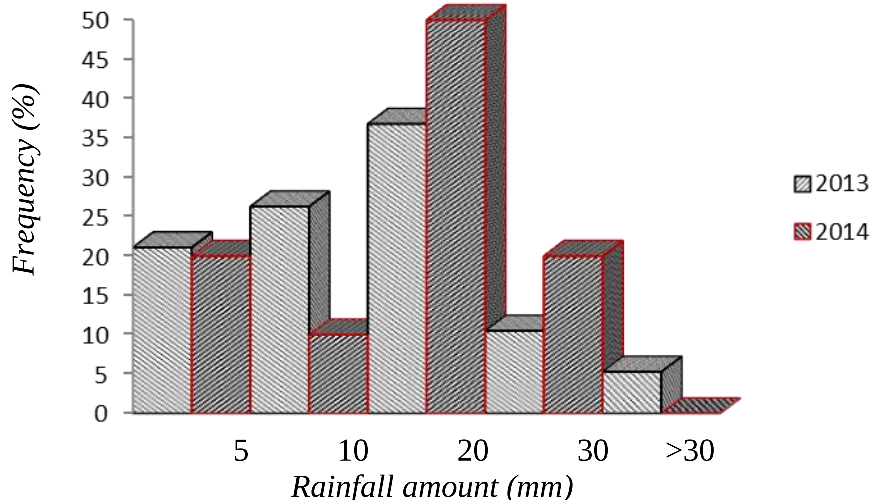


Figure 6.2: Rainfall Amount due to Disturbance Lines

In 2013 rainstorm events, the rainfall amount produced ranged between 1.3 mm and 35.8 mm, with an average of 12.3 mm. The standard deviation was 9.1. However, in 2014, the rainfall amount produced ranged between 3.3 mm and 27.5 mm, with an average of 13.6 mm. The standard deviation for this data was 8.2.

Figure 6.2 shows the frequency distribution of rainfall amount. In the two data, it was found that there were variations in the frequency of occurrence of rainstorms. The frequency of occurrence of rainfall events during the 2013 rainstorms events was greater than the frequency of occurrence of rainfall events in 2014. The results indicated that the amounts of rainfall in 2013 were more than the amounts of rainfall in 2014. This also manifested in the standard deviation values. Figure 6.2 shows the frequency distribution of rainfall amount. Also, 21.1% and 20% of rainfall amount measured less than 5.0 mm, while 5.3% and less than 1% measured above 30.0 mm in 2013 and 2014, respectively.

Similarly, a total of 19 rainstorms due to disturbance lines events in 2013 showed an average rainfall intensity of 0.28 mm h^{-1}. Also, 2.56 mm h^{-1} was the maximum rainfall intensity due to disturbance lines events in this data, while 0.10 mm h^{-1} was the minimum. The standard deviation was 0.56.

On the other hand, a total of 71 rainstorms in 2014 showed an average rainfall intensity of 0.14 mm h^{-1}. The maximum rainfall intensity was 0.34 mm h^{-1} and was 0.03 mm h^{-1} was the minimum. The standard deviation was 0.18. In the two data sets, it was found that there were variations in the average rainfall intensity.

The intensity of rainfall during the 2013 rainstorms events was greater than the intensity of rainfall events in 2014. The results indicated that the intensities of rainfall in 2013 were more than the intensities of rainfall in 2014. This also manifested in the standard deviation values. Figure 6.3 shows the frequency distribution of rainfall intensities. Also, 21% and 10% of rainfall intensity measured less than 0.05 mm h^{-1}, while 11% and 70% measured between 0.05 and 0.10 mm h^{-1}, 36% and 10% between 0.10 and 0.20 mm h^{-1}, 16% and 10% between 0.20 and 0.30 mm h^{-1} and 16% and 10% measured above 0.30 mm h^{-1} in 2013 and 2014, respectively.

During the 2013 rainstorm events, wind gusts associated with this type of rainstorm ranged between 22 and 48 knots, with an average of 32 knots and standard deviation of 8.6. Also, during the 2014 rainstorm events, wind gusts associated with this type of rainstorm ranged between 22 and 48 knots, with an average of 34 knots and standard deviation of 7.2. The direction of the disturbance lines was generally from the east or north-east. The result supports the findings of Sekoni (1992).

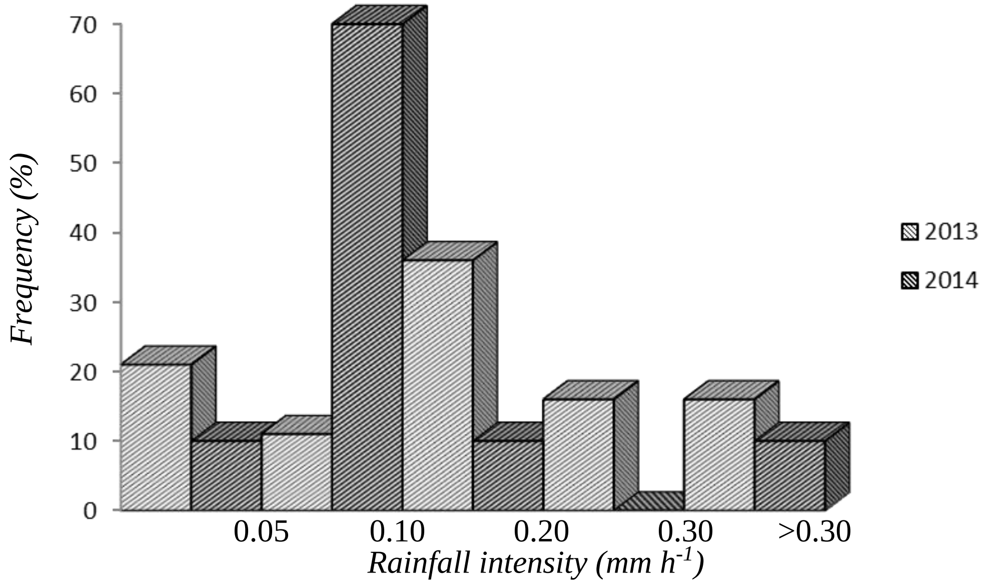


Figure 6.3: Rainfall Intensity due to Disturbance Lines

6.2 Diurnal Variations of Rainstorms due to Disturbance Lines

On a seasonal basis, frequencies of rainstorms, rainfall amounts and intensities of rainfall due to disturbance lines occurring during various periods of the day in 2013 and 2014 rainstorm events are shown in the section below.

6.2.1 Diurnal Variations in the Occurrences of Rainstorms due to Disturbance Lines in 2013 and 2014

The diurnal variations in the frequency (%) of occurrences of rainstorms on a seasonal basis in 2013 and 2014 rainstorm events are shown in Tables 6.1 and 2.

6.2.1.1 Diurnal Variations in the Occurrences of Rainstorms due to Disturbance Lines in 2013

The diurnal variations in the frequency (%) of occurrence of rainstorms due to disturbance lines during the 2013 rainstorm events are shown in Tables 6.1.

6.2.1.1a Dry Season

There was a general tendency of frequency of rainstorm events to decrease during all the periods of the day during the dry season of 2013. However, the few occurrences in Ibadan were recorded in December in the afternoon and early evening between 1200 h and 1500 h, and 1800 h and 2100 h, with the values of 33.3% and 67.3%, respectively (Table 6.1).

6.2.1.1b Early Rainy Season

During the early and late rainy seasons, about 80.0% of the total frequencies of rainstorm events were recorded in March concentrated in the late afternoon and early evening between 1500 h and 1800 h and 1800 h and 2100 h, in 2013 (Table 6.1). The highest frequency of rainstorm events was recorded in the early evening between 1800 h and 2100 h, with a value of 60.0% while the lowest values (20.0%) were recorded in March and April in the late afternoon and early evening between 1500 h and 1800 h and 1800 h and 2100 h (Table 6.1) respectively.

Table 6.1: Diurnal Variations in the Frequency (%) of Rainstorms due to Disturbance Lines during the Dry, Early, Late and Rainy Seasons in the 2013 Rainstorm Events

		Frequency (%) of Rainstorms due to Disturbance Lines during the Eight Periods of the Day								
Season	Month	0 h-3 h	3 h-6 h	6 h-9 h	9 h-12 h	12 h-15 h	15 h-18 h	18 h-21 h	21 h-24 h	Total
Dry	January	-	-	-	-	-	-	-	-	100%
	February	-	-	-	-	-	-	-	-	
	November	-	-	-	-	-	-	-	-	
	December	-	-	-	-	33.3	-	66.7	-	
Early	March	-	-	-	-	-	20.0	60.0	-	100%
	April	-	-	-	-	-	-	20.0	-	
Late	September	-	-	-	-	14.3	-	-	-	100%
	October	-	-	-	14.3	-	28.6	42.8	-	
Rainy	May	-	-	-	-	50.0	-	-	-	100%
	June	-	-	-	25.0	-	-	-	-	
	July	-	-	25.0	-	-	-	-	-	
	August	-	-	-	-	-	-	-	-	

Table 6.2: Diurnal Variations in the Frequency (%) of Rainstorms due to Disturbance Lines during the Dry, Early, Late and Rainy Seasons in the 2014 Rainstorm Events

		Frequency (%) of Rainstorms due to Thunderstorm during the Eight Periods of the Day								
Season	Month	0 h-3 h	3 h-6 h	6 h-9 h	9 h-12 h	12 h-15 h	15 h-18 h	18 h-21 h	21 h-24 h	Total
Dry	January	-	-	-	-	-	-	-	-	100%
	February	-	-	-	-	-	50.0	50.0	-	
	November	-	-	-	-	-	-	-	-	
	December	-	-	-	-	-	-	-	-	
Early	March	-	-	-	-	-	-	-	-	100%
	April	33.4	33.3	33.3	-	-	-	-	-	
Late	September	-	-	-	-	-	-	-	-	100%
	October	-	-	-	-	-	-	-	-	
Rainy	May	-	-	-	-	20.0	-	-	-	100%
	June	-	-	20.0	-	20.0	-	-	-	
	July	-	-	-	-	-	-	20.0	-	
	August	-	-	-	20.0	-	-	-	-	

6.2.1.1c Late Rainy Season

There was also a tendency for the frequency of rainstorms to decrease during any of the eight periods into which the day has been divided during late rainy season in 2013. Some frequencies of rainstorms were recorded in the late morning via early evening, between 0600 h and 0900 h and between 1800 h and 2100 h in (Table 6.1). Over 85% of the total frequencies during this season were recorded in October. The highest frequency was recorded in the late evening, between 1800 h and 2100 h, with a value of 42.8% while the lowest frequency of rainstorms were recorded in September and October in the late morning and afternoon, between 0900 h and 1200 h, with value of 14.3% (Table 6.1).

6.2.1.1d Rainy Season

During the rainy season months of May-August, there was a tendency of frequency of rainstorms to decrease during any of the eight periods into which the day has been divided. Though during this period, few of the rainstorm events were still recorded in the morning via afternoon (Tables 6.1). The highest frequency of rainstorms was recorded in May, in the afternoon between 1200 h and 1500 h, with a value of 50.0% (Tables 6.1a). The lowest frequency of rainstorms was recorded during the rainy season months of June-July, from the morning via late morning between 0600 h and 0900 h and 0900 h to 1200 h, with a value of 25.0% (Tables 6.1). In this period, the month of August recorded no rainstorm event during any of the eight periods into which the day has been divided. This was due to the occurrence of the little dry season phenomenon in the month.

6.2.1.2 Diurnal Variations in the Occurrences of Rainstorms due to Disturbance Lines in 2014

The diurnal variations in the frequency (%) of occurrence of rainstorms due to disturbance lines during the 2014 rainstorm events are shown in Tables 6.2.

6.2.1.2a Dry Season

In 2014, few of the rainstorm events in Ibadan were recorded in February in the late afternoon and early morning between 1500 h and 1800 h, with values of 50.0% (Table 6.2).

6.2.1.2b Early Rainy Season

About 100% of the frequency of rainstorm events were recorded in April in the night via morning between 0000 h and 0300 h, 0300 h and 0600h and 0600 h and 0900 h in 2014 (Tables 6.2). The highest rainstorm events were concentrated in the night between 0000 h and 0300 h, with a value of 33.4%. The remaining values (66.6%) were recorded in the early morning via morning between 0300 h and 0600 h and 0600 h and 0900 h, respectively. No rainstorm event due to disturbance lines was recorded in March, 2014 (Tables 6.2).

6.2.1.2c Late Rainy Season

In 2014, no rainstorm event due to disturbance lines was recorded during this period (Tables 6.2).

6.2.1.2d Rainy Season

In 2014, there was also a tendency of the frequency of rainstorms to decrease during any of the eight periods into which the day has been divided during the rainy season months of May-August. Though during this season, much of the rainstorm events recorded were concentrated in the morning via early evening between 0600 h and 0900 h, 0900 h and 1200 h, 1200 h and 1500 h (Tables 6.2). Few of the rainstorm events were still concentrated in the early evening between 1800 h and 2100 h (Tables 6.2). Also in this period, especially in June, about 40.0% of the total percentage of frequency of rainstorms was recorded, in the late morning and afternoon between 0600 h and 0900 h and 1500 h and 1800 h, with a value of 20.0% (Tables 6.2).

6.2.1.3 Deduction from the Diurnal Variations in the Frequency of Rainstorms due to Disturbance Lines in 2013 and 2014

Of the total storms studied, 63.0% and 30.0% occurred in the late afternoon and early evening between 1500 h and 1800 h and 1800 h and 2100 h in 2013 and 2014, respectively. The implication of this pattern is that most of the rainwater in the rainstorms that occurred in the late afternoon via early evening was available for soil moisture replenishment, since little evaporation takes place during the night.

Generally, from the tables (6.1 and 6.2), two things clearly emerged. One is the fact that the early rains through late rains are often associated with this system, that is, rainstorm events occurring between March and April and between September and October occurred in the afternoon and late afternoons. The other fact is that, when the rainy season has been fully established, between June and July, though most rainstorms are still concentrated in the afternoons and later afternoons, some definitely take place in the early mornings and in the night. This shows the significance of the oceanic influences on Ibadan rainstorms when the Inter-tropical Discontinuity has moved northwards beyond Ibadan. However, temporal variations in the frequencies of rainstorms due to disturbance lines relate to the certainty of occurrence of rainstorms. The results of this section help to support conclusions from other studies concerning the onset and end of the wet season for this particular area (Sekoni, 1992; Ayoade, 2012).

6.2.2 Diurnal Variations in the Duration of Rainstorms due to Disturbance Lines

Figure 6.4 captures the diurnal variations in the duration of rainstorms for Ibadan based on duration of each storm due to disturbance lines.

6.2.2.1 Diurnal Variations in the Duration of Rainstorms due to Thunderstorm in 2013

The diurnal variations in the duration of rainstorms on a seasonal basis in 2013 rainstorm events are presented in this section.

6.2.2.1a Dry Season

Nearly all the rainstorm events occurring during the dry period of 2013 lasted more than one hour in duration and the majority of these events occurred in the afternoon and early evening between 1200 h and 1500 h and 1800 h and 2100 h (Figure 6.4). In this period, the highest duration of rainstorm events was recorded in December, in the afternoon between 1200 h and 1500 h, with a value of 115 minutes (Figure 6.4). Similarly, during this period, the month of December recorded the lowest duration was 97 minutes (Figure 6.4). However, no rainstorm event recorded at Ibadan in January, February and November 2013 (Figure 6.4).

6.2.2.1b Early Rainy Season

During the early rainy season months in 2013, most of the rainstorm events were of medium duration which occurred in March and April, in the late afternoon and early evening (Figure 6.4). In this period, the highest duration was recorded in March, in the late afternoon between 1500 h and 1800 h, with a value of 115 minutes. The month of March also recorded the lowest duration of rainstorms in the early evening between 1800 h and 2100 h, with a value of 70 minutes (Figure 6.4).

6.2.2.1c Late Rainy Season

In 2013, most of the rainstorm events were of short and medium durations which occurred in September and October, in the late morning via early evening between 0900 h and 1200 h, 1200 h and 1500 h, 1500 h and 1800 h and 1800 h and 2100 h (Figure 6.4). Rainstorm events of short duration occurred mostly in October, in the late afternoon via late evening between 1500 h and 1800 h and 1800 h and 2100 h (Figure 6.4). The values of rainstorms duration during these periods of the day ranged between 58 minutes and 82 minutes (Figure 6.4). However, most of the rainstorm events with medium duration also occurred in October, in the late morning between 0900 h and 1200 h (Figure 6.4). The highest duration of rainstorms was 141 minutes which was recorded in October, in the late morning between 0900 h and 1200 h (Figure 6.4). The month of October also recorded the lowest duration of rainstorms in the late afternoon between 1500 h and 1800 h, with a value of 58 minutes (Figure 6.4).

4.2.2.1d Rainy Season

During this season in 2013, close to 100.0% of the durations of rainstorm events were of the medium durations with the exception of the month of August which recorded no rainstorm event (Figure 6.4). During this period, the month of July recorded the highest duration of rainstorm events in the morning between 0600 h and 0900 h, with a value of 107 minutes; the month of June recorded the lowest duration of rainstorm events in the late morning, between 0900 h and 1200 h, with a value of 72 minutes (Figure 6.4).

6.2.2.2 Diurnal Variations in the Duration of Rainstorms due to Disturbance Lines in 2014

The diurnal variations in the duration of rainstorms on a seasonal basis in 2014 rainstorm events are presented in this section.

6.2.2.2a Dry Season

In 2014, about 50.0% of the rainstorm events were of the short duration, which occurred in February, in the early evening between 1800 h and 2100 h (Figure 6.4). The remaining 50.0% of the rainstorm events were of the medium duration, which occurred in the late afternoon between 1500 h and 1800 h (Figure 6.4). However, there was no rainstorm event recorded at Ibadan in January, November and December 2014 (Figure 6.4).

6.2.2.2b Early Rainy Season

Majority of the durations of rainstorm events obtained in Ibadan during this period in 2014 were of the long durations also during the early and late rainy season; close to 100.0% of the durations of rainstorm events lasted more than two hours, which occurred in April, in the night via morning between 0000 h and 0300 h and 0600 h and 0900 h (Figure 6.4). In this period, the month of March recorded no rainstorm event (Figure 6.4).

6.2.2.2c Late Rainy Season

In 2014, none of the late rainy season months recorded rainstorm event. There was total disappearance of rainstorm events due to disturbance lines during this period (Figure 6.4).

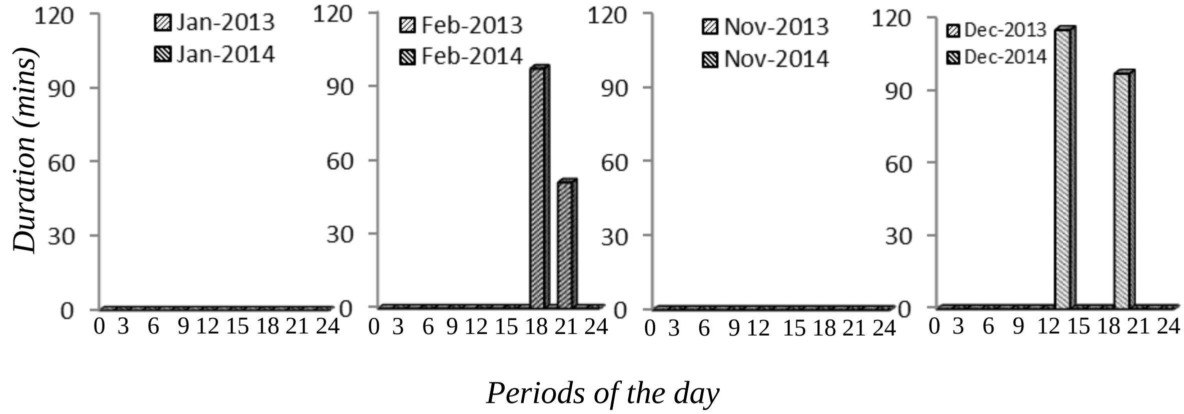
6.2.2.2d Rainy Season

In 2014, close to 80.0% of the rainstorm events lasted more than two hours from May through August and occurred in the morning via early evening, between 0600 h and 0900 h, 0900 h and 1200 h 1200 h and 1500 h, 1500 h and 1800 h and 1800 h and 2100 h (Figure 6.4). The remaining 20.0% of the rainstorm events were of the short durations which occurred in June, in the afternoon between 1200 h and 1500 h (Figure 6.4).

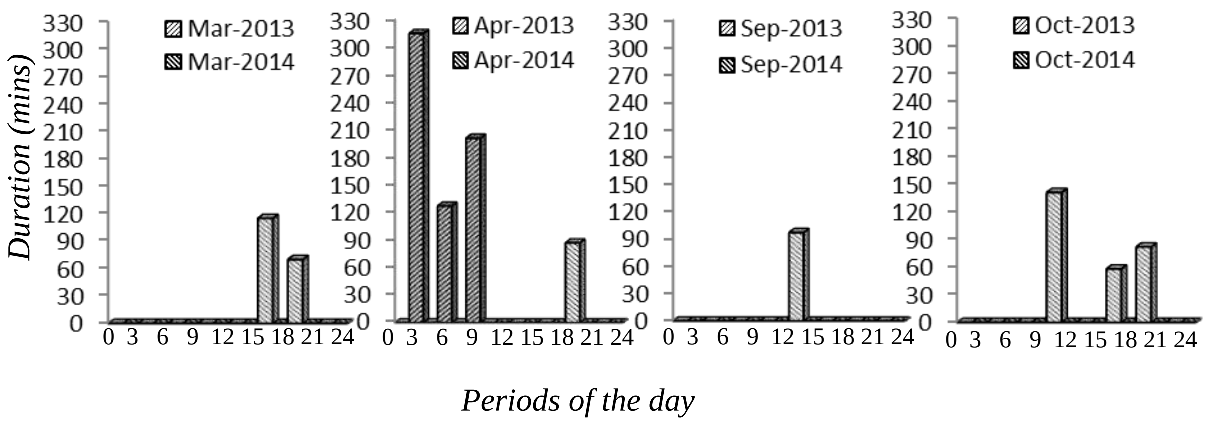
6.2.2.3 Deduction from the Diurnal Variations in the Duration of Rainstorms due to Disturbance Lines in 2013 and 2014

Figure 6.4 shows the seasonal distribution of rainstorm durations. Rainstorms of short duration occurred mostly during the dry season period. Figure 6.4 shows the frequencies of rainstorm durations set out at 30 minutes intervals. The distribution was skewed towards medium durations. Most of the rainstorms last between 72 and 315 minutes. From the findings, the rainstorm events were generally of the medium durations and tended to have a relatively longer length of duration than the isolated thunderstorms.

Dry Season Rainstorms



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



Rainy Season Rainstorms

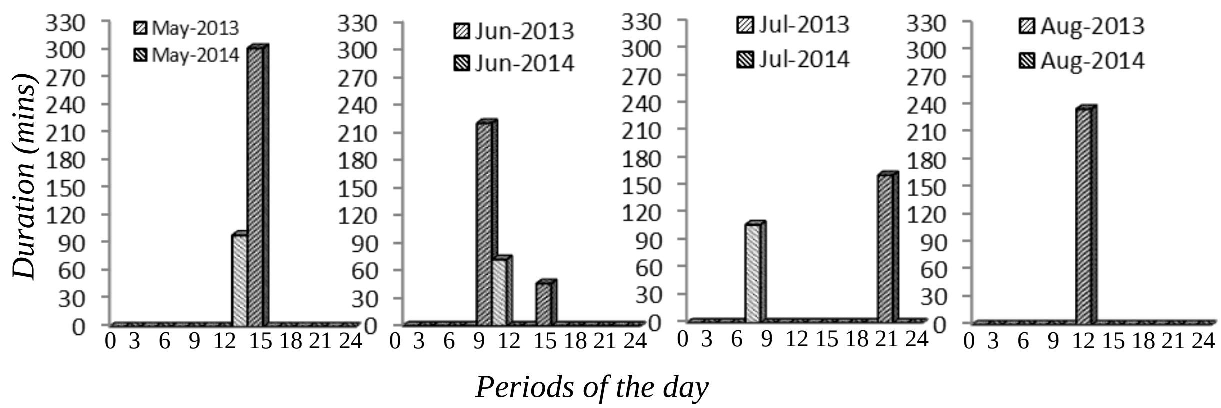


Figure 6.4: Mean Diurnal Variations in the Duration of Rainstorms due to Disturbance Lines

6.2.3 Diurnal Variations in the Amount of Rainfall due to Disturbance Lines

Figure 6.5 shows the diurnal variations in the amount of rainfall for Ibadan based on rainfall amounts of each storm due to disturbance lines. The rainfall amount due to disturbance lines in Ibadan is highly seasonal. The rainfall amounts vary a great deal.

6.2.3.1 Diurnal Variations in the Amount of Rainfall due to Disturbance Lines in 2013

The diurnal variations in the amount of rainfall on a seasonal basis in 2013 rainstorm events are presented in this section.

6.2.3.1a Dry Season

During the dry season months, the rainfall amounts were generally low. About 9.1% (14.8 mm) of the rainfall amount was recorded in this season in 2013, with the highest rainfall amount of about 8.6% (14.0 mm) were recorded in December, concentrated in the early evening, between 1800 h and 2100 h (Figure 6.5). In this period, the month of December also recorded the lowest rainfall amount in the afternoon, between 1200 h and 1500 h (Figure 6.5).

6.2.3.1b Early Rainy Season

In the early rainy season months in 2013, about 38.2% of the rainfall amounts were recorded, representing about 62.1 mm. About 26.7% (43.3 mm) of the rainfall amounts were recorded in March, while the remaining 11.5% (7.5 mm) of the rainfall amount were recorded in April. The highest rainfall amount was recorded in March, in the late afternoon between 1500 h and 1800 h, with a value of 35.8 mm (Figure 6.5). The month of March also recorded the lowest rainfall amounts, in the early evening between 1800 h and 2100 h, with a value of 7.5 mm (Figure 6.5).

6.2.3.1c Late Rainy Season

During the rainy season in 2013, the total rainfall amount was about 46.2 mm, representing about 28.5%. The highest rainfall amount of about 12.5% (20.3) mm was recorded in September, in the afternoon between 1200 h and 1500 h (Figure 6.5). In this period, the lowest rainfall amount was recorded October, in the late afternoon between 1500 h and 1800 h (Figure 6.5).

6.2.3.1d Rainy Season

In this season, about 39.3 mm of the rainfall amounts were recorded, representing about 24.2% of the total rainfall amount. The highest rainfall amount was recorded in July, in the morning, between 0600 h and 0900 h, with a value of 10.5% (17.0 mm) (Figure 6.5); while the lowest rainfall amount was recorded in June, in the late morning, between 0900 h and 1200 h, with a value of 6.5% (10.5 mm) (Figure 6.5). The remaining 7.3% (11.8 mm) of the rainfall amount was recorded in May, concentrated in the afternoon between 1200 h and 1500 h (Figure 6.5).

6.2.3.2 Diurnal Variations in the Amount of Rainfall due to Disturbance Lines in 2014

The diurnal variations in the amount of rainfall on a seasonal basis in 2014 rainstorm events are presented in this section.

6.2.3.2a Dry Season

In this season, rainfall amount of about 7.0% (9.6 mm) was recorded during this season (Figure 6.5). About 4.6% (6.3 mm) of the rainfall amount were recorded in February, concentrated in the early evening, between 1800 h and 2100 h (Figure 6.5). The remaining rainfall amounts were also recorded in February, in the late afternoon between 1500 h and 1800 h (Figure 6.5).

6.2.3.2b Early Rainy Season

In 2014, about 37.3% (51.0 mm) of the amounts of rainfall were recorded in April. About 18.6% (25.5 mm) of the rainfall amounts were concentrated in the night between 0000 h and 0300 h. The remaining 9.1% (12.5 mm) and 9.4% (13.0 mm) of the amounts of rainfall were concentrated in the early morning via morning, between 0300 h and 0600 h and 0600 h and 0900 h, respectively (Figure 6.5). In this period, the month of March recorded no rainfall amount (Figure 6.5).

6.2.3.2c Late Rainy Season

During this period in 2014, no rainfall amount was recorded during any eight periods of the day in which the day has been divided due to total disappearance of rainstorm events during this period in Ibadan (Figure 6.5).

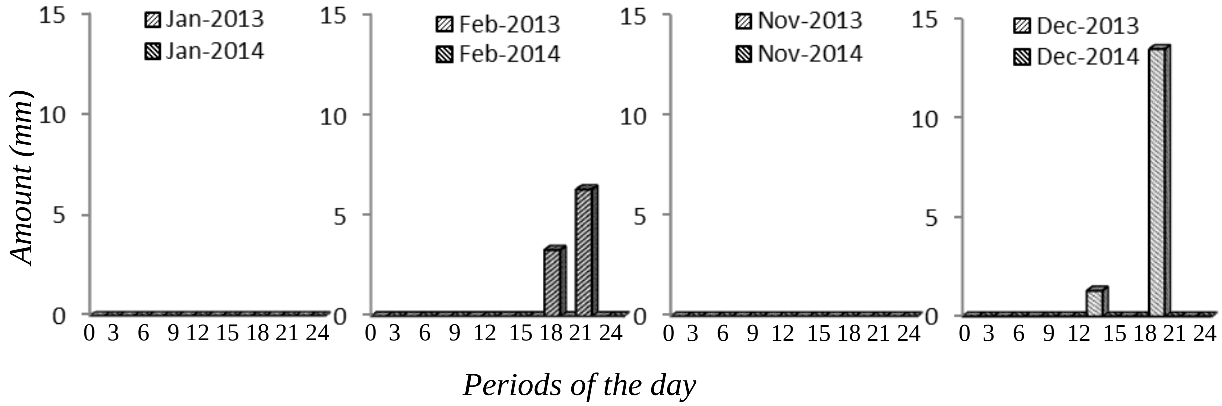
6.2.3.2d Rainy Season

During this season in 2014, about 55.7% (76.3 mm) of the total rainfall amount was recorded and about 20.1% (27.5 mm) of the rainfall amount was recorded in May as the highest rainfall amount, in the afternoon between 1200 h and 1500 h (Figure 6.5). The lowest rainfall amount was recorded in June, in the afternoon between 1200 h and 1500 h (Figure 6.5).

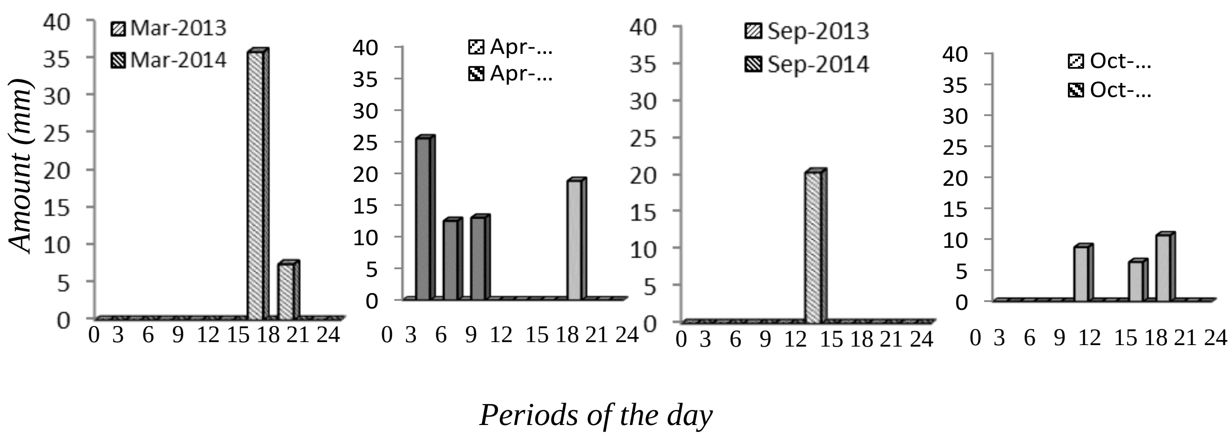
6.2.3.3 Deduction from the Diurnal Variations in the Amounts of Rainfall due to Disturbance Lines in 2013 and 2014

The rainfall amounts in these seasons are characteristic of weather zone C. The showers at the beginning and the end of the rainy season are linesqualls of organization of convective rains over Ibadan, consisting of lines of thunderstorms.

Dry Season Rainstorms



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



Rainy Season Rainstorms

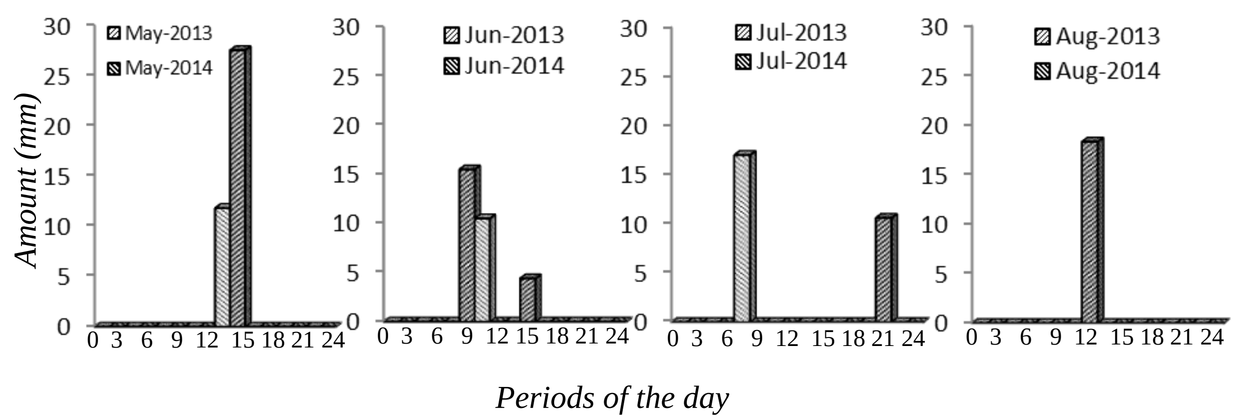


Figure 6.5: Mean Diurnal Variations in the Amount of Rainfall due to Disturbance Lines

6.2.4 Diurnal Variations in the Intensity of Rainfall due to Disturbance Lines

Figure 6.6 shows the diurnal variations of rainfall intensities for Ibadan based on rainfall intensities of each storm due to disturbance lines. The rainfall intensity in Ibadan is found to be highly seasonal. The intensities of rainfall vary a great deal.

6.2.4.1 Diurnal Variations in the Intensity of Rainfall due to Disturbance Lines in 2013

The diurnal variations in the intensity of rainfall on a seasonal basis in 2013 rainstorm events are presented in this section.

6.2.4.1a Dry Season

In the dry season months in 2013, the intensities of the rainfall due to disturbance lines were generally low. The highest intensities of rainfall reaching about 0.20 mm h^{-1} were concentrated in the early evening, between 1800 h and 2100 h (Figure 6.6). The lowest intensity of rainfall was recorded in the afternoon between 1200 h and 1500 h, with a value of 0.010 mm h^{-1} (Figure 6.6).

6.2.4.1b Early Rainy Season

During the early rainy season in 2013, the rainfall intensities recorded in each period of the day during these seasons were relatively high. The early rainy season months had the highest intensities of rainfall reaching up to 0.30 mm h^{-1} of the rainstorms, which concentrated in the late afternoon, between 1500 h and 1800 h (Figure 6.6).

6.2.4.1c Late Rainy Season

During this season in 2013, the highest rainfall intensities reaching up to 0.20 mm h^{-1} of the rainstorms were recorded in the afternoon, between 1200 h and 1500 h (Figure 6.6). The lowest rainfall intensities were recorded in the late morning, between 0900 h and 1200 h, with a value of 0.060 mm h^{-1} (Figure 6.6).

4.2.4.1d Rainy Season

During the rainy season months in 2013, the highest intensities of rainfall of about 0.20 mm h^{-1} were concentrated in the morning, and late morning between 0300 h and 0600 h and 0900 h and 1200 h (Figure 6.6).

6.2.4.2 Diurnal Variations in the Intensity of Rainfall due to Disturbance Lines in 2014

The diurnal variations in the intensity of rainfall on a seasonal basis in 2013 rainstorm events are presented in this section.

6.2.4.2a Dry Season

In 2014, the highest intensities of rainfall , reaching about 0.10 mm h^{-1} were concentrated in the early evening between 1800 h and 2100 (Figure 6.6). The lowest intensities of rainfall were recorded in the late afternoon between 1500 h and 1800 h, with a value of 0.030.mm h^{-1} (Figure 6.6).

6.2.4.2b Early Rainy Season

During this season in 2014, the highest rainfall intensities of about 0.10 mm h^{-1} were concentrated in the early morning, between 0300 h and 0600 h (Figure 6.6).

6.2.4.2c Late Rainy Season

In 2014, no rainfall intensity was recorded during this season, owing to total disappearance of the rain-producing weather system (Figure 6.6).

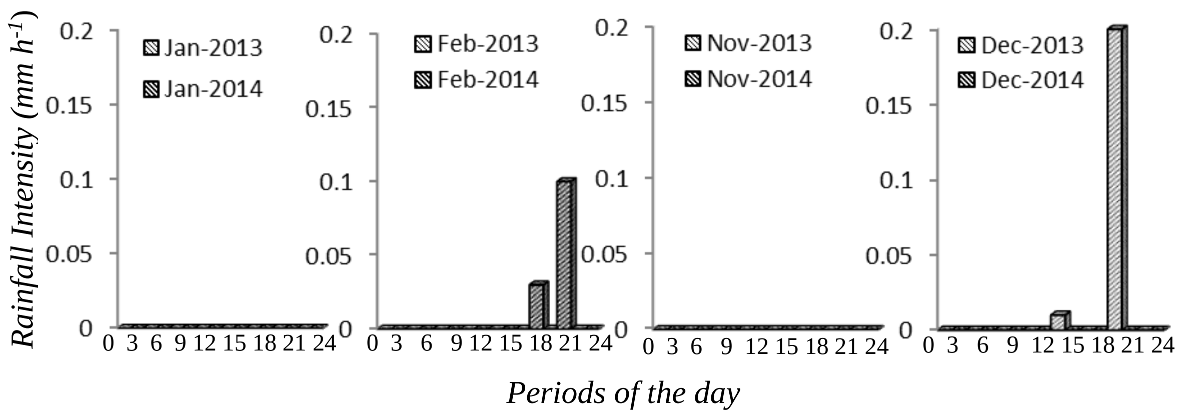
6.2.4.2d Rainy Season

In 2014, the highest intensities of rainfall of about 0.10 mm h^{-1} were concentrated in the afternoon, between 1200 h and 1500 h (Figure 6.6).

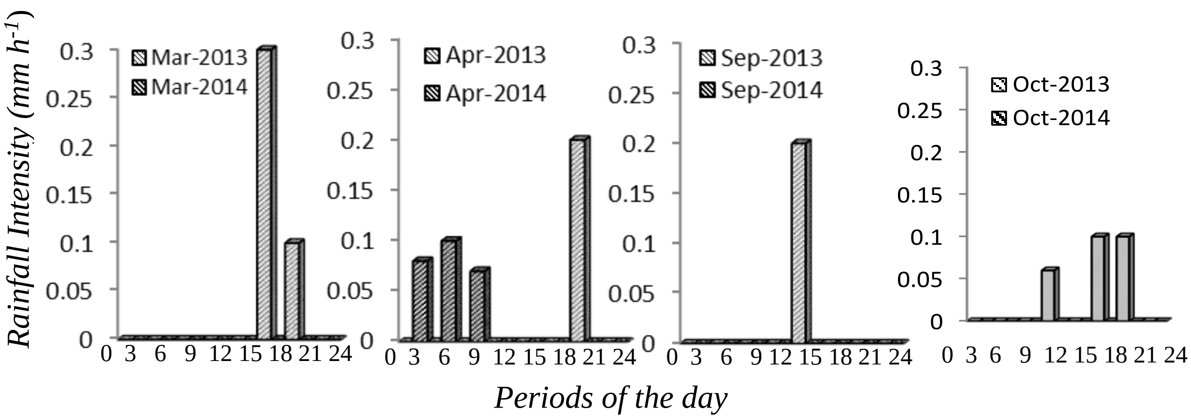
6.2.4.3 Deduction from the Diurnal Variations in the Intensities of Rainfall due to Disturbance Lines in 2013 and 2014

Majority of the rainfall with highest intensities were concentrated in the afternoon and late afternoon, between 1200 h and 1500 h and 1500 h and 1800 during the periods of the study (Figure 6.6). The rainfall intensities in these seasons are characteristic of weather zone C (Sekoni, 1992).

Dry Season Rainstorms



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



Rainy Season Rainstorms

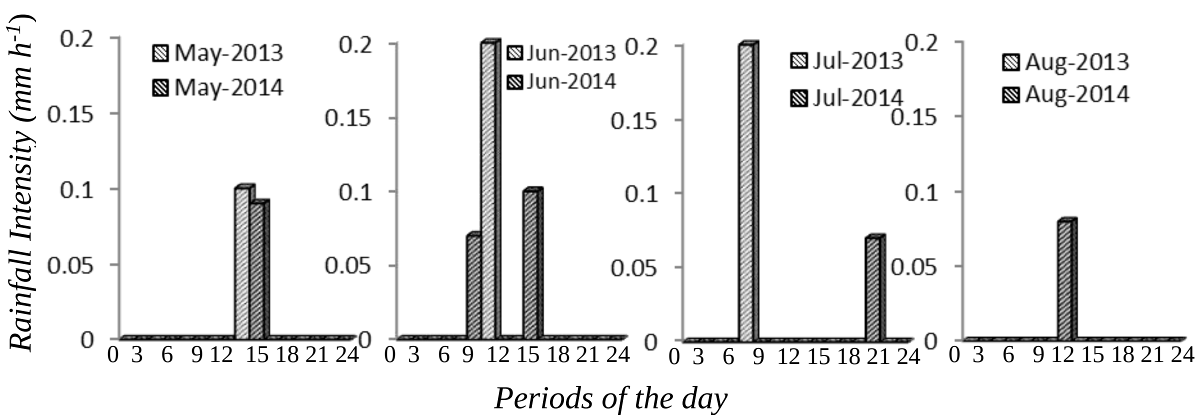


Figure 6.6: Mean Diurnal Variations in the Intensity of Rainfall due to Disturbance Lines

6.3 Seasonal Variations of Frequency of Rainstorms due to Disturbance Lines in Ibadan

On a seasonal basis, the variations of frequency of rainstorms due to disturbance lines in Ibadan are illustrated below.

6.3.1 Seasonal Variations in the Frequency of Rainstorms due to Disturbance Lines in 2013

During the dry season in 2013, there was a general decline of frequency of rainstorm events on all sections of the city, with the exception of the December, which recorded relatively high frequencies, with a value of three rainstorm events. Other months, such as January, February and November, recorded no rainstorm event during the dry season in 2013 (Figure 6.7).

More so, during the early rainy season in 2013, the month of March stood out as the month of high frequency of rainstorm events, with a value of four rainstorm events. April recorded a value of one rainstorm event (Figure 6.7).

In the late rainy season of 2013, rainstorm events varied between one (the lowest in September) and six in October which had the highest value (Figure 6.7). However, no rainstorm event was recorded at any section of Ibadan during the months of September and October 2014, respectively.

The highest rainstorm event due to disturbance lines during the main rainy season in 2013 occurred in the month of May, with a value of two rainstorm events. The rainstorm events during the main rainy season in 2013 declined to a value of one rainstorms event in the months of June and July, and the month of August recorded no rainstorms event (Figure 6.7).

6.3.2 Seasonal Variations in the Frequency of Rainstorms due to Disturbance Lines in 2014

During the dry season in 2014, there was also a general tendency of frequency of rainstorm events due to this system to decrease on all sections of the city, though there was a change in the pattern of distribution over the city. The month of February recorded relatively high frequencies, with a value of two rainstorm events. No rainstorm event was recorded in January, November and December (Figure 6.7).

In 2014, the month of April stood out as month of high frequency of rainstorm event during the early rainy season, with a value of three rainstorm events. There was no rainstorm event in March (Figure 6.7). However, no rainstorm event was recorded at any section of Ibadan during the months of September and October 2014, respectively.

The highest rainstorm events during the main rainy season in 2014 were at the peak of the rainy season month-June, with a value of two rainstorm events. The lowest value was in May, July and August recorded one rainstorm event, respectively (Figure 6.7).

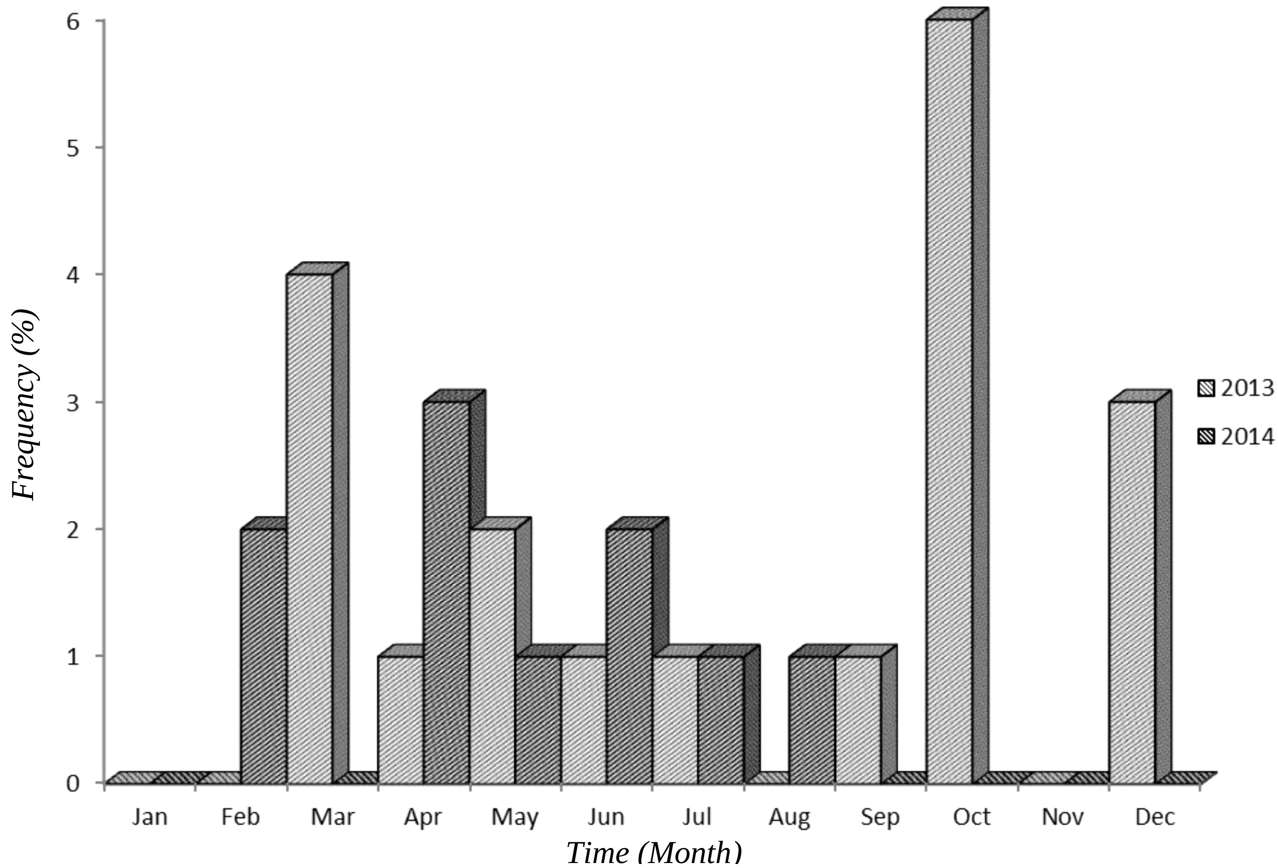


Figure 6.7: Seasonal Variations in the Frequency of Rainstorms due to Disturbance Lines

6.4 Spatial Pattern of Rainstorms due to Disturbance Lines in Ibadan

The spatial pattern of frequency of rainstorms, duration and rainfall amount due to disturbance lines in Ibadan are illustrated below.

6.4.1 Spatial Pattern in the Frequency of Rainstorms due to Disturbance Lines in Ibadan

Comparison of the spatial pattern in the frequency of rainstorms due to disturbance lines of the two years-2013 and 2014, shown in Figures 6.8, 6.10, 6.12 and 6.9, 6.11, 6.13, respectively, has been included in the discussion because it presents different spatial patterns of rainstorms over Ibadan.

Generally, the rains from the rainstorms were linearly arranged and often start from the east and move westwards at relatively predictable speeds of 50 km per hour, covering an apparently large longitudinal swath of area. From the Figure 6.8 below, it can been seen that the frequency of the rainstorms varied seasonally in the selected stations in Ibadan and the overall disturbance lines events started from the east and move westwards. During the dry season in 2013, there was a general tendency of frequency of rainstorm events due to disturbance lines to decrease on all sections of the city, with the exception of the eastern section in the area around Alakia, which recorded relatively high frequencies, with a value of three rainstorm events. It decreased to one at UI educational and low-density landuse area. Other areas, such as Oluyole, Agbowo, Akobo and Eleyele, respectively recorded no rainstorm event during the dry season in 2013 (Figure 6.8). However, as seen in the Figure 6.8 below, the “dry season rains” did not appear in all sections of the study area. Generally, the rainy phases during the “dry season rains” began in December and ended in the same month. During this period in 2013, other months recorded no rainstorm event. However, in the northern part of the city, the rains set in slightly earlier, to the east, in the upper lying zone in the area around Alakia, a bit later, which means about the second week of December.

In the dry season of 2014, there was also a general tendency of frequency of rainstorm events due to this system to decrease on all sections of the city, though there was a change in the pattern of distribution over the city. The areas around Alakia – Basorun – Gbagi axis recorded relatively high frequencies, with a value of two rainstorm events. It went low to one rainstorm event at UI – Papa-Malu – Apete medium-and Ijokodo axis. At Onireke, the dry season rainstorm event was also one. Other areas, such as Oluyole and Lagelu recorded a value of two and one rainstorm events of dry season rainstorms, respectively (Figure 6.9). However, as seen in the Figure 6.9 below, the “dry season rains” did not appear in all sections of the study area. Generally, the rainy phases during the “dry season rains” began in began in February and ended in the same month. During this period, other months recorded no rainstorm event.

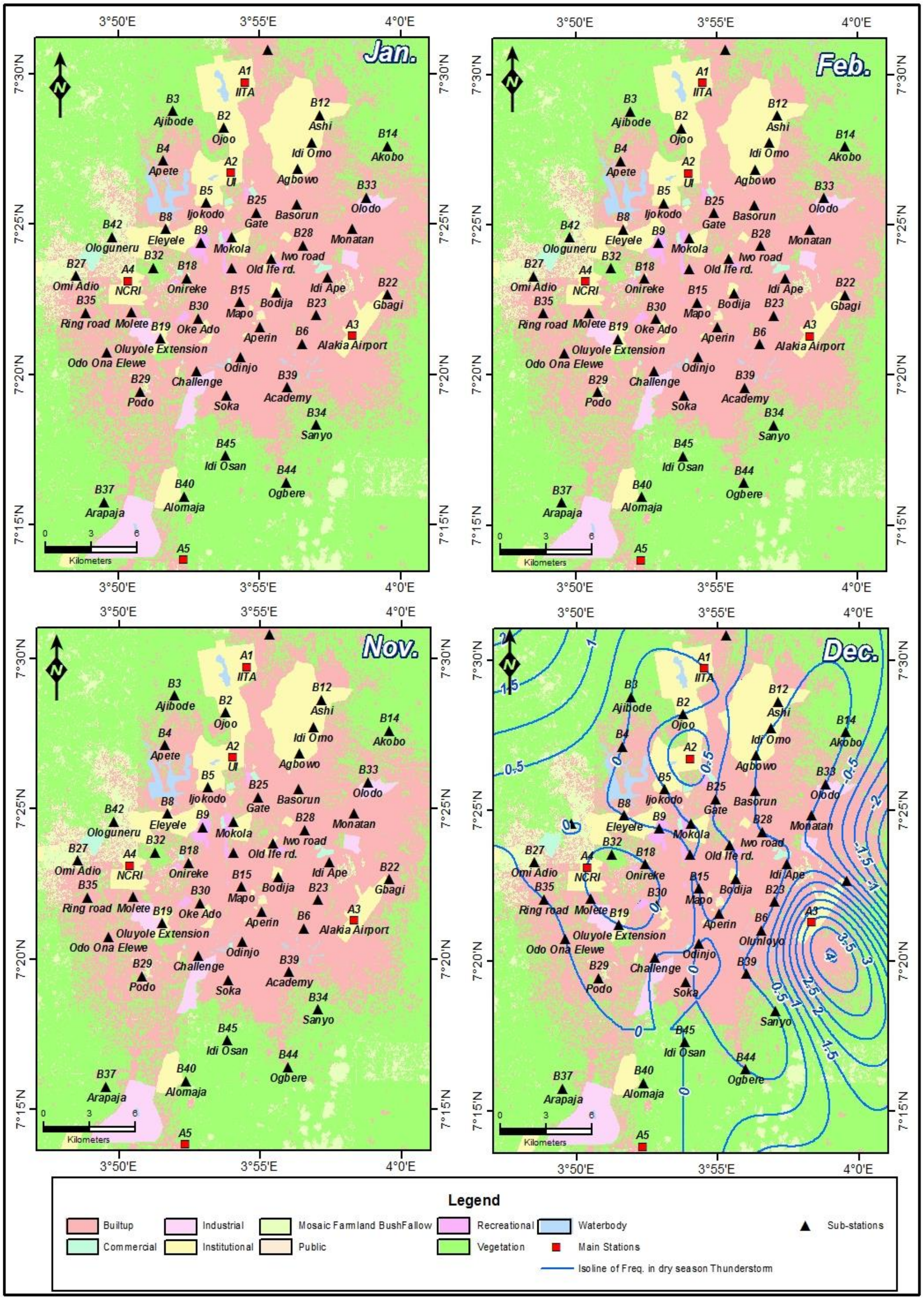


Figure 6.8: Spatial Pattern of Frequency of Rainstorms due to Disturbance Lines during the Dry Season in 2013

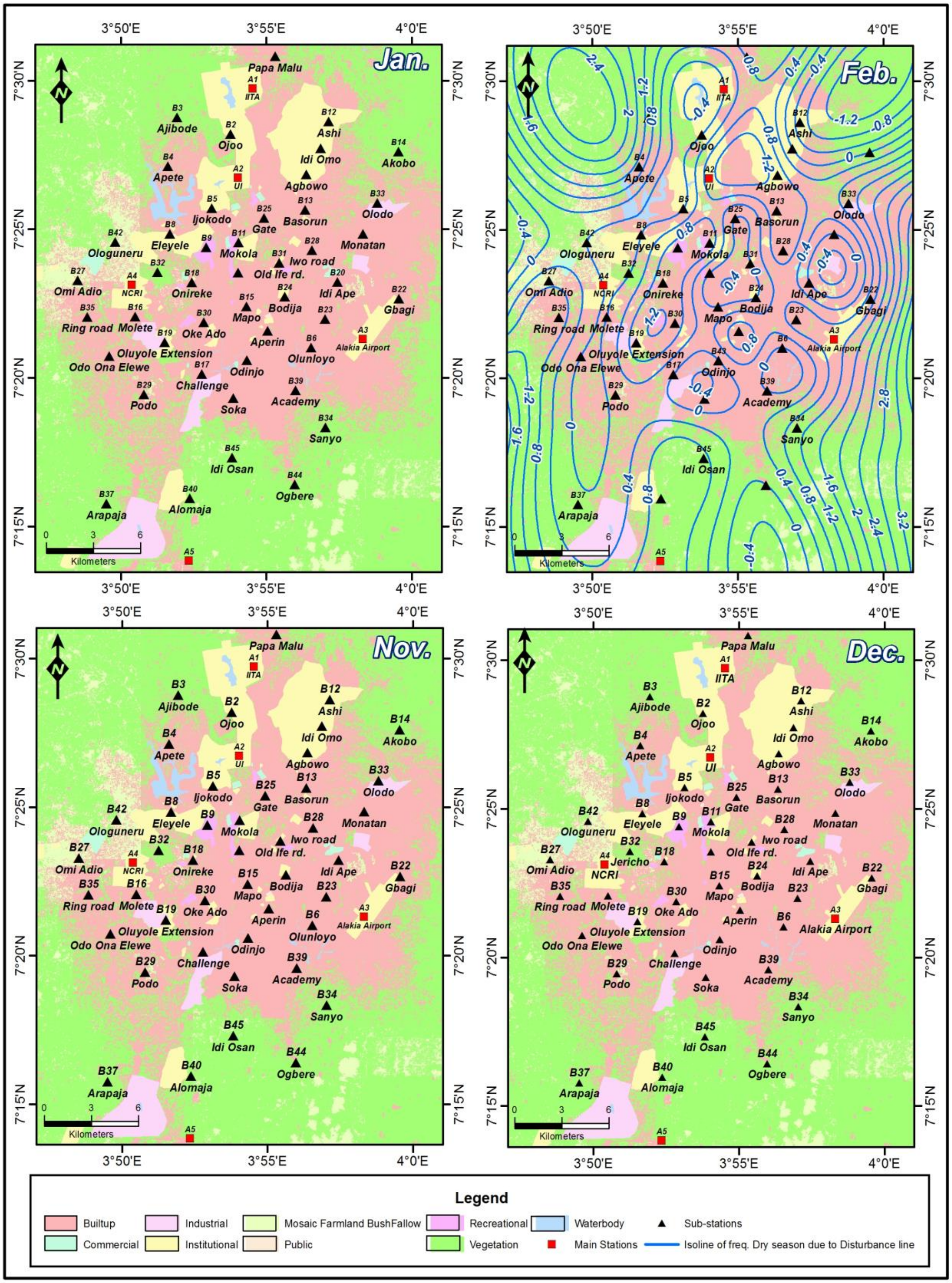


Figure 6.9: Spatial Pattern of Frequency of Rainstorms due to Disturbance Lines during the Dry Season in 2014

During the early rainy season in 2013, two areas of the city stood out as sections of high frequency of rainstorms; they were around IITA and, with a value of five rainstorm events, respectively (Figure 6.10). However, during the early rainy season in 2013, two areas of the city stood out as the sections of high frequency of rainstorms and these were the IITA on the northern section, and on the eastern section in the area around Alakia. On every other sections of the city, there was a reduction in frequency of rainstorms.

In 2014, three areas of the city stood out as sections of high frequency of rainstorms during the early rainy season. These were CRIN, IITA and Alakia had a value of three rainstorm events (Figure 6.11). Similarly, during the early rainy season in 2014, two areas of the city stood out as the sections of high frequency of rainstorms and these were the IITA on the northern section, and on the eastern section in the area around Alakia. On every other sections of the city, there was a reduction in frequency of rainstorms.

During the late rainy season in 2013, rainstorm events varied between one (the lowest at Molete) and seven rainstorm events at Alakia (Figure 6.10). During the late rainy season in 2013, there was a change in the pattern of frequency, three areas of the city stood out as sections of high frequency of rainstorms and these were the areas around IITA on the northern section, on the eastern section around Alakia and on the southern section of the city in the area around CRIN.

In 2014, no late rainy season rainstorm event was recorded at any section of Ibadan (Figure 6.11).

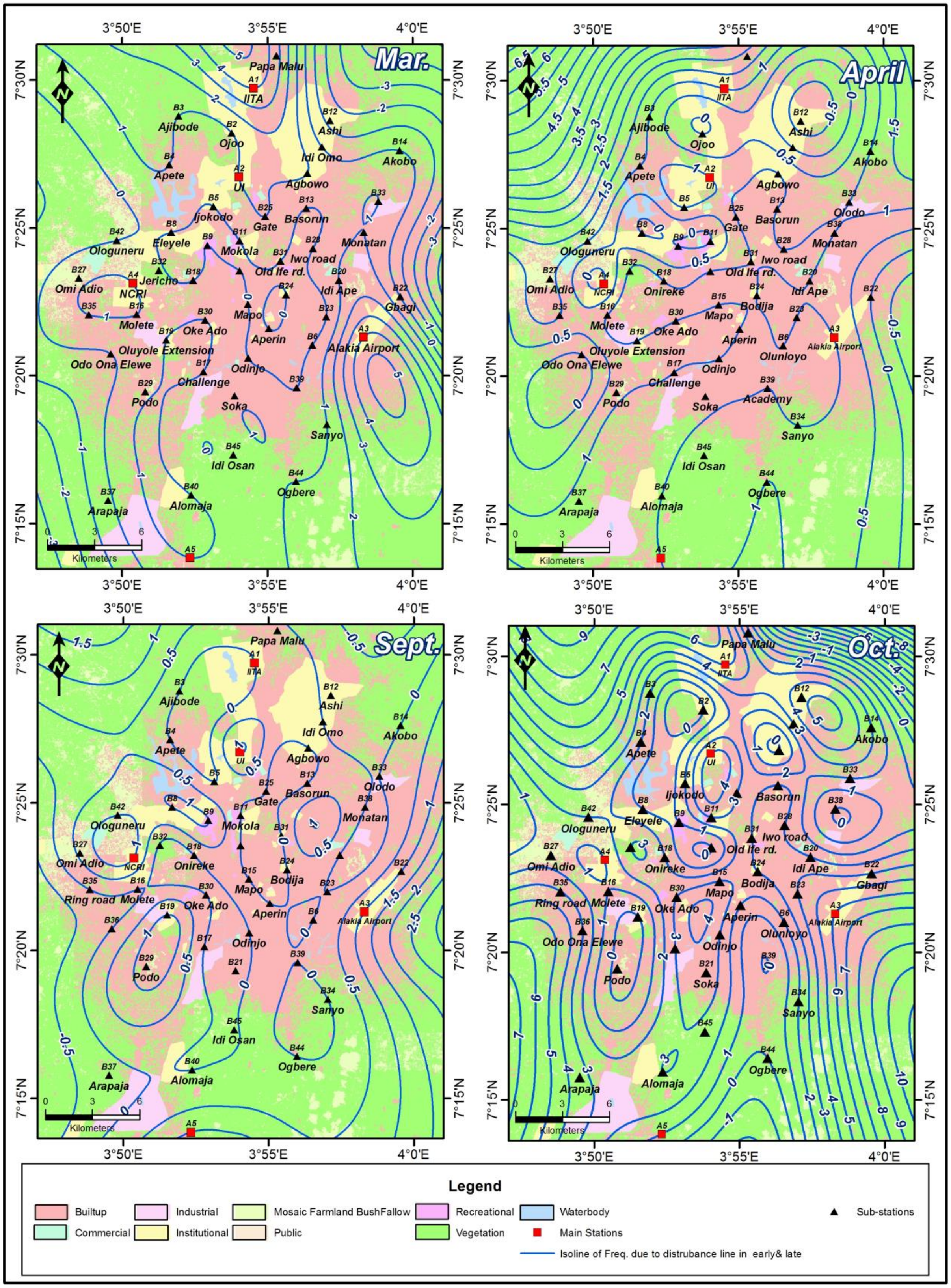


Figure 6.10: Spatial Pattern of Frequency of Rainstorms due to Disturbance Lines during the Early and Late Rainy Seasons in 2013

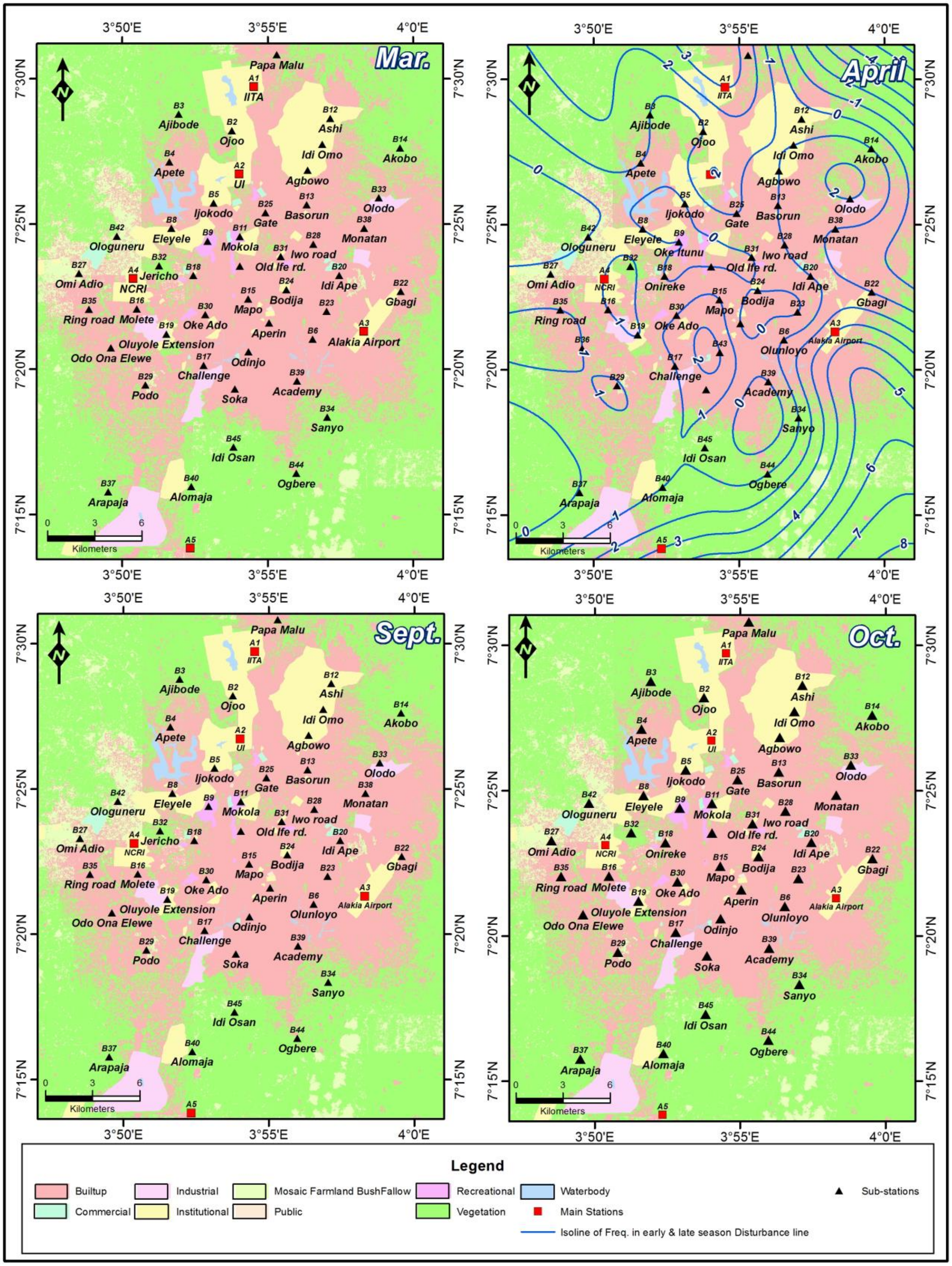


Figure 6.11: Spatial Pattern of Frequency of Rainstorms due to Disturbance Lines during the Early and Late Rainy Seasons in 2014

The highest rainstorm event during the main rainy season in 2013 was at Ijokodo and Bodija – Alakia axis, with four rainstorm events. Agbowo and Gbagi had three rainstorm events. The rainstorm events during this season varied between Alomaja and Omi-Adio, respectively, with two rainstorm events and Oluyole and Lagelu with a one rainstorm event. At Eleyele, there was one rainstorm event (Figure 6.12). Besides, during the main rainy season in 2013, the frequency of rainstorms was highest in the area around Ijokodo and Bodija – Alakia axis, here the figure stood at four. Towards the south, rainstorm events decreased rapidly. The central axis showed rainstorm events about three (Figure 6.12).

The highest rainstorm event during the main rainy season in 2014 was at Alakia and IITA, with five and four rainstorm events, respectively. Aperin and Babanla had three rainstorm events and Ologuneru and Onireke followed, with two rainstorm events. The lowest value was recorded at Ojoo, and Agbowo, Challenge and Gbagi recorded one rainstorm event, respectively. Eleyele and the Oluyole was also recorded one rainstorm event (Figure 6.13). However, during this period in 2014, the frequency of rainstorms was highest in the area around Alakia, with five rainstorm events. Towards the south, west and north, rainstorm events decreased rapidly. The central axis showed rainstorm events of about two (Figure 6.13).

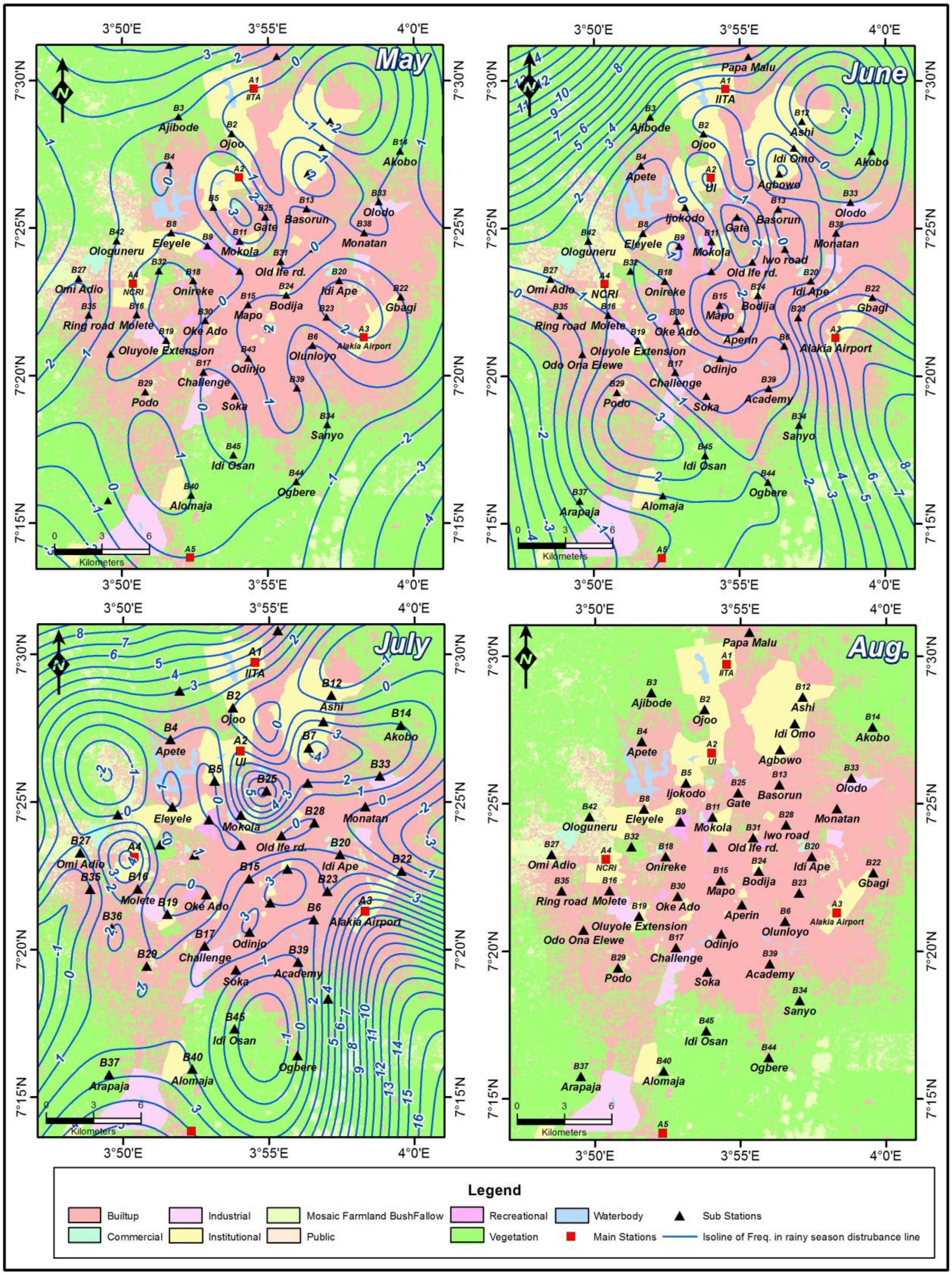


Figure 6.12: Spatial Pattern of Frequency of Rainstorms due to Disturbance Lines during the Rainy Season in 2013

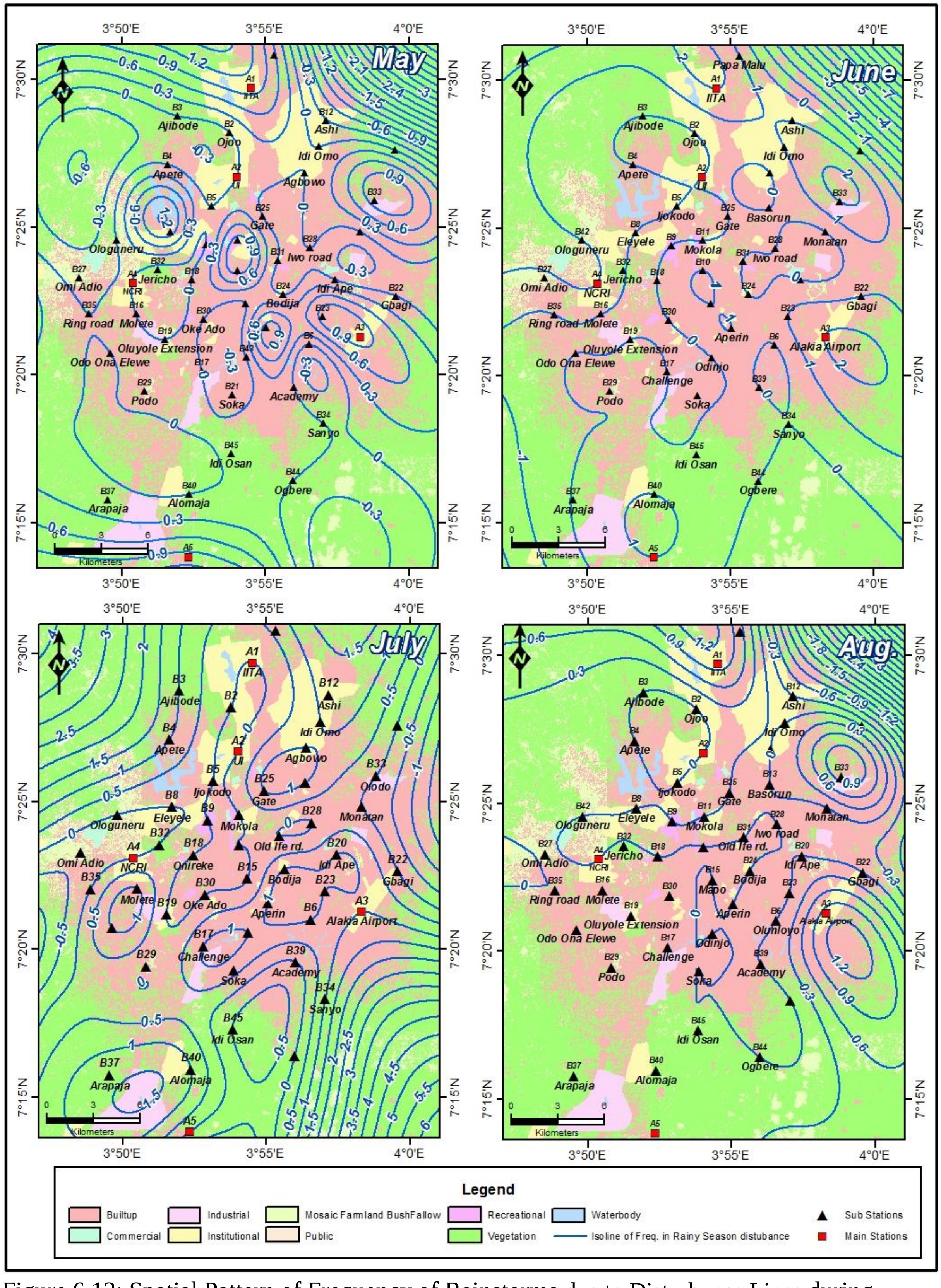


Figure 6.13: Spatial Pattern of Frequency of Rainstorms due to Disturbance Lines during the Rainy Season in 2014

6.4.2 Spatial Pattern in the Duration of Rainstorms due to Disturbance Lines in Ibadan

The spatial pattern of duration of rainstorms due to disturbance lines in Ibadan is shown in Figures 6.14, 6.16, 6.18 and 6.15, 6.17, 6.19 for 2013 and 2014, respectively. During the dry season in 2013, there was a general tendency of duration of the rainstorms to decrease rapidly all over the sections of the city. The highest duration of rainstorm was recorded at UI with 125 minutes in December. It went low to 65 minutes at Alakia. No rainstorm duration was recorded on other sections of the city during this period (Figure 6.14). However, during this period in 2013, the longest rainy phase, with duration of 125 minutes, were found on the northern section of upper lying zone of the city in the area around UI, the duration decreased, reaching 65 minutes, were found on the northeastern section of the city in the around Alakia (Figure 6.14).

The highest duration of rainstorm during the dry season in 2014 was recorded at CRIN, with 180 minutes in February. At Ijokodo and UI, 145 minutes and 120 minutes of duration of rainstorms were recorded, respectively. At Ajibode, the dry season duration of rainstorms was 113 minutes, while Ojoo, Basorun and Alomoja had 90 minutes, 75 minutes, and 53 minute, respectively. No rainstorm was recorded at Eleyele, Mapo, Monotan, Idi-Omo, Omi-Adio, IITA and NCIR areas, respectively. The lowest duration of rainstorm was recorded at Oke-Ado and Agbowo, with 15 minutes and 10 minutes, respectively (Figure 6.15). During this period in 2014, the longest rainy phases, with durations of 180 minutes, were found on the southern section of lower lying zones of the city in the areas around CRIN, the duration decreased, reaching 10 minutes, were found on the northwestern sections of the city in the around Agbowo (Figure 6.15).

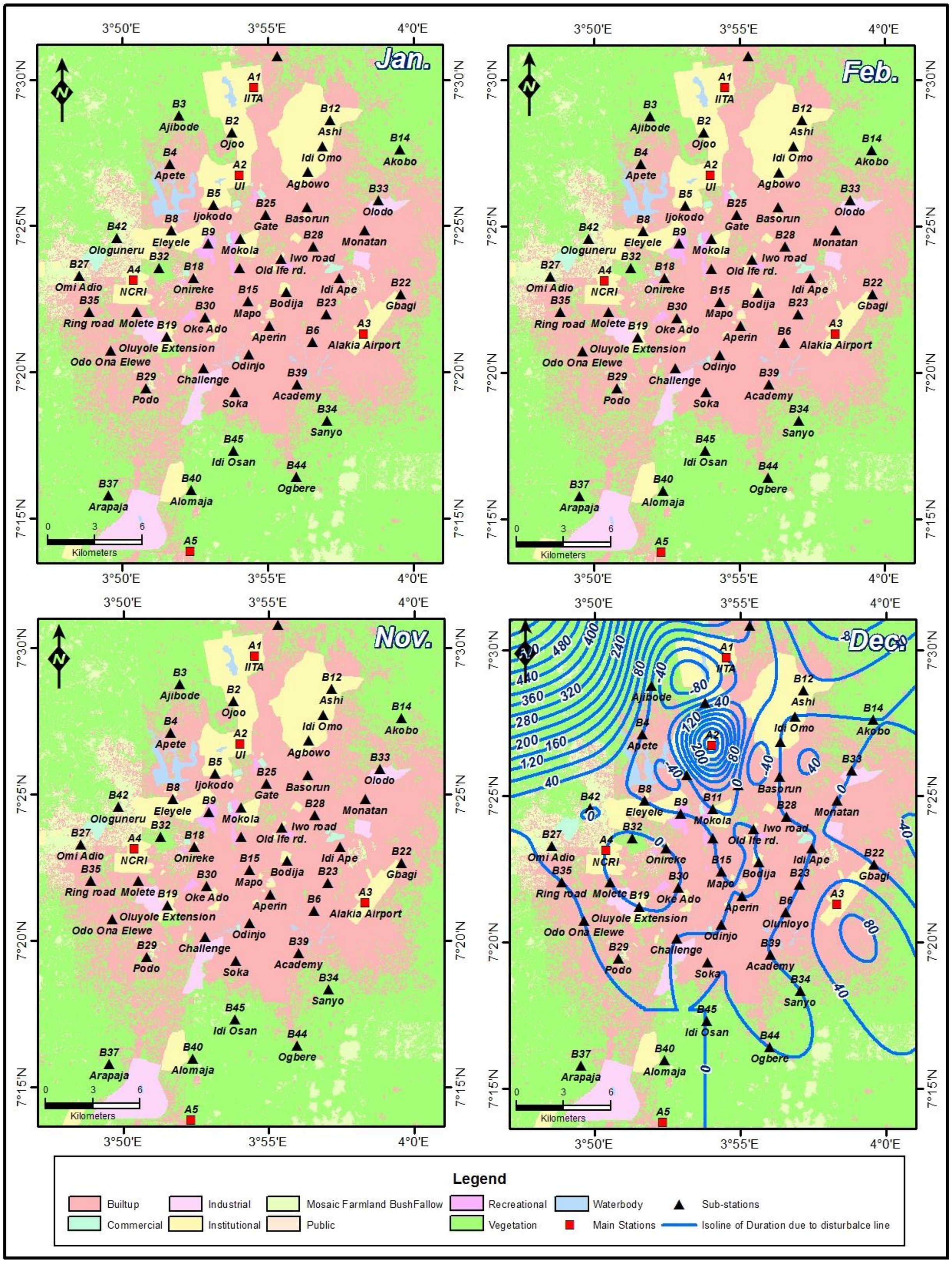


Figure 6.14: Spatial Pattern of Average Duration (mins) of Rainstorms due to Disturbance Lines during the Dry Season in 2013

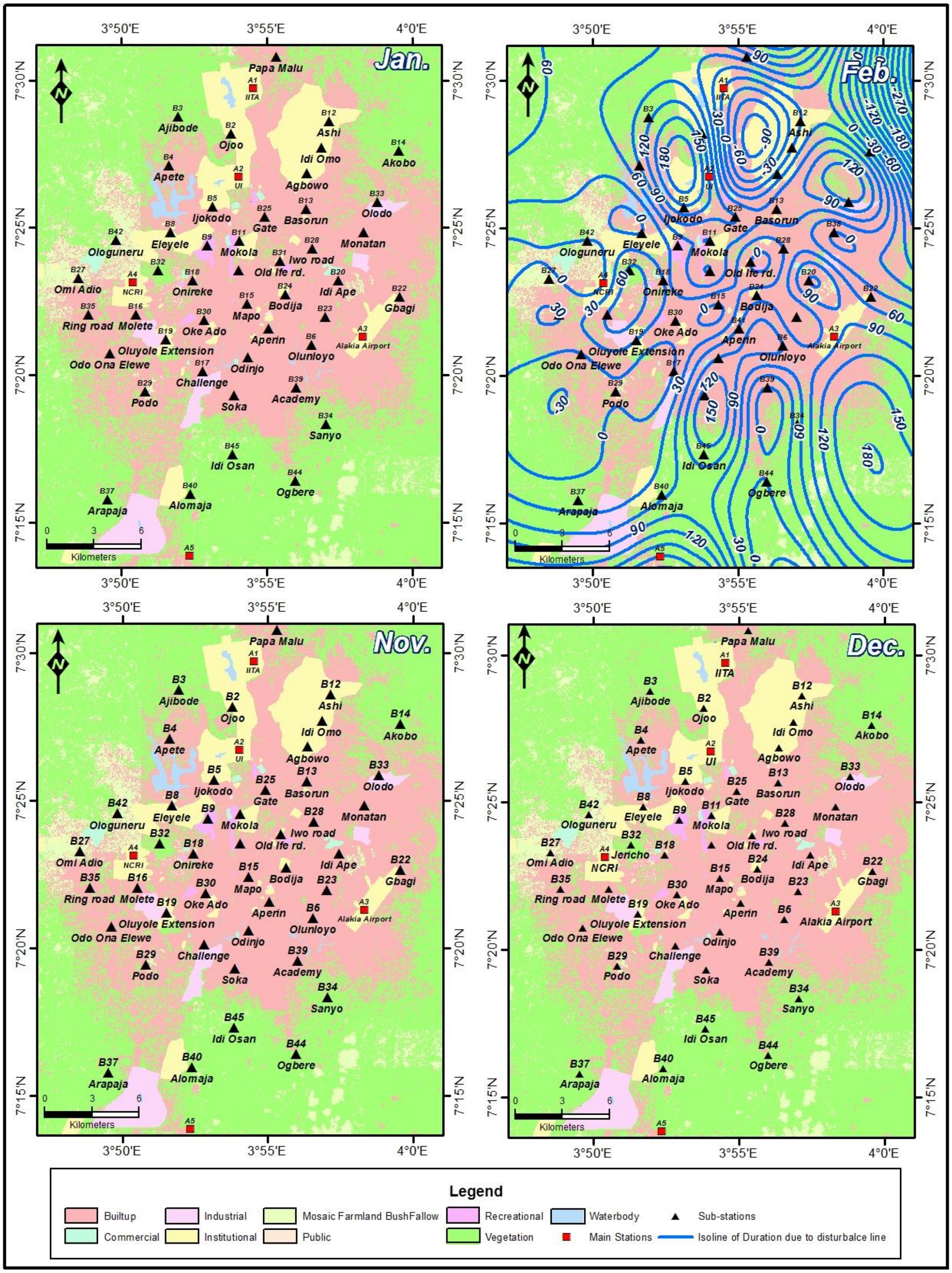


Figure 6.15: Spatial Pattern of Average Duration (mins) of Rainstorms due to Disturbance Lines during the Dry Season in 2014

During the early rainy season in 2013, durations of rainstorm varied between 5 minutes (the lowest at Omi-Adio, Idi-Osan, and Mapo) and 215 minutes at Ijokodo, Onireke, Total Garden, and Academy and Babanla. It went low to 210 minutes at UI and 185 minutes at Aperin. IITA, and Molete, the duration of rainstorm during the early rainy season was 135 minutes. At Agbowo, and Monotan, the duration of rainstorms was 110 minutes, respectively. Apete and Lagelu had 93 minutes and 90 minutes of rainstorm durations, respectively. At Odinjo and CRIN, the rainstorm durations were 65 minutes and 40 minutes, respectively. Jericho, Ring-Road and Oke-Ado, the rainstorm durations were 35 minutes and 30 minutes, respectively. Alakia and Akobo, had 29 minutes and 20 minutes of rainstorm durations, respectively. At Eleyele, the duration of rainstorms was 8 minutes (Figure 6.16). However, during this period in 2013, the longest rainy phases were found in the areas around Ijokodo, Onireke, Total Garden, Academy and Babanla, and lasted for 215 minutes. The central axis of the city in the area around Mapo showed values between 5 minutes-30 minutes. The durations rose towards western direction at the upper lying zone of the city.

The durations of rainstorm during the early rainy season in 2014 varied between 30 minutes (the lowest at Jericho and Sanyo) and 240 minutes at Babanla. It went low to 220 minutes at Idi-Osan and Olunloyo and 210 minutes at Papa-Malu, Ring-Road, Ogbere and Ikolaba, respectively; 180 minutes at Aperin and Lagelu. At IITA, CRIN and Olodo, the values of rainstorm durations were 135 minutes and 140 minutes, next to Lagelu. Challenge, Iwo-Road, Agbowo and Gbagi, had 130 minutes, 120 minutes, and 110 minutes of duration of rainstorms, respectively. The durations of rainstorm varied between 105 minutes at NCRI, and 120 minutes at Basorun and 125 minutes at Ashi. At Omi-Adio and Idi-Omo, value of duration of rainstorms in 2014 was 90 minutes (Figure 6.17). However, during this period in 2014, the longest rainy phases were found in the area around Babanla and lasted for 240 minutes, respectively. The southern axis of the city in the area around Sanyo showed values of duration of rainstorm between 10 minutes-30 minutes. The durations rose towards southeastern direction at the lower lying zone of the city.

The highest duration of rainstorm during the late rainy season of 2013 was recorded at UI, with duration of rainstorms of 240 minutes. It went low to 200 minutes at NCRI. At Oluyole, Odinjo and Alakia, 159 minutes, 151 minutes and 121 minutes of duration of rainstorms were recorded, respectively. At Ajibode and Ashi, the value of duration of rainstorms was 104 minutes, while the Ring-Road, Ikolaba, Odo-Ona Elewe and Idi-Ape had values of duration of rainstorms of 97 minutes, 96 minutes, 91 minutes and 88 minutes, respectively. At Eleyele and Lagelu had rainstorm durations of 87 minutes and 51 minutes, respectively (Figure 6.16). However, during this period in 2013, the longest rainy phases were found on the northern section of upper lying zone of the city around UI with a maximum duration of rainstorms of 240 minutes. The northwestern section around Eleyele and southern section of the city around Lagelu ranged showed short phases of 51 minutes-87 minutes, while the central section of the city in the area around Mapo received rainfall for less than 30 minutes (Figure 6.16).

Conversely, during the late rainy season of 2014, no rainstorm due to disturbance lines was recorded on every section of the city of Ibadan (Figure 6.17).

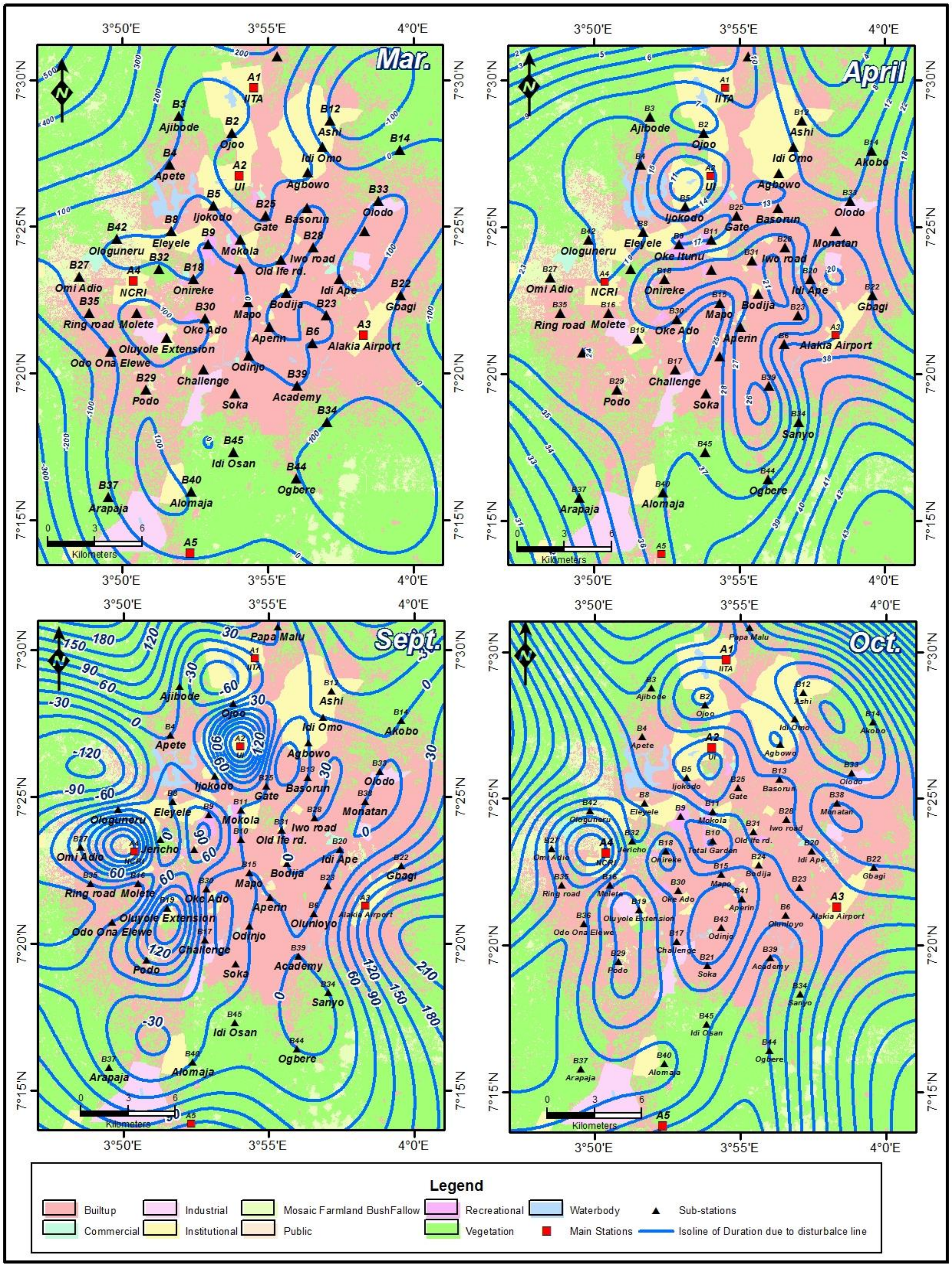


Figure 6.16: Spatial Pattern of Average Duration (mins) of Rainstorms due to Disturbance Lines during the Early and Late Rainy Seasons in 2013

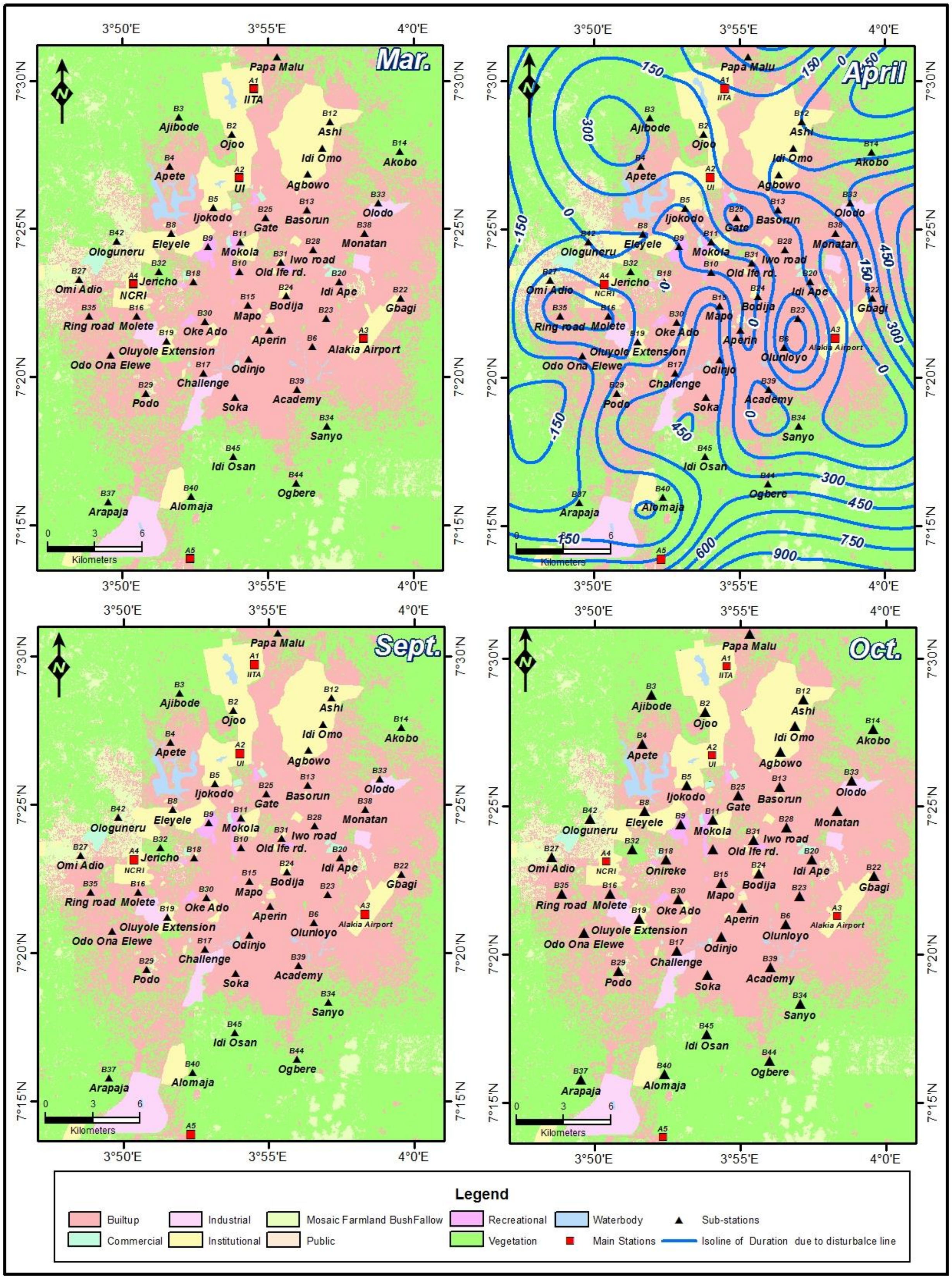


Figure 6.17: Spatial Pattern of Average Duration (mins) of Rainstorms due to Disturbance Lines during the Early and Late Rainy Seasons in 2014

During the main rainy season in 2013, the duration of rainstorms was highest at Agbowo and Alakia with 210 minutes and 205 minutes, respectively. UI had a value of duration of rainstorms of 175 minutes; Sanyo followed, with a value of rainstorm durations of 170 minutes. The main rainy season duration of rainstorms however varied between Odinjo, with a value of duration of rainstorms of 155 minutes, and Omi-Adio, with a value of duration of rainstorms of 150 minutes. Both Lagelu and Oluyole had values of duration of rainstorms of 77 minutes and 45 minutes, respectively. At Eleyele, the main rainy season duration of rainstorms was 35 minutes. The lowest duration was recorded at Bodija, with a value of duration of rainstorms of 20 minutes (Figure 6.18). During this period in 2013, the longest rainy phases, with durations of 210 minutes, were found on the northern section of the city around Agbowo. However, towards the northern section in the area Bodija, the durations decreased, reaching 20 minutes. A similar reduction appeared between Eleyele (less than 40 minutes) and IITA (less than 80 minutes).

During the main rainy season in 2014, the highest duration of rainstorms was at the Olodo and Babanla, with values of duration of rainstorms of 175 minutes and 160 minutes, respectively. Mokola and Total Garden had a value of duration of rainstorms of 140 minutes. Sanyo followed, with a value of duration of rainstorms of 125 minutes. The rainstorm duration values varied between Eleyele, with a value of duration of rainstorms of 135 minutes and Idi-Omo, Ajibode and Papa-Malu, with a value of duration of rainstorms of 130 minutes, respectively. It went lower to 115 minutes at Gbagi and 110 minutes in Mapo. Both Olunloyo and Apete, and IITA had values of duration of rainstorms of 95 minutes, 80 minutes, and 75 minutes, respectively. No rainstorm was recorded at Lagelu and Oluyole. The lowest duration of rainstorms was recorded at Omi-Adio, with a value of duration of rainstorms of 25 minutes (Figure 6.19). During this period in 2014, the longest rainy phases, with durations of 175 minutes, were found on the northern section of the city around Olodo. However, towards the western section in the area Omo-Adio, the durations decreased, reaching 25 minutes. A similar reduction appeared between Eleyele (less than 40 minutes) and IITA (less than 80 minutes).

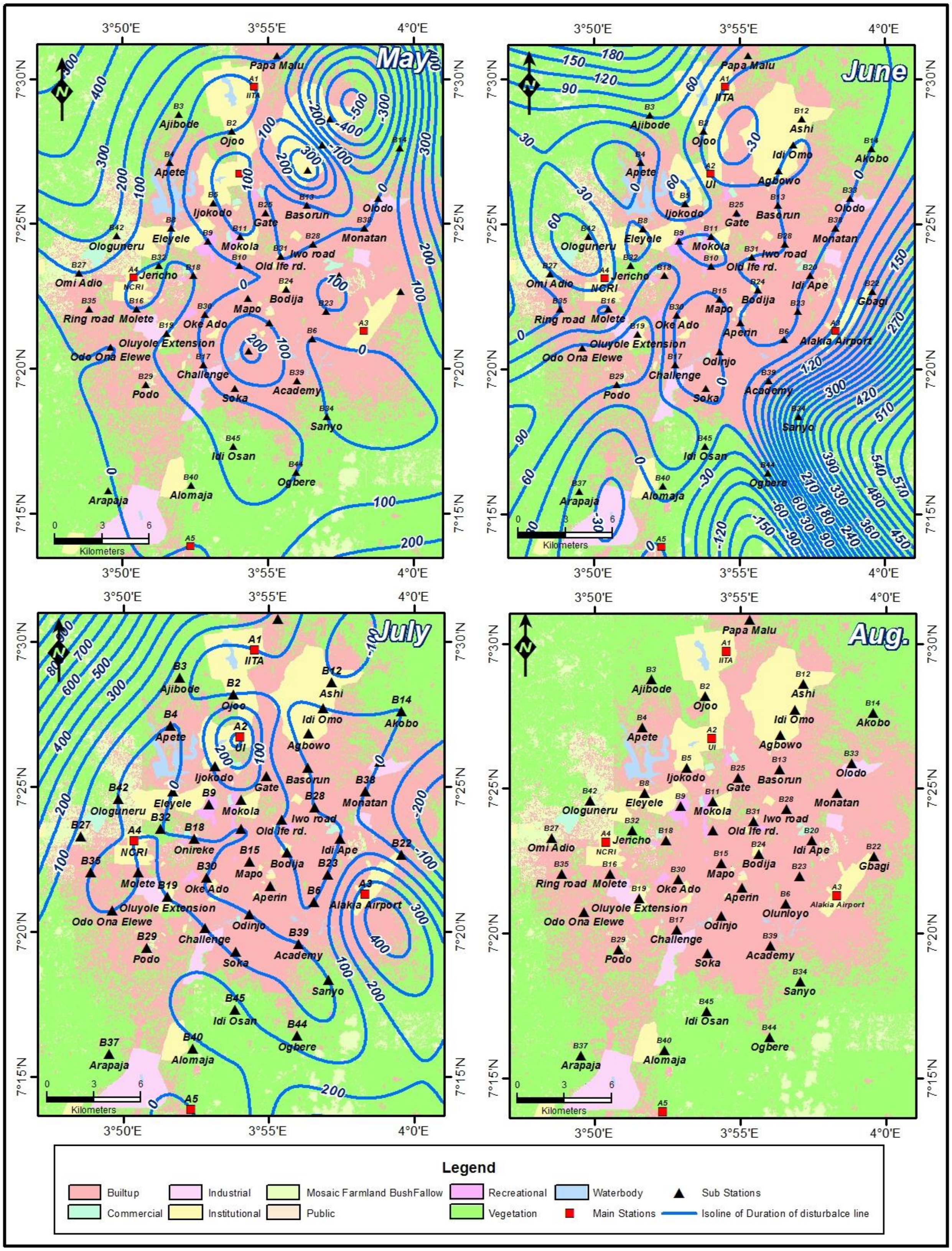


Figure 6.18: Spatial Pattern of Average Duration (mins) of Rainstorms due to Disturbance Lines during the Rainy Season in 2013

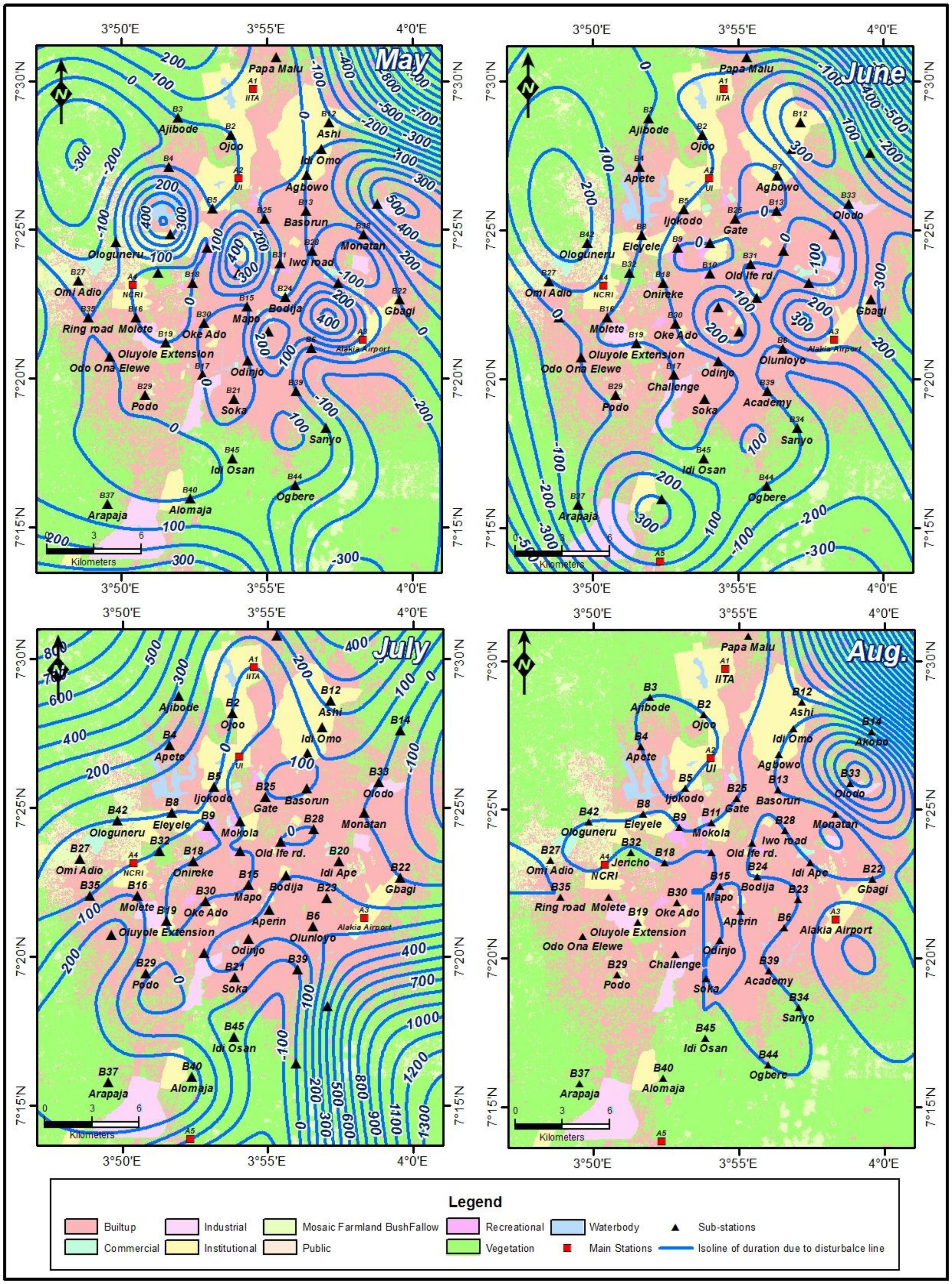


Figure 6.19: Spatial Pattern of Average Duration (mins) of Rainstorms due to Disturbance Lines during the Rainy Season in 2014

6.4.3 Spatial Pattern in the Amount of Rainfall due to Disturbance Lines in Ibadan

The spatial pattern of amounts of rainfall due to disturbance lines in 2013 and 2014 in Ibadan varied a great deal (Figures 6.20, 6.22, 6.24 and 6.21, 6.23, 6.25), respectively. During the dry season in 2013, the highest rainfall amount was recorded at Alakia, with a value of rainfall amount of 9.6 mm. It went low to 2.6 mm at UI. However, at every other section of the city, no rainstorm was recorded during the dry season (Figure 6.20). However, during the dry season in 2013, high rainfall amount was recorded in the eastern section of the city in the area around Alakia (9.6 mm). A relative minimum could be noticed on the northern section around UI (2.6 mm).

During the dry season in 2014, the highest rainfall amount was recorded at Apete and Papa Malu, with a value of rainfall amount of 22.2 mm and 20.2 mm, respectively. It went low to 11.5 mm at Ajibode; 10.2 mm at Alakia. At Lagelu industrial area and Idi-Ape, values of rainfall amount of 8.2 mm and 6.8 mm were recorded, respectively. At CRIN, a value of rainfall amount of 5.0 mm was recorded. At Babanla, a value of rainfall amount of 4.3 mm was recorded. At Gbagi, a value of rainfall amount of 2.2 mm was recorded. At Eleyele, a value of rainfall amount was 7.2 mm. Oluyole recorded 1.7 mm of rainfall amount (Figure 6.21). Besides, during the dry season in 2014, high rainfall amount was recorded in the northwestern section of the city around Apete with a value of rainfall amount of 22.2 mm. A relative minimum could be noticed on the southern section around Oluyole with a value of rainfall amount of 1.7 mm.

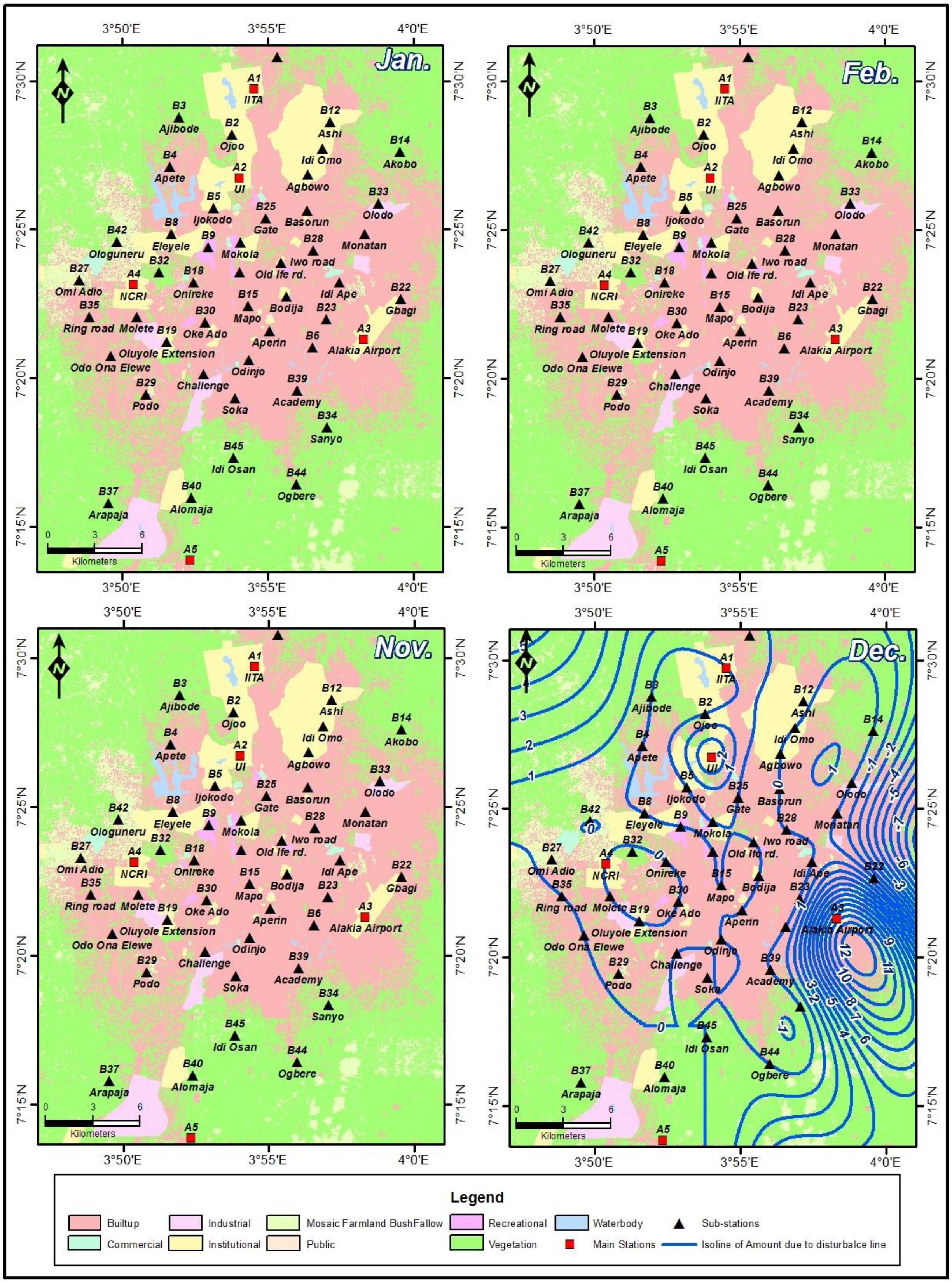


Figure 6.20: Spatial Pattern of Rainfall Amount (mm) due to Disturbance Lines during the Dry Season in 2013

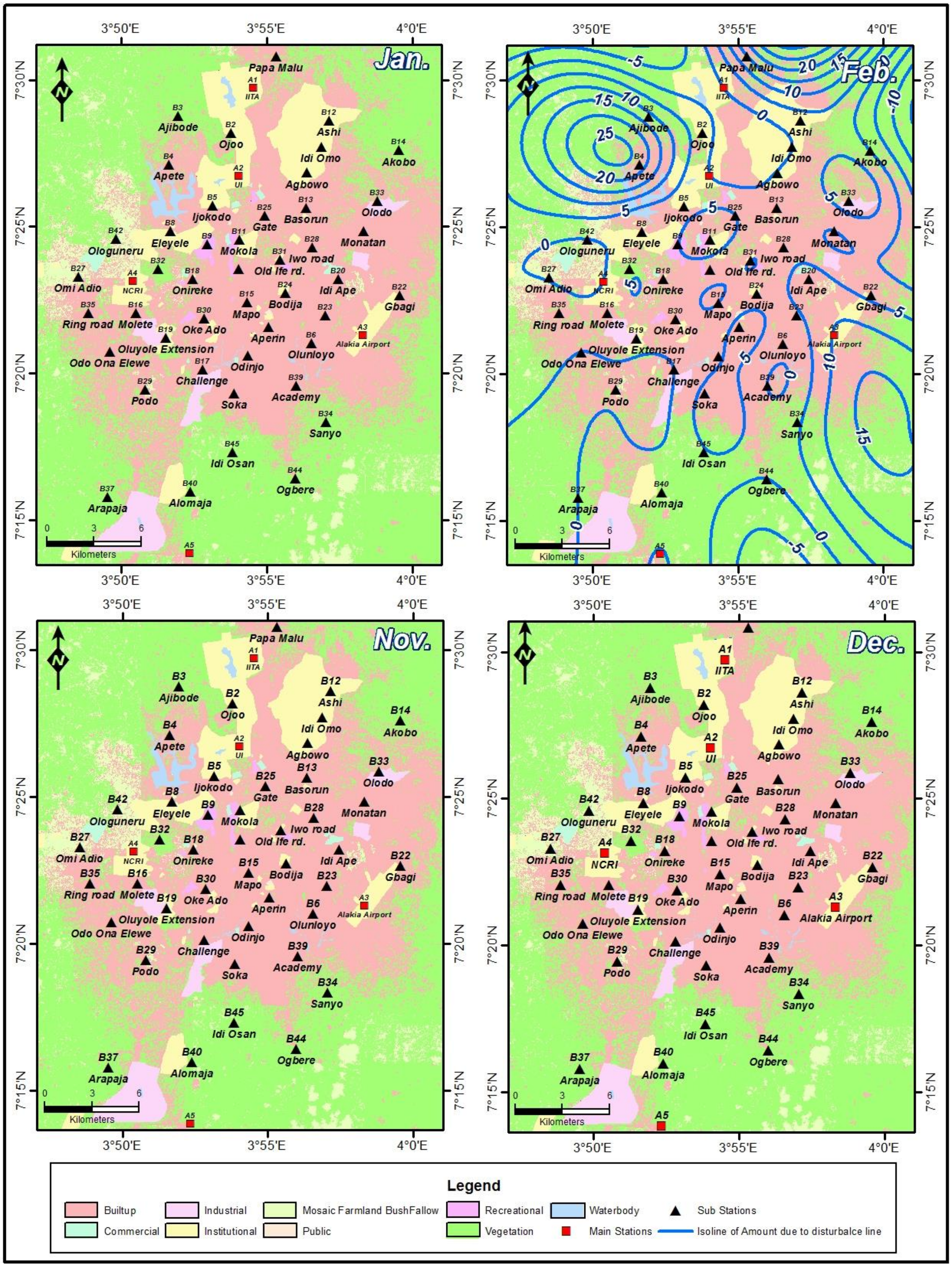


Figure 6.21: Spatial Pattern of Rainfall Amount (mm) due to Disturbance Lines during the Dry Season in 2014

There was a change in pattern of distribution of rainfall amount during the early rainy season in 2013 and 2014. During the early rainy season in 2013 rainfall amount varied between 0.1 mm (the lowest at Mapo) and 56.5 mm at Adegbayi. It went low to 55.5 mm and 54.5 mm at Olunloyo and Iwo-Road, respectively. At Babanla and Aperin, the value of rainfall amount was 53.6 mm and 52.6 mm, respectively. At Onireke, the value of rainfall amount was at 51.5 mm. The rainfall amount values during early rainy season in 2013 varied between 16.0 mm at Papa Malu, and 47.2 mm at UI and 51.2 mm at Total Garden. At IITA, CRIN, and Alakia, the values of rainfall amount were 40.0 mm, 24.0 mm, and 10.7 mm, respectively. At Eleyele, the value of rainfall amount was 9.0 mm. However, Oluyole and Lagelu had 13.4 mm and 11.0 mm of rainfall amount, respectively (Figure 6.22). However, there was a change in pattern of rainfall amount during the early rainy season in 2013. The rains that accompanied the rainstorms due to this system at the early rainy season tend to be more intense than the rains that accompanied the rainstorms that occur at the height of the rainy season. During this period, all the sections of the city received rainfall amount yielded rainfall amounts of between 10.5 mm and 56.5 mm. But, two areas of the city stood out as sections of high frequency of rainstorms due to this system, on the eastern and core eastern sections in the areas around Babanla and Alakia where the rainproducing system yielded rainfall amounts of between 53.6 mm and 56.5 mm.

Conversely, during the early rainy season period in 2014, rainfall amount varied between 0.6 mm (the lowest at UI) and 50.4 mm at Babanla. It went low to 33.6 mm at Olunloyo and 33.2 mm at NCRI. At CRIN, the value of rainfall amount was 26.9 mm. At Mapo and Papa Malu, the values of rainfall amount were 22.4 mm and 22.2 mm, respectively. At Eleyele, the value of rainfall amount was 20.0 mm, next to the Papa Malu. At Challenge, the value of rainfall amount was 19.4 mm. At Lagelu and Oluyole, the values of rainfall amount were of 17.8 mm and 16.7 mm, respectively. However, Alakia had a value of rainfall amount as 21.4 mm. The values of rainfall amount varied between 3.3 mm at Akobo, and 8.8 mm at Ashi and 10.6 mm at Ogbere and 11.2 mm at Idi-Osan. At Ajibode and Alomoja, the values of rainfall amount were 12.4 mm and 9.8 mm, respectively (Figure 6.23). Similarly, there was a change in pattern of rainfall amount during the early rainy season in 2014. The rains that accompanied the rainstorms due to this system at the early rainy season tend to be more intense than the rains that accompanied the rainstorms that occur at the height of the rainy season. During this period, all the sections of the city received rainfall amount yielded rainfall amounts of between 0.6 mm and 50.4 mm. But, two areas of the city stood out as sections of high frequency of rainstorms due to this system, on the eastern and core southern sections in the areas around Babanla and Olunloyo where the rainproducing system yielded rainfall amounts of between 50.4 mm and 33.6 mm.

During the late rainy season in 2013, rainfall amount varied between 2.6 mm (the lowest at Mapo) and 50.0 mm at NCRI. The amount of rainfall went low to 48.6 mm at Alakia and 44.8 mm at UI. At Onireke, the value of rainfall amount was 36.0 mm. At the Papa Malu, the late rainy season period rainfall amount was put at 31.0 mm. At Apete, the value of rainfall amount was of 29.5 mm, next to Papa Malu. At Gbagi and Iwo-Road, the values of rainfall amount were 27.7 mm and 27.1 mm, respectively. At Ijokodo and Babanla, the values of rainfall amount were 26.2 mm and 23.3 mm, and 20.0 mm at Oluyole. At IITA and Lagelu, the values of rainfall amount were 10.7 mm and 10.5 mm, respectively. Ologuneru and Eleyele had values of rainfall amount of 12.2 mm and 9.0 mm, respectively. At Idi-Omo and Arapaja, the values of rainfall amount were 8.6 mm and 6.4 mm, respectively (Figure 6.22). Besides, during the late rainy season in 2013, there was a general tendency of amount of rainfall to decrease on all the sections of the city. The only exception was the late rainy period of September and October 2013 which displayed a tendency of rainfall amount towards eastern section of the city in the area around NCRI and Alakia recorded high amount of rainfall reaching up to 50.0 mm.

Conversely, no rainfall amount was recorded at every section of the city of Ibadan during the late rainy season in 2014 (Figure 6.23).

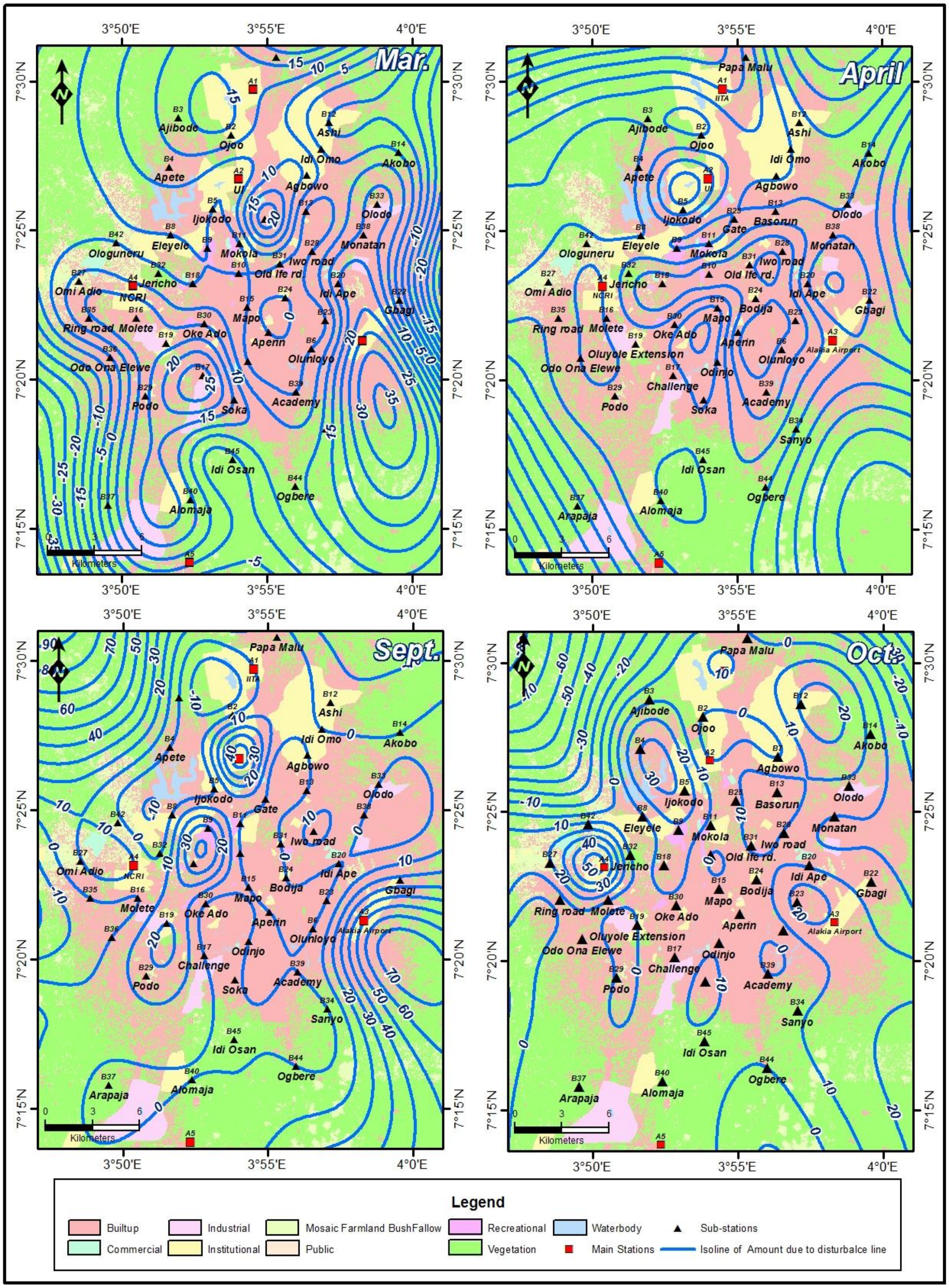


Figure 6.22: Spatial Pattern of Rainfall Amount (mm) due to Disturbance Lines during the Early and Late Rainy Seasons in 2013

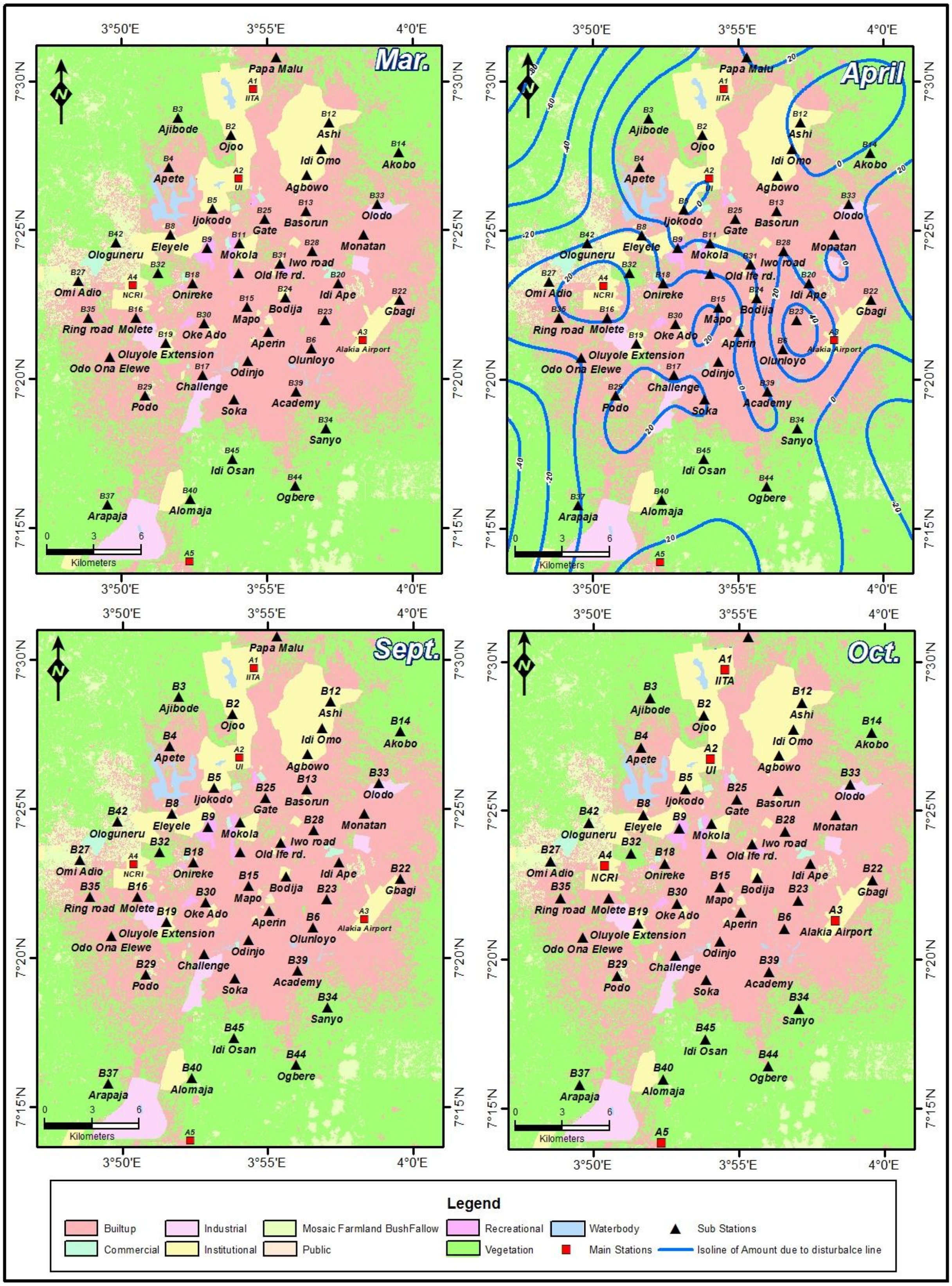


Figure 6.23: Spatial Pattern of Rainfall Amount (mm) due to Disturbance Lines during the Early and Late Rainy Seasons in 2014

During the main rainy season in 2013, the highest rainfall amount was observed at Ijokodo; Odo-Ona Elewe and Idi-Osan with a value of rainfall amount of 50.0 mm, 37.0 mm, and 33.1 mm, respectively. Omi-Adio and Ajibode had 32.5 mm and 25.0 mm of rainfall amount, respectively. Alakia had 23.2 mm of rainfall amount. Monotan and Mapo followed, with a value of rainfall amount of 23.0 mm. The rainfall amount however varied between UI, with a value of rainfall amount of 8.6 mm, and Agbowo with a value of rainfall amount of 22.0 mm. The rainfall amount went lower to 20.1 mm at Gbagi and 20.5 mm at Oke-Itunu and 14.5 mm at Podo. The lowest value of rainstorm amount was recorded at NCIR, and Bodija and Sanyo, with 3.0 mm and 2.9 mm, respectively. Eleyele and Oluyole had values of rainfall amount of 9.5 mm and 7.0 mm, respectively (Figure 6.24). However, during the main rainy season in 2013, rainfall amount was highest in the area around Ijokodo and northwest of the city, with 50.0 mm. Besides, towards the south, east and north, rainfall decreased rapidly. The central section showed total of about 2.0 mm.

During the main rainy season in 2014, the highest rainfall amount was observed at CRIN and Total Garden, with 60.2 mm and 58.2 mm, respectively. Eleyele had 45.6 mm. The institutional and medium-density landuse areas of Alakia and NCRI had 35.7 mm and 30.2 mm and Mokola followed, with 22.7 mm. The rainfall amount varied between Alomoja with 22.2 mm, Babanla, with a value of rainfall amount of 19.4 mm. At IITA, the value of rainfall amount was 18.4 mm. Both Gbagi and Challenge had values of rainfall amount of 15.2 mm and 6.8 mm, respectively. The lowest value of rainfall amount was recorded at Apete, with a value of rainfall amount of 0.8 mm. At Oluyole, the main rainy season period rainfall amount was 4.8 mm (Figure 6.25). During this period in 2014, rainfall amount was highest in the area around CRIN and south of the city, with 60.2 mm. Besides, towards the west, east and north, rainfall decreased rapidly. The central section showed total of rainfall amount of about 19.4 mm.

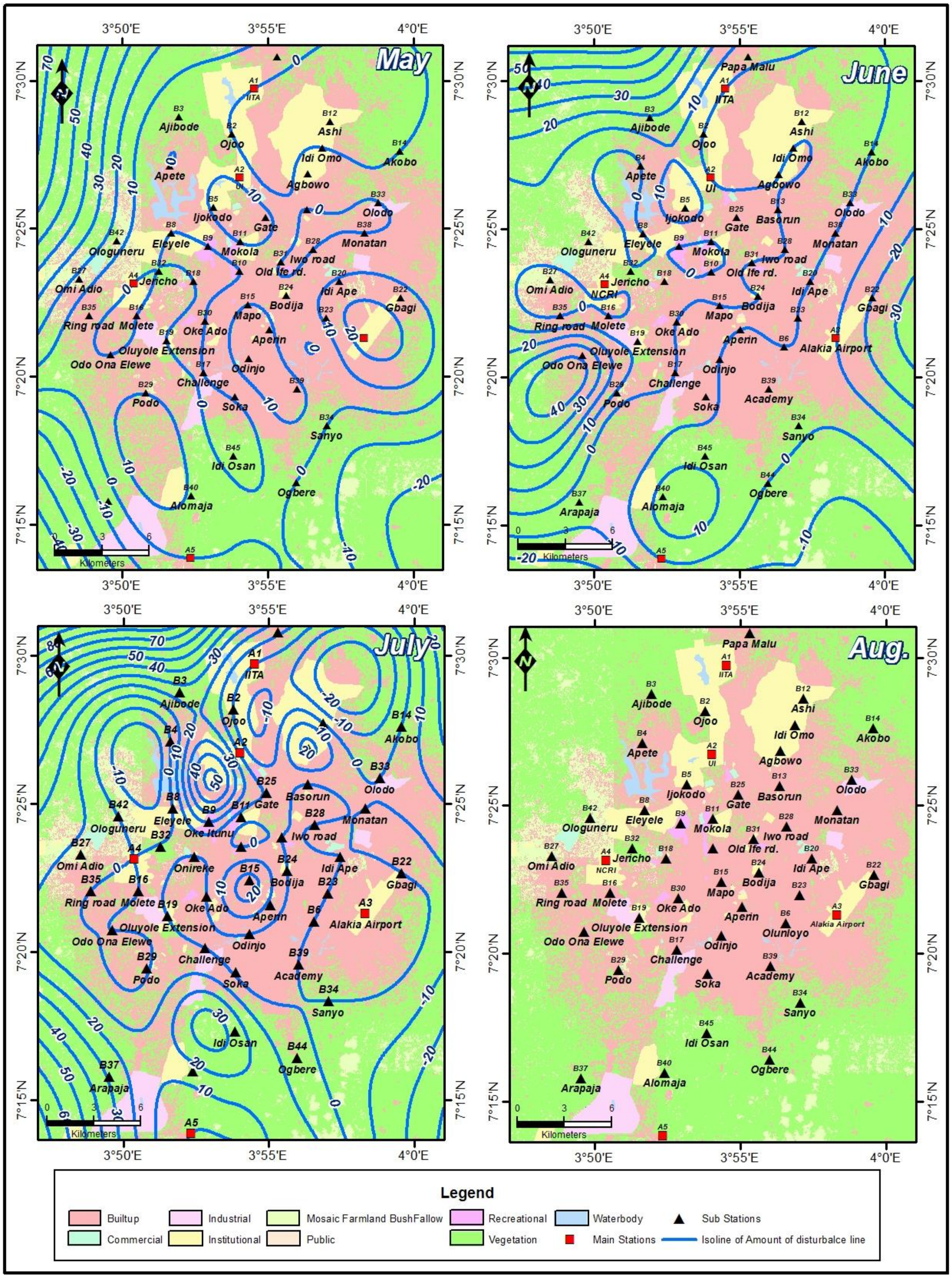


Figure 6.24: Spatial Pattern of Rainfall Amount (mm) due to Disturbance Lines during the Rainy Season in 2013

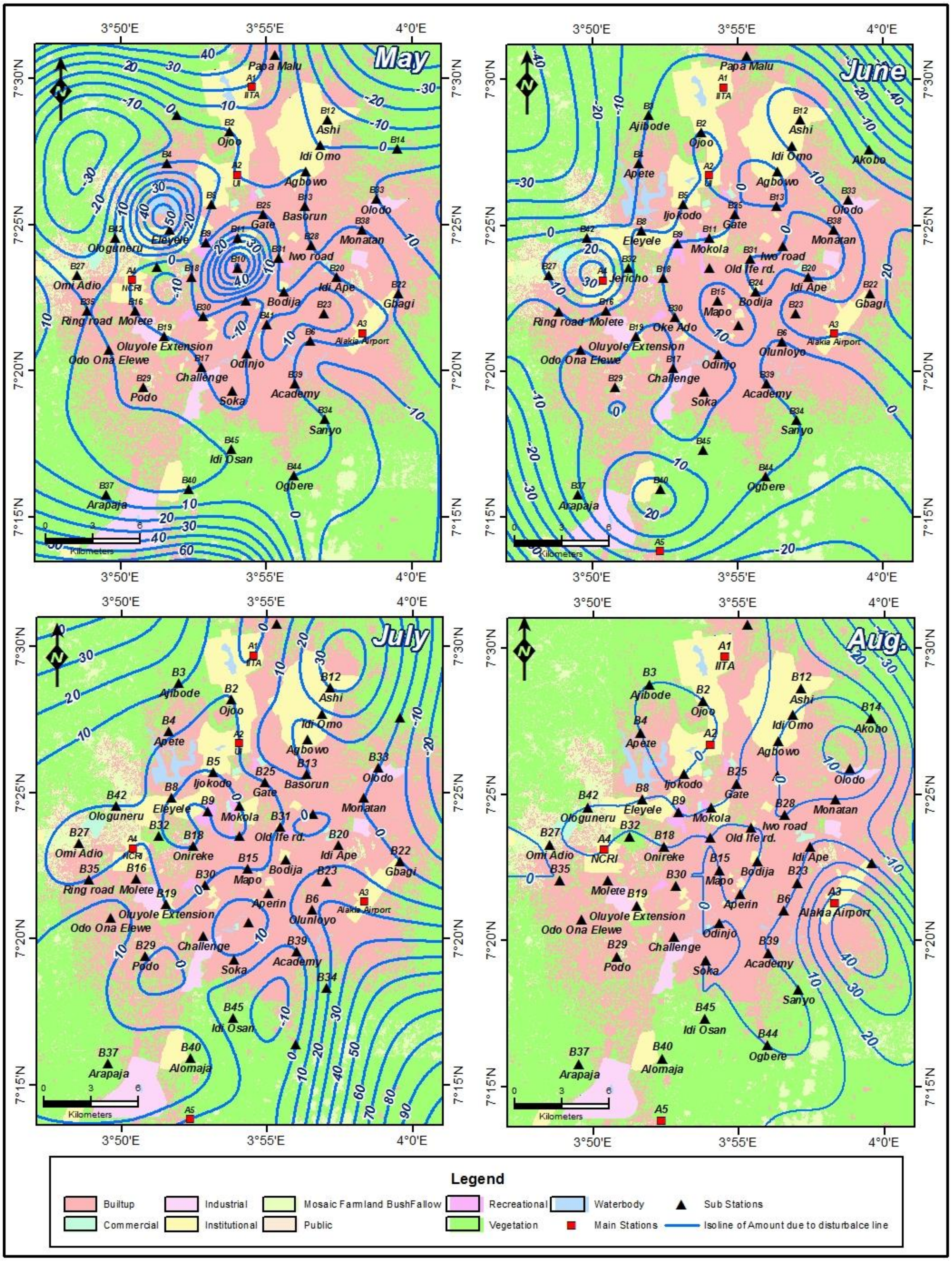


Figure 6.25: Spatial Pattern of Rainfall Amount (mm) due to Disturbance Lines during the Rainy Season in 2014

6.5 Effect of Duration, Rainfall Amount and Speed of Rainstorms on the Areal Coverage of Rainstorms due to Disturbance Lines during the Early and Late Rainy Seasons in Ibadan

This section examines the effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms due to disturbance lines during the early and late rainy seasons of 2013 and 2014 in Ibadan.

6.5.1 Effect of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Disturbance Lines during the Early and Late Rainy Seasons of 2013 and 2014

The effect of duration, rainfall amount and speed of rainstorms on the areal coverage of rainstorms during the early rainy season of 2013 and 2014 was examined. Regression result and model for areal coverage, duration, rainfall amount and speed of rainstorms was produced during the early rainy season (Table 6.5). The correlation coefficient between the areal coverage of rainstorms and the duration, rainfall amount and speed of rainstorms during the early rainy season showed that, only duration of rainstorms (0.129), related directly with the areal coverage of rainstorms during the early rainy season. But, rainfall amount (-0.022) and speed of rainstorms (-0.369) related inversely with the areal coverage of rainstorms (Table 6.3). The correlation further revealed that there was no significant correlation between the duration, rainfall amount and speed of rainstorms during the early rainy season.

As shown in Appendix V (a), an R value of 0.429, R^2 value of 0.184 and coefficient of determination value of 18.40% means that, jointly, the duration, rainfall amount and speed of rainstorms accounted for 18.40% variation in the areal coverage of rainstorms due to disturbance lines during the late rainy season. The p-value, (in Appendix V (a)), revealed that the independent variables, when taken together, were not significant predictors (0.824), explaining the areal coverage of rainstorms due to disturbance lines during the early rainy season. Therefore, the hypothesis one that states that areal coverage of rainstorms due to disturbance lines during the early rainy season is not a function of the duration, amount and speed of rainstorms was rejected.

The regression equation stating the relationship between the areal coverage of rainstorms and the duration, rainfall amount and speed of rainstorms of rainstorms during early rainy season is shown in table 6.5. The variable that contributed most to predicting the areal coverage of rainstorms during the early rainy season was duration of rainstorms (-0.019 mins), which means that X_1 was the one that gave the best explanation on areal coverage of rainstorms due to disturbance lines during the early rainy season. However, the three independent variables (duration, rainfall amount and speed of rainstorms) were not significant at 0.05 level (that is, 0.973 mins; 0.667 mm; 0.425 ms^{-1}) (see Appendix V (a)). The predictive models of the independent variables are shown in Table 6.5.

The regression model for the areal coverage, duration, rainfall amount and speed of rainstorms was produced during the late rainy season. The correlation of coefficient of areal coverage, duration, rainfall amount and speed of rainstorms due to disturbance lines revealed that during the late rainy season, duration (0.202), rainfall amount (0.114) and speed of rainstorms (0.479) related directly with the areal coverage of rainstorms. The correlation further revealed that, there was significant correlation between the duration and speed of rainstorms during the late rainy season. The other variable compared, as shown in Table 6.4 had no significant correlation.

As shown in Appendix V (b), an R value of 0.785, R^2 value of 0.617 and coefficient of determination value of 61.70%, means that, jointly, the duration, rainfall amount and speed of rainstorms accounted for 61.70% variation in the areal coverage of rainstorms during the late rainy season. The p-value of the model was 0.353, which was greater than 0.05. That is, the independent variables, when taken together, were not significant predictors, explaining the areal coverage of rainstorms during the late rainy season. This implies that the predictor variables are inadequate for the prediction of variability in areal coverage of rainstorms during the late rainy season. Therefore, the hypothesis two which states that areal coverage of rainstorms due to disturbance lines during the late rainy season is not a function of the duration, rainfall amount and speed of rainstorms was rejected.

The regression equation stating the relationship between the areal coverage of rainstorms and the duration, rainfall amount and speed of rainstorms is shown in Table 6.5. The R^2 statistics further revealed that none of the predictor variable explained the areal coverage of rainstorms during the late rainy season. However, the variable that contributed most to predicting the areal coverage of rainstorms was speed of rainstorms (1.695) which means that X_3 was the one that gave best explanation on the areal coverage of rainstorms during the late rainy season. However, the three independent variables (duration, rainfall amount and speed of rainstorms) were not significant at 0.05 level (that is, 0.194 mins; 0.233 mm; 0.125 ms^{-1}) (see Appendix V (b)). The predictive models of the independent variables are shown in Table 6.5.

Table 6.3: Correlation Coefficient of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Disturbance Lines during the Early Rainy Season

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Speed (ms^{-1})
Areal coverage (km^2)	1.00	0.129	-0.022	-0.363
Duration (mins)		1.00	0.407	0.502
Rainfall amount (mm)			1.00	-0.465
Speed (ms^{-1})				1.00

Table 6.4: Correlation Coefficient of Duration, Rainfall Amount and Speed of Rainstorms on Areal Coverage of Rainstorms due to Disturbance Lines during the Late Rainy Season

	Areal coverage (km^2)	Duration (mins)	Rainfall amount (mm)	Speed (ms^{-1})
Areal coverage (km^2)	1.00	0.202	0.114	0.479
Duration (mins)		1.00	0.272	0.813*
Rainfall amount (mm)			1.00	-0.139
Speed (ms^{-1})				1.00

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

Table 6.5: Predictive Model Summary of Areal Coverage of Rainstorms due to Disturbance Lines during the Early and the Late Rainy Seasons

Model S/N	Seasons	Prediction model
1	Early rainy season	Areal coverage $=335.681 - 0.019_{duration} - 0.243_{amount} - 0.491_{speed}$
2	Late rainy season	Areal coverage $=545.719 - 1.372_{duration} + 0.722_{amount} + 1.695_{speed}$

Model 1 can be expressed as:

$$y = 335.681 - 0.019X_1 - 0.243X_2 - 0.491X_3 \quad 6.1$$

Model 2 can be expressed as:

$$y = 545.719 - 1.372X_1 + 0.722X_2 + 1.695X_3 \quad 6.2$$

where:

X_1 is duration of rainstorms due to disturbance lines

X_2 is rainfall amount due to disturbance lines

X_3 is speed of rainstorms due to disturbance lines

6.6 Comparison of the Duration of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Seasons 2013 and 2014

This section is aimed at comparing the duration of rainstorms due to disturbance lines examined in this study between the early and the late rainy seasons in Ibadan. Paired Sample T-test was used to do this.

6.6.1 Comparison of the Duration of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

The comparison of the duration of rainstorms between the early rainy season and the late rainy season is presented under this section. The analysis of two-independent sample comparison of means of duration of rainstorms between the early and the late rainy seasons was done using paired sample t-test method (see Appendix V (c)). The summary of the result is shown in Table 6.6. The results of the analysis of the differences between the mean of durations of rainstorms between the early and the late rainy seasons, (Table 6.4) revealed that there was no significant difference in the duration of rainstorms during the early and the late rainy seasons, with calculated T-value of 1.33, which was less than the T-critical value of 2.16 at 0.05 confidence level. This result means that the duration of rainstorms between both the early and the late rainy seasons did not vary significantly.

6.7 Comparison of the Amount of Rainfall due to Disturbance Lines between the Early Rainy Season and the Late Rainy Seasons of 2013 and 2014

This section is aimed at comparing the amount of rainfall due to disturbance lines examined in this study between the early and the late rainy seasons in Ibadan. Paired Sample T-test was used to do this.

6.7.1 Comparison of the Amount of Rainfall due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

The comparison of the amount of rainfall between the early rainy season and the late rainy season is presented under this section. The analysis of two-independent sample comparison of means of amount of rainfall between the early and the late rainy seasons was done using paired sample t-test method (see Appendix V (d)). The summary of the result is shown in Table 6.7. The results of the analysis of the differences between the mean of amounts of rainfall between the early and the late rainy seasons, (Table 6.5) revealed that there was no significant difference in the amount of rainfall during the early and the late rainy seasons, with calculated T-value of 1.14, which was less than the T-critical value of 2.16 at 0.05 confidence level. This result means that the amount of rainfall between both the early and the late rainy seasons did not vary significantly.

Table 6.6: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Duration of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

Season of duration of rainstorms	T-cal	T-critical	Level of significance
Early and late rainy seasons	1.33	2.16	Not significant at 0.05 level

Table 6.7: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Amount of Rainfall due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season of 2013 and 2014

Season of amount of rainfall	T-cal	T-critical	Level of significance
Early and late rainy seasons	1.14	2.16	Not significant at 0.05 level

CHAPTER SEVEN

THE LIFETIME, SPEED AND AREAL COVERAGE OF RAINSTORMS DUE TO DISTURBANCE LINES IN IBADAN

7.1 Characteristics of the Lifetime and Speed of Rainstorms due to Disturbance Lines

A total of 19 speeds of rainstorms due to disturbance lines events in 2013 showed an average speed of 17.6 ms^{-1}. The maximum speed was 92 ms^{-1} while 0.2 ms^{-1} was the minimum. The standard deviation was 26.2. In 2014, a total of 10 speeds of rainstorms showed an average speed of 7.2 ms^{-1}. Besides, 25.4 ms^{-1} was the maximum speed of rainstorms in this data, while 1.6 ms^{-1} was the minimum with the standard deviation of 7.6 ms^{-1}. About 58% [D= 105 mins; V= 3.2 ms^{-1}] and 70% [D= 129 mins; V= 3.0 ms^{-1}] of the average speed of rainstorms in the study area was under the influence of the short-lived slow-moving systems, while the remaining 42% [D= 132 mins; V= 29.7 ms^{-1}] and 30% [D= 283 mins; V= 16.8 ms^{-1}] was under the influence of the fast-moving short-lived systems in 2013 and 2014, respectively (Figure 7.1).

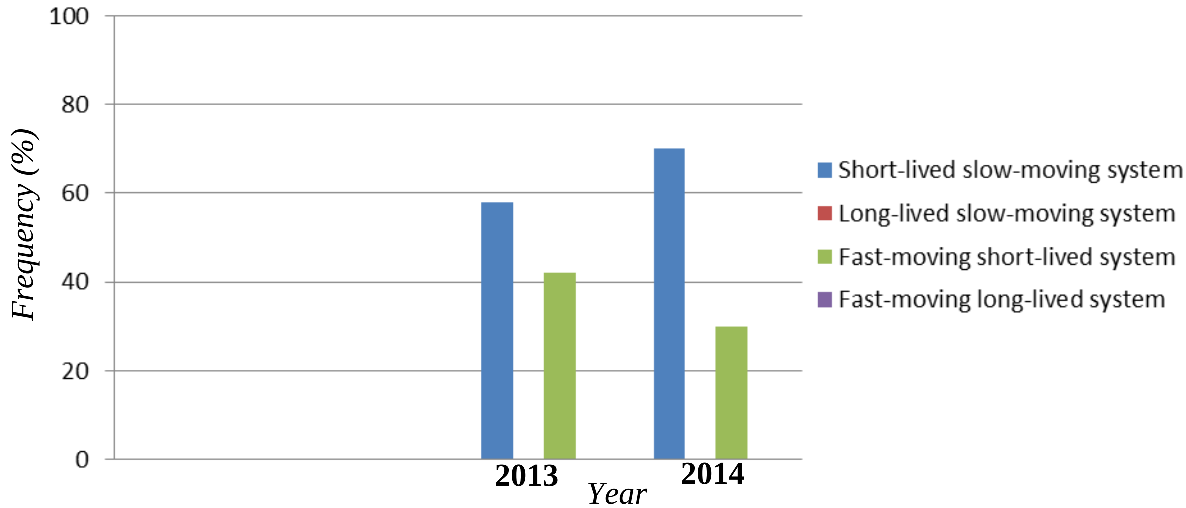


Figure 7.1: Pattern of the Lifetime and Speed of Rainstorms due to Disturbance Lines of 2013 and 2014

7.2 Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Disturbance Lines

The seasonal pattern in the lifetime and speed of rainstorms due to disturbance lines in 2013 and 2014 are illustrated in this section.

7.2.1 Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Disturbance Lines in 2013

The seasonal pattern in the lifetime and speed of rainstorms due to disturbance lines in 2013 are illustrated in Figure 7.2. During the dry season of 2013, the fast-moving systems seemed to be prevalent systems during the rainstorm events in the study area. About 67% [D= 97 mins; V= 25.6 ms^{-1}] and 33% [D= 115 mins; V= 1.5 ms^{-1}] of the speeds of rainstorms in the study area were under the influence of the fast-moving systems and slow-moving systems, respectively which occurred especially in December 2013, (Figure 7.2).

During the early rainy season of 2013, the slow-moving systems and the fast-moving systems were also analysed and recorded as the prevailing systems during the rainstorms events in the study area. About 40% [D= 106 mins; V= 5.1 ms^{-1}] and 60% [D= 66 mins; V= 42.5 ms^{-1}] of the speeds of rainstorm in the study area were under the influence of the slow-moving systems and the fast-moving systems, which occurred especially in March and April 2013 (Figure 7.2).

The slow-moving systems and the fast-moving systems were the prevalent systems during the late rainy season in the study area. Besides, about 85% [D= 78 mins; V= 1.5 ms^{-1}] of the slow-moving systems prevailed over the months of September and October, while the remaining 15% [D= 141 mins; V= 92.0 ms^{-1}] were recorded as the fast-moving systems during the late period of October, 2013 (Figure 7.2).

During the main rainy season, two different types of the systems were the prevalent speed systems during rainstorm events in the study area. At the peak of the rainy season, that is June/July, the fast-moving systems were the prevalent systems during rainstorm events in the study area, besides, the slow-moving systems, were recorded as the prevailing systems in the months of May and August 2013. However, about 75% [D= 77 mins; V= 5.1 ms^{-1}] of the slow-moving systems and 25% [D= 147 mins; V= 27.9 ms^{-1}] of the fast-moving systems prevailed over the rainy season in 2013 (Figure 7.2).

7.2.2 Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Disturbance Lines in 2014

The seasonal pattern in the lifetime and speed of rainstorms due to disturbance lines in 2014 are illustrated in Figure 7.2. In 2014, the slow-moving systems were the prevailing systems during the dry season. About 100% [D= 74 mins; V= 2.3 ms^{-1}] of the speeds in the study area were under the influence of the slow-moving systems which were recorded in February 2014 (Figure 7.2).

Further, about 67% [D= 164 mins; V= 4.4 ms^{-1}] and 33% [D= 315 mins; V= 13.0 ms^{-1}] of the speeds of rainstorm were under the influence of the slow-moving systems and the fast-moving systems which were analysed and recorded in the early rainy season during the rainstorm events in April 2014, respectively.

However in 2014, no speed of movement of rainstorm was recorded during the late rainy season due to total disappearance of the rainstorm events in the study area (Figure 7.2).

During the main rainy season, another pattern was observed and recorded during rainstorm events during the main rainy season in 2014. At the peak of the rainy season, that is June/July, about 60% [D= 252 mins; V= 13.3 ms^{-1}] of the fast-moving systems were recorded as the prevalent speed systems during rainstorm events in the study area, while the remaining 40% [D= 103 mins; V= 2.7 ms^{-1}] were the slow-moving systems, which occurred in May and August 2014 (Figure 7.2).

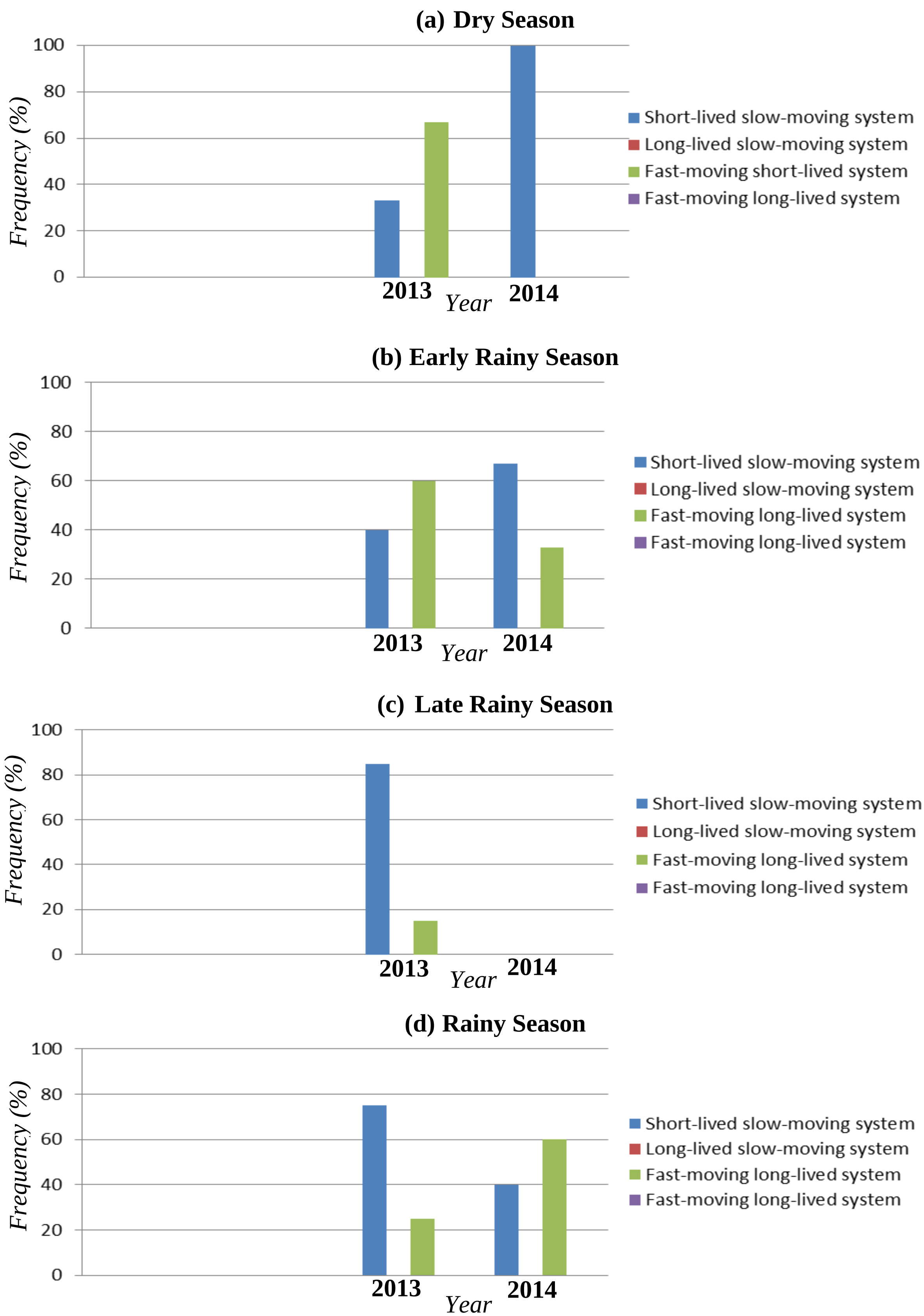


Figure 7.2: Seasonal Pattern in the Lifetime and Speed of Rainstorms due to Disturbance Lines at different Periods (a-d)

One thing that can be deduced from these results is that during these periods, there was variation in the pattern of the lifetime and speed of rainstorms over the study area in the 2013 and 2014 rainstorm events. The slow-moving systems and the fast-moving systems were the only systems that associated with disturbance lines. Some fast-moving long-lived systems were also observed during these periods, which revealed that the systems can only appear during rainstorm events. The implication of the systems over the city of Ibadan is that the rainstorm events associated with fast-moving long-lived systems tend to generate flash floods which may occur within few hours after heavy rainfall, tropical storm, failure of dams or levees or releases of ice jams. They cause the greatest damage to society. The slow-moving systems and the fast-moving systems also associates with this kind of rain-producing system, when they accounted for highest percentages of the lifetime and speed of rainstorm events in the study area. The slow-moving systems and the fast-moving systems also associated with this kind of rainstorm events, especially in 2013. They were also recorded as the prevalent systems over the city of Ibadan in 2014. There was a total disappearance of the long-lived slow-moving systems and the fast-moving long-lived systems over the city of Ibadan during rainstorm events in 2014.

7.3 Speed of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season

This section is aimed at comparing the speed of rainstorms due to disturbance lines examined in this study between the early and the late rainy seasons in Ibadan. Paired Sample T-test was used to do this.

7.3.1 Speed of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season

The comparison of speed of rainstorms between the early rainy season and the late rainy season is presented under this section. The analysis of two-independent-sample comparison of means of speed of rainstorms between the early and the late rainy seasons was done using paired sample t-test method (see Appendix VI (a)). The summary of the result is shown in Table 7.1. The result of the analysis of the differences between the means of speed of rainstorms between the early and the late rainy seasons, (Table 7.1) revealed that there was no significant difference in the speed of rainstorms during the early and the late rainy seasons, with calculated T-value of 0.34, which was less than the

T-critical value of 2.16 at 0.05 confidence level. Therefore, hypothesis three, which states that there are no significant differences in the speed of rainstorms during the early and the late rainy seasons, was rejected. This result means that the speed of rainstorms between both the early and the late rainy seasons did not vary significantly.

Table 7.1: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Speed of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season

Season of speed of rainstorms	T-cal	T-critical	Level of significance
Early and late rainy seasons	0.34	2.16	Not significant at 0.05 level

7.4 Areal Coverage of Rainstorms due to Disturbance Lines

The areal coverage of rainstorm events during the period of the study, as observed from the data recorded in 2013 showed that the areal coverage of rainstorms ranged from 22.5 km^2 to as much as 436.5 km^2. The average areal coverage of rainstorms was 164.6 km^2, with standard deviation of 140.6. Besides, in 2014, the areal coverage of rainstorms, as observed from the total data recorded, showed that the areal coverage of rainstorms covered during this period ranged from 52.5 km^2 to as much as 435.0 km^2. The average areal coverage of rainstorms was 181.0 km^2. The standard deviation was 118.4. Figure 7.3 depicts the frequency distribution of the areal coverage of rainstorms in 2013 and 2014. As evident in the total data, 32% of the areal coverage of rainstorms measured less than 50.0 km^2 in 2013 whereas in 2014, no areal coverage of rainstorms was measured less than 50.0 km^2. 16% and 20% measured between 50.0 and 100.0 km^2, 26% and 40% measured between 100.0 and 200.0 km^2, while 26% and 40% measured between 200.0 km^2 and above in 2013 and 2014, respectively.

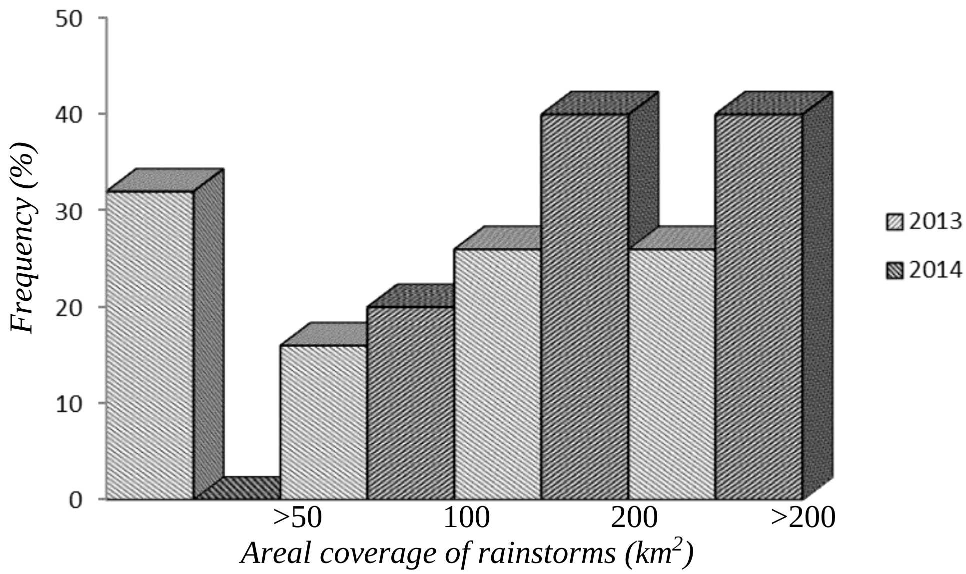


Figure 7.3: Areal Coverage of Rainstorms due to Disturbance Lines

7.4.1 Distribution Patterns of the Areal Coverage of Rainstorms due to Disturbance Lines

The distribution patterns of the areal coverage of rainstorms due to the events of disturbance lines in 2013 and 2014 exhibited different patterns over the city, as illustrated in this section.

7.4.1.1 Distribution Patterns of the Areal Coverage of Rainstorms due to Disturbance Lines in 2013

The distribution patterns of the areal coverage of rainstorms due to the events of disturbance lines in 2013 are illustrated in Figure 7.4. During the dry season months of 2013, the highest areal coverage of rainstorm received in the study area was in December, as 301.5 km^2 (67%) of the total area, oriented roughly north to south. During this season, the months of January, February and November recorded no rainstorm. However, by February 2014, all the sections of the city received wider coverage of rainstorms of about 351.2 km^2 (about 78%) of the total area (Figure 7.4).

During the early rainy season months (March and April), there was a tendency for the areal coverage of rainstorms to decrease westwards from the area east (Figures 7.4). Generally, during the early rainy season of 2013, the highest areal coverage of rainstorms was recorded in April, as 418.5 km^2 (about 93%) of the total area; followed by 352.5 km^2 (78.3%) in March.

Similar patterns of coverage of rainstorms was experienced during late rainy season months of September and October 2013, where the city received increase in the total coverage of rainstorms all over the stations (Figure 7.4). The areal coverage of rainstorms increased southwards from the north and the pattern of movement of propagation of coverage of rainstorms due to disturbance lines also decreased westwards from the area east. Generally, during the late rainy season of 2013, the highest areal coverage of rainstorms was recorded in October as 447.1 km^2 (about 99.4%) of the total area; followed by 304.5 km^2 (67.7%) in September.

Moreover, during the main rainy season months of May to August, in 2013, more than 95% of the total area was covered by the rainstorms (Figures 7.4). Generally, during the main rainy season months of 2013, the highest areal coverage of rainstorms received was recorded in May as 325.5 km^2 (about 72.3%) of the total area; followed by 316.5 km^2 (70.3%) in June and 306 km^2 (68%) in July. No rainstorm event due to disturbance lines was recorded in August.

7.4.1.2 Distribution Patterns of the Areal Coverage of Rainstorms due to Disturbance Lines in 2014

The distribution patterns of the areal coverage of rainstorms due to the events of disturbance lines in 2014 are illustrated in Figure 7.4. During the dry season months in February 2014, all the sections of the city received wider coverage of rainstorms of about 351.2 km^2 (about 78%) of the total area (Figure 7.4). Similarly, during this season in 2014, the months of January, November and December recorded no rainstorm event (Figure 7.4). Similar patterns of the orientation and movement were also described during the dry season months in 2013 were also observed (Figures 7.4).

Generally, during the early rainy season of 2014, the highest areal coverage of rainstorms was recorded in April, as 447.1 km^2 (about 99.4%) of the total area. However, the month of March recorded no rainstorm event. In 2014, no rainstorm event due to disturbance lines during the late rainy season of was recorded (Figures 7.4).

During the main rainy season of 2014, the highest areal coverage of rainstorms received in the study area was recorded in May as 435 km^2 (about 96.7%) of the total area; followed by 370.8 km^2 (82.4%) in July and 330 km^2 (73.3%) in June. The month of August recorded 307.5 km^2 (68.3%) (Figures 7.4).

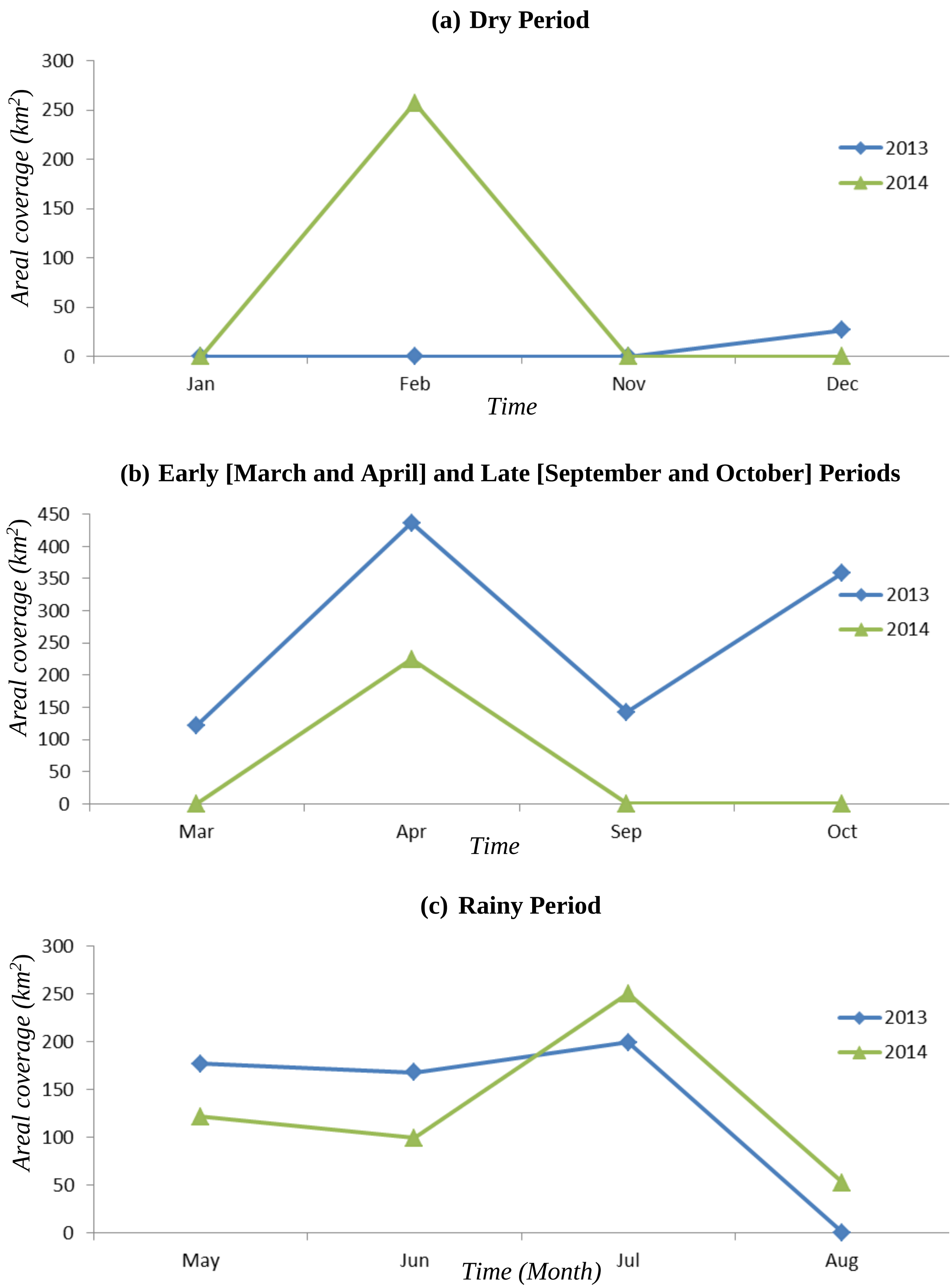


Figure 7.4: Areal Coverage of Rainstorms due to Disturbance Lines at different Periods (a-c)

7.5 Areal Coverage of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season

The section compares the areal coverage of rainstorms due to disturbance lines between the early and the late rainy seasons using paired sample t-test statistics.

7.5.1 Areal Coverage of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season

The comparison of the areal coverage of rainstorms between the early rainy season and the late rainy season is captured in this section. The analysis of two-independent-sample comparison of means of areal coverage of rainstorms between the early and the late rainy seasons was done using paired sample t-test method (Appendix VI (b)). The summary of the result is shown in Table 7.2. The results of the analysis of the differences between the means of the areal coverage of rainstorms between the early and the late rainy seasons (Table 7.1) revealed that there was no significant difference in the areal coverage of rainstorms during the early and the late rainy seasons, with the calculated T-value of 0.01, which was less than the T-critical value of 2.16 at 0.05 confidence level. This result means that the areal coverage of rainstorms between the early and the late rainy seasons did not vary significantly. Therefore, hypothesis four, which states that there are no significant differences in the areal coverage of rainstorms during the early and the late rainy seasons, was rejected.

Table 7.2: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Areal Coverage of Rainstorms due to Disturbance Lines between the Early Rainy Season and the Late Rainy Season

Season of areal coverage of rainstorms	T-cal	T-critical	Level of significance
Early and late rainy seasons	0.01	2.16	Not significant at 0.05 level

CHAPTER EIGHT

COMPARISON OF THE CHARACTERISTICS OF RAINSTORMS DUE TO THUNDERSTORM AND THOSE DUE TO DISTURBANCE LINES

8.1 Introduction

This section attempts to compare the characteristics of rainstorm events due to thunderstorm and those due to disturbance lines in terms of rainstorm durations, rainfall amounts, speeds and areal coverage of rainstorms received during the period of the study. The need to compare such characteristics becomes critical as stressed by Byers, (1951), Rennick, (1976), Simmon, (1977) and Bolton, (1981) who observed that differences exist between the characteristics of rainstorms due to thunderstorm and those due to disturbance lines. The two rain-producing weather systems are major forms of organisation of convective rains over West Africa; they however tend to exhibit different rainstorm behaviours. In order to calculate the difference of mean test for the comparison of the rainstorm characteristics-durations of rainstorms, rainfall amounts, speeds and areal coverage of rainstorms between the rainstorms due to thunderstorm and those due to disturbance lines, the analysis of two-independent sample comparison of means of durations of rainstorms, rainfall amounts, speeds and areal coverage of rainstorms due to thunderstorm and those due to disturbance lines was done using paired sample t-test method.

8.1.1 Characteristics of Rainstorms due to Thunderstorm and those due to Disturbance Lines

A total of 125 and 29 rainstorm events due to thunderstorm and those due to disturbance lines respectively were recorded from January to December during the 2013 and 2014 rainstorm events. In this data, the rainstorm events due to thunderstorm and those due to disturbance lines showed an average durations of 102 minutes and 119 minutes, respectively. The maximum durations of rainstorm due to thunderstorm and those due to disturbance lines events were 286 minutes and 240 minutes, respectively, while 20 minutes and 10 minutes were the minimum. The standard deviations of the rainstorm events due to thunderstorm and those due to disturbance lines were 51.8 and 75.9, respectively. The results of the analysis of the difference between the means of the durations of rainstorms due to thunderstorm and those due to disturbance lines, (Table 8.1) revealed that there was no significant difference in the durations of rainstorms due to thunderstorm and disturbance lines. The calculated T-value was 1.18, which was less than the T-critical value of 1.96 at 0.05 confidence level.

Furthermore, the data showed the 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 due to thunderstorm and those due to disturbance lines events were 45.2 mm and 38.5 mm, respectively, while 0.30 mm and 1.30 mm were the minimum. The standard deviations of amounts of rainfall due to thunderstorm and those due to disturbance lines were 9.6 and 8.7, respectively. The results of the analysis of the difference between the means of the rainfall amounts due to thunderstorm and those due to disturbance lines, (Table 8.1) revealed that there was no significant difference in the rainfall amounts due to thunderstorm and those due to disturbance lines. The calculated T-value was 0.44, which was less than the T-critical value of 1.96 at 0.05 confidence level.

The average speeds of rainstorm events due to thunderstorm and those due to disturbance lines were 8.6 ms^{-1} and 14.0 ms^{-1}, respectively. The maximum speeds of rainstorm events due to thunderstorm and those due to disturbance lines were 174.2 ms^{-1} and 92.1 ms^{-1}, respectively, while 0.20 ms^{-1} and 0.20 ms^{-1} were the minimum. The standard deviations of speeds of rainstorm events due to thunderstorm and those due to disturbance lines were 20.8 and 22.1, respectively. The results of the analysis of the difference between the means of the speeds of rainstorms due to thunderstorm and those due to disturbance lines, (Table 8.1) revealed that there was no significant difference in the speeds of rainstorm events due to thunderstorm and those due to disturbance lines. The calculated T-value was 1.20, which was less than the T-critical value of 1.96 at 0.05 confidence level.

The average areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 172.0 km^2 and 170.3 km^2, respectively. The maximum areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 426.4 km^2 and 436.5 km^2, respectively, while 16.6 km^2 and 22.5 km^2 were the minimum. The standard deviations of the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 105.4 and 131.5. The results of the analysis of the difference between the means of the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines, (Table 8.1) revealed that there was no significant difference in the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines. The calculated T-value was 0.07, which was less than the T-critical value of 1.96 at 0.05 confidence level.

Table 8.1: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Durations, Rainfall Amounts, Speeds and Areal Coverage of Rainstorms due to Thunderstorm and those due to Disturbance Lines

Characteristics of rainstorms	T-cal	T-critical	Level of significance
Durations of rainstorms	1.18	1.96	Not significant at 0.05 level
Amounts of rainfall	0.44	1.96	Not significant at 0.05 level
Speeds of rainstorms	1.20	1.96	Not significant at 0.05 level
Areal coverage of rainstorms	0.07	1.96	Not significant at 0.05 level

8.1.2 Seasonal Variations in the Frequency of Rainstorms due to Thunderstorm and those due to Disturbance Lines

Comparison of the seasonal variations of frequency of rainstorms due to thunderstorm and those due to disturbance lines, as shown in Figure 8.1, has been included in the discussion because it presents different patterns of rainfall frequency of rainstorms due to thunderstorm and disturbance lines over Ibadan. During the dry season, the highest frequencies of rainstorms due to thunderstorm and disturbance lines were recorded in November, with values of eight and two rainstorm events. It went low to three and one rainstorm events in January and December, respectively. No rainstorm event due to thunderstorm and those due to disturbance lines was recorded at Ibadan in December and January, respectively (Figure 8.1).

During the early rainy season, the highest frequencies of rainstorms due to thunderstorm and those due to disturbance lines were recorded at Ibadan in March and April with values of twelve and three rainstorm events. March recorded no rainstorm event due to disturbance lines (Figure 8.1). During the late rainy season, the highest frequencies of rainstorms due to thunderstorm and those due to disturbance lines were recorded in September and October, and with a value of twelve and three rainstorm events, respectively (Figure 8.1).

The highest rainstorm events due to thunderstorm and those due to disturbance lines observed during the rainy season were in May and August, with values of fifteen and six, respectively. In addition, the month of June had value of fourteen and four rainstorm events. July followed with a value of eleven and one rainstorm events due to thunderstorm and those due to disturbance lines, respectively. However, in August, the rainy season rainstorm event due to thunderstorm was two (Figure 8.1).

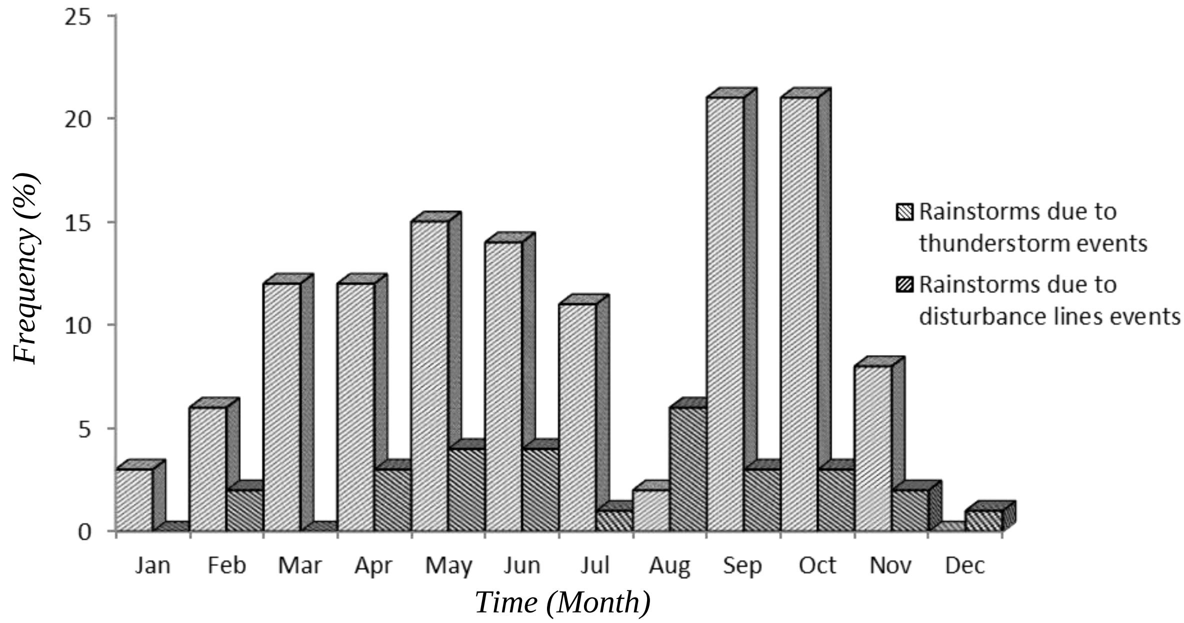


Figure 8.1: Rainstorms due to Thunderstorm and those due to Disturbance Lines

8.2 Comparison of the Durations, Rainfall Amounts, Speeds and Areal Coverage of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry Early, Late and Rainy Seasons

This section attempts to compare the characteristics of rainstorms due to thunderstorm and those due to disturbance lines in terms of rainstorms durations, rainfall amounts, speeds and areal coverage of rainstorms received during the dry, early, late and rainy seasons. This was done by calculating the T-cal and T-critical of each of the parameters and determining their level of significance at the 5% level of significance. The results are shown in Tables 8.2-8.5 and are discussed in sections 8.2.1-8.2.16.

8.2.1 Comparison of the Durations of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry Season

Analysis of the differences between the durations of rainstorms due to thunderstorm and those due to disturbance lines during the dry season showed that there are differences in the duration during the dry season. During the dry season, the average duration of rainstorms due to thunderstorm and those due to disturbance lines events were 81 minutes and 91 minutes, respectively. The maximum durations of rainstorms due to thunderstorm and due to disturbance lines were 192 minutes and 185 minutes, respectively, while 39 minutes and 10 minutes were the minimum. The standard deviations of durations of rainstorm events due to thunderstorm and those due disturbance lines were 36.7 and 66.3, respectively. The results of the analysis of the difference between the means of the durations of rainstorm events due to thunderstorm and those due to disturbance lines, (Table 8.2) revealed that there was no significant difference in the duration of rainstorms due to thunderstorm and those due to disturbance lines during the dry season. The calculated T-value was 0.33, which was less than the T-critical value of 2.09 at 0.05 confidence level.

8.2.2 Comparison of the Durations of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Early Rainy Season

Analysis of the differences between the durations of rainstorms due to thunderstorm and those due to disturbance lines during the early rainy season showed that there are differences in the duration during the early rainy season. During the early rainy season, the average duration of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 120 minutes and 131 minutes, respectively. The maximum durations of rainstorm events due to thunderstorm and those due to disturbance lines were 226 minutes and 240 minutes, respectively, while the minimum durations were 41 minutes and 25 minutes, respectively. The standard deviations of durations of rainstorm events due to thunderstorm and those due to disturbance lines were 54.4 and 88.8. The results of the analysis of the differences between the mean of duration of rainstorms due to thunderstorm and those due to disturbance lines during the early rainy season, (Table 8.2) revealed that there was no significant difference in the durations of rainstorms due to thunderstorm and those due to disturbance lines during the early rainy season. The calculated T-value was 0.34, which was less than the T-critical value of 2.04 at 0.05 confidence level.

8.2.3 Comparison of the Durations of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Late Rainy Season

Analysis of the differences between the durations of rainstorms due to thunderstorm and those due to disturbance lines during the late rainy season showed that there are differences in the duration during the late rainy season. During the late rainy season, the average duration of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 107 minutes and 87 minutes, respectively. The maximum durations of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 241 minutes and 141 minutes, respectively, while the minimum durations were 26 minutes and 54 minutes, respectively. The standard deviations of durations of rainstorm events due to thunderstorm and those due to disturbance lines were 51.2 and 28.7, respectively. The results of the analysis of the differences between the mean of durations of rainstorms due to thunderstorm and those due to disturbance lines during the late rainy season, (Table 8.2) revealed that there was no significant difference in the duration of rainstorms due to thunderstorm and those due to disturbance lines during the late rainy season. The calculated T-value was 1.52, which was less than the T-critical value of 2.02 at 0.05 confidence level.

8.2.4 Comparison of the Durations of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Rainy Season

Analysis of the differences between the durations of rainstorms due to thunderstorm and those due to disturbance lines during the rainy season showed that there are differences in the order of the duration during the rainy season. During the rainy season, the average durations of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 94 minutes and 149 minutes, respectively. The maximum durations of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 286 minutes and 301 minutes, respectively, while the minimum durations were 20 minutes and 46 minutes, respectively. The standard deviations of durations of rainstorm events due to thunderstorm and those due to disturbance lines were 53.3 and 89.0, respectively. The results of the analysis of the differences between the mean of durations of rainstorm events due to thunderstorm and those due to disturbance lines during the rainy season, (Table 8.2) revealed that there was no significant difference in the duration of rainstorms due to thunderstorm and those due to disturbance lines during the rainy season. The calculated T-value was 1.77, which was less than the T-critical value of 2.02 at 0.05 confidence level.

Table 8.2: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Durations of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry, Early, Late and Rainy Seasons

Season of the duration of rainstorms	T-cal	T-critical	Level of significance
Durations of rainstorms during the dry season	0.33	2.09	Not significant at 0.05 level
Durations of rainstorms during the early rainy season	0.34	2.04	Not significant at 0.05 level
Durations of rainstorms during the late rainy season	1.52	2.02	Not significant at 0.05 level
Durations of rainstorms during the rainy seasons	1.77	2.02	Not significant at 0.05 level

8.2.5 Comparison of the Amounts of Rainfall due to Thunderstorms and those due to Disturbance Lines during the Dry Season

Analysis of the differences between the amounts of rainfall due to thunderstorm and those due to disturbance lines during the dry season showed that there are differences in the amounts of rainfall during the dry season. During the dry season, the average amount of rainfall due to thunderstorm and those due to disturbance lines events were put at 10.9 mm and 7.7 mm, respectively. The maximum amounts of rainfall due to thunderstorm and those due to disturbance lines were found to be 28.4 mm and 25.6 mm, respectively, while the minimum rainfall amounts were 2.3 mm and 1.3 mm, respectively. The standard deviations of amounts of rainfall due to thunderstorm and those due to disturbance lines were 8.9 and 10.2, respectively. The results of the analysis of the difference between the means of the amounts of rainfall due to thunderstorm and those due to disturbance lines during the dry season, as (Table 8.3) revealed that there was no significant difference in the amounts of rainfall due to thunderstorm and those due disturbance lines during the dry season. The calculated T-value was 0.63, which was less than the T-critical value of 2.09 at 0.05 confidence level.

8.2.6 Comparison of the Amounts of Rainfall due to Thunderstorm and those due to Disturbance Lines during the Early Rainy Season

Analysis of the differences between the amounts of rainfall due to thunderstorm and those due to disturbance lines during the early rainy season showed that there are differences in the amount of rainfall during the early rainy season. During the early rainy season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines were recorded as 14.5 mm and 16.1 mm, respectively. The maximum amounts of rainfall due to thunderstorm and those due to disturbance lines were 45.2 mm and 35.8 mm, respectively while the minimum amounts of rainfall were 0.6 mm and 1.3 mm, respectively. The standard deviations amounts of rainfall due to thunderstorm and those due to disturbance lines were 11.8 and 10.8, respectively. The results of the analysis of the differences between the mean of amounts of rainfall due to thunderstorm and those due to disturbance lines during the early rainy season, (Table 8.3) revealed that there was no significant difference in the amounts of rainfall due to thunderstorm and those due to disturbance lines during the early rainy season The calculated T-value was 0.36, which was less than the T-critical value of 2.04 at 0.05 confidence level.

8.2.7 Comparison of the Amounts of Rainfall due to Thunderstorm and those due to Disturbance Lines during the Late Rainy Season

Analysis of the differences between the amounts of rainfall due to thunderstorm and those due to disturbance lines during the late rainy season showed that there are differences in the amounts of rainfall during the late rainy season. During the late rainy season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines were recorded as 14.3 mm and 10.9 mm, respectively. The maximum amounts of rainfall due to thunderstorm and those due to disturbance lines were found to be 38.8 mm and 22.1 mm, respectively, while the minimum amounts of rainfall were 1.4 mm and 2.9 mm, respectively. The standard deviations of amounts of rainfall due to thunderstorm and those due to disturbance lines were 8.6 and 6.6, respectively. The results of the analysis of the differences between the mean of amounts of rainfall due to thunderstorm and those due to disturbance lines during the late rainy season, (Table 8.3) revealed that there was no significant difference in the amounts of rainfall due to thunderstorm and those due to disturbance lines during the late rainy season. The calculated T-value was 1.21, which was less than the T-critical value of 2.02 at 0.05 confidence level.

8.2.8 Comparison of the Amounts of Rainfall due to Thunderstorm and those due to Disturbance Lines during the Rainy Season

Analysis of the differences between the amounts of rainfall due to thunderstorm and those due to disturbance lines during the rainy season showed that there are differences in the amounts of rainfall during the rainy season. During the rainy season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines were recorded as 13.5 mm and 14.1 mm, respectively. The maximum amounts of rainfall due to thunderstorm and those due disturbance lines were found to be 34.8 mm and 27.5 mm, while the minimum amounts of rainfall were 0.3 mm and 4.4 mm, respectively. The standard deviations of amounts of rainfall due to thunderstorm and those due to disturbance lines were 9.7 and 7.1, respectively. The results of the analysis of the differences between the mean of amounts of rainfall due to thunderstorm and those due to disturbance lines during the rainy season, (Table 8.3) revealed that there was no significant difference in the amounts of rainfall due to thunderstorm and those due to disturbance lines during the rainy season. The calculated T-value was 0.21, which was less than the T-critical value of 2.02 at 0.05 confidence level.

Table 8.3: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Amounts of Rainfall due to Thunderstorm and those due to Disturbance Lines during the Dry, Early, Late and Rainy Seasons

Season of the rainfall amounts	T-cal	T-critical	Level of significance
Amounts of rainfall during the dry season	0.63	2.09	Not significant at 0.05 level
Amounts of rainfall during the early rainy season	0.36	2.04	Not significant at 0.05 level
Amounts of rainfall during the late rainy season	1.21	2.02	Not significant at 0.05 level
Amounts of rainfall during the rainy season	0.21	2.02	Not significant at 0.05 level

8.2.9 Comparison of the Speeds of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry Season

Analysis of the differences between the speeds of rainstorms due to thunderstorm and those due to disturbance lines during the dry season showed that there are differences in the speeds during the dry season. During the dry season, the average speeds of rainstorm events due to thunderstorm and those due to disturbance lines were recorded as 7.9 ms^{-1} and 11.4 ms^{-1}, respectively. The maximum speeds of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 75.6 ms^{-1} and 25.9 ms^{-1}, respectively, while the minimum speeds of rainstorms were 0.2 ms^{-1} and 1.5 ms^{-1}, respectively. The standard deviations of speeds of rainstorm events due to thunderstorm and those due to disturbance lines were 20.1 and 12.9, respectively. The results of the analysis of the differences between the mean of speeds of rainstorm events due to thunderstorm and those due to disturbance lines during the dry season, (Table 8.4) revealed that there was no significant difference in the speeds of rainstorm events due to thunderstorm and those due to disturbance lines during the dry season. The calculated T-value was 0.47, which was less than the T-critical value of 2.09 at 0.05 confidence level.

8.2.10 Comparison of the Speeds of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Early Rainy Season

Analysis of the differences between the speeds of rainstorms due to thunderstorm and those due to disturbance lines during the early rainy season showed that there are differences in the speeds during the early rainy season. During the early rainy season, the average speeds of rainstorm events due to thunderstorm and those due to disturbance lines were recorded as 10.8 ms^{-1} and 19.9 ms^{-1}. The maximum speeds of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 76.7 ms^{-1} and 79.4 ms^{-1}, respectively, while the minimum speeds of rainstorms were 0.4 ms^{-1} and 1.6 ms^{-1}. The standard deviations of speeds of rainstorm events due to thunderstorm and those due to disturbance lines were 20.2 and 25.7, respectively. The results of the analysis of the differences between the mean of speeds of rainstorm events due to thunderstorm and those due to disturbance lines during the early rainy season, (Table 8.4) revealed that there was no significant difference in the speeds of rainstorms due to thunderstorm and those due to disturbance lines during the early rainy season. The calculated T-value was 0.92, which was less than the T-critical value of 2.04 at 0.05 confidence level.

8.2.11 Comparison of the Speeds of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Late Rainy Season

Analysis of the differences between the speeds of rainstorms due to thunderstorm and those due to disturbance lines during the late rainy season showed that there are differences in the order of the speeds during the late rainy season. During the late rainy season, the average speeds of rainstorm events due to thunderstorm and those due to disturbance lines were recorded as 5.2 ms^{-1} and 14.5 ms^{-1}. The maximum speeds of rainstorms due to thunderstorm and those due to disturbance lines were found to be 43.0 ms^{-1} and 92.1 ms^{-1}, respectively, while the minimum speeds of rainstorms were 0.4 ms^{-1} and 0.2 ms^{-1}, respectively. The standard deviations speeds of rainstorms due to thunderstorm and those due to disturbance lines were 8.1 and 34.3, respectively. The results of the analysis of the differences between the mean of speeds of rainstorm events due to thunderstorm and those due to disturbance lines during the late rainy season, (Table 8.4) revealed that there was no significant difference in the speed of rainstorms due to thunderstorm and those due to disturbance lines during the late rainy season. The calculated T-value was 0.72, which was less than the T-critical value of 2.02 at 0.05 confidence level.

8.2.12 Comparison of the Speeds of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Rainy Season

Analysis of the differences between the speeds of rainstorms due to thunderstorm and those due to disturbance lines during the rainy season showed that there are differences in the speeds during the rainy season. During the rainy season, the average speeds of rainstorm events due to thunderstorm and those due to disturbance lines were recorded as 10.9 ms^{-1} and 9.8 ms^{-1}, respectively. The maximum speeds of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 174.2 ms^{-1} and 27.9 ms^{-1}, respectively, while the minimum speeds of rainstorms were 0.2 ms^{-1} and 1.3 ms^{-1}, respectively. The standard deviations speeds of rainstorm events due to thunderstorm and those due to disturbance lines were 28.9 and 10.2, respectively. The results of the analysis of the differences between the mean of speeds of rainstorms due to thunderstorm and those due to disturbance lines during the rainy season, (Table 8.4) revealed that there was no significant difference in the speeds of rainstorm events due to thunderstorm and those due to disturbance lines during the rainy season. The calculated T-value was 0.19, which was less than the T-critical value of 2.02 at 0.05 confidence level.

Table 8.4: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Speeds of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry, Early, Late and Rainy Seasons

Season of the speed of rainstorms	T-cal	T-critical	Level of significance
Speeds of rainstorms during the dry season	0.47	2.09	Not significant at 0.05 level
Speeds of rainstorms during the early rainy season	0.92	2.04	Not significant at 0.05 level
Speeds of rainstorms during the late rainy season	0.72	2.02	Not significant at 0.05 level
Speeds of rainstorms during the rainy seasons	0.19	2.02	Not significant at 0.05 level

8.2.13 Comparison of the Areal Coverage of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry Season

Analysis of the differences between the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the dry season showed that there are differences in the areal coverage during the dry season. During the dry season, the average areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were recorded as 138.1 km^2 and 118.8 km^2, respectively. The maximum areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 326.6 km^2 and 279.0 km^2, respectively, while the minimum areal coverage were 16.6 km^2 and 22.5 km^2, respectively. The standard deviations of areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 109.6 and 127.4, respectively. The results of the analysis of the differences between the mean of areal coverage of rainstorms due to thunderstorm and those due to disturbance lines during the dry season, (Table 8.5) revealed that there was no significant difference in the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines during the dry season. The calculated T-value was 0.31, which was less than the T-critical value of 2.09 at 0.05 confidence level.

8.2.14 Comparison of the Areal Coverage of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Early Rainy Season

Analysis of the differences between the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the early rainy season showed that there are differences in the areal coverage during the early rainy season. During the early rainy season, the average areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were recorded as 213.9 km^2 and 199.7 km^2, respectively. The maximum areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 426.4 km^2 and 436.5 km^2, respectively, while the minimum areal coverage were 23.8 km^2 and 39.0 km^2, respectively. The standard deviations of areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 124.5 and 176.2, respectively. The results of the analysis of the differences between the mean of areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the early rainy season, (Table 8.5) revealed that there was no significant difference in the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the early rainy season. The calculated T-value was 0.21, which was less than the T-critical value of 2.04 at 0.05 confidence level.

8.2.15 Comparison of the Areal Coverage of Rainstorms due to Thunderstorm and those due Disturbance Lines during the Late Rainy Season

Analysis of the differences between the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the late rainy season showed that there are differences in the areal coverage during the late rainy season. During the late rainy season, the average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 204.1 km^2 and 200.6 km^2, respectively. The maximum areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 389.6 km^2 and 397.5 km^2, respectively, while the minimum areal coverage were 33.4 km^2 and 43.5 km^2, respectively. The standard deviations of areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 102.8 and 152.1, respectively. The results of the analysis of the differences between the mean of areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the late rainy season, (Table 8.5) revealed that there was no significant difference in the areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the late rainy season. The calculated T-value was 0.06, which was less than the T-critical value of 2.02 at 0.05 confidence level.

8.2.16 Comparison of the Areal coverage of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Rainy Season

Analysis of the differences between the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines during the rainy season showed that there are differences in the areal coverage during the rainy season. During the rainy season, the average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 129.8 km^2 and 149.3 km^2, respectively. The maximum areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were found to be 327.4 km^2 and 250.5 km^2, respectively, while the minimum areal coverage were 16.6 km^2 and 52.5 km^2, respectively. The standard deviations areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines were 72.6 and 63.9, respectively. The results of the analysis of the differences between the mean of areal coverage of rainstorm events due to thunderstorm and those due to disturbance lines during the rainy season, (Table 8.5) revealed that there was no significant difference in the areal coverage of rainstorms due to thunderstorm and those due to disturbance lines during the rainy season. The calculated T-value was 0.81, which was less than the T-critical value of 2.02 at 0.05 confidence level.

Table 8.5: Summary of the Analysis of T-Test for Two-Independent-Sample Comparison of the Areal Coverage of Rainstorms due to Thunderstorm and those due to Disturbance Lines during the Dry, Early, Late and Rainy Seasons

Season of areal coverage of rainstorms	T-cal	T-critical	Level of significance
Areal coverage of rainstorms during the dry season	0.31	2.09	Not significant at 0.05 level
Areal coverage of rainstorms during the early rainy season	0.21	2.04	Not significant at 0.05 level
Areal coverage of rainstorms during the late rainy season	0.06	2.02	Not significant at 0.05 level
Areal coverage of rainstorms during the rainy season	0.81	2.02	Not significant at 0.05 level

CHAPTER NINE
SUMMARY AND CONCLUSION

9.1 Summary of Findings

This study examined the seasonal dynamics and areal patterns of rainstorms over Ibadan, with particular emphasis on the seasonal variations in rainstorms characteristics within the city of Ibadan. The aim of the work is to examine the seasonal variations in rainstorms duration, rainfall amount and speed of rainstorms on areal coverage of rainstorms over Ibadan metropolis, Nigeria. In order to achieve this aim, the study analysed the spatial and temporal distributions of duration, rainfall amount, speed and areal coverage of rainstorms. The study examined the diurnal and seasonal variations of rainstorms. The study analysed the lifetime and speed of rainstorms. The study determined the relationship between the duration, rainfall amount, speed and areal coverage of rainstorms. The study also examined the difference in the duration, rainfall amount, speed and areal coverage of rainstorms due to thunderstorm and those due to disturbance lines in Ibadan. Five hypotheses were postulated. The first hypothesis is that the areal coverage of rainstorms during the early rainy season is not a function of the duration, rainfall amount and speed of rainstorms. The second hypothesis states that the areal coverage of rainstorms during the late rainy season is a not function of the duration, rainfall amount and speed of rainstorms. The third hypothesis is that there are no significant differences in the speed of rainstorms during the early and the late rainy seasons. The forth hypothesis is that there are no significant differences in the areal coverage of rainstorms during the early and the late rainy seasons. The last hypothesis is that there are no significant differences in the durations, rainfall amounts, speeds and areal coverage of rainstorms due to thunderstorm and those due to disturbance lines.

Related works by different authors were reviewed. This was based on the need to justify the study. The conceptual framework of the study was based on the circulation systems and rainfall producing mechanisms in West Africa. The literature reviewed showed that depth, duration and motion of the rain-producing weather systems influenced the areal coverage of rainstorms and distribution in tropical environment.

Daily rainstorms data and associated weather information for fifty rain gauge stations in Ibadan were used to classify rainstorms into rainstorms due to thunderstorm and those due to disturbance lines. The data was extracted from daily weather registers kept by the research and academic institutions in Ibadan over a two-year period (2013 to 2014). The study also involved the measurement of the rainstorm characteristics such as frequency, duration, rainfall amount, intensity, speed, and areal coverage of rainstorms. The characteristics of rainstorms were measured with the aid of three major instruments. The first instrument used was an autographic rain gauge station. The second equipment was a non-recording rainfall gauge station. The third instrument used was an eTrex Venture Garmin GPS which displays the elevation, latitude and longitude grids were used to determine the X and Y geographical coordinates of each of the selected stations.

The relief and drainage, landuse and building density characteristics of the city of Ibadan were used as the basis for gathering and explaining the relationship between the rainstorm characteristics, spatial and seasonal variations in the characteristics of rainstorms over the urban canopy of Ibadan. The landuse types were analysed through information gathered from a Landsat enhanced Thematic Mapper Plus (ETM+) image of 2012 covering Ibadan metropolis obtained for this study. Eight landuse types were consequently identified in the study area. The identified landuse types in the study area are: low-density landuse area; educational landuse area; institutional landuse area; low, medium-and high-density residential landuse areas; industrial area; water body area; commercial landuse area and open spaces. A 3x3 km grid was superimposed on the map of Ibadan metropolis and one raingauge was installed in each of the 50 resultant grids. Data on rainstorms duration (mins) and rainfall amount (mm) were recorded daily from the 50 weather stations during 2013 and 2014 rainstorm events.

The speed of the storm (ms^{-1}) is calculated from the perpendicular distance between the two stations and the difference between their time values. The areal coverage of rainstorm (km^2) is area covered by the rainstorm events. However, the values of each weather station of a particular landuse type represented the data for that landuse. The data collected were subjected to descriptive statistics, multiple regression analysis and difference of mean tests. The results were further subjected to graphical presentation and mapping using ArcGIS 10.3 software.

The study revealed some features about the urban climatology of the city with respect to frequency, duration, rainfall amount, intensity, lifetime and speed, and areal coverage of rainstorms. 54 and 71 rainstorms due to thunderstorm events were recorded from January to December during the 2013 and 2014 rainstorm events, respectively. The average durations of rainstorm events in 2013 and 2014 were 107 and 98 minutes, respectively. The study found that there was a variation in the durations of rainstorms. About 18% and 25% of rainstorm events lasted less than 1 hour, 50% and 48% between 1 and 2 hours, while 30% and 27% lasted for as long as 2 hours or more in 2013 and 2014, respectively. The average amounts of rainfall in 2013 and 2014 were 15.1 and 12.5 mm. It was further revealed that 19% and 27% of rainfall amount measured less than 5.0 mm, while 2% and less than 1% measured above 40.0 mm in 2013 and 2014. The average rainfall intensities in 2013 and 2014 were recorded as 0.15 mm h^{-1} and 0.13 mm h^{-1}. Also, about 11% and 17% of rainfall intensity measured less than 0.05 mm h^{-1}, while 17% and 28% measured between 0.05 and 0.10 mm h^{-1}, 56% and 41% between 0.10 and 0.20 mm h^{-1}, 9% and 9% between 0.20 and 0.30 mm h^{-1} and 7% and 5% measured above 0.30 mm h^{-1} in 2013 and 2014, respectively. During the periods of the study, the intensities of rainfall were generally low. The average speeds of rainstorms were 6.5 ms^{-1} and 10.2 ms^{-1}. The average areal coverage of rainstorms was 169.5 km^2 and 174.0 km^2 in 2013 and 2014, respectively.

An evaluation of the diurnal variations in rainstorms was done using 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 (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 h) and late evening (between 2100 h and 2400 h). The analysis of the diurnal frequency of rainstorms revealed that highest frequencies of rainstorm events during the period were recorded in the afternoon via late evening between 1200 h and 1500 h, 1500 h and 1800 h and 1800 and 2100 h. 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, with most of the rainstorms lasted between 30 and 120 min. In fact, over 70% of all the storms lasted for less than 2 hours in 2013 and 2014 rainstorm events. About 40% and 65% have rainfall amounts with 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. In addition, the intensities of the rainstorms were between 0.04 mm h^{-1} and 0.4 mm h^{-1} in 2013 and 2014 rainstorm events.

The study also revealed that there were seasonal variations in the frequency of rainstorm events in Ibadan. During the dry period in 2013, the highest frequency of rainstorms was recorded in February, with a value of five. During the early rainy period, the highest frequency was eight in April. The month of September recorded 11 rainstorm events as the highest during the late rainy period, while rainy period recorded six rainstorm events in 2013. Similar values were recorded during the dry season of 2014, where the highest rainstorm events were recorded in November, with a value of five rainstorm events. The early rainy season recorded highest rainstorm events in April, with a value of in nine rainstorm events. The month of October recorded the highest frequency of rainstorms during the late rainy period, with a value of 15 rainstorm events. The rainy season recorded the highest frequency of rainstorms in May, with a value of 11 rainstorm events. However, the values of the rainstorm events in the other months in 2013 and 2014 varied between 1 and 4 rainstorm events.

The results of the spatial pattern of occurrence of rainstorms in Ibadan revealed that rainstorm event is predominantly convective in origin and showed therefore high variability in space and time. In 2013, the rainy phases during the “dry season rains” began in February and ended in November. On the western part, the rains set in slightly earlier, to the east, in the upper lying zone, a bit later, which means about the first week of February. The same held true for the northeastern part of the city. There was a general decrease of rainstorm events over the city especially in March during the early rainy season. The rainstorm events during the early rainy season began in the middle of March. There was an increase in the occurrence of rainstorms in April which appeared all over the sections of the city. During the late rainy season, the rainstorm events increased southeastwards axis of the city. During the rainy season, towards the south, west and north, rainstorm events decreased rapidly. Similar patterns of rainstorm events were observed over the city of Ibadan in 2014. On the western section of the city, the rains generally began in mid-November at the earliest, and in mid-February at the latest during the dry period. The rainstorm events during the early rainy season began in the middle of March. There was an increase in the occurrence of rainstorms in April which appeared all over the sections of the city, just like the spatial patterns of rainstorm events experienced during the early rainy season in 2013. Also, during the late period, the rainstorm events increased southwards. Besides, towards the south, west and north, rainstorm events decreased rapidly during the rainy period.

The study further revealed that during the dry season in 2013, the longest rainy phases, with duration of 210 minutes, were found on the northern section of upper lying zone of the city in the area around UI, the durations decreased, reaching 33 minutes and 30 minutes, were found on the northwestern and southwestern sections of the city in the around Eleyele and Challenge. Similar pattern was observed during the dry season period of 2014, only that the longest rainy phases, with durations of 225 minutes and 210 minutes, were found on the northern and southern sections of upper and lower lying zones of the city in the areas around Idi-Ape and Lagelu, the durations decreased, reaching 30 minutes and 25 minutes, were found on the northwestern and southwestern sections of the city in the around Eleyele and Challenge. Also, during the early rainy season in 2013, the longest rainy phases were found in the areas around CRIN and Ashi, and lasted for 245 minutes and 240 minutes, respectively. The central axis of the city in the area around Mapo showed values between 108 minutes-99 minutes. The durations rose towards southern direction at the lower lying zone of the city. Whereas in 2014, the longest rainy phases were found in the areas around Academy and Bodija, and lasted for 220 minutes and 210 minutes, respectively. The central axis of the city in the area around Mapo showed values between 98 minutes-90 minutes. The durations rose towards southern direction at the lower lying zone of the city.

The longest rainy phases during the late rainy season in 2013 were found on the northern and southern sections of upper and lower lying zones with a maximum of 227 minutes and 211 minutes at Agbowo and Alakia, respectively. The eastern section of the Gbagi and Adegbayi axis showed short phases of 60 minutes-180 minutes, while the central section of the city in the area around Mapo and Ogbere, and Lagelu and Oluyole received rainfall for less than 60 minutes. The same pattern of rainstorms duration was observed during the late rainy period of 2014. During the rainy period in 2013, the longest rainy phases, with durations of 240 minutes and 230 minutes, were found on the southern and northern sections of the city around Idi-Osan and UI, respectively. However, towards the western and southern sections in the areas around NCRI, Oluyole and Lagelu, the durations decreased, reaching 55 minutes, and 35 minutes and 30 minutes, respectively. In 2014, the longest rainy phases, with durations of 190 minutes and 180 minutes, were found on the northern and southern sections of the city around UI and CRIN, respectively. However, towards the western and southern sections in the areas around NCRI and Oluyole and Lagelu, the durations decreased, reaching 55 minutes, and 35 minutes and 30 minutes, respectively.

Furthermore, there were notable variations in the spatial pattern of rainfall amount due to thunderstorm in the course of a season over the study area. During the dry season in 2013, high rainfall amount was recorded in the southern section of the city in the area around CRIN; a relative minimum could be noticed on the northern section around IITA (9.2 mm). The same held true for the dry season in 2014, only that the northern axis around Mokola, had the highest rainfall amount, with a value of 44.5 mm. During the early season in 2013, there was an island of increased rainfall amount in the area around IITA-Olodo-Alakia-CRIN-NCRI-Mapo axis, reached at 27.1 mm – 46.8 mm. Although in every other section of the city, there was a reduction in the received rainfall amount due to this system. The similar pattern held true during this season in 2014. Also, the pattern of rainfall amount during the late rainy seasons in 2013 and 2014 were similar to that described in early rainy season, only that the received rainfall amount was relative high reached at 29.0 mm – 112.7 mm and 31.0 mm – 110.2 mm, respectively. During the rainy season in 2013, rainfall amount was highest in the area around Ijokodo and northwest of the city, with 60.0 mm; towards the south, east and north, rainfall decreased rapidly. During this period in 2014, rainfall amount was highest in the area around Omi-Adio and west of the city, with 50.2 mm; towards the south, rainfall decreased rapidly.

The study revealed (using the coefficient of correlation) that the duration (0.443) and rainfall amount (0.491) related directly with the areal coverage of rainstorms. But only speed of rainstorms (-0.419) related inversely with the areal coverage of rainstorms during the early rainy season of 2013. The correlation coefficient further revealed that there is significant correlation between the duration and rainfall amount during this season. The rainstorms duration, rainfall amount and speed jointly accounted for 39.20% variation in the areal coverage of rainstorms during the early rainy season. The p-value, revealed that the independent variables, when taken together, were not significant predictors (0.295), explaining the areal coverage of rainstorms during the early rainy season. The variable that contributed most to the predicting the areal extent of rainstorms during the early rainy season was rainfall amount (0.500 mm), which means that X_2 was the one that gave the best explanation on areal coverage of rainstorms during the early rainy season. In 2014, duration (-0.171), rainfall amount (-0.252) and speed of rainstorms (-0.154) related inversely with the areal coverage of rainstorms. The correlation statistics further revealed that there is significant correlation between the duration and rainfall amount during this period. The duration, rainfall amount and speed of rainstorms jointly accounted for 90.0% variation in the areal coverage of rainstorms during the early rainy season. The p-value, revealed that the independent variables, when taken together, were not significant predictors (0.828), explaining the areal coverage of rainstorms during this season. The variable that contributed most to predicting the areal coverage of rainstorms during the early rainy season was duration of rainstorms (0.007 mins), which means that X_1 was the one that gave the highest explanation on the areal coverage of rainstorms during this season.

Furthermore, the study revealed (using the coefficient of correlation) that the correlation coefficient between the areal coverage, duration, rainfall amount and speed of rainstorms during the late rainy season showed that, duration (0.075), rainfall amount (0.565), and speed (0.495) related directly with the areal coverage of rainstorms during the late rainy season of 2013. There was significant correlation between the duration and rainfall amount of rainstorms during this season of 2013. The duration, rainfall amount and speed of rainstorms jointly accounted for 52.10% variation in the areal coverage of rainstorms during the late rainy season. The p-value revealed that the independent variables, when taken together, were significant predictors (0.020) at 0.05 level, explaining the areal coverage of rainstorms during the late rainy season in 2013. The variable that contributed mostly to predicting the areal coverage of rainstorms was rainfall amount (0.691 mm), which means that X_2 was the one that gave the best explanation on the areal coverage of rainstorms during this season. During this season in 2014, the correlation of coefficient of the areal coverage, duration, rainfall amount and speed of rainstorms revealed that, duration (-0.335) and rainfall amount (-0.197) related inversely with the areal coverage of rainstorms. But, only speed of rainstorms (0.215) related directly with the areal coverage of rainstorms during this season. The correlation further revealed that there was significant correlation between the duration and rainfall amount during this season. The duration, rainfall amount and speed of rainstorms jointly accounted for 14.40% variation in the areal coverage of rainstorms during the late rainy season of 2014. The p-value of the model was 0.341, which was greater than 0.05. That is, the independent variables, when taken together, were not significant predictors. The variable that contributed most to predicting the areal coverage of rainstorms was rainfall amount (0.234) which means that rainfall amount was the one that gave highest explanation on the areal coverage of rainstorms during the late rainy season.

Furthermore, the results showed through the analysis of the comparison of the mean sample of the different in the durations of rainstorm events during the early and late rainy seasons, showed that there was no significant difference in the mean of duration of rainstorms during the early and the late rainy seasons of 2013 (t=0.45, T=2.06) and 2014 (t=0.83, T=2.04), at 0.05 significance level. Also, during the early and late rainy seasons, there was no statistically significant in the rainfall amount at 0.05 significance level for both seasons in 2013 (t=0.58, T=2.06) and 2014 (t=0.63, T=2.06).

Also, an evaluation of characteristics of the lifetime and speed of rainstorms due to thunderstorm during the period of the study revealed that the average speed of rainstorm events in 2013 and 2014 were 6.5 ms^{-1} and 10.2 ms^{-1}. Majority of the rainstorms for the study period were influenced by slow-moving systems. In 2013, about 85% of the rainstorms lasted 108 minutes with velocity 1.6 ms^{-1} were influenced by this slow-moving system. Similarly in 2014, about 79% of the rainstorms lasted 108 minutes with velocity 2.6 ms^{-1} were influenced by the slow-moving system. The results of the analysis of the lifetime and speed of rainstorms further revealed that there is seasonal variation in the pattern of the speed of rainstorms over the city during the 2013 and 2014 rainstorm events. The slow-moving systems accounted for the highest systems (100%, 75%, 73%, 85% and 88%, 84%, 82%, 72%) during the dry, the early, the late and the rainy seasons, respectively. The fast-moving systems followed with 25%, 27%, 15% and 12%, 16%, 18%, 28% next to the slow-moving systems, especially during the early and the late rainy seasons. Long-lived slow-moving systems and fast-moving long-lived systems were not recorded during these seasons in 2013 and 2014 rainstorm events.

The results showed through the analysis of the comparison of the mean sample of the difference in the speed of rainstorms between the rainstorm events during the early and late rainy seasons, showed that there were no significant differences in the mean of speed of rainstorms during the early and the late rainy seasons of 2013 ($t=0.92$, $T=2.06$) and 2014 ($t=0.89$, $T=2.04$), at 0.05 significance level.

It was also shown that during the period of the study in 2013 and 2014, the average areal coverage of rainstorms were 169.5 km^2 and 174.0 km^2, respectively. About 11% and 7% of rainstorms measured less than 50.0 km^2, 39% and 16% measured between 50.0 and 100.0 km^2, 13% and 45% measured between 100.0 and 200.0 km^2, while 37% and 32% measured between 200.0 km^2 and above in 2013 and 2014, respectively. The results of the analysis of the seasonal variation in the pattern of the areal coverage of rainstorms over the city in 2013 and 2014 revealed that the lowest areal coverage (about 63% and 55.8% in November, 12% and 52.8% in January, 7.3% and 35.9% in February, respectively) followed by areal coverage of rainstorms during the rainy season (about 63.5% and 46.8% in May, 23.4% and 38.2% in June, 54.4% and 52.1% in July and 17.2% and 5.3% in August next to the dry season areal extent of rainstorms. The early rainy season areal coverage recorded about 60.8% and 36.6% in March and 82.7% and

82.7% in April of 2013 and 2014, respectively. The highest areal coverage of rainstorms was recorded during late rainy season month of October 2014, with a value of 97.9%.

The results showed through the analysis of the comparison of the mean sample of the different in the areal coverage of rainstorms between the rainstorm events during the early and late rainy seasons, showed that there were significant difference in the mean of areal coverage of rainstorms during the early and the late rainy seasons of 2013 (t=3.36, T=2.06) and 2014 (t=3.82, T=2.04), at 0.05 significance level.

In the case of rainstorms due to disturbance lines, 19 and 10 rainstorm events were recorded from January to December during the 2013 and 2014 rainstorm events, respectively. The average durations were 90 and 175 minutes, respectively. The data of duration indicated that only 5.3% and 50% lasted more than 180 minutes, while 94.7% lasted between 30 and 180 minutes during this period. The average rainfall amounts were 12.3 and 13.6 mm. The rainfall data indicated that about 21.1% and 20% of rainfall amount measured less than 5.0 mm, while 5.3% and less than 1% measured above 30.0 mm in 2013 and 2014, respectively. The average rainfall intensities in 2013 and 2014 were 0.28 and 0.14 mm h^{-1}, respectively. About 21% and 10% of rainfall intensity measured less than 0.05 mm h^{-1}, while 11% and 70% measured between 0.05 and 0.10 mm h^{-1}, 36% and 10% between 0.10 and 0.20 mm h^{-1}, 16% and 10% between 0.20 and 0.30 mm h^{-1} and 16% and 10% measured above 0.30 mm h^{-1} in 2013 and 2014, respectively.

There were notable variations in rainstorms due to disturbance lines incidence in the course of a day over the study area. The analysis of the diurnal frequency of rainstorms revealed that highest frequencies of rainstorm events during the period were recorded in the late afternoon and early evening between 1500 h and 1800 h and 1800 h and 2100 h in 2013 and 2014, respectively. In this period of the study, most of the rainstorms last between 72 and 315 minutes.

It was further showed that the rainfall amount in Ibadan is highly seasonal and characterised by weather zone C. The showers at the beginning and the end of the rainy season are linesqualls of organization of convective rains over Ibadan, consisting of lines of thunderstorms. Generally, the rainfall intensity in Ibadan is also highly seasonal. Majority of the highest rainfall intensities were concentrated in the afternoon and late afternoon, between 1200 h and 1500 h and 1500 h and 1800 during the periods of the study.

The study further revealed that there were variations in the frequency of rainstorm events in the course of a season over the study area. The highest frequencies of rainstorms in 2013 were recorded in the months of March and October, with a value of four and six rainstorm events during the early and late rainy season, respectively. However, the month of April stood out as month of high frequency of rainstorm event during the early rainy season of 2014, with a value of three rainstorm events. The late rainy season months recorded no rainstorm event due to disturbance lines.

An evaluation of spatial pattern of frequency of rainstorms during the period of the study showed that generally, in 2013, the rainy phases during the "dry season rains" began in December and ended in the same month. Other months recorded no rainstorm event. However, in the northern part of the city, the rains set in slightly earlier, to the east, in the upper lying zone in the area around Alakia, a bit later, which means about the second week of December. In 2014, the "dry season rains" did not appeared in all sections of the study area. Generally, the rainy phase during the "dry season rains" began in February and ended in the same month. Other months recorded no rainstorm event. However, during the early rainy season in 2013, two areas of the city stood out as the sections of high frequency of rainstorms and these were the IITA on the northern section, and on the eastern section in the area around Alakia; the same pattern held true during the early rainy season in 2014, where the IITA on the northern section, and on the eastern section in the area around Alakia, recorded highest rainstorm events. On every other sections of the city, there was a reduction in frequency of rainstorms. There was a change in the pattern of frequency during the late rainy season in 2013, three areas of the city stood out as sections of high frequency of rainstorms and these were the areas around IITA on the northern section, on the eastern section around Alakia and on the southern section of the city in the area around CRIN. No rainstorm event was recorded at any section of the study area during this season in 2014. During the main rainy season in 2013, the frequency of rainstorms was highest in the area around Ijokodo and Bodija – Alakia axis, here the figure stood at four; towards the south, rainstorm events decreased rapidly. In 2014, the frequency of rainstorms was highest in the area around Alakia, with five rainstorm events. Towards the south, west and north, rainstorm events decreased rapidly.

The spatial pattern of duration of rainstorms during the dry season in 2013, revealed that during this period, the longest rainy phase, with duration of 125 minutes, were found on the northern section of upper lying zone of the city in the area around UI, the duration decreased, reaching 65 minutes, were found on the northeastern section of the city in the around Alakia. In 2014, the longest rainy phases, with durations of 180 minutes, were found on the southern section of lower lying zones of the city in the areas around CRIN, the duration decreased, reaching 10 minutes, were found on the northwestern sections of the city in the around Agbowo.

The longest rainy phases during the early rainy season of 2013 were found in the areas around Ijokodo, Onireke, Total Garden, Academy and Babanla, and lasted for 215 minutes. The central axis of the city in the area around Mapo showed values between 5 minutes-30 minutes. The durations rose towards western direction at the upper lying zone of the city. However in 2014, the longest rainy phases were found in the area around Babanla and lasted for 240 minutes, respectively. The southern axis of the city in the area around Sanyo showed values of duration of rainstorm between 10 minutes-30 minutes. The durations rose towards southeastern direction at the lower lying zone of the city.

In 2013, the longest rainy phases during the late rainy season were found on the northern section of upper lying zone of the city around UI with a maximum duration of rainstorms of 240 minutes. The northwestern section around Eleyele and southern section of the city around Lagelu ranged showed short phases of 51 minutes-87 minutes, while the central section of the city in the area around Mapo received rainfall for less than 30 minutes. In 2014, no rainstorm due to disturbance lines during the late rainy season was recorded on every section of the city of Ibadan. During rainy period in 2013, the longest rainy phases, with durations of 210 minutes, were found on the northern section of the city around Agbowo. However, towards the northern section in the area Bodija, the durations decreased, reaching 20 minutes. Besides in 2014, the longest rainy phases, with durations of 175 minutes, were found on the northern section of the city around Olodo. However, towards the western section in the area Omo-Adio, the durations decreased, reaching 25 minutes.

In addition, there were notable variations in the spatial pattern of rainfall amount due to disturbance lines in the course of a season over the study area. During the dry season in 2013, high rainfall amount was recorded in the eastern section of the city in the area around Alakia (9.6 mm), whereas in 2014, high rainfall amount was recorded in the northwestern section of the city around Apete with a value of rainfall amount of 22.2 mm.

There was also a change in pattern of distribution of rainfall amount during the early rainy season in 2013. The rains that accompanied the rainstorms due to this system at the early rainy season tend to be more intense than the rains that accompanied the rainstorms that occur at the height of the rainy season. During this period, all the sections of the city received rainfall amount yielded rainfall amounts of between 10.5 mm and 56.5 mm. In 2014, all the sections of the city received rainfall amount yielded rainfall amounts of between 0.6 mm and 50.4 mm. during the late rainy season in 2013, there was a general tendency of amount of rainfall to decrease on all the sections of the city. The only exception was the late rainy period of September and October 2013 which displayed a tendency of rainfall amount towards eastern section of the city in the area around NCRI and Alakia recorded high amount of rainfall reaching up to 50.0 mm. no rainfall amount was recorded at every section of the city of Ibadan during the late rainy season in 2014. During the main rainy season in 2013, rainfall amount was highest in the area around Ijokodo and northwest of the city, with 50.0 mm. Besides, towards the south, east and north, rainfall decreased rapidly. Also, in 2014, rainfall amount was highest in the area around CRIN and south of the city, with 60.2 mm. Besides, towards the west, east and north, rainfall decreased rapidly.

The study revealed (using the coefficient of correlation) that the duration (0.129), related directly with the areal coverage of rainstorms during the early rainy season. But, rainfall amount (-0.022) and speed of rainstorms (-0.369) related inversely with the areal coverage of rainstorms. The correlation further revealed that there was no significant correlation between the duration, rainfall amount and speed of rainstorms during the early rainy season. The rainstorms duration, rainfall amount and speed jointly accounted for 18.40% variation in the areal coverage of rainstorms due to disturbance lines during the late rainy season. The p-value, revealed that the independent variables, when taken together, were not significant predictors (0.824), explaining the areal coverage of rainstorms due to disturbance lines during the early rainy season. The variable that mostly contributed to the predicting the areal coverage of rainstorms during the early rainy season was duration of rainstorms (-0.019 mins), which means that X_1 was the one that gave the best explanation on areal coverage of rainstorms due to disturbance lines during the early rainy season. During the late rainy season, duration (0.202), rainfall amount (0.114) and speed of rainstorms (0.479) related directly with the areal coverage of rainstorms. The correlation coefficient further revealed that, there was significant correlation between the duration and speed of rainstorms during the late rainy season. The rainstorms duration, rainfall amount and speed jointly accounted for 61.70% variation in the areal coverage of rainstorms during the late rainy season. The p-value of the model was 0.353, which was greater than 0.05. That is, the independent variables, when taken together, were not significant predictors, explaining the areal coverage of rainstorms during the late rainy season. The variable that mostly contributed to predicting the areal coverage of rainstorms was speed of rainstorms (1.695) which means that X_3 was the one that gave best explanation on the areal coverage of rainstorms during the late rainy season.

Furthermore, the results showed through the analysis of the comparison of the mean sample of the different in the duration of rainstorm events during the early and late rainy seasons, showed that there was no significant difference in the mean of duration of rainstorms during the early and the late rainy seasons (t=1.33, T=2.16), at 0.05 significance level. Also, during the early and late rainy seasons, there was no statistically significant means difference in the rainfall amount at 0.05 significance level for late rainy season both seasons (t=1.14, T=2.16).

Besides, an evaluation of characteristics of the lifetime and speed of rainstorms due to thunderstorm during the period of the study revealed that the average speed of rainstorm events in 2013 and 2014 were 17.6 $ms^{-1}$and 7.2 ms^{-1}. Majority of the rainstorms for the study period were influenced by slow-moving systems. The results of the analysis of the lifetime and speed of rainstorms further revealed that there is seasonal variation in the pattern of the speed of rainstorms over the city during the 2013 and 2014 rainstorm events. The slow-moving systems and the fast-moving systems were the only systems that associated with disturbance lines. Some fast-moving long-lived systems were also observed during these periods, which revealed that the systems can only appear during rainstorm events. There was a total disappearance of the long-lived slow-moving systems and the fast-moving long-lived systems over the city of Ibadan during rainstorm events in 2014.

The results showed through the analysis of the comparison of the mean sample of the different in the speed of rainstorms between the rainstorm events during the early and late rainy seasons, showed that there was no significant difference in the mean of speed of rainstorms during the early and the late rainy seasons (t=0.34, T=2.16), at 0.05 significance level.

It was also shown that during the period of the study in 2013 and 2014, the average areal coverage of rainstorms were 164.6 km^2 and 181.0 km^2. About 32% of the areal coverage of rainstorms measured less than 50.0 km^2 in 2013 whereas in 2014, no areal coverage of rainstorms was measured less than 50.0 km^2. 16% and 20% measured between 50.0 and 100.0 km^2, 26% and 40% measured between 100.0 and 200.0 km^2, while 26% and 40% measured between 200.0 km^2 and above in 2013 and 2014, respectively.

The results of the analysis of the seasonal variations in the pattern of the areal coverage of rainstorms over the city in 2013 and 2014 revealed that the lowest areal coverage recorded during the dry season period in the months of December and February 2013 and 2014, respectively, followed by areal coverage of rainstorms during the rainy season next to the dry season areal coverage of rainstorms. The highest areal coverage of rainstorms was recorded during early rainy season month of April 2014, with a value of 447.1 km^2 (about 99.4%) of the total area.

The results showed through the analysis of the comparison of the mean sample of the different in the areal coverage of rainstorms between the rainstorm events during the early and late rainy seasons, showed that there was no significant difference in the mean of areal coverage of rainstorms during the early and the late rainy seasons (t=0.01, T=2.16), at 0.05 significance level.

However, a total of 125 and 29 rainstorm events due to thunderstorm and those due to disturbance lines were recorded from January to December over the period of the study. The average durations of rainstorms due to thunderstorm and those due to disturbance lines were 102 minutes and 119 minutes, respectively. The average amounts of rainfall were 13.6 mm and 12.8 mm, respectively. The average speeds of rainstorms were 8.6 0 ms^{-1} and 14.0 ms^{-1}, respectively. The average areal coverage of rainstorms was 172.0 and 170.3 km^2, respectively.

The highest frequencies of rainstorms due to thunderstorm and those due to disturbance lines during the dry season were recorded in November, with values of eight and two. It went low to three and one in January and December, respectively. During the early rainy season, the highest frequencies of rainstorms due to thunderstorm and those due to disturbance lines were recorded at Ibadan in March and April with values of twelve and three. March recorded no rainstorm event due to disturbance lines. During the late rainy season, the highest frequencies of rainstorms due to thunderstorm and those due to disturbance lines were recorded in September and October, and with a value of twelve and three, respectively. The highest rainstorm events due to thunderstorm and those due to disturbance lines observed during the rainy season were in May and August, with values of fifteen and six, respectively. The month of June had value of fourteen and four. July followed with a value of eleven and one rainstorm events due to thunderstorm and those disturbance lines, respectively. However, in August, the rainy season rainstorm event due to thunderstorm was two.

The average durations of rainstorms due to thunderstorm and those due to those due to disturbance lines events during the dry season were 81 minutes and 91 minutes, respectively. During the early rainy season, the average duration of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 120 minutes and 131 minutes, respectively. During the late rainy season, the average duration of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 107 minutes and 87 minutes. Also during the rainy season, the average duration of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 94 minutes and 149 minutes, respectively. During the dry season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines events were put at 10.9 mm and 7.7 mm, respectively. During the early rainy season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines were recorded as 14.5 mm and 16.1 mm. Besides, during the late rainy season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines were recorded as 14.3 mm and 10.9 mm. Also, during the rainy season, the average amounts of rainfall due to thunderstorm and those due to disturbance lines were recorded as 13.5 mm and 14.1 mm.

Furthermore, the average speed of rainstorms due to thunderstorm and those due to disturbance lines during the dry season were recorded as 7.9 ms^{-1} and 11.4 ms^{-1}, respectively. It was also shown that during the early rainy season, the average speed of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 10.8 ms^{-1} and 19.9 ms^{-1}. For the late rainy season, the study revealed that the average speeds of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 5.2 ms^{-1} and 14.5 ms^{-1}. Also, during the rainy season, the average speed of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 10.9 ms^{-1} and 9.8 ms^{-1}, respectively. However, during the dry season, the average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 138.1 km^2 and 118.8 km^2, respectively. Generally, during the early rainy season, the average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 213.9 km^2 and 199.7 km^2. During the late rainy season, the average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 204.1 km^2 and 200.6 km^2. For the rainy season, the average areal coverage of rainstorms due to thunderstorm and those due to disturbance lines were recorded as 129.8 km^2 and 149.3 km^2, respectively.

Subjection of the results of duration, rainfall amount, speed, and areal coverage of rainstorms due to thunderstorm and those due to disturbance lines to statistical tests showed that there were no significant differences in the mean duration (t=1.18, T=1.96), rainfall amount (t=0.44, T=1.96), speed (t=1.20, T=1.96) and areal coverage (t=0.07, T=1.96) of rainstorms due to thunderstorm and those due to disturbance lines, respectively, at 0.05 significance level. In addition, there were no significant differences in the mean duration (t=0.33, T=2.09; t=0.34, T=2.04; t=1.52, T=2.02; t=1.77, T=2.02), rainfall amount (t=0.63, T=2.09; t=0.36, T=2.04; t=1.21, T=2.02; t=0.21, T=2.02), speed (t=0.47, T=2.09; t=0.92, T=2.04; t=0.72, T=2.02; t=0.19, T=2.02) and areal coverage (t=0.31, T=2.09; t=0.21, T=2.04; t=0.06, T=2.02; t=0.81, T=2.02) of rainstorms due to thunderstorm and those due to disturbance lines during the dry, early, late and rainy seasons, respectively, at 0.05 significance level.

9.2 Conclusion of the Study

The study led to some conclusions. The frequency of rainstorms due to thunderstorm and those due to disturbance lines in Ibadan varied seasonally over the city of Ibadan. The average durations of rainstorms in Ibadan were between one and two hours. Results of seasonal variation of rainfall amounts over Ibadan showed that there has been a decline in total rainfall amount received during the early and the late rainy seasons. Also, results of lifetimes and speeds of rainstorms over Ibadan revealed that the short-lived slow-moving systems were the prevailing lifetimes and speeds of rainstorm events over Ibadan followed by the fast-moving short-lived systems. There was an increase in the total areal coverage of rainstorms during the early rainy season rainstorm events while there was a decrease in the total areal coverage of rainstorms during the late rainy season. It has shown that the duration, rainfall amount and speed of rainstorms played an important role in the areal coverage of rainstorms in the urban canopy of Ibadan metropolis especially and generally there were strong relationships between the characteristics of rainstorms–duration and rainfall amount related directly with the areal coverage of rainstorms during the early and late rainy seasons. The duration, rainfall amount and speed of rainstorms significantly contributed to the areal coverage of rainstorms during the early and the late rainy season rainstorms. There were no significant differences in the mean speed of rainstorms due to thunderstorm between the early and late rainy season. Significant differences also existed between the areal coverage of rainstorms due to thunderstorms during the early and the late rainy season rainstorms. There were no significant differences in the mean speed and AC of rainstorms due to disturbance lines between the early and late rainy seasons. There were no significant differences in the mean rainstorms duration, rainfall amount, speed and AC of rainstorms due to thunderstorm and those due to disturbance lines. In general, the seasonal dynamics and areal patterns of rainstorms over Ibadan were described, analyzed and interpreted in the light of the existing urban climatological knowledge and concepts. The seasonal dynamics and areal patterns of rainstorms in Ibadan became well understood with a deeper knowledge on the spatio-temporal differences between rainstorms due to thunderstorm and those due to disturbance lines and how rainstorm characteristics such as duration, rainfall amount and speed of rainstorms had affected the areal coverage of rainstorms over Ibadan. The study contributed to knowledge by examining the difference between the characteristics of rainstorms due to thunderstorm and those due to disturbance lines.

This study has provided a basic climatological investigation of Ibadan rainstorms conditions, especially the study of the characteristics of rainstorms and their interrelationship, which will aid better understanding of the rainstorms climatology of the southwest Nigeria, in general.

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APPENDICES

Appendix I

Data logger/EXCEL gauge files

A_1.TXT - Editor

Datei Bearbeiten Format ?

Date	Time	Event
01.01.2013	11:22:01.0	
01.01.2013	11:22:55.0	
02.01.2013	00:33:11.5	
02.01.2013	00:36:47.0	
02.01.2013	00:39:24.0	
02.01.2013	00:41:08.5	
02.01.2013	00:46:06.5	
02.01.2013	00:50:47.0	
02.01.2013	01:07:44.5	
02.01.2013	01:08:43.0	
02.01.2013	01:09:30.5	
02.01.2013	01:09:50.5	
02.01.2013	01:10:49.5	
02.01.2013	01:11:39.5	
02.01.2013	01:12:48.0	
02.01.2013	01:13:49.5	
02.01.2013	01:16:52.0	
02.01.2013	01:17:59.5	
02.01.2013	01:43:42.5	
02.01.2013	02:18:45.0	
02.01.2013	02:58:25.5	
02.01.2013	03:05:33.0	
02.01.2013	03:13:54.5	
02.01.2013	03:17:08.0	
	03:23:41.5	

A	B	C	D	E	F	G	H
	days	hours	mins	secs	Seconds	Intervals	Intensity (tips/sec)
01.01.2013	6	11	22	1			
01.01.2013	6	11	22	55			
02.01.2013	7	0	33	11.5	606791.5		
02.01.2013	7	0	36	47	607007	215.5	0.004640371
02.01.2013	7	0	39	24	607164	157	0.006369427
02.01.2013	7	0	41	8.5	607268.5	104.5	0.009569378
02.01.2013	7	0	46	6.5	607566.5	298	0.003355705
02.01.2013	7	0	50	47	607847	280.5	0.003565062
02.01.2013	7	1	7	44.5	608864.5	1017.5	0.000982801
02.01.2013	7	1	8	43	608923	58.5	0.017094017
02.01.2013	7	1	9	30.5	608970.5	47.5	0.021052632
02.01.2013	7	1	9	50.5	608990.5	20	0.05
02.01.2013	7	1	10	49.5	609049.5	59	0.016949153
02.01.2013	7	1	11	39.5	609099.5	50	0.02
02.01.2013	7	1	12	48	609168	68.5	0.01459854
02.01.2013	7	1	13	49.5	609229.5	61.5	0.016260163
02.01.2013	7	1	16	52	609412	182.5	0.005479452
02.01.2013	7	1	17	59.5	609479.5	67.5	0.014814815
02.01.2013	7	1	43	42.5	611022.5	1543	0.000648088
02.01.2013	7	2	18	45	613125	2102.5	0.000475624

Appendix II

(a)

Sample copy of computer printout of regression analysis using SPSS version 17.0 software

```
DESCRIPTIVES VARIABLES=AREAL_EARLYRAIN DURATION_EARLY AMOUNT_EARLY
SPEED_EARLY   /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_early rainstorms.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The areal coverage of early rainstorms_thunderstorm	11	56.00	426.40	309.8000	101.20213
Duration of early rainstorms_thunderstorm	11	51.00	226.00	121.1818	62.06741
Rainfall amount of early rainstorms_thunderstorm	11	5.10	45.20	18.6091	12.19684
Speed of early rainstorms_thunderstorm	11	.40	61.10	11.1545	18.54445
Valid N (listwise)	11				

```
CORRELATIONS   /VARIABLES=AREAL_EARLYRAIN DURATION_EARLY AMOUNT_EARLY
SPEED_EARLY   /PRINT=TWOTAIL NOSIG   /MISSING=PAIRWISE.
```

Correlations

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_early rainstorms.sav
```

Correlations

		The areal coverage of early rainstorms_ thunderstorm	Duration of early rainstorms_ thunderstorm	Rainfall amount of early rainstorms_ thunderstorm	Speed of early rainstorms_ thunderstorm
The areal coverage of early rainstorms_thunderstorm	Pearson Correlation	1	.443	.491	-.419
	Sig. (2-tailed)		.173	.125	.200
	N	11	11	11	11
Duration of early rainstorms_thunderstorm	Pearson Correlation	.443	1	.767**	-.263
	Sig. (2-tailed)	.173		.006	.434
	N	11	11	11	11
Rainfall amount of early rainstorms_thunderstorm	Pearson Correlation	.491	.767**	1	-.065
	Sig. (2-tailed)	.125	.006		.850
	N	11	11	11	11
Speed of early rainstorms_thunderstorm	Pearson Correlation	-.419	-.263	-.065	1
	Sig. (2-tailed)	.200	.434	.850	
	N	11	11	11	11

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

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_EARLYRAIN
/METHOD=ENTER DURATION_EARLY AMOUNT_EARLY SPEED_EARLY
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.
```

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_early rainstorms.sav
```

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Speed of early rainstorms_thunderstorm, Rainfall amount of early rainstorms_thunderstorm, Duration of early rainstorms_thunderstorm[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.626[a]	.392	.131	94.31655

a. Predictors: (Constant), Speed of early rainstorms_thunderstorm, Rainfall amount of early rainstorms_thunderstorm, Duration of early rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of early rainstorms_thunderstorm

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40149.444	3	13383.148	1.504	.295[a]
	Residual	62269.276	7	8895.611		
	Total	102418.720	10			

a. Predictors: (Constant), Speed of early rainstorms_thunderstorm, Rainfall amount of early rainstorms_thunderstorm, Duration of early rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of early rainstorms_thunderstorm

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	265.850	73.687		3.608	.009
	Duration of early rainstorms_thunderstorm	-.075	.794	-.046	-.094	.928
	Rainfall amount of early rainstorms_thunderstorm	4.152	3.906	.500	1.063	.323
	Speed of early rainstorms_thunderstorm	-2.173	1.709	-.398	-1.271	.244

a. Dependent Variable: The areal coverage of early rainstorms_thunderstorm

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_EARLYRAIN
/METHOD=STEPWISE DURATION_EARLY AMOUNT_EARLY SPEED_EARLY
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.
```

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_early rainstorms.sav
```

Warnings

No variables were entered into the equation

Appendix II
(b)

Sample copy of computer printout of regression analysis using SPSS version 17.0 software

```
DESCRIPTIVES VARIABLES=AREAL_EARLYRAIN DURATION_EARLY AMOUNT_EARLY
SPEED_EARLY   /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_early rainstorms.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The areal coverage of early rainstorms_thunderstorm	13	23.80	295.00	132.7231	75.02326
Duration of early rainstorms_thunderstorm	13	41.00	201.00	119.8462	49.64012
Rainfall amount of early rainstorms_thunderstorm	13	.60	35.90	10.9538	10.57912
Speed of early rainstorms_thunderstorm	13	.40	76.70	10.4846	22.30780
Valid N (listwise)	13				

```
CORRELATIONS   /VARIABLES=AREAL_EARLYRAIN DURATION_EARLY AMOUNT_EARLY
SPEED_EARLY   /PRINT=TWOTAIL NOSIG   /MISSING=PAIRWISE.
```

Correlations

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_early rainstorms.sav
```

Correlations

		The areal coverage of early rainstorms_ thunderstorm	Duration of early rainstorms_ thunderstorm	Rainfall amount of early rainstorms_ thunderstorm	Speed of early rainstorms_ thunderstorm
The areal coverage of early rainstorms_thunderstorm	Pearson Correlation	1	-.171	-.252	-.154
	Sig. (2-tailed)		.577	.406	.616
	N	13	13	13	13
Duration of early rainstorms_thunderstorm	Pearson Correlation	-.171	1	.556*	.199
	Sig. (2-tailed)	.577		.049	.514
	N	13	13	13	13
Rainfall amount of early rainstorms_thunderstorm	Pearson Correlation	-.252	.556*	1	-.033
	Sig. (2-tailed)	.406	.049		.916
	N	13	13	13	13
Speed of early rainstorms_thunderstorm	Pearson Correlation	-.154	.199	-.033	1
	Sig. (2-tailed)	.616	.514	.916	
	N	13	13	13	13

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

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_EARLYRAIN
/METHOD=ENTER DURATION_EARLY AMOUNT_EARLY SPEED_EARLY
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.
```

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_early rainstorms.sav
```

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Speed of early rainstorms_thunderstorm, Rainfall amount of early rainstorms_thunderstorm, Duration of early rainstorms_thunderstorm[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.299[a]	.090	-.214	82.65286

a. Predictors: (Constant), Speed of early rainstorms_thunderstorm, Rainfall amount of early rainstorms_thunderstorm, Duration of early rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of early rainstorms_thunderstorm

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6058.425	3	2019.475	.296	.828[a]
	Residual	61483.458	9	6831.495		
	Total	67541.883	12			

a. Predictors: (Constant), Speed of early rainstorms_thunderstorm, Rainfall amount of early rainstorms_thunderstorm, Duration of early rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of early rainstorms_thunderstorm

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	157.540	62.646		2.515	.033
	Duration of early rainstorms_thunderstorm	.010	.599	.007	.017	.987
	Rainfall amount of early rainstorms_thunderstorm	-1.850	2.756	-.261	-.671	.519
	Speed of early rainstorms_thunderstorm	-.550	1.109	-.163	-.496	.632

a. Dependent Variable: The areal coverage of early rainstorms_thunderstorm

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_early rainstorms.sav
```

Warnings

No variables were entered into the equation

Appendix II
(c)

Sample copy of computer printout of regression analysis using SPSS version 17.0 software

```
DESCRIPTIVES VARIABLES=AREAL_LATERAIN DURATION_LATE AMOUNT_LATE
SPEED_LATE   /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_late rainstorms.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The areal coverage of late rainstorms_thunderstorm	17	33.40	389.60	164.6941	125.87655
Duration of late rainstorms_thunderstorm	17	30.00	241.00	110.6471	57.85860
Rainfall amount of late rainstorms_thunderstorm	17	2.50	38.80	16.1471	8.98945
Speed of late rainstorms_thunderstorm	17	.40	43.00	5.5765	10.29591
Valid N (listwise)	17				

```
CORRELATIONS   /VARIABLES=AREAL_LATERAIN DURATION_LATE AMOUNT_LATE
SPEED_LATE   /PRINT=TWOTAIL NOSIG   /MISSING=PAIRWISE.
```

Correlations

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_late rainstorms.sav
```

Correlations

		The areal coverage of late rainstorms_ thunderstorm	Duration of late rainstorms_ thunderstorm	Rainfall amount of late rainstorms_ thunderstorm	Speed of late rainstorms_ thunderstorm
The areal coverage of late rainstorms_thunderstorm	Pearson Correlation	1	.075	.565*	.495*
	Sig. (2-tailed)		.776	.018	.043
	N	17	17	17	17
Duration of late rainstorms_thunderstorm	Pearson Correlation	.075	1	.621**	-.184
	Sig. (2-tailed)	.776		.008	.479
	N	17	17	17	17
Rainfall amount of late rainstorms_thunderstorm	Pearson Correlation	.565*	.621**	1	.192
	Sig. (2-tailed)	.018	.008		.460
	N	17	17	17	17
Speed of late rainstorms_thunderstorm	Pearson Correlation	.495*	-.184	.192	1
	Sig. (2-tailed)	.043	.479	.460	
	N	17	17	17	17

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

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

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_LATERAIN
/METHOD=ENTER DURATION_LATE AMOUNT_LATE SPEED_LATE
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.
```

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013 thunderstorm only_late rainstorms.sav
```

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Speed of late rainstorms_thunderstorm, Duration of late rainstorms_thunderstorm, Rainfall amount of late rainstorms_thunderstorm[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.721[a]	.521	.410	96.69947

a. Predictors: (Constant), Speed of late rainstorms_thunderstorm, Duration of late rainstorms_thunderstorm, Rainfall amount of late rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of late rainstorms_thunderstorm

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	131958.261	3	43986.087	4.704	.020[a]
	Residual	121560.228	13	9350.787		
	Total	253518.489	16			

a. Predictors: (Constant), Speed of late rainstorms_thunderstorm, Duration of late rainstorms_thunderstorm, Rainfall amount of late rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of late rainstorms_thunderstorm

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.
1	(Constant)	59.114	57.364		1.031	.322
	Duration of late rainstorms_thunderstorm	-.647	.580	-.297	-1.116	.285
	Rainfall amount of late rainstorms_thunderstorm	9.673	3.738	.691	2.588	.023
	Speed of late rainstorms_thunderstorm	3.759	2.603	.307	1.444	.172

a. Dependent Variable: The areal coverage of late rainstorms_thunderstorm

Appendix II
(d)

Sample copy of computer printout of regression analysis using SPSS version 17.0 software

```
DESCRIPTIVES VARIABLES=AREAL_LATERAIN DURATION_LATE AMOUNT_LATE
SPEED_LATE   /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_late rainstorms.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The areal coverage of late rainstorms_thunderstorm	25	116.20	355.20	230.8640	75.14594
Duration of late rainstorms_thunderstorm	25	26.00	222.00	106.0000	47.41044
Rainfall amount of late rainstorms_thunderstorm	25	1.40	33.40	13.0840	8.24023
Speed of late rainstorms_thunderstorm	25	.40	27.30	4.9680	6.39249
Valid N (listwise)	25				

```
CORRELATIONS   /VARIABLES=AREAL_LATERAIN DURATION_LATE AMOUNT_LATE
SPEED_LATE   /PRINT=TWOTAIL NOSIG   /MISSING=PAIRWISE.
```

Correlations

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_late rainstorms.sav
```

Correlations

		The areal coverage of late rainstorms_ thunderstorm	Duration of late rainstorms_ thunderstorm	Rainfall amount of late rainstorms_ Thunderstorm	Speed of late rainstorms_ thunderstorm
The areal coverage of late rainstorms_thunderstorm	Pearson Correlation	1	-.335	-.197	.215
	Sig. (2-tailed)		.102	.346	.303
	N	25	25	25	25
Duration of late rainstorms_thunderstorm	Pearson Correlation	-.335	1	.833**	-.278
	Sig. (2-tailed)	.102		.000	.179
	N	25	25	25	25
Rainfall amount of late rainstorms_thunderstorm	Pearson Correlation	-.197	.833**	1	-.133
	Sig. (2-tailed)	.346	.000		.528
	N	25	25	25	25
Speed of late rainstorms_thunderstorm	Pearson Correlation	.215	-.278	-.133	1
	Sig. (2-tailed)	.303	.179	.528	
	N	25	25	25	25

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

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_LATERAIN
/METHOD=ENTER DURATION_LATE AMOUNT_LATE SPEED_LATE
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.

[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_late rainstorms.sav
```

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Speed of late rainstorms_thunderstorm, Rainfall amount of late rainstorms_thunderstorm, Duration of late rainstorms_thunderstorm[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.380[a]	.144	.022	74.30854

a. Predictors: (Constant), Speed of late rainstorms_thunderstorm, Rainfall amount of late rainstorms_thunderstorm, Duration of late rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of late rainstorms_thunderstorm

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	19568.942	3	6522.981	1.181	.341[a]
	Residual	115956.955	21	5521.760		
	Total	135525.898	24			

a. Predictors: (Constant), Speed of late rainstorms_thunderstorm, Rainfall amount of late rainstorms_thunderstorm, Duration of late rainstorms_thunderstorm

b. Dependent Variable: The areal coverage of late rainstorms_thunderstorm

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.
1	(Constant)	280.732	44.702		6.280	.000
	Duration of late rainstorms_thunderstorm	-.793	.607	-.500	-1.305	.206
	Rainfall amount of late rainstorms_thunderstorm	2.132	3.385	.234	.630	.536
	Speed of late rainstorms_thunderstorm	1.256	2.514	.107	.500	.623

a. Dependent Variable: The areal coverage of late rainstorms_thunderstorm

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2014 thunderstorm only_late rainstorms.sav
```

Warnings

No variables were entered into the equation

Appendix II
(e)

T-Test analysis of paired two sample means for the duration of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2013

T-Test analysis of paired two sample means of duration of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2013

	Variable 1	Variable 2
Mean	121.2	110.6
Standard deviation	62.1	57.9
Observations	11	17
Difference	0	0
df	26	26
t Statistics	0.45	
P (T<=t) one-tail		
t Critical one-tail	1.71	
P (T<=t) two-tail		
t Critical two-tail	2.06	

Appendix II
(f)

T-Test analysis of paired two sample means for the duration of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2014

T-Test analysis of paired two sample means
of duration of rainstorms due to thunderstorm
between the early rainy season and the late
rainy season of 2014

	Variable 1	Variable 2
Mean	119.9	106.0
Standard deviation	49.6	47.4
Observations	13	25
Difference	0	0
df	36	36
t Statistics	0.83	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix II
(g)

T-Test analysis of paired two sample means for the rainfall amount due to thunderstorm between the early rainy season and the late rainy season of 2013

T-Test analysis of paired two sample means of rainfall amount due to thunderstorm between the early rainy season and the late rainy season of 2013

	Variable 1	Variable 2
Mean	18.6	16.2
Standard deviation	12.2	8.9
Observations	11	17
Difference	0	0
df	26	26
t Statistics	0.58	
P (T<=t) one-tail		
t Critical one-tail	1.71	
P (T<=t) two-tail		
t Critical two-tail	2.06	

Appendix II
(h)

T-Test analysis of paired two sample means for the rainfall amount due to thunderstorm between the early rainy season and the late rainy season of 2014

T-Test analysis of paired two sample means of rainfall amount due to thunderstorm between the early rainy season and the late rainy season of 2014

	Variable 1	Variable 2
Mean	10.9	13.1
Standard deviation	10.6	8.2
Observations	13	25
Difference	0	0
df	36	36
t Statistics	0.63	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix I11

Four classes of lifetime and speed (*after Lafore and Moncrieff, 1989)*

The C1 class [$D < 9$ *hr;* $V < 10$ $m.s^{-1}$] corresponds to small numerous diurnal and slow-moving MCS. They are located between 3°N and 13°N mainly over the mountains and the ocean. They contribute the most to the total nebulosity because of their number.

The C2 class [$D > 9$ *hr;* $V < 10$ $m.s^{-1}$] includes long-lived slow-moving MCS located more over the coasts and the ocean and less on the relief with regard to the C1 class. The MCS in the C2 class are bigger than those in the C1 class.

The C3 class [$D < 9$ *hr;* $V > 10$ $m.s^{-1}$] corresponds to fast-moving systems, which dissipate in the evening. They are few and located over the continent.

The last C4 class [$D > 9$ *hr;* $V > 10$ $m.s^{-1}$] corresponds to fast-moving long-lived squall line type systems. They are less numerous but the largest. Their track coincides with the Sahelean band (10°N-15°N). A warm low-level equivalent potential temperature, a strong wind-shear (due to a rapid AEJ around 600 hPa), and a dry middle atmosphere facilitate the well-organized deep convection in this band.

Appendix IV
(a)

T-Test analysis of paired two sample means for the speed of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2013

T-Test analysis of paired two sample means of speed of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2013

	Variable 1	Variable 2
Mean	11.2	5.6
Standard deviation	18.6	10.3
Observations	11	17
Difference	0	0
df	26	26
t Statistics	0.92	
P (T<=t) one-tail		
t Critical one-tail	1.71	
P (T<=t) two-tail		
t Critical two-tail	2.06	

Appendix IV
(b)

T-Test analysis of paired two sample means for the speed of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2014

T-Test analysis of paired two sample means of speed of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2014

	Variable 1	Variable 2
Mean	10.5	4.9
Standard deviation	22.3	6.3
Observations	13	25
Difference	0	0
df	36	36
t Statistics	0.89	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix IV
(c)

T-Test analysis of paired two sample means for the areal coverage of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2013

T-Test analysis of paired two sample means
of areal coverage of rainstorms due to thunderstorm
between the early rainy season and the late
rainy season of 2013

	Variable 1	Variable 2
Mean	309.8	164.7
Standard deviation	101.2	125.9
Observations	11	17
Difference	0	0
df	26	26
t Statistics	3.36	
P (T>=t) one-tail		
t Critical one-tail	1.71	
P (T>=t) two-tail		
t Critical two-tail	2.06	

Appendix IV
(d)

T-Test analysis of paired two sample means for the areal coverage of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2014

T-Test analysis of paired two sample means of areal coverage of rainstorms due to thunderstorm between the early rainy season and the late rainy season of 2014

	Variable 1	Variable 2
Mean	132.7	230.9
Standard deviation	75.0	75.2
Observations	13	25
Difference	0	0
df	36	36
t Statistics	3.82	
P (T>=t) one-tail		
t Critical one-tail	1.70	
P (T>=t) two-tail		
t Critical two-tail	2.04	

Appendix V

(a)

Sample copy of computer printout of regression analysis using SPSS version 17.0 software

```
DESCRIPTIVES VARIABLES=AREAL_EARLYRAIN DURATION_EARLY AMOUNT_EARLY
SPEED_EARLY   /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_early rainstorms.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The areal coverage of early rainstorms_disturbance lines	8	39.00	436.50	199.6875	176.14887
Duration of early rainstorms_disturbance lines	8	25.00	315.00	131.8750	88.81673
Rainfall amount of early rainstorms_disturbance lines	8	1.30	35.80	16.0500	10.76078
Speed of early rainstorms_disturbance lines	8	1.60	79.40	19.9875	25.73477
Valid N (listwise)	8				

```
CORRELATIONS   /VARIABLES=AREAL_EARLYRAIN DURATION_EARLY AMOUNT_EARLY
SPEED_EARLY   /PRINT=TWOTAIL NOSIG   /MISSING=PAIRWISE.
```

Correlations

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_early rainstorms.sav
```

Correlations

		The areal coverage of early rainstorms_ disturbance lines	Duration of early rainstorms_ disturbance lines	Rainfall amount of early rainstorms_ disturbance lines	Speed of early rainstorms_ disturbance lines
The areal coverage of early rainstorms_disturbance lines	Pearson Correlation	1	.129	-.022	-.369
	Sig. (2-tailed)		.761	.959	.369
	N	8	8	8	8
Duration of early rainstorms_disturbance lines	Pearson Correlation	.129	1	.407	-.502
	Sig. (2-tailed)	.761		.316	.205
	N	8	8	8	8
Rainfall amount of early rainstorms_disturbance lines	Pearson Correlation	-.022	.407	1	-.465
	Sig. (2-tailed)	.959	.316		.245
	N	8	8	8	8
Speed of early rainstorms_disturbance lines	Pearson Correlation	-.369	-.502	-.465	1
	Sig. (2-tailed)	.369	.205	.245	
	N	8	8	8	8

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_EARLYRAIN
/METHOD=ENTER DURATION_EARLY AMOUNT_EARLY SPEED_EARLY
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.
```

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_early rainstorms.sav
```

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Speed of early rainstorms_disturbance lines, Rainfall amount of early rainstorms_disturbance lines, Duration of early rainstorms_disturbance lines[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.429[a]	.184	-.428	210.48352

a. Predictors: (Constant), Speed of early rainstorms_disturbance lines, Rainfall amount of early rainstorms_disturbance lines, Duration of early rainstorms_disturbance lines

b. Dependent Variable: The areal coverage of early rainstorms_disturbance lines

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	39985.724	3	13328.575	.301	.824[a]
	Residual	177213.245	4	44303.311		
	Total	217198.969	7			

a. Predictors: (Constant), Speed of early rainstorms_disturbance lines, Rainfall amount of early rainstorms_disturbance lines, Duration of early rainstorms_disturbance lines

b. Dependent Variable: The areal coverage of early rainstorms_disturbance lines

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	335.681	237.116		1.416	.230
	Duration of early rainstorms_disturbance lines	-.038	1.064	-.019	-.036	.973
	Rainfall amount of early rainstorms_disturbance lines	-3.974	8.577	-.243	-.463	.667
	Speed of early rainstorms_disturbance lines	-3.364	3.787	-.491	-.888	.425

a. Dependent Variable: The areal coverage of early rainstorms_disturbance lines

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_early rainstorms.sav
```

Warnings

No variables were entered into the equation

Appendix V
(b)

Sample copy of computer printout of regression analysis using SPSS version 17.0 software

```
DESCRIPTIVES VARIABLES=AREAL_LATERAIN DURATION_LATE AMOUNT_LATE
SPEED_LATE   /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_late rainstorms.sav
```

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The areal coverage of late rainstorms_disturbance lines	7	43.50	397.50	200.5714	152.11192
Duration of late rainstorms_disturbance lines	7	54.00	141.00	87.5714	28.68134
Rainfall amount of late rainstorms_disturbance lines	7	2.90	22.10	10.9286	6.54974
Speed of late rainstorms_disturbance lines	7	.20	92.10	14.4714	34.26688
Valid N (listwise)	7				

```
CORRELATIONS   /VARIABLES=AREAL_LATERAIN DURATION_LATE AMOUNT_LATE
SPEED_LATE   /PRINT=TWOTAIL NOSIG   /MISSING=PAIRWISE.
```

Correlations

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_late rainstorms.sav
```

Correlations

		The areal coverage of late rainstorms_ disturbance lines	Duration of late rainstorms_ disturbance lines	Rainfall amount of late rainstorms_ disturbance lines	Speed of late rainstorms_ disturbance lines
The areal coverage of late rainstorms_disturbance lines	Pearson Correlation	1	.202	.114	.479
	Sig. (2-tailed)		.664	.808	.277
	N	7	7	7	7
Duration of late rainstorms_disturbance lines	Pearson Correlation	.202	1	.272	.813*
	Sig. (2-tailed)	.664		.555	.026
	N	7	7	7	7
Rainfall amount of late rainstorms_disturbance lines	Pearson Correlation	.114	.272	1	-.139
	Sig. (2-tailed)	.808	.555		.767
	N	7	7	7	7
Speed of late rainstorms_disturbance lines	Pearson Correlation	.479	.813*	-.139	1
	Sig. (2-tailed)	.277	.026	.767	
	N	7	7	7	7

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

```
REGRESSION   /MISSING LISTWISE   /STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)   /NOORIGIN   /DEPENDENT AREAL_LATERAIN
/METHOD=ENTER DURATION_LATE AMOUNT_LATE SPEED_LATE
/SCATTERPLOT=(*SDRESID ,*ZPRED)   /SAVE PRED ZPRED ADJPRED SEPRED.
```

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_late rainstorms.sav
```

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Speed of late rainstorms_disturbance lines, Rainfall amount of late rainstorms_disturbance lines, Duration of late rainstorms_disturbance lines[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785[a]	.617	.234	133.16214

a. Predictors: (Constant), Speed of late rainstorms_disturbance lines, Rainfall amount of late rainstorms_disturbance lines, Duration of late rainstorms_disturbance lines

b. Dependent Variable: The areal coverage of late rainstorms_disturbance lines

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	85631.749	3	28543.916	1.610	.353[a]
	Residual	53196.465	3	17732.155		
	Total	138828.214	6			

a. Predictors: (Constant), Speed of late rainstorms_disturbance lines, Rainfall amount of late rainstorms_disturbance lines, Duration of late rainstorms_disturbance lines

b. Dependent Variable: The areal coverage of late rainstorms_disturbance lines

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	545.719	277.361		1.968	.144
	Duration of late rainstorms_disturbance lines	-7.277	4.369	-1.372	-1.665	.194
	Rainfall amount of late rainstorms_disturbance lines	16.765	11.250	.722	1.490	.233
	Speed of late rainstorms_disturbance lines	7.523	3.554	1.695	2.117	.125

a. Dependent Variable: The areal coverage of late rainstorms_disturbance lines

Regression

```
[DataSet0] C:\Users\ADESHOLA\Desktop\Analysis\Final Chaps\ANALYSIS OF
RAINSTORM\2013_2014 disturbance lines only_late rainstorms.sav
```

Warnings

No variables were entered into the equation

Appendix V
(c)

T-Test analysis of paired two sample means for the duration of rainstorms due to disturbance lines between the early rainy season and the late rainy season of 2013 and 2014

T-Test analysis of paired two sample means
of duration of rainstorms due to disturbance lines
between the early rainy season and the late
rainy season of 2013 and 2014

	Variable 1	Variable 2
Mean	131.9	87.6
Standard deviation	88.8	28.7
Observations	8	7
Difference	0	0
df	13	13
t Statistics	1.33	
P (T<=t) one-tail		
t Critical one-tail	1.77	
P (T<=t) two-tail		
t Critical two-tail	2.16	

Appendix V
(d)

T-Test analysis of paired two sample means for the rainfall amount due to disturbance lines between the early rainy season and the late rainy season of 2013 and 2014

T-Test analysis of paired two sample means of rainfall amount due to disturbance lines between the early rainy season and the late rainy season of 2013 and 2014

	Variable 1	Variable 2
Mean	16.1	10.9
Standard deviation	10.8	6.6
Observations	8	7
Difference	0	0
df	13	13
t Statistics	1.14	
P (T<=t) one-tail		
t Critical one-tail	1.77	
P (T<=t) two-tail		
t Critical two-tail	2.16	

Appendix VI

(a)

T-Test analysis of paired two sample means for the speed of rainstorms due to disturbance lines between the early rainy season and the late rainy season of 2013 and 2014

T-Test analysis of paired two sample means of speed of rainstorms due to disturbance lines between the early rainy season and the late rainy season of 2013 and 2014

	Variable 1	Variable 2
Mean	19.9	14.5
Standard deviation	25.7	34.3
Observations	15	15
Difference	0	0
df	8	7
t Statistics	0.34	
P (T<=t) one-tail		
t Critical one-tail	1.77	
P (T<=t) two-tail		
t Critical two-tail	2.16	

Appendix VI
(b)

T-Test analysis of paired two sample means for the areal coverage of rainstorms due to disturbance lines between the early rainy season and the late rainy season of 2013 and 2014

T-Test analysis of paired two sample means
of areal coverage of rainstorms due to disturbance lines
between the early rainy season and the late
rainy season of 2013 and 2014

	Variable 1	Variable 2
Mean	199.7	200.5
Standard deviation	176.2	152.1
Observations	8	7
Difference	0	0
df	13	13
t Statistics	0.01	
P (T<=t) one-tail		
t Critical one-tail	1.77	
P (T<=t) two-tail		
t Critical two-tail	2.16	

Appendix VII
(a)

T-Test analysis of paired two sample means for the duration of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the 2013 and 2014 rainstorm events

T-Test analysis of paired two sample means
for the duration of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during
the 2013 and 2014 rainstorm events

	Variable 1	Variable 2
Mean	102.2	119.6
Standard deviation	51.8	75.9
Observations	125	29
Difference	0	0
df	152	152
t Statistics	1.18	
P (T<=t) one-tail		
t Critical one-tail	1.64	
P (T<=t) two-tail		
t Critical two-tail	1.96	

Appendix VII
(b)

T-Test analysis of paired two sample means for the rainfall amount between the rainstorms due to thunderstorm and disturbance lines during the 2013 and 2014 rainstorm events

T-Test analysis of paired two sample means
for the rainfall amount between the rainstorms
due to thunderstorm and disturbance lines during
the 2013 and 2014 rainstorm events

	Variable 1	Variable 2
Mean	13.6	12.8
Standard deviation	9.6	8.7
Observations	125	29
Difference	0	0
df	152	152
t Statistics	0.44	
P (T<=t) one-tail		
t Critical one-tail	1.64	
P (T<=t) two-tail		
t Critical two-tail	1.96	

Appendix VII
(c)

T-Test analysis of paired two sample means for the speed of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the 2013 and 2014 rainstorm events

T-Test analysis of paired two sample means
for the speed of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during
the 2013 and 2014 rainstorm events

	Variable 1	Variable 2
Mean	8.6	14.0
Standard deviation	20.8	22.2
Observations	125	29
Difference	0	0
df	152	152
t Statistics	1.20	
P (T<=t) one-tail		
t Critical one-tail	1.64	
P (T<=t) two-tail		
t Critical two-tail	1.96	

Appendix VII
(d)

T-Test analysis of paired two sample means for the areal coverage of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the 2013 and 2014 rainstorm events

T-Test analysis of paired two sample means
for the areal coverage of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during
the 2013 and 2014 rainstorm events

	Variable 1	Variable 2
Mean	172.0	170.3
Standard deviation	105.4	131.5
Observations	125	29
Difference	0	0
df	152	152
t Statistics	0.07	
P (T<=t) one-tail		
t Critical one-tail	1.64	
P (T<=t) two-tail		
t Critical two-tail	1.96	

Appendix VII
(e)

T-Test analysis of paired two sample means for the duration of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the dry season

T-Test analysis of paired two sample means
for the duration of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the dry season

	Variable 1	Variable 2
Mean	81.4	91.6
Standard deviation	36.7	66.3
Observations	17	5
Difference	0	0
df	20	20
t Statistics	0.33	
P (T<=t) one-tail		
t Critical one-tail	1.72	
P (T<=t) two-tail		
t Critical two-tail	2.09	

Appendix VII
(f)

T-Test analysis of paired two sample means for the duration of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the early rainy season

T-Test analysis of paired two sample means
for the duration of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the early rainy season

	Variable 1	Variable 2
Mean	120.5	131.9
Standard deviation	54.4	88.8
Observations	24	8
Difference	0	0
df	30	30
t Statistics	0.34	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix VII
(g)

T-Test analysis of paired two sample means for the duration of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the late rainy season

T-Test analysis of paired two sample means
for the duration of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the late rainy season

	Variable 1	Variable 2
Mean	107.9	87.6
Standard deviation	51.3	28.7
Observations	42	7
Difference	0	0
df	47	47
t Statistics	1.52	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII
(h)

T-Test analysis of paired two sample means for the duration of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the rainy season

T-Test analysis of paired two sample means
for the duration of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the rainy season

	Variable 1	Variable 2
Mean	94.5	149.0
Standard deviation	53.3	89.0
Observations	42	9
Difference	0	0
df	49	49
t Statistics	1.77	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII

(i)

T-Test analysis of paired two sample means for the rainfall amount between the rainstorms due to thunderstorm and disturbance lines during the dry season

T-Test analysis of paired two sample means
for the rainfall amount between the rainstorms
due to thunderstorm and disturbance lines during the dry season

	Variable 1	Variable 2
Mean	10.9	7.7
Standard deviation	8.9	10.2
Observations	17	5
Difference	0	0
df	20	20
t Statistics	0.63	
P (T<=t) one-tail		
t Critical one-tail	1.72	
P (T<=t) two-tail		
t Critical two-tail	2.09	

Appendix VII
(j)

T-Test analysis of paired two sample means for the rainfall amount between the rainstorms due to thunderstorm and disturbance lines during the early rainy season

T-Test analysis of paired two sample means
for the rainfall amount between the rainstorms
due to thunderstorm and disturbance lines during the early rainy season

	Variable 1	Variable 2
Mean	14.5	16.1
Standard deviation	11.8	10.8
Observations	24	8
Difference	0	0
df	30	30
t Statistics	0.36	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix VII
(k)

T-Test analysis of paired two sample means for the rainfall amount between the rainstorms due to thunderstorm and disturbance lines during the late rainy season

T-Test analysis of paired two sample means
for the rainfall amount between the rainstorms
due to thunderstorm and disturbance lines during the late rainy season

	Variable 1	Variable 2
Mean	14.3	10.9
Standard deviation	8.6	6.6
Observations	42	7
Difference	0	0
df	47	47
t Statistics	1.21	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII
(l)

T-Test analysis of paired two sample means for the rainfall amount between the rainstorms due to thunderstorm and disturbance lines during the rainy season

T-Test analysis of paired two sample means
rainfall amount between the rainstorms
due to thunderstorm and disturbance lines during the rainy season

	Variable 1	Variable 2
Mean	13.5	14.1
Standard deviation	9.7	7.1
Observations	42	9
Difference	0	0
df	49	49
t Statistics	0.21	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII
(m)

T-Test analysis of paired two sample means for the speed of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the dry season

T-Test analysis of paired two sample means
for the speed of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the dry season

	Variable 1	Variable 2
Mean	7.9	11.5
Standard deviation	20.1	12.9
Observations	17	5
Difference	0	0
df	20	20
t Statistics	0.47	
P (T<=t) one-tail		
t Critical one-tail	1.72	
P (T<=t) two-tail		
t Critical two-tail	2.09	

Appendix VII
(n)

T-Test analysis of paired two sample means for the speed of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the early rainy season

T-Test analysis of paired two sample means
for the speed of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the early rainy season

	Variable 1	Variable 2
Mean	10.8	19.9
Standard deviation	20.2	25.7
Observations	24	8
Difference	0	0
df	30	30
t Statistics	0.92	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix VII
(o)

T-Test analysis of paired two sample means for the speed of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the late rainy season

T-Test analysis of paired two sample means
for the speed of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the late rainy season

	Variable 1	Variable 2
Mean	5.2	14.5
Standard deviation	8.1	34.3
Observations	42	7
Difference	0	0
df	47	47
t Statistics	0.72	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII
(p)

T-Test analysis of paired two sample means for the speed of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the rainy season

T-Test analysis of paired two sample means
for the speed of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the rainy season

	Variable 1	Variable 2
Mean	10.9	9.8
Standard deviation	28.9	10.2
Observations	42	9
Difference	0	0
df	49	49
t Statistics	0.19	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII
(q)

T-Test analysis of paired two sample means for the areal coverage of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the dry season

T-Test analysis of paired two sample means
for the areal coverage of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the dry season

	Variable 1	Variable 2
Mean	138.1	118.8
Standard deviation	109.6	127.4
Observations	17	5
Difference	0	0
df	20	20
t Statistics	0.31	
P (T<=t) one-tail		
t Critical one-tail	1.72	
P (T<=t) two-tail		
t Critical two-tail	2.09	

Appendix VII
(r)

T-Test analysis of paired two sample means for the areal coverage of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the early rainy season

T-Test analysis of paired two sample means
for the areal coverage of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the early rainy season

	Variable 1	Variable 2
Mean	213.9	199.7
Standard deviation	124.6	176.2
Observations	24	8
Difference	0	0
df	30	30
t Statistics	0.21	
P (T<=t) one-tail		
t Critical one-tail	1.70	
P (T<=t) two-tail		
t Critical two-tail	2.04	

Appendix VII
(s)

T-Test analysis of paired two sample means for the areal coverage of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the late rainy season

T-Test analysis of paired two sample means
for the areal coverage of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the late rainy season

	Variable 1	Variable 2
Mean	204.1	200.6
Standard deviation	102.8	152.1
Observations	42	7
Difference	0	0
df	47	47
t Statistics	0.06	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	

Appendix VII
(t)

T-Test analysis of paired two sample means for the areal coverage of rainstorms between the rainstorms due to thunderstorm and disturbance lines during the rainy season

T-Test analysis of paired two sample means
for the areal coverage of rainstorms between the rainstorms
due to thunderstorm and disturbance lines during the rainy season

	Variable 1	Variable 2
Mean	129.8	149.3
Standard deviation	72.6	63.9
Observations	42	9
Difference	0	0
df	49	49
t Statistics	0.81	
P (T<=t) one-tail		
t Critical one-tail	1.68	
P (T<=t) two-tail		
t Critical two-tail	2.02	