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TEMPORAL TREND IN DAILY RAINFALL INTENSITY IN A CHANGING CLIMATE IN THE MIDDLE BELT REGION OF NIGERIA

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Abstract

The study analyzed the temporal variability of daily rainfall intensity of selected stations in the Middle Belt region (MBR) of Nigeria for 46-year period (1961-2006). Daily rainfall (≥0.3mm) data were collected from eight weather stations in the study area. Daily rainfall intensity categories were classified into six categories using percentiles (P) namely; extremely light (≤ P10), light (P11 - P20), moderately light (P21 – P50), moderately heavy (P51 – P80), heavy (P81 – P90) and extremely heavy (> P90). To compute the percentile threshold values of the six daily rainfall intensity categories, the population of rain days was first extracted then ranked. The threshold values of the percentiles were extracted for each of the eight stations and the annual number of daily rainfall for each station were then determined. Trend in the series of the six daily rainfall intensity classes is analyzed using Mann Kendall's test statistics (τ) and the values obtained are plotted to show the temporal variability in the region. The result shows a general increasing trend towards the light and extremely light intensity categories, though the rate of increase varies across stations and with time ranges. Light rains are increasing in the Jos plateau whereas the number of heavy events are on the decline. There is a peculiar situation in Makurdi where both extremely light and extremely heavy intensity conditions are observed to be increasing. The study recommends that drought resistant crops, water conserving farming techniques and rainwater harvesting should be practiced in areas experiencing increased light events. Records, forecasts and warnings from experts on destructive storms, floods, landslides and droughts should be cautiously adhered to by individuals and the government.

Keywords: *Changing climate, Daily rainfall, Intensity, Trend, Percentile*

1. INTRODUCTION

The Middle Belt Region is a unique geographical and climatic region of Central Nigeria (Anyadike, 1987). It is a transitional region between southern and northern Nigeria. In this study, the Middle Belt Region is defined to cover the six states within the North central geo–

political zone and Adamawa and Taraba states. This definition uses the northern state boundaries of Niger, FCT, Nasarawa, Plateau, Taraba and Adamawa as the northern limit of the region. The Middle Belt region as defined is located within latitude $6^{o}24^{1}$ to $11^{o}30^{1}$ N and longitude $2^{o}42^{1}$ to $15^{o}\,00^{1}$ E. This covers a total land area of about 333 815 Km^2. The area occupies about 36.14 % of the total land area of Nigeria (Figure 1).

The Middle Belt region is found within the tropical wet and dry climate (Aw). It is the zone of gradual change in climate character from the wetter equatorial margin towards the drier polar ward regions. Two seasons are experienced in the region. The dry season, which starts from late November to March and wet season, which prevails from April to October. The wet season is characterized by the tropical maritime air mass which brings rainfall and wet conditions to the region.

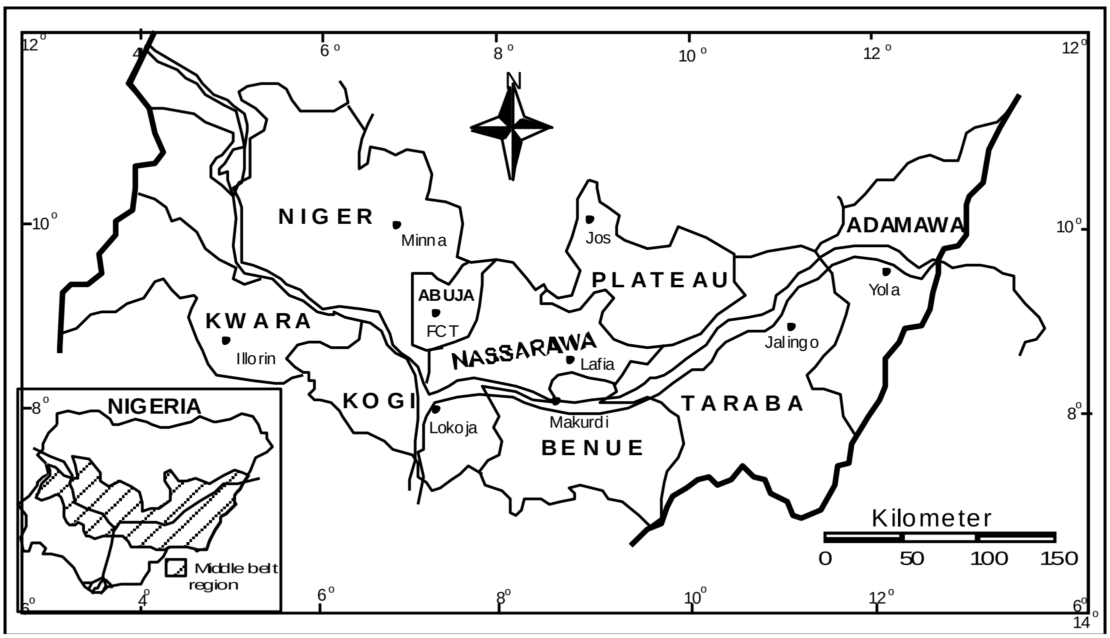

Figure 1. Study area - Middle Belt Region of Nigeria

2. BACKGROUND

The Middle Belt Region (MBR) is an important agriculturally productive part of Nigeria. This is partly because of the inherent high fertility of the soils and the moderate and variable climate (Nnamchi and Ozor, 2009). Being an ecological transition zone between the Sahel and the southern forest region, crops characteristic of these two flanking regions are also cultivated in the MBR. Cereal crops such as maize, guinea corn, millet, rice, sesame, soya beans as well as tuber and root crops like yam, cassava, potatoes (Irish and sweet) are cultivated in commercial quantities without and with irrigation. Animal rearing is also practiced in the region especially at the northern fringes as well as the highland areas. Transhumance is the commonest practice among the Fulani herdsmen. They move their animals to the highlands during the rainy season to avoid the abundant tsetse flies in the valleys but return to the valleys in the dry season where fresh pasture is available at that time of the year. Fishing activities are common among the Jukuns and other tribes along the river-line areas. Commercial fishing activities are carried out in rivers Niger and Benue and their major tributaries where different fresh water fish species are caught and sold. There are dotted light and heavy industries across the region. Geological formations within the region provides raw materials for Tin and Iron ore industry in Jos, Steel rolling industry at Ajaoukuta, Cement factories at Yandev and Obajana in Benue and Kogi States respectively. Multi-purpose river development projects for hydro-electric power generation, dry season irrigation farming, fishing, water supply and flood control have been carried out at Kainji and Jebba dams on river Niger and Shiroro Gorge on river Kaduna. Several other light processing industries exist across States in the region. Consistent functionality of these industries, expansion capabilities and constant power supply are challenges States in the Middle Belt region are contending with. With increasing global temperature and the concern about climate change and global warming, previous studies (Trenberth and Stepaniak, 2003, Chang and Fu, 2002, Paciorek, 2002, Nakamura, 2002) suggest that storm activities and intensities are on the increase. This will pose serious challenges to agriculture and water resources in the MBR.

Changing pattern of daily rainfall intensity will have resultant effects on the agricultural practices and production of the Middle Belt Region. Moisture availability for crop use will be altered leading to adjustment in agricultural productivity within the region. Excess rain at harvest can affect grain crops quality. Variability in daily rainfall intensity will affect water infiltration and percolation impacting on underground water aquifers and subsequent availability of water for domestic and industrial uses. Other issues of water resources such as those considered in the planning and construction of dams, reservoirs, drainage canals, culverts and bridges are all dependent to a large extent on variability of daily rainfall intensity. In addition; the Middle Belt Region of Nigeria contains the two major rivers in the country-Rivers Niger and Benue. The low lying valleys of these rivers are prone to annual flooding; therefore increasing intensity of daily rainfall will have an adverse effect on the occurrence of flood within the valleys of these two major rivers. The region also contains the north central highland and the eastern highlands which are watersheds for many rivers and streams. Changes in daily rainfall intensity will also have adverse effects on soil erosion and soil erosion control on the highlands in the MBR. Both rainfall intensity and runoff factors are considered in assessing water erosion problem(Wall, Baldwin and Shelton, 2003). A rainfall of high intensity will give more runoff, this is because less of the high intensity rainfall will infiltrate into the soil in contrast to low intensity rainfall. In this study, the daily rainfall intensity is classified and the temporal trend of the different intensity categories is investigated in a changing climate in the Middle Belt region of Nigeria.

2.1 Literature review

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), there is a gradual warming of the globe. Global temperature observations over the past 157 years show that temperature at the surface has risen with important regional variations. Confirmation of global warming comes from warming of the oceans, rising sea levels, glacial melting, sea ice retreating in the arctic and diminished ice cover in the northern Hemisphere. Expressed as a global average, surface temperatures have increased by about 0.74^{o}C over the past hundred years (between 1906 and 2007).However, the warming has been neither steady nor the same in different seasons or in different locations (IPCC, 2007). Changes in global temperature have tremendous impact on global climate system. As global temperature change, atmospheric moisture, precipitation and atmospheric circulation also change as the whole system is affected. Radioactive forcing alters heating, and at the earth's surface this directly affects evaporation as well as sensible heating.

Further increases in temperature lead to increases in the moisture holding capacity of the atmosphere at a rate of about 7% per degree centigrade (Trenberth and Stepaniak, 2003). As the climate changes and sea surface temperatures (SSTs) continue to increase, the environment in which tropical storms form is changed. Higher SSTs are generally accompanied by increased water vapours in the lower troposphere, thus the moist static energy that fuels convection and thunder storm is also increased. Together, these effects alter the hydrological circle, especially characteristic of precipitation i.e. amount, frequently, intensity, duration and type as well as precipitation extremes (IPCC, 2007).

Previous studies have shown that storm frequencies and intensities over both hemispheres have changed over the second half of the 20th century. General features of the change include a pole-ward shift in storms track location and increased storm intensity. Significant increasing trends of storms over both the pacific and Atlantic are found in eddy meridians velocity variance at 300hpa and other statistics (Change and Fu, 2002;Paciorek, 2002). Increases in storm track activity have also been reported by eddy statistics based on National Centre for Environmental prediction/Atmospheric Research (NRA) data. North pacific storm activity, identified as pole ward eddy heat transport at 850hpa, was significantly stronger during the late 1980s and early 1990s than during the previous years (Nakamura, 2002). Hurricanes and typhoons currently form from pre-existing disturbances only where SSTs exceed about 26ºC and, as SSTs have increased, it thereby potentially expands the areas over which such storms can form. In weather systems, convergence of increased water vapor leads to more intense precipitation, but reduction in duration and/or frequency (Trenberth and Stepaniak, 2003). Because precipitation comes mainly from weather systems that feed on the water stored in the atmosphere, this has generally increased precipitation intensity and the risk of heavily rain and snow events (Trenberth and Stepaniak, 2003). Basic theory, climate model simulation and empirical evidence all confirm that warmer climates, owing to increased water vapor lead to more intense storm activity and frequency (IPCC, 2007). The warmer climate therefore increases risk of both drought where there is increasing light rains and floods where there is increasing heavy rains.

2.2 Climate Change and Global Warming

IPCC (2007) defines climate change as a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and /or the variability of its properties, and that persists for an extended period typically decades or longer. Although the length of time it takes the changes to manifest matters, the level of deviation from the normal and its impacts on the ecology are most paramount. Ayoade (2004) stated that secular variations in climate occurring over a period of 100 to 150 years may not qualify as a climate change if conditions will quickly reverse later, but a change in climate usually takes place over a long period of time

of at least 150 years with clear and permanent impacts on the ecosystem. Climate change is different from the generally known terms like climatic fluctuations or climatic variability. These terms denote inherent dynamic nature of climate on various temporal scales. Such temporal scale variations could be monthly, seasonal, annual, decadal, periodic, quasi-periodic or non-periodic **(**Odjugo, 2010). According to O' Brien *et al* (2006), climate change is a natural phenomena but is also accelerated by human activities.

Global warming on the other hand is synonymous with enhanced green house effect, implying an increase in the amount of green house gasses in the earth's atmosphere leading to entrapment of more and more solar radiations, and thus increasing the overall temperature of the earth (

Bureau of Australian Meteorology, 2008). It is an aspect of climate change. The instrumental temperature record shows global warming of around 0.6°C over the entire 20th century (Pratt 2006). The future level of global warming is uncertain, but a wide range of estimates (projections) have been made (Green and Armstrong, 2007). The Intergovernmental panel on climate change (IPCC's, 2000) Special Report on Emissions (SRES) scenarios have been frequently used to make projections of future climate change. Climate models using the six SRES "marker" scenarios suggest future warming of 1.1 to 6.4°C by the end of the 21st century, above average global temperatures over the 1980 to 1999 time period. The range in temperature projections partly reflects different projections of future social and economic development (e.g., economic growth, population level, energy policies), which in turn affects projections of greenhouse gas (GHG) emissions. The range also reflects uncertainty in the response of the climate system to past and future GHG emissions (measured by the climate sensitivity).

The projected rate of warming under these scenarios would very likely be without precedent during at least the last 10,000 years. The most recent warm period comparable to these projections was the mid-Pliocene, around 3 million years ago. At that time, models suggest that mean global temperatures were about 2–3°C warmer than pre-industrial temperatures (IPCC, 2007).

2.2.1 Theories of Possible Causes of Climate Change and Global Warming

There are many theories that have been propounded over the years in attempt to explain various aspects of the climate changes and variations that have occurred in the climate of the earth since geologic time. These various factors may operate together to bring about a change in climate. Many theories of possible causes of climate change have been advanced. These theories relate to terrestrial (anthropogenic/human and non anthropogenic), astronomical and extraterrestrial causes (Ayoade, 2004). The objective is not to say which of these theories is right or best, but only to present them to the reader in a format that allows reflection and balanced consideration (Blast, 2010). The terrestrial theories of possible causes of climate change link climate changes in the distribution of land and water surfaces, changes in earths topography, changes in atmospheric composition and chemistry and changes in the ice or snow cover of the earth surface.

Changes in the Distribution of Land and Water Surfaces

The theories of polar wandering, continental drift and plate tectonic have explained the changing distribution of the continents and oceans in the geological past (Wegener, 1915, Hess and Dietz, 1960). As land and water surfaces have different thermal properties and also their effect on patterns of radiation distribution, shifts in the locations of continents and oceans would affect radiation distribution and hence climate (Gray, 2009).

Changes in the Earth’s Topography

Changes in the earth's topography through endogenetic and mountain building process may affect climate in two major ways: Change in topography may result in concomitant changes in insolation, airflow, temperature and precipitation. Mountain formation processes may involve the emissions of aerosols and gasses that will affect the composition and chemistry of the atmosphere and the earth (Jorgenson *et al*, 2001).

Changes in Atmospheric Composition and Chemistry

Chemistry here refers to the behaviour of the constituents of the atmosphere. There are theories of possible cause of climate change relating changes in climate to changes in atmospheric constituents and chemistry especially the amount of particulate matter (aerosols). Green house gasses such as carbon dioxide, water vapour and variation in ozone layer. Atmospheric constituents play a vital role in the earth's energy budget through regulating energy exchange between the earth and the sun (Matsui and Pielke Sr., 2006; Knorr, 2009)

Changes in Snow and Ice Cover of the Earth Surface

Snow and ice cover have higher albedo. They reflect a greater percentage of incident solar radiation on them with a concomitant effect on the earth energy and climate. Changes in the past climate have been linked to changes in the geographical extent of snow and ice (cryosphere) over the earth surface (EPA, 2016).

Changes in Vegetal Cover of the Earth

Vegetation has the ability to reduce atmospheric carbon dioxide through respiration which is used in the process of photosynthesis for the manufacture of glucose. The continues removal of vegetal cover obstruct this natural process ensures a higher concentration of carbon dioxide which is a exhibits green house effect. Also, vegetated surfaces have a different albedo compared to bare surfaces, changes in the vegetal cover of the earth means changing amount of energy recipient on the earth (Wolfgang, *et al* 2001).

The Astronomical Causes of Climate Change relate climate change to changes in the earth geometry. The parameters of earth geometry include: eccentricity of the earth surface, obliquity of the plane of ecliptic and the orbital precession. The astronomical theory covering these three parameters was put forward by (Milankovitch, 1941) popularly known as Milankovitch theory.

Changes in the Eccentricity of the Earth Theory

The earth orbit vary from eccentric (elliptical or circular in a pseudo cyclic way) completing the circle in about 92 000 yrs. The amount of solar radiation received by the earth vary with the eccentricity of the earth orbit (E). The larger the value of E, the smaller the amount of annual incident radiation on the earth. The eccentricity of the earth orbit also affect the duration of the season and the variation between the seasons. At the perihelion when the earth is nearest the sun, insolation receipt is 6 percent more than at the aphelion when the earth is farthest away from the sun. The current eccentricity of the earth orbit (E) is 0.017 but varies from 0.000483 to 0.60791 in the last 5 million years resulting to changes in the incident radiation of plus + 0.0142 to – 0.17 from the current value. This means that in about 50 000 years the earth in its orbit will be nearest to the sun in July and not in January as it is at present. Summers in the northern hemisphere may therefore be warmer and winters colder during the next 50 000 years (Blast, 2010).

Changes in the Obliquity in the Planes of Ecliptic

The obliquity of the plane of ecliptic refers to the tilt of the axis of rotation of the earth. It is the angel between the earth’s axis and the plane of ecliptic i.e. the plane in which the bodies of the solar system lies. This tilt varies for about 21½ degrees to 24½ degrees for a period of about 41 000 years. The present obliquity is about 23½ degrees. The seasons result from the fact that the earth is inclined at this angle to its orbit round the sun thus seasonal variations depend upon the degree of obliquity so that the larger the obliquity, the large the range of seasonality. Thus a decrease in the obliquity of the ecliptic would decrease the difference between seasons but increase the distinction of climatic zones. On the other hand an increase in the angle would cause marked seasonal differences but geographical zones would be less distinct or even disappear (Blast, 2010).

Changes in the Precision of the Equinoxes

The precision of the equinoxes refer to the regular change in the time the earth is at a given distance from the sun. The precession of the equinoxes varies with a periodicity of 23 000 years and 19 000 years respectively. Currently the equinoxes occur on 21st march and 23rd September while the solstices occur on 21st June and 21st December. The displacement of the four seasonal points will result to the migration in the seasons along the earth's orbit. This displacement is believed to be caused by the gravitational attraction between the sun, the moon and the earth. The fluctuations in the precession of the equinoxes like those of the obliquity do not only affect the total radiation received by the earth but also affect the spatial variation in the radiation (Scafetta, 2009).

Extraterrestrial Causes of Climate Change include:

Variation in Solar Radiation Amount

There are changes in the amount of solar radiation reaching the earth due to changes in solar output. There are short term, medium term and long term cyclical fluctuations in the amount of solar output. Sunspot cause fluctuations of output with cycles of 11 years ,22 years, 44 years etc. Solar flares also cause short term fluctuations in the nature and amount of solar radiation. Such fluctuations are known to occur in the solar spectrum especially in the ultraviolet range and in the x-ray (cosmic radiation) which increase during the solar flares. Tidal oscillations on the sun raised by planets in their orbits also cause fluctuations in solar output (Carslaw *et al*, 2002; Soon 2005; Scafetta, 2009).

Variation in the Absorption of Solar Radiation Outside the Earth's Atmosphere

Variations in intersteller dust particles cause variations in the amount of solar energy reaching the top of the earth's atmosphere. The more the intersteller dust particles the lesser the energy reaching the earth's environment and vice versa (Shaviv and Veizer, 2003).

3. MATERIALS AND METHODS

3.1 Data

The data used in the study were daily rainfall data ($\geq$ 0.30mm). Daily rainfall data were obtained from 8 synoptic weather stations in the Middle Belt region for a 46-year period (1961 – 2006). The data are acquired at the Nigerian Meteorological Agency Operational Headquarters, Oshodi, Lagos. The 8 synoptic weather stations are selected because of geographical spread and data availability covering the study period (Table 1).

3.2 Classification of daily rainfall intensity

The classification of daily rainfall into six categories namely extremely light, light, moderately light, moderately heavy, heavy and extremely heavy according to the quantitative method of Tarhule, Zakari and Lamb (2009) was used to classify daily rainfall (Table 2). The procedure of classifying daily rainfall intensity using percentiles (Tyubee, 2009) shows that the raw population of daily rainfall events from the eight stations was first extracted for the 46 - year period. The population of rainfall was then ranked in a descending order and the six intensity categories were determined based on percentile thresholds (Table 2).

Table 1. Meteorological stations selected for the study.

Station	Code	Latitude (N)	Longitude (E)	Elevation (m)
Bida	65112	9^o06^1	6^o01^1	142
Ibi	65145	8^o 11^1	9^o45^1	108
Ilorin	65101	8^o29^1	4^o35^1	307
Jos	65134	9^o38^1	8^o52^1	1286
Makurdi	65271	7^o45^1	8^o32^1	92
Minna	65123	9^o37^1	6^o32^1	259
Yola	65167	9^o14^1	12^o28^1	186

Source: Nigerian Meteorological Agency, Lagos (2011)

Table 2. Classification of daily rainfall intensity.

Percentile threshold	Rainfall status
X < 10	Extremely light
10 < x ≤ 20	Light
20 < x ≤ 50	Moderately light
50 < x ≤ 80	Moderately heavy
80 < x ≤ 90	Heavy
X > 90	Extremely heavy

Source: Adapted from Tarhule, et al, (2009)

3.3 Analytical technique

Trend in the series of the six daily rainfall intensity classes is analyzed using Mann Kendall's test statistics (τ). This statistic indicates whether between the beginning and end of the series, there is a monotonic increase or decrease in the values of a time series (Kendall and Stuart, 1961). The statistic is expressed as:

$\tau = [4\sum ni/N (N-1)]-1$ -------------------------------------(1)

Where ni = the number of values larger than the i^{th} value in the series subsequent to its position in the series of N values and N = the number of observations.

The expected value of Mann Kendall's test (ţ) in a random series is zero and its variance (i.e. the square of its standard deviation) is given by:

$$\sqrt{\tau} = (4N+10)/\ [9N\ (N-1)] \text{ ----------------------------------}(2)$$

The ratio of τ to its standard deviation √τ, (i.e. $\gamma/\delta\gamma$ or $\gamma/\sqrt{\delta\gamma^2}$) is an indicator of trend in the data set. If the ratio lies within the limits of +/- 1.96, then, there is no significant trend in the data series at 95% level of confidence.

4. RESULT AND DISCUSSION

Trends in the series of the six daily rainfall intensity categories for the 46-year period in the MBR are presented in figures 2 to 7. For the extremely light daily rainfall intensity category, there is positive and significant trend in central areas of the region (Figure 2). The western and southern parts of the region show positive but insignificant trend. There is a northern small section of the region that indicates a negative significant trend. The eastern section of the Middle Belt indicates an insignificant negative trend. Increasing (decreasing) trend suggests a tendency towards droughty (wetter) conditions.

Trends of light daily rainfall intensity show that the north eastern and central parts of the MB region have a significant negative trend. Conversely, the central western part of the study area experienced a significant positive trend while both the western and eastern flanks of the region show an insignificant positive trend (Figure 3).

The pattern of light daily rainfall intensity shows that while the western parts of the MBR have an increasing trend indicating drier conditions, the eastern parts have a decreasing trend indicating wetter conditions. The spatial pattern of trend in figure 2 is similar to figure 3 because in both figures conditions are increasingly wetter in the east and increasingly drier in the west.

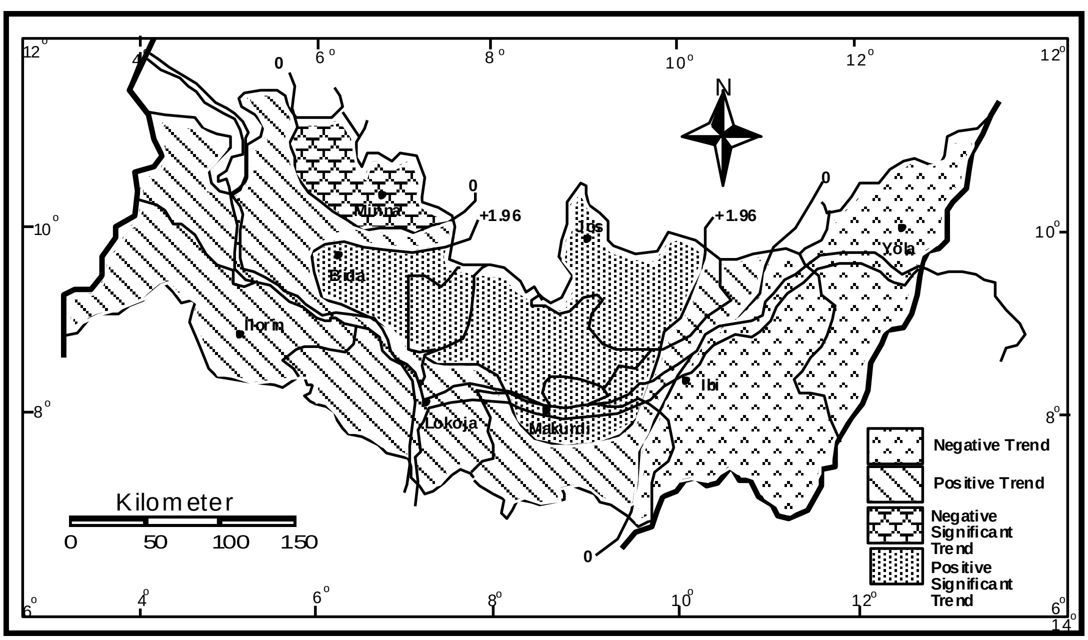

Figure 2: Trend areas of extremely light daily rainfall intensity category in the MBR.

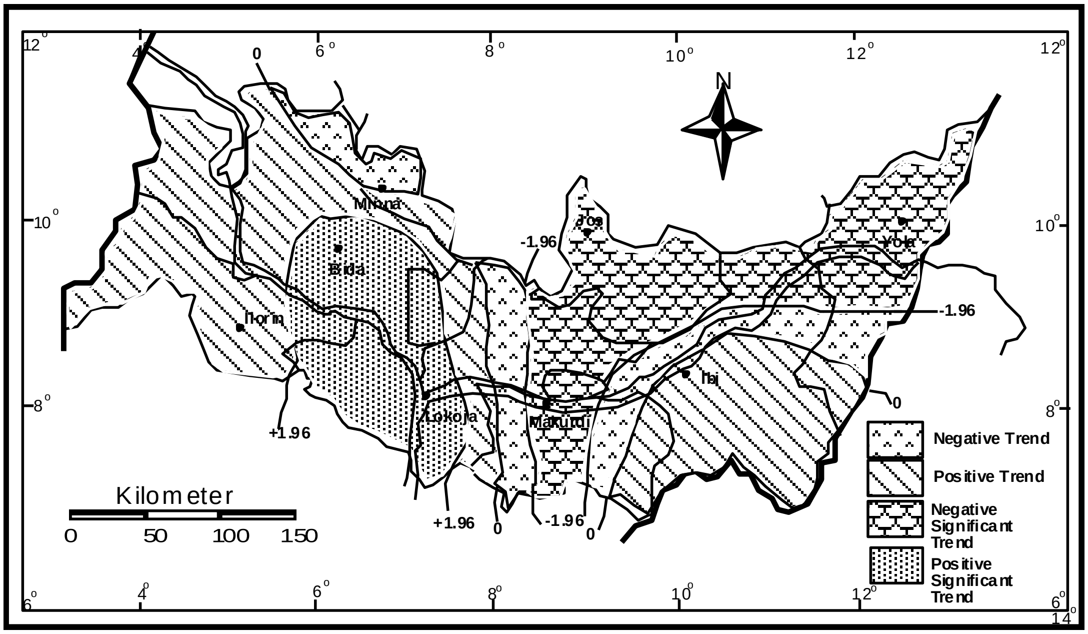

Figure 3:Trend areas of light daily rainfall intensity category in the MBR.

The result of moderately light daily rainfall intensity category in the MBR shows most of the region having significant negative trend. This spans from the west across the centre to the eastern part (Figure 4). The north western section of the region has a negative but insignificant trend while a section of the central south has a positive but insignificant trend.

For moderately heavy daily rainfall events, the spatial pattern of trend in the MBR (Figure 5) shows a vast section of the region spanning from the west to the east having an insignificant negative trend. There is however two section in the central North West and south west having significant negative trends while two other sections south west and central south have insignificant positive trends.

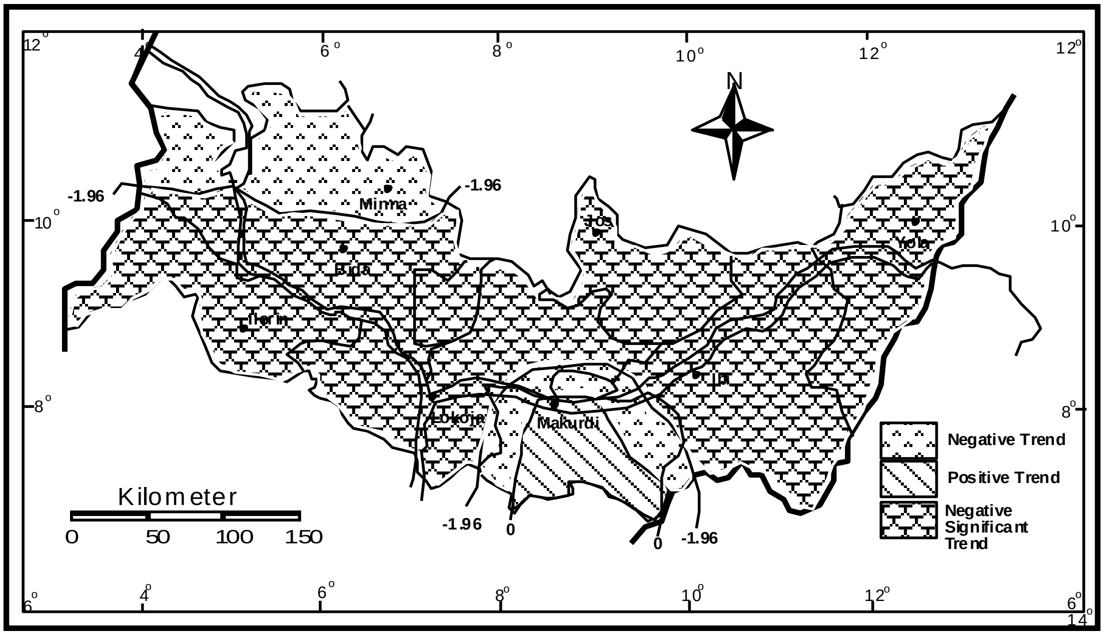

Figure 4:Trend areas of moderately light daily rainfall intensity category in the MBR.

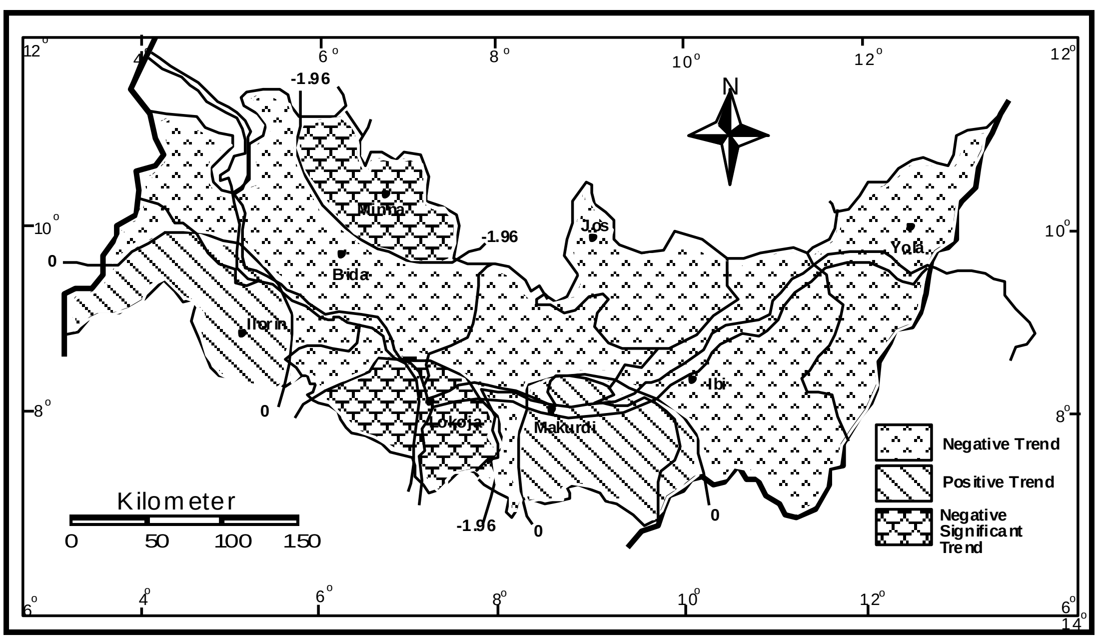

Figure 5:Trend areas of moderately heavy daily rainfall intensity category in the MBR.

The result of heavy daily rainfall in the MBR (Figure 6) shows that the central plateau area has a significant negative trend. Vast areas of the south and west have insignificant negative trend. North eastern section and western north central parts both have positive but insignificant trend. The result suggests that heavy daily events decrease over the Jos plateau. This implies that in highland areas, there is tendency for light daily rains to increase and heavy events to decrease. The warming avail conditions for sporadic light rains in highland areas that are moisture laden.

The spatial patterns of trend in extremely heavy daily rainfall in the MBR (Figure 7) indicate that the central south eastern areas have a significant negative trend while the south central portion has an insignificant positive trend. A large part of the region spanning from the west through the east as well as the entire northern areas of the Middle Belt region have an insignificant negative trend.

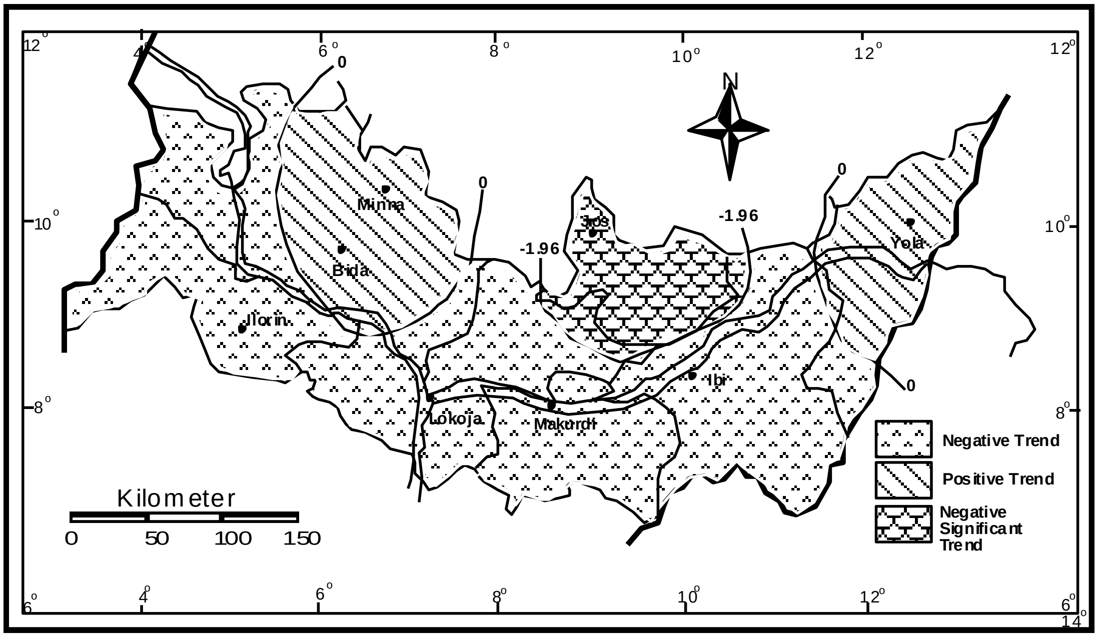

Figure 6:Trend areas of heavy daily rainfall intensity category in the MBR.

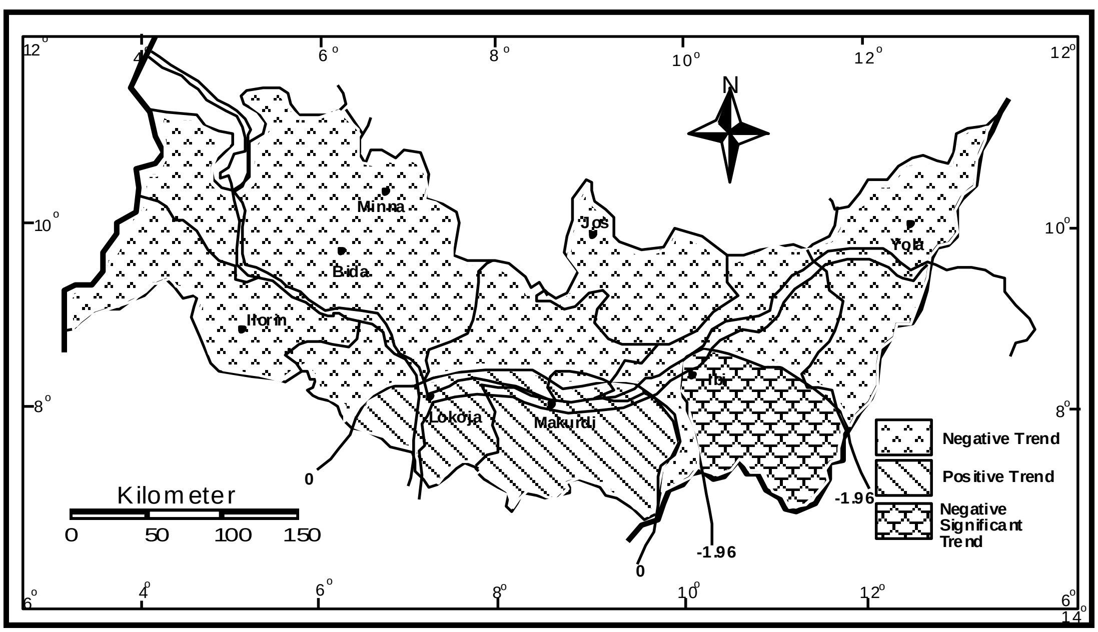

Figure 7:Trend areas of extremely heavy daily rainfall intensity category in the MBR.

The result of spatial variation and patterns of trend in the six daily rainfall intensity categories (Figures 2 – 7) shows orographic effect. Light rains are increasing in the Jos plateau whereas the numbers of heavy rains are on the decline. Elsewhere the pattern is diffused. There is a peculiar situation in Makurdi where both extremely light and extremely heavy intensity conditions are observed to be increasing. This means most of the events are occurring at the extremes.

5 CONCLUSION

The variability of rainfall over time and space is not an uncommon phenomenon globally. The situation is even more pronounced in the tropics. However, the changing pattern in wind movements accompanying global warming and climate change has made local and regional studies more relevant. Current global climatic problems are remarkably complex and despite an increasing intensive research effort, they are even now not completely understood (Oyediran, Kayode and Feyi, 2001). This situation has to be changed for solutions to be found. The Middle Belt Region of Nigeria because of its importance agriculturally and water resources wise due to the prevailing alternating wet and dry climatic conditions within the region needs an understanding on its response to changing global climatic conditions. This study becomes useful in this regard.

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