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Climate Subtleties and Urban Heat Island Effects and Their Adaptability: A Case Study of Lokoja, Nigeria

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Abstract:
This study examines weather patterns and thermal characteristics over a 20-year period. Key findings include changes in land use and cover, with a notable increase in impervious surfaces and a reduction in vegetal cover. Urbanisation plays a role in this transformation. In recent years, the impact of weather on human health, particularly in urban centers, has gained significant attention. The study investigates the degree and coverage of thermal discomfort among residents of Lokoja, Nigeria, focusing on the impact of decreased vegetation cover. Climatic data, including temperature and relative humidity, were sourced from the Nigerian Meteorological Agency (NiMet) archive. Rainfall patterns reveal Lokoja's highest rainfall occurring in September, while the lowest is in October during the dry season. The average monthly temperature shows a peak in April, and the annual temperature reached its highest in 2010. Statistical tools, such as Thom's Discomfort Index and the Humidex Calculator, were employed. Results revealed that thermal discomfort in Lokoja ranged from "noticeable discomfort" to "evident discomfort." Less than 50% of residents experienced thermal discomfort, while other extreme forms (such as "intense" or "dangerous") were not prevalent. The study recommends measures to mitigate thermal discomfort in Lokoja, emphasising the importance of addressing urban heat island effects and promoting green spaces.

Keywords: *Thermal discomfort, urbanisation, Thom's discomfort index*

1. Introductions

The impact of weather on human health, particularly in urban centres, has gained significance due to global warming and the urban heat island effect resulting from urbanisation. Understanding local climate dynamics is crucial for sustainable urban planning. The heating of houses comprises a considerable share of the total energy consumption in many developed countries in temperate and colder climates. While most of the factors affecting space heating depend on individual choices (e.g. inhabitants' behaviour, interior building design, heating system efficiency) that are tough to influence through urban planning, the spatial context of individual housing units is within the sphere of influence of planners. So far, the effect of spatial setting has hitherto received inadequate research attention due to the lack of geospatial data and the massive computer processing required to capture the shape and surroundings of individual housing units (Rafieea, Diasa & Koome, 2019).

Climate change has caused numerous issues in the urban environment. High temperatures, poor air quality, and high gusts can lead to heatstroke, dyspnea, and injury, respectively. Mitigating the urban heat island effect is a significant difficulty for modern cities, particularly in dry and tropical climates. The term "urban heat island" refers to the higher temperatures found in densely populated metropolitan regions compared to neighboring rural areas. The US EPA divides the phenomenon into two categories: surface and air. Surface temperature differences can reach 15°C, while air temperature differences can reach 12°C (EPA, 2008). High temperatures can cause heat stress for occupants and increase energy demands for structures. According to Santamouris et al. (2015), a 1°C increase in air temperature in a metropolitan region can increase electricity consumption by up to 8.5%.

Human bio-meteorological approaches have an important role in applied urban climatology. Several different thermal indices were developed in the last decades to describe human comfort or heat stress of the human body based on the energy fluxes between the body and environment. One of the environmental stress factors on human beings living in urban areas is the effect of partly artificial climate conditions, which are formed mainly by the area's building up. An important task of bio-climatological research is to evaluate the physiological effects of the thermal and radiating environments on human beings because it basically determines the energy balance of the body (Höppe, 1993).

Due to the immense importance of urban areas to human beings, the urban climate should be considered from the point of view of the human organism (Oke, 1987; Matzarakis & Mayer, 1991). The urban climate is formed by the change in land use and land cover from the urbanisation or expansion of urban areas where the road area and building increase; meanwhile, the green area decreases with the changed urban streams. The urban climate is characterised by the heat island by the air temperature increase, the change of wind, visibility, high smog and fog with low humidity (Simpson, Levitt, Grimmond, McPherson and Rowntree, 1994). One of the ecological strain factors on human beings living in the urban area of North Central Nigeria and any other urban centers in the world is the consequence of partly artificial climate conditions, which are shaped mainly by the urbanising areas. A significant chore of bio-climatological studies is to assess thermo-physiologically the thermal and radiating environment of human beings because it determines basically the energy equilibrium of the body (Höppe, 1993).

The physiologically relevant assessment of urban climate and particularly dissimilar urban microclimates, which requires a combination of meteorological elements with personal parameters, creates priceless information for urban planners, helping them boost the well-being of urban inhabitants by preparing suitable and healthy environments (Mayer, 1993; VDI, 1998).

Analysis of the human thermal environment is a subject of special examination among scientists. It focuses on diverse disciplines such as climatology, urban planning, architecture, biology, and physics. A lot of human bioclimatic research has been carried out recently, indicating the impact of urban bio-climate on human morbidity (Schwartz *et al.*, 2004; Nastos & Matzarakis, 2006), mortality, tourism potentials, decision-making, and urban planning. Although a heat/cold wave is a meteorological event, it cannot be assessed without reference to its impacts on humans. An analysis of weather elements should always include the assessment of the human sensation of heat/cold (Baccini, Biggeri & Accetta, 2008).

2. Study Area

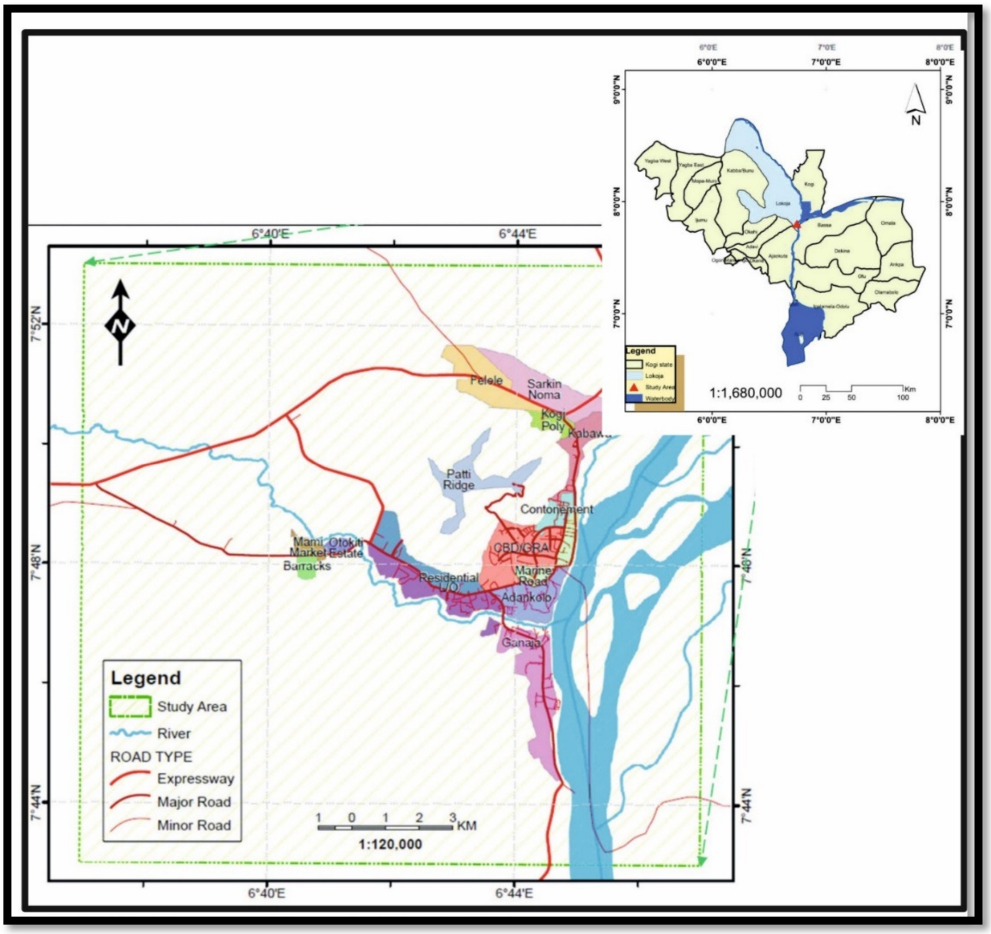

Figure 1: Lokoja, the Study Area
Source: GIS Lab, Department of Geography and Environmental Studies, PAUU

Lokoja is the capital city of Kogi State, located on latitude 7°45'N-7°51'N and longitude 6°41'E-6°45'E and lies at an altitude of 45 to 125 meters above sea level. It is located on the western bank of the River Niger, close to its confluence with River Benue and sandwiched amid the River and Mount Patti. The town connects with strategic roads which serve as a gateway to the northern and southern parts of the country. Being the commercial nerve center of the region, it plays a prominent role in its markets. The town is characterised by a tropical climate that comprises wet and dry seasons and falls within the Guinea Savannah vegetation belt. Lokoja falls within the tropical savannah climate and the Koppen - AW climatic group. There are two main seasons: the wet and dry seasons. The wet season starts from May till October, and the dry season from November till April. The highest temperature of 36.7^0C occurs in March, while the lowest temperature of 30.8^0C occurs in July at the peak of the rainy season. This indicates the hotness throughout the year in Lokoja.

3. Methodology

This study aims to interpret weather patterns, thermal characteristics, and land cover changes in Lokoja over a 20-year period. We investigate climatic conditions (rainfall, air temperature, and humidity) and their implications for thermal discomfort and urban heat islands. This research uses ArcGIS 10.5 and IDRISI Selva to analyse Landsat imagery to get the imprecise changes in land-use/land-cover changes. Copies of the questionnaire administration were used to collect data on the thermal perceptions of Lokoja residents concerning vegetation loss, population increase, thermal discomfort and adaptability, among others.

The regression equation of heat index calculation, according to Rothfusz (1990), is:

$$HI = -42.379 + 2.04901523*T + 10.14333127*RH - .22475541*T*RH - .00683783*T*T - .05481717*RH*RH + .00122874*T*T*RH + .00085282*T*RH*RH - .00000199*T*T*RH*RH$$

Where:

T = ambient dry bulb temperature (°C)

R = relative humidity (integer percentage).

RH is relative humidity in percent.

HI is the heat index expressed as an apparent temperature in degrees.

4. Results and Discussion

In recent years, the impact of weather on human health, predominantly in urban centers, has become a concerning issue of increased significance, especially considering the potential impacts of global warming and an increased urban heat island effect due to urbanisation (Kunst*et al.*, 1993; Kalkstein & Greene, 1997; Guest *et al.*, 1999; Smoyer*et al.*, 2000).

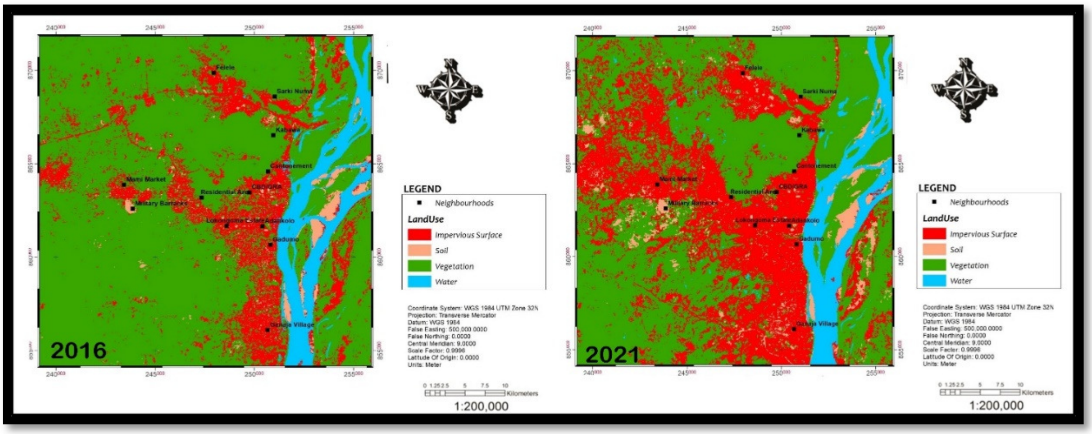

Figure 2: Land Use/Land Cover of 2016 and 2021
Source: Author's Analysis

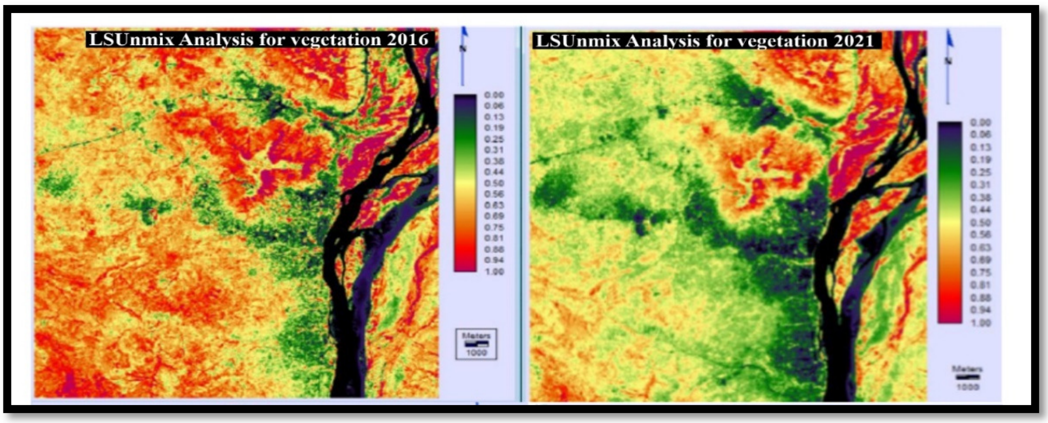

Figure 3: LSUnmix Analysis for Vegetation

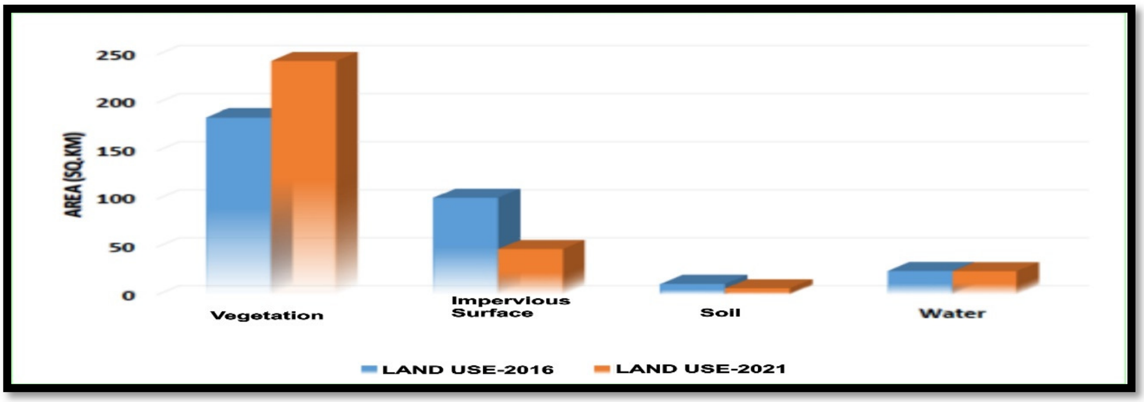

Figure 4: Land Use/Land Cover of 2016 and 2021

The chart and maps of the land cover of Lokoja metropolis clearly show that there is a huge increase in impervious surface with a reduction in vegetal cover. While the latter occupied an area of 234.16sq.km (75.47%) in 2014, it reduced drastically to about 184.681sq.km (57.32%) in 2018, and the former (i.e. impervious surface) increased from 47.63sq.km (14.78%) in 2014 to about 101.20sq.km (31.41%) in 2018. On the other hand, soil and water fractions experienced relatively little change in their area coverages. The area of exposed soils, as noted earlier in the previous section, increased from 6.84sq.km (2.12%) in 2014 to about 11.56sq.km (3.59%) in 2018, which can be attributed to the gradual opening up of new areas in the study area, either for farming or building development. Urbanisation is currently destroying vegetative land cover as it is converted into other cover types, as shown in figures 2, 3, and 4. Meanwhile, areas ranging from 0.50 to 0.63 have been revealed through ground truth observation to be sparse grassland and/or farmlands in some situations and have likewise increased over the time period studied in this study. This conclusion has been reported by a number of authors (Ifatimehin et al., 2009; Ifatimehin et al., 2012; Abubakar, 2013) who have worked in the study region and have submitted their findings.

The study explains and interprets the weather patterns and various categories of thermal characteristics of inhabitants of Lokoja in relation to the climatic conditions such as rainfall, air temperature and humidity of the evaluation and measuring the change in local weather conditions over a period of twenty (20) years in Lokoja, as well as using statistical measures describing the significance of the ideal of people's perspective on Thermal Discomfort and the relationships to urban heat island changes.

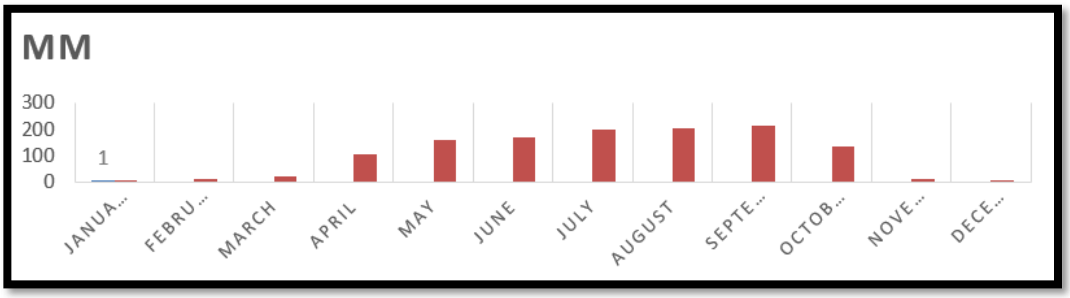

Figure 5: Mean Monthly Rainfall Pattern Lokoja
Source: Author's Analysis

Figure 5 shows that Lokoja recorded the highest rainfall in September. The record also shows a continuous increase in rainfall in ascending order from January 1.1mm to September and a decrease from October 133.5mm when the dry season started approaching.

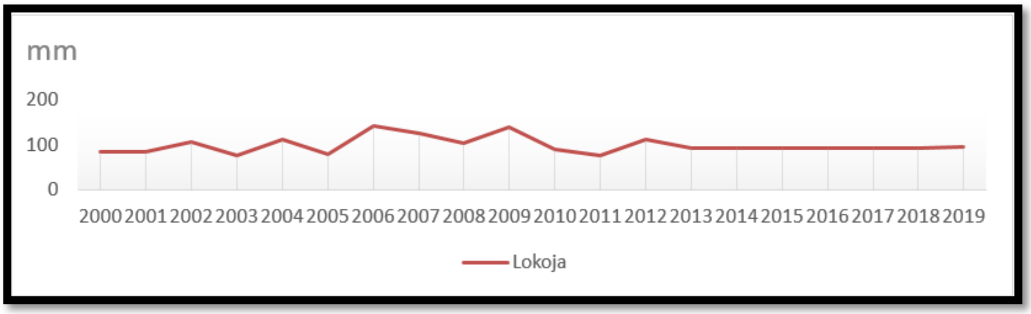

Figure 6: Lokoja Mean Annual Rainfall from 2000 to 2019
Source: Author's Analysis

Lokoja, as shown in figure 6, recorded the highest rainfall in the year 2006 at the rate of 140.3mm and the lowest. Lokoja also recorded the lowest in the year 2003, with 76.9mm. Lokoja had its four highest rainfalls in the years 2006 (140.3mm), 2007 (125.1mm) and, 2009 (137.7mm), 2012 (111.9mm), and it was noticed that the rainfall was above 70mm all through the 20 study years.

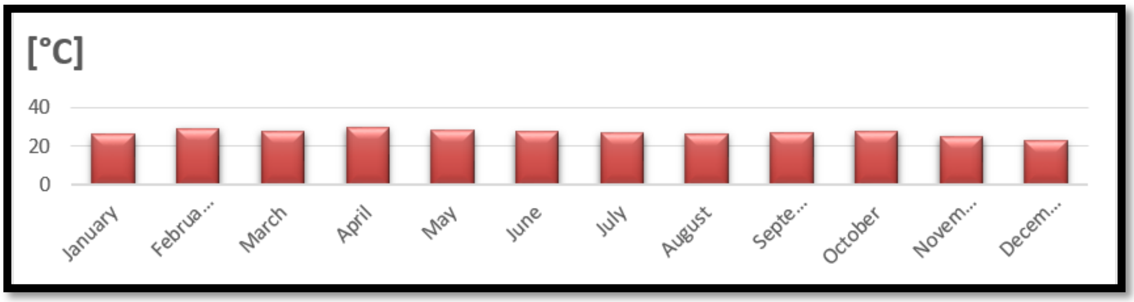

Figure 7: Lokoja Average Monthly Temperature
Source: Author's Analysis

Figure 7 shows the Average Monthly temperature of Lokoja from January to December within the period of Twenty (20) years, 2000 to 2019. The highest temperature recorded in Lokoja was in April at 30.03⁰C. The similarity is that both Lokoja recorded their highest temperature in the month of April.

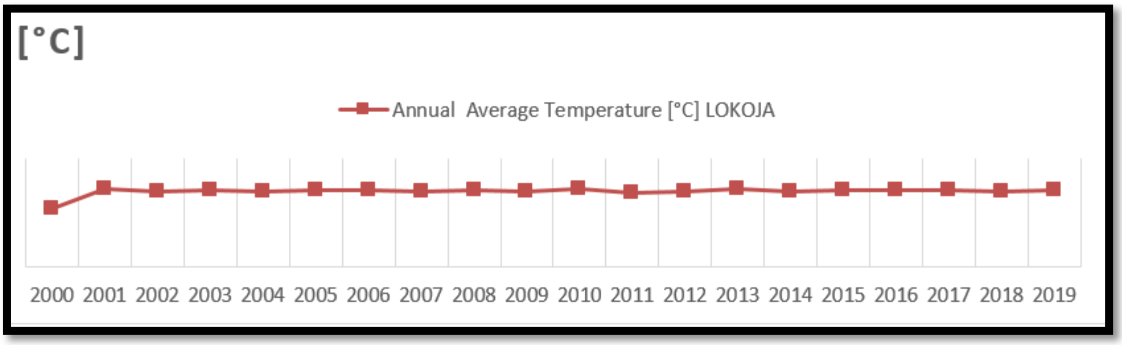

Figure 8: Lokoja Average Annual Temperature
Source: Author's Analysis

Figure 8 shows the average annual temperature of Lokoja for a period of 20 years, from 2000 to 2019. The highest temperature recorded in Lokoja is 28.55⁰C (2010), and the lowest temperature is 21.21⁰C (2000). Lokoja's highest annual temperature was 28.55⁰C in 2010.

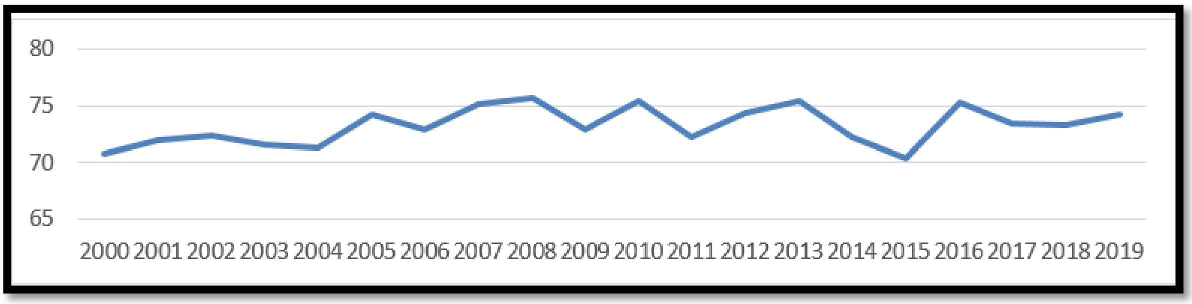

Figure 9: Lokoja Average Annual Pattern of Humidity
Source: Author's Analysis

Figure 9 shows that during the twenty (20) years of study in Lokoja, the highest humidity rate of 80.11 was recorded in 2006, and the lowest humidity rate of 70.38 was recorded in 2015.

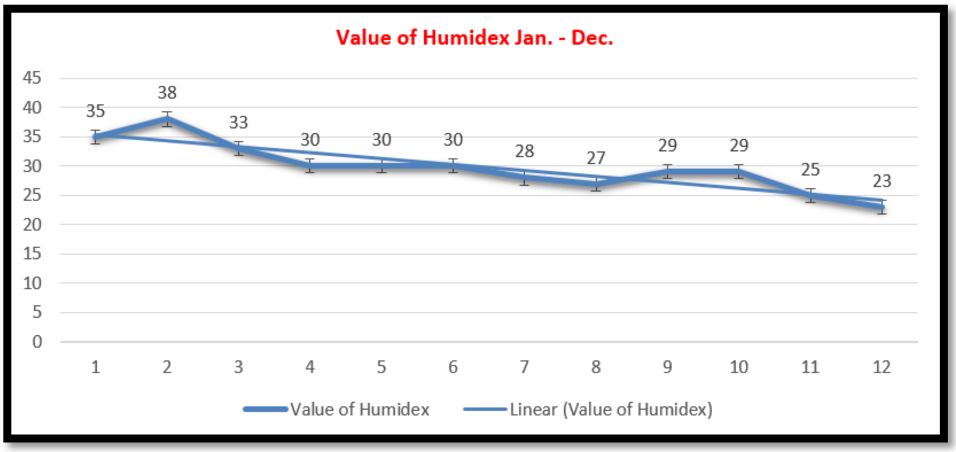

Figure 10: Calculated Average Value of Humidex for Lokoja
Source: Researcher's Field Work

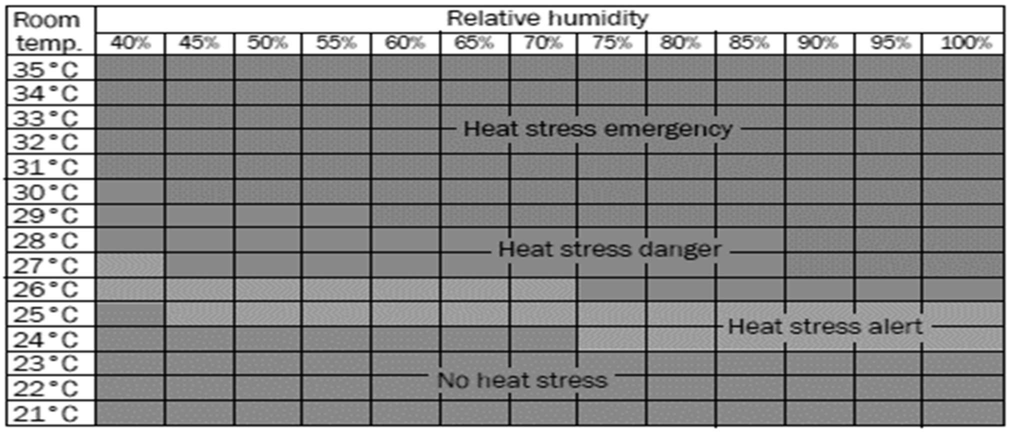

Table 1: The Scale of Humidex and the Degree of Comfort
Source: Adapted from Masterson & Richardson (1979)

The humidity comfort level is based on the dew point, as it determines whether perspiration can evaporate from the skin, thereby cooling the body. Lower dew points feel drier, and higher dew points feel more humid. Unlike temperature, which typically varies significantly between night and day, dew point tends to change more slowly, so while the temperature may drop at night, a muggy day is typically followed by a muggy night.

Perceptions of this environment are affected basically by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing. In January, the humidex value rose to 35 in Lokoja, and some discomfort became obvious and ran through till May at various discomfort values; the month of February recorded the highest value of 38 in Lokoja, which was classified as great discomfort. From the months of June to December, the drop started gradually, fluctuating between 25 to 28 humidex value. From January to May discomfort value was intense.

4.1. Residents' Perception of Decrease in Vegetation Leading to Thermal Discomfort

The studies show that Lokoja over the years has grown, with a population below 40,0000 before it became the state capital, and a population of about 43,784 by 1991, and declared by the 2006 census to house about 82,673 population with inhabitants of about 63.82/Km^2 of its land mass, this increase in population, however, has had a lot of impact on Lokoja which has resulted to increased human activities; clearing of vegetation and increasing area land usage (Ifatimehin & Ufuah, 2008).

A questionnaire administered to the inhabitants of Lokoja revealed their awareness about such increased area usage, which led to the conversion of predominantly thick vegetation areas to built-up areas over time and caused Thermal Discomfort due to rapid population growth and space usage.

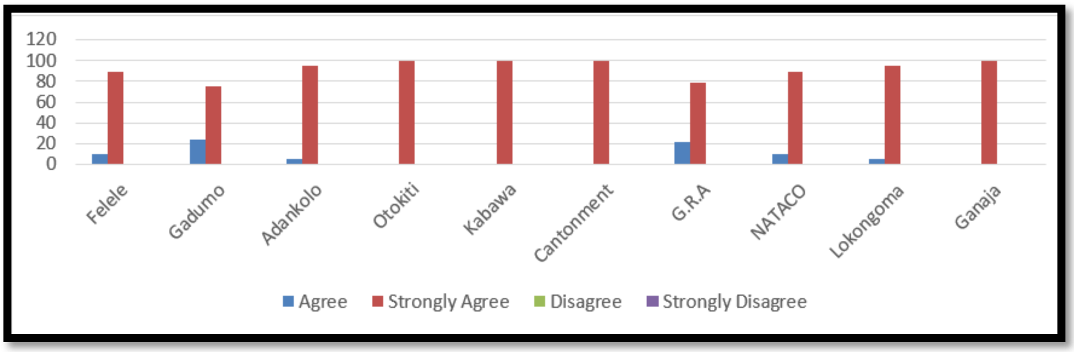

Figure 11: Respondents' Perception of Level of Thermal Discomfort per Area
Source: Author's Analysis

The perception of respondents, as shown in the figure, revealed that urbanisation has brought about an increase in built-up area and a decrease in vegetation distribution. Figures 2 and 3 also confirm this, as vegetation has drastically reduced from 2016 to 2021.

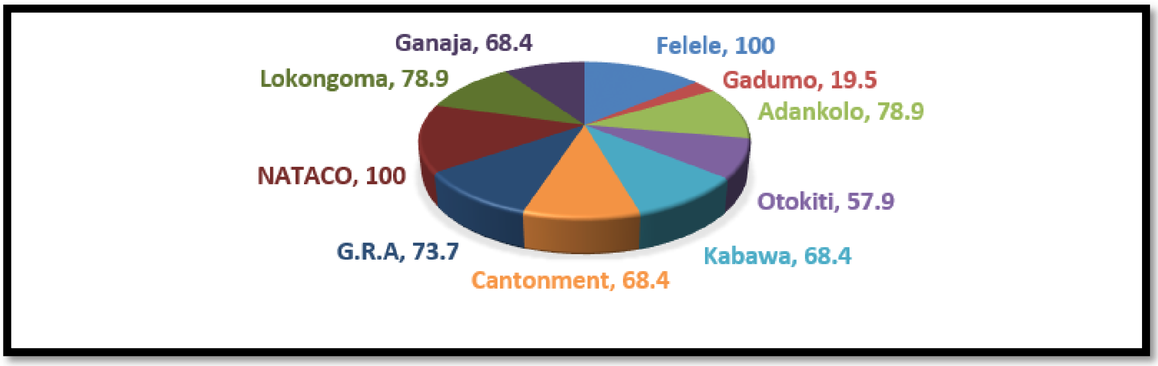

Figure 12: Respondents' Perception of Decrease in Vegetation and Increase in Built Up Area Leading to Thermal Discomfort Per Area
Source: Author's Analysis

As a result of the increased population, built-up area and human activities in the area, it is believed that temperature has also increased, generally and differently, in the individual neighbourhoods, which suggests that there's the effect of urban heat island in the area as a whole. Figures 13 and 14 revealed that the respondents perceive air temperature in Lokoja town to be hot and on the rise in general as a result of an increase in population and a decrease in vegetation distribution.

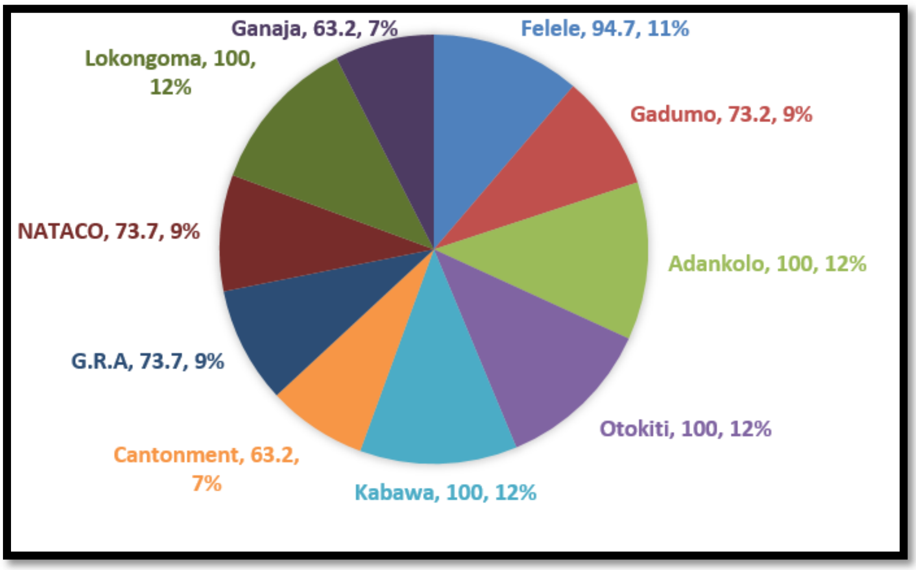

Figure 13: Respondents' Perception of Air Temperature as Hot by Area
Source: Author's Analysis

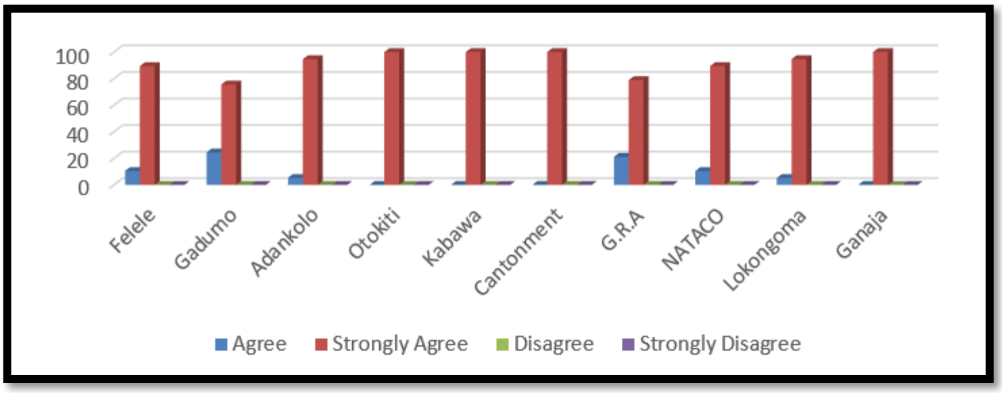

Figure 14: Respondents' Perception of Increase in Temperature Resulting from Increased Population and Decrease in Vegetation per Area
Source: Author's Analysis

From figure 14, it is strongly agreed that air temperature in Lokoja is not perceived as the same at each of the microclimatic scenarios. This, however, suggests that the concept of urban heat islands exists in Lokoja, where temperature degrees vary from one area to the other.

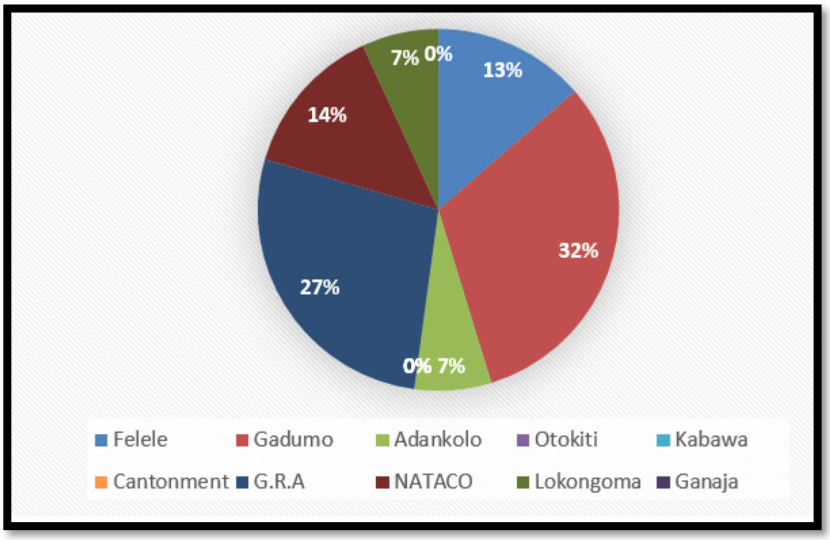

Figure 15: Respondents' Perception of Air Temperature Is Not the Same in Every Lokoja Neighbourhood
Source: Author's Analysis

With the rate and type of outdoor activities in Lokoja, especially in areas like Ganaja junction, NATACO area, Adakolo area as well as areas like Obasanjo Square around Cantonment where major commercial activities take place and which recorded high humidex values, there's the urgent need to assess thermal conditions of the inhabitants as well as other possibly contributing factors that have led to increased thermal perception or heat stress. Figure 16 represents the level at which outdoor activities are engaged in by respondents daily and the position and application of parts of the body in such activities.

4.2. Impact of Urban Heat Stress on Behaviourism of the Inhabitants of Lokoja Town

The urban heat stress in Lokoja was revealed to have a significant influence on certain behaviours of the inhabitants of Lokoja. Heat stress in this fast-growing town has generally influenced the way its occupants dress, particularly when going outdoors, as inhabitants may not want to put on heavy garments due to the perceived harsh weather of the town. A question drawn sought to investigate the clothing habits of inhabitants to find out how hot temperatures have influenced clothing and to register whether or not the clothing habits of the inhabitants have influenced their thermal perception of comfort.

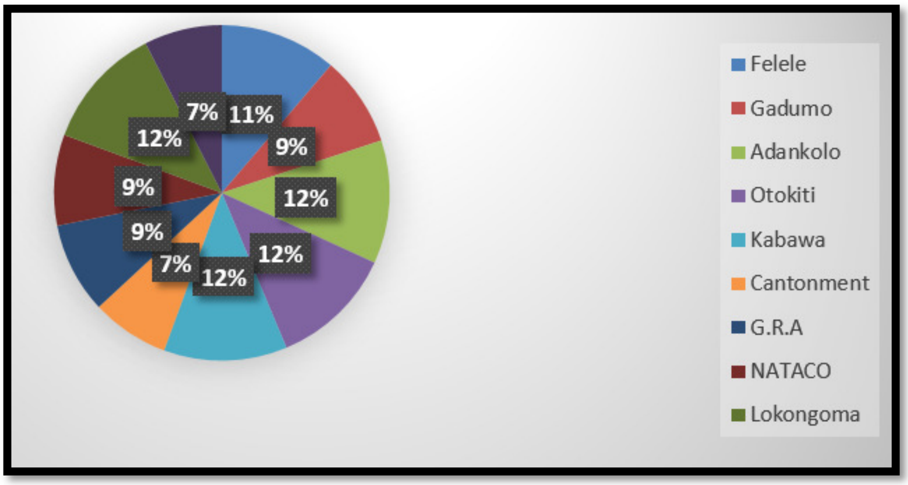

Figure 16: Majority of Inhabitants of Lokoja Put on Light Weight Clothes
Source: Author's analysis

Increased heat stress and exertion influence human water intake. Hot air temperatures and perhaps high humidex values, as seen in the table, coupled with a high rate of metabolism, as indicated, explain the high rate of water intake, as suggested by the respondents.

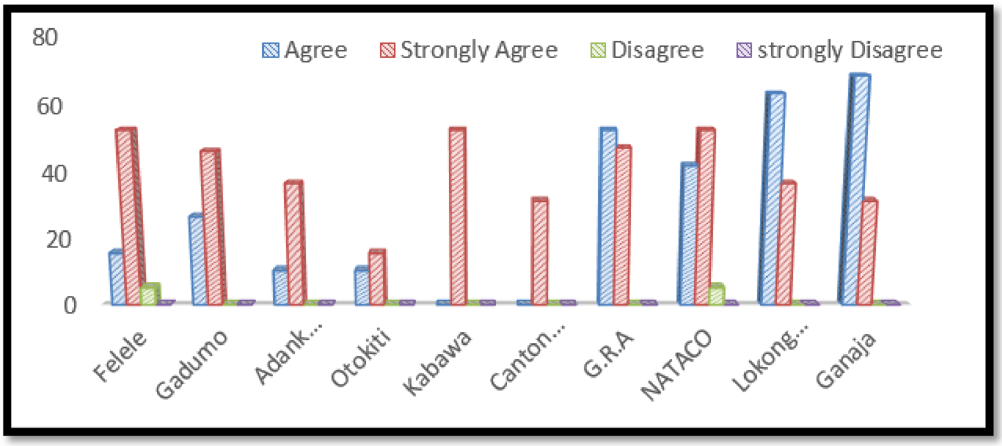

Figure17: Increased Temperature as a Major Source of Heat Stress and Possible Measures to Adopt to Reduce Its Effects
Source: Author's analysis

As revealed in figure 17, certain areas (Kabawa, Cantonment, Adankolo, etc) and their inhabitants recorded high Humidex values, which may have resulted from a number of factors in the area, out of which poor planning, which, in turn, results into the congestion of building and poor ventilation was revealed by respondents to be a contributing factor. Areas such as Kabawa and cantonment, which are highly congested recorded the highest humidex values throughout the months of July, August and September. Whereas poor ventilation increases the concentration of hot and humid air in the atmosphere which may have accounted for the high recorded humidex values of these areas even though Lokoja is perceived to be generally hot.

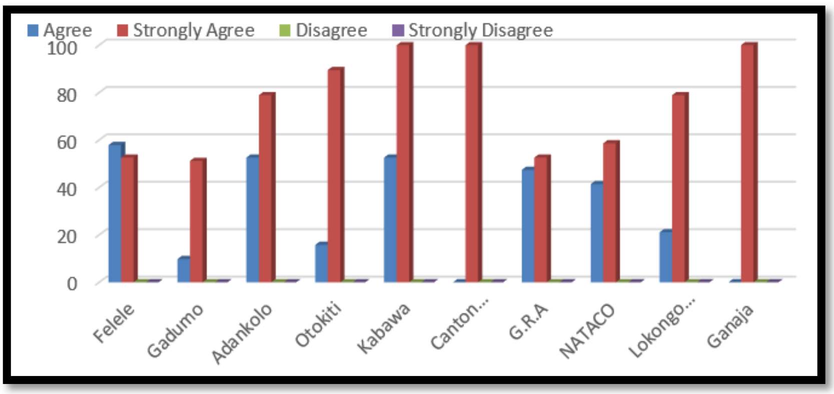

Figure 18: Poor Ventilation from Poor Planning and Congestion
Source: Author's Analysis

Possible measures to be adopted to reduce the induced urban heat stress remain the way out, and as such, the opinion of the inhabitants was sought since they are more familiar with their individual areas. The questionnaire administered suggested possible measures to be adopted to help couple the menace of heat stress in Lokoja.

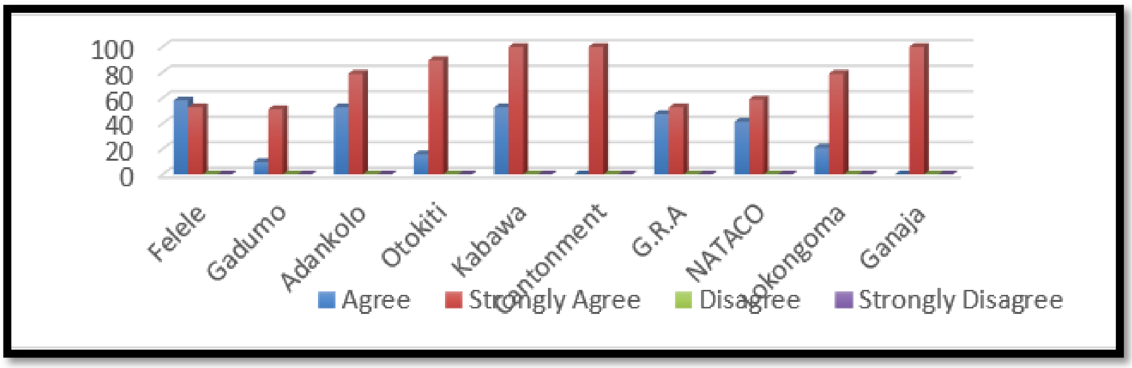

Figure 19: Urban Renewal, Planting of Urban Tress and Creation of Open Spaces Will Improve Thermal Comfort in Lokoja
Source: Author's Analysis

A high proportion of the respondents strongly agreed with adoption of the Urban Green Economy to help discourage emission and encourage reforestation and adoption of usage of energy with minimal impact on the ozone layer.

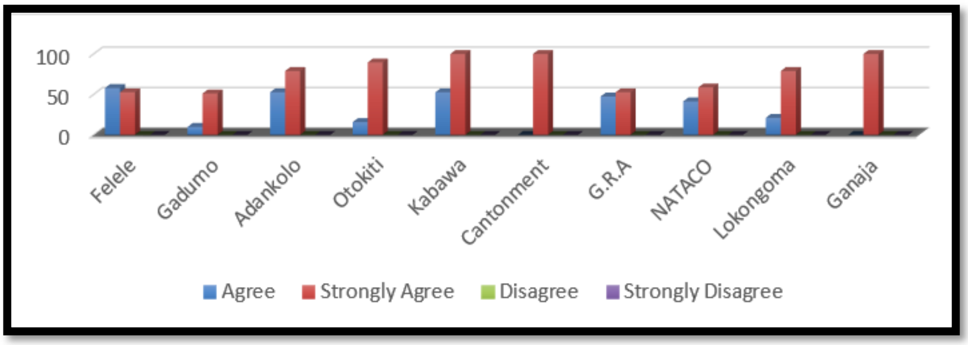

Figure 20: Implementation of the Urban Green Economy
Source: Author's Analysis

This research contributed to the wealth of information already available on climate change by going beyond the context of specific urban case studies and to an understanding of the common ingredients that can help urban centres become better prepared and more resilient to respond to the changes in bio-climate. It extracts ideas and findings from policy and academic writings on the multiple interactions between urban centres and bio-climate change. It provides an overview of the current state of knowledge and practices and looks not only at what is known but also at existing gaps in our knowledge and new directions for work in this area.

5. Conclusion

The land cover analysis reveals significant changes in Lokoja's metropolis. Impervious surfaces increased, while vegetal cover decreased. Soil and water fractions remained relatively stable. Urbanisation plays a role in this transformation, while rainfall patterns show a consistent rise from January to September, followed by a decrease during the dry season. Lokoja experienced varying annual rainfall levels, with peaks in 2006, 2007, 2009, and 2012. Monthly temperature data indicate that April consistently records the highest temperatures. The average annual temperature reached a maximum of 28.55°C in 2010.

Urbanisation has a considerable impact on land cover, resulting in less vegetation and more impermeable surfaces. This shift influences local climatic dynamics, which contributes to the urban heat island effect. Rainfall patterns are critical for determining water availability and flood risk. Monitoring these patterns can help inform long-term water management policies. Temperature fluctuations affect human comfort, energy consumption, and health. Mitigating severe temperatures necessitates environmentally responsible urban development.

6. Recommendations

The following recommendations can be adopted:

- Balance out impermeable surfaces.
- Create green infrastructure such as parks, green roofs, and tree-lined avenues.
- Promote vegetation and sustainable landscaping approaches to improve cooling effects.

- Design for Climate Resilience Implementing heat-resilient urban architecture, such as cool roofs, reflective surfaces, and energy-efficient structures.
- Encourage architecture designs that incorporate passive cooling measures (natural ventilation and shading).
- Increase public awareness and education regarding climate adaptation and the impact of land use changes on local climate.

Local climate changes and variations in Lokoja town have already had a measurable impact on its natural systems, including an increase in Malaria outbreaks (Ifatimehin. 2009), the timing of life cycle events, and especially changes in its forest systems. Engage residents, governments, and companies in sustainable practices. Addressing climate concerns requires a joint effort from researchers, policymakers, and the community. The study provides vital insights toward making Lokoja more climate resilient.

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