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# APPLICATION OF GEO-INFORMATICS IN THE MAPPING OF AREAS VULNERABLE TO SURFACE WATER STRESS IN KADUNA STATE, NIGERIA

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***ABSTRACT***

*The main purpose of this paper is to identify water-stressed areas as a response to land use/land cover (LULC), climate variability, and increasing population in Kaduna State using Remote Sensing and Geographic Information systems. To achieve this aim, the paper set out to identify/map out areas vulnerable to water stress in the study area. The Meteorological data for the study were sourced from twelve remotely sensed stations around Kaduna State for thirty-seven years (1984 to 2021), land use data from remotely sensed satellite imageries that covered thirty-seven years, and projected population for thirty-seven years respectively. There are several indices used to compute water stress and the paper opted for indices that could monitor climate variability and surface water resources. Thereafter, the six indicators were standardized, weighted, and aggregated in Microsoft Excel, and imported into the ArcGIS 10.2.1 environment, and a weightier vulnerability model analysis was used to determine the weights of each variable's contribution to water stress. The result achieved indicated that: 54.41% of the entire study area is vulnerable to water stress, 15.80% is moderately vulnerable, 26.23% is less vulnerable and 3.56% is not vulnerable to water stress within the period under study. Furthermore, Birnin Gwari, Chikun, Igabi, Ikara, and Kajuru Local Government Areas (LGAs) were the most vulnerable areas in the State while not vulnerable areas are; Kauru, Kagarko, and Jaba LGAs. The paper recommends the implementation of water conservation measures which include the creation of wetlands and shelter belts in areas vulnerable to water stress.*

**Keywords:** Vulnerability, GIS, Remote sensing, Climate variability, Water stress

## INTRODUCTION

Water stress is an event that occurs when water demand is greater than supply over a certain period. It is also referred to as the inability to meet human and ecological water needs. Population activities influence water demand, whilst the nature of available water resources, the provision of infrastructure, and the condition of the ecosystem have an impact on water supply (Shiao and Stockholm, 2013). Plant water content, soil moisture, surface, and ground water resources, or climatic conditions are examples of water stress indicators (Maliva and Missimer, 2012; Shiao and Stockholm, 2013). The world is currently facing high levels of water stress, which occur when more than 80% of the water available for agriculture, industries, and domestic use is withdrawn annually (Hofste, Reig, and Schleiter, 2019).

Warmer temperatures, rising sea levels, increased floods and droughts affect the quality and availability of water. There are huge variations in rainfall between Northern and Southern Nigeria, making it all the more important to plan better and manage water resources to minimize the impact of climate change and drought (Merem and Twumasi, 2018; Krueger *et. al*., 2017). According to UNICEF (2017), about 600 million children representing one in every four worldwide will be living in areas where water demand far surpasses supply by 2040. This will result in threats to children's nutrition and wellbeing caused by depleted sources of water and climate change which will intensify these risks in coming years. At the same time, the gap between those areas that have reasonable surface water resources and those without is growing wide. In that light, urban areas experience greater stress than semi-urban and rural areas (Adah, 2013). Even with that, sporadic water shortage not only persists across the State but Nigeria has been projected to face acute water stress by 2020 and 2025 (Ali, 2012). As a result, Nigeria has failed to attain the Millennium Development Goals (MDGs) set a target of 75% for improved water access in 2015 (Bademosi, 2015). This is compounded by the drying of lakes and streams due to droughts and climate change impacts that negatively contribute to agricultural decline and water stress. Kaduna State has endured the dilemma of unsolved problems of inadequate water resources on a recurrent basis in the face of a teeming population, increasing agricultural activities, and rapid urbanization (Ishaku, 2011**).** Also, there is great pressure on available water resources due to the exponential population growth rate. A lot of anthropogenic activities occurred in recent times in the State which contributed to climate change and coupled with massive uncoordinated surface and underground water withdrawals informed the need for spatial distribution of water resources investigation in Kaduna State. Precipitation and temperature are two dominant climatic factors that affect the changes in surface water area (Melillo, Richmond, and Yohe, 2014). Various anthropogenic activities were also found related to the change of surface water bodies, including dam construction (Pekel *et. al*., 2016), water withdrawals for public water supply, agriculture, hydropower production, and settlement (Ochekpe, 2013). Water resource managers in Kaduna State face the challenges of adapting to unprecedented droughts and uncertain impacts of climate change (Taiwo, 2012). The spatial distribution, temporal dynamics, and long-term trends of Kaduna State surface water bodies, if documented in remote-sensing images in the last three decades, can provide valuable information for water resource managers in water planning and coping with drought (Gaupp, Hall, and Dadson, 2015).

Geographical Information Systems (GIS) and Remote Sensing (RS) are widely used tools to monitor and manage water resources. Various researchers have applied them to map water bodies, evaluate water content in vegetation (vegetation water stress), measure soil moisture, and even investigate groundwater availability. Some applications of GIS and Remote Sensing were to develop methods for classifying dry lands to prepare consistent maps identifying water stress regions (Ghosh *et al.* 2013; Klemas and Pieterse 2015). To monitor water stress in vegetation, the Normalized Difference Vegetation Index (NDVI) has been mostly utilized to measure vegetation greenness. Some opted for the use of the Normalized Difference Water Index (NDWI) which measures the quantity of water in vegetation, and recently, the new Normalized Difference Drought Index (NDDI) method that has been created to measure moisture deficiency and is said to be a better method for this purpose (Guimaraes *et al.* 2017; Ghosh *et al.* 2013). Other methods such as the Standardized Precipitation Index (SPI) are designed to use rainfall alone to determine whether an area is under water stress (Hughes and Saunders 2002). Very little has been done in Kaduna State to assess these challenges using the Geo-informatics technique. Without such a geo-based approach, managers can lose sight of locational severity and the tracking of stress factors impeding water resources. The applications of GIS in that setting can pinpoint the threats and practices impacting water resource availability and spatial patterns (Merem *et. al.*, 2017). While much of the challenges emanate from unrestrained urban expansion leading to demands for water resources, negligence of water infrastructure and the resultant decay continue to threaten water quality. The paper focuses on the use of geo-informatics techniques to map out and create a framework for water planning using a scale approach.

**STUDY AREA**

Kaduna State is located between latitudes 9º 02″N and 11º32″ North of the equator and between longitudes 6º15″E and 8º50″E East of the Greenwich meridian in the Northwestern region of Nigeria. Kaduna State is bordered to the North by Katsina, Zamfara, and Kano States, to the West by Niger State, to the East by Bauchi, and to the South by Plateau, Nasarawa, and Federal Capital Territory, Abuja (Yusuf, 2015) respectively (see Figure 1).

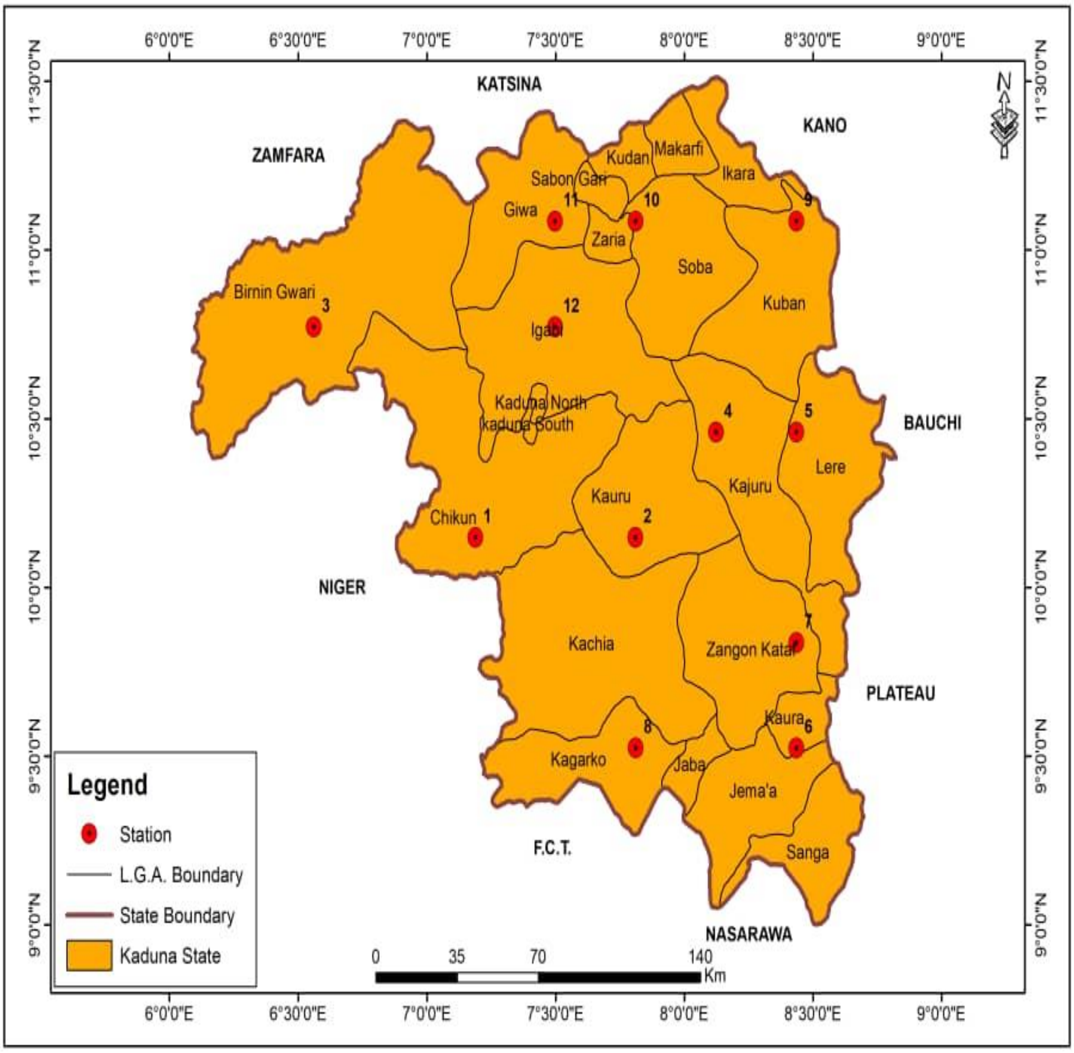


**Figure 1: Map of Kaduna State showing Sampled Areas.**

The climate of the study area can be described as the Sub-Humid type (Nigeria Vision 20:2020, 2009) characterized by tropical wet and dry or savannah climate (Aw). Rainfall is the most important climatic variable and its seasonality and amount are of overriding interest to farmers, pastoralists, and foresters. As both South Maritime and North Continental air masses are dominant for roughly half a year over Kaduna, there are two contrasting seasons. From April or May, the moist south-westerly winds bring rain and both cultivation and tree growth respond immediately. However, from October to April/May, the study area is subjected to cool dry North-easterly wind which yields virtually no rain. This is the period that which irrigation farming mostly takes place (Yusuf, 2015). The variation in the onset of rainfall is attributed to the fluctuations of the boundary between these two air masses. The annual rainfall received in

Kaduna State ranges from 1000 mm to 1270 mm, with a rainy period of 160-180 days. The peak of the rainy season occurred during August (NiMET, 2018).

The combined Temperature and Rainfall of the State show that the mean maximum and minimum temperature experienced in the State increases during the first part of every year to its peak during the hot season in late March and April. At the beginning of the rain, the mean maximum temperature usually falls below 33.0ºC, and subsequently, minimum temperatures are experienced during the rainy season, which remains fairly constant (Yusuf, 2015). Toward the end of the rainy season, the daily maximum temperature rises throughout the little hot season which allows crops to ripe (KDSG, 2018).

Before the establishment of major institutions in Kaduna State that attracted the influx of population, the State had a population of 529,322 people in 1984 most farmers found new opportunities, some went into menial jobs and some others took up security jobs and many women served as cleaners. The population of the State increased substantially in 2019 with about 1,096,706 people with a population growth rate of about 1.28% and many went into different commercial businesses (Kaduna State Bureau of Statistics (KSBS), 2020).

## MATERIALS AND METHODS

The study focused on mapping surface water stress or vulnerability areas due to land use/land cover (LULC) changes, increase in population, and climatic elements such as rainfall, temperature, solar radiation, and relative humidity in Kaduna State. This paper utilized land use data from remotely sensed Satellite imagery that covered 37 years (1984 – 2021). The choice of this period for study is to help detect the change in LULC in the State.

Data for this study were obtained from primary and secondary sources (see Table 1). The primary source data were obtained through ground truthing by taking the coordinates and control points of the study area for geo-referencing purposes using the Global Positioning System (GPS 76SX) which includes latitude and longitude to assist in mapping areas vulnerable to water scarcity. Secondary source data are records taken for thirty-seven years (1984-2021) of temperature, rainfall, relative humidity, and solar radiation, Kaduna State boundary map and hydrological data were also obtained. The climatic data were obtained from NASA (National Aeronautics and Space Administration) through the net, http://power.larc.nasagov/data-access-viewer/. This is because the climatic data were only available till the end of 2021. The Data were collected from twelve (12) remotely sensed stations around Kaduna state (Figure 1).

A Digital Elevation Model (DEM) was developed with ArcGIS 10.2.1 version to identify vulnerable areas in the State. The DEM was reclassified into highly vulnerable, moderate vulnerable, low vulnerable, and non-vulnerable zones using equal intervals of separation based on elevation. Then the vulnerability map of the area was produced. After sharpening, the bands of interest were selected and stacked. The band combination has been regarded as efficient and adequate when using Landsat image data for water vulnerability studies about LULC mostly because it has to do with vegetation, farmland, water bodies, bare surfaces, rock outcrop, and built-up areas (Ojigi, 2010). The image was classified using maximum likelihood classification and defined LULC classes. Post-classification operations including confused matrix using ground truth ROI (a confusion matrix value of 94.2% was achieved for the classification), sieve class clump class, majority/minority analysis, segmentation, and classification to vector were done. The image was then imported to ArcGIS 10.2.1 version where it was vectorized and the area extent of surface water area and other LULC classes were determined after the post-classification operations.

**Table 1: Source of Data Sets**

| S/N | Data Type | Resolution (m)/Scale | Date | Sources |
|---|---|---|---|---|
| | | **Satellite Imageries** | | |
| 1. | Landsat TM imagery | 30m | 25/10/1984 | United States Geological Survey USGS |
| 2. | Landsat TM imagery | 30m | 5/11/1994 | USGS |
| 3. | Landsat TM imagery | 30m | 21/12/2004 | USGS |
| 4. | Landsat ETM imagery | 30m | 12/11/2014 | USGS |
| 5. | Landsat8 imagery | 30m | 12/12/2021 | USGS |
| 6. | Kaduna State Boundary map | 1:50,000 | | NCRS |
| | | **Climatic Parameters** | | |
| 7. | Temperature data | ⁰C | 1984-2021 | National Aeronautics and Space Administration (NASA) |
| 8. | Rainfall/ Precipitation Data | Mm | 1984-2021 | NASA |
| 9. | Relative Humidity Data | Mm | 1984-2021 | NASA |
| 10. | Solar Radiation Data | | 1984-2021 | NASA |
| 11. | Population Figures (Projected to 2021 | | | NPC 2006 |

(**Source: Field Survey, 2023).**

On vulnerability, the surface water stress or vulnerable area boundary was extracted from the DEM which was generated from the digitized contours of the Shuttle Radar Topography Mission (SRTM). Kaduna was also digitized from the administrative map and overlaid on the map of the surface water vulnerable area. Triangular Irregular Networks (TIN) were also generated from the contours extracted from these SRTMs. The study area was thereafter categorized using six indicators where weights were placed on each of them (Eastman, 2006; Aller *et al.*, 1987) and categorized into different target systems, spatial scales, data sources, and frameworks. The six indicators were standardized, weighed, and aggregated. The weightier vulnerability model and Analytical Hierarchy Process (AHP) were used to determine the weights of each variable's contribution to water stress. These weights represent the individual influence of the indicators on the values provided by the composite indicators. Weights are also used to represent the individual influence of the composite indicators on the overall physical vulnerability (index value). The vulnerability index (VI) from the time-series data (having I time steps) was calculated using the ratio in the equation. Indicated negligible vulnerability of the system to external stressors (Climate change/variability VI- deviating from 1(VI>1 or VI<1) indicated a higher vulnerability of the system to external stressors. The wider the deviation from 1, the greater the stress. This was overlaid on the produce vector map to identify and show the spatial vulnerability over the study areas as polygons. This enables the researchers to classify the water resources vulnerable areas in the study area. The level of vulnerability was graded into highly vulnerable, moderately vulnerable, less vulnerable, and not vulnerable.

## RESULTS AND DISCUSSION

The land cover classified is presented in square kilometers and percentages as shown in Table 2. The result indicated that vegetation in 1984 occupied 26516km² which represents 60% of the total land. In 1994 it decreased to 22055km² which accounted for 50% of the total area; in 2004 it further decreased to 20585km² which constituted 47% of the total area while in 2014 it occupied 11874 and it covered 27% of the total area and in 2021 it was lowered up to 9285km² which represents 21% of the total area. This finding is like that of Hammad *et al.* (2018) in the Southern Syria coastal basin where vegetation area decreased from about 64% in 1987 to about

38% in 2017. Gaughan *et al*. (2009) underlined that land use changes in watersheds could be related to these factors, which were triggered by explosive growth in human activities such as tourism, agriculture, mining, and infrastructural development.

**Table 2: Percentage change in Land use/ Land cover of the study area**

| Class Name | Area km² 1984 | Area% (1984) | Area km² 1994 | Area% (1994) | Area km² 2004 | Area% (2004) | Area km² 2014 | Area% (2014) | Area km² 2021 | Area% (2021) |
|---|---|---|---|---|---|---|---|---|---|---|
| Water Body | 57 | 0.13 | 96 | 0.22 | 72 | 0.16 | 158 | 0.36 | 167 | 0.38 |
| Vegetation | 26516 | 60 | 22055 | 50 | 20585 | 47 | 11874 | 27 | 9285 | 21 |
| Built-Up | 1176 | 3 | 1210 | 3 | 2693 | 6 | 3113 | 7 | 3211 | 7 |
| Farmland | 9978 | 23 | 12010 | 27 | 16220 | 37 | 20107 | 45 | 26416 | 60 |
| Bare Land | 225 | 1 | 1535 | 3 | 457 | 1 | 31 | 0 | 268 | 1 |
| Rock Outcrop | 6269 | 12.87 | 7314 | 16.78 | 4193 | 8.84 | 8938 | 20.64 | 4874 | 10.62 |
| **Total** | **44221** | **100** | **44221** | **100** | **44221** | **100** | **44221** | **100** | **44221** | **100** |

**Source: Researcher's Analysis, 2023 classified satellite imageries**

In 1984 the farmland occupied 9978km² which represents 23% of the total land but in 1994 it increased to 12010km² which constituted 27% of the total land area. The progressive significant increase continued to 2004 which occupied 16220km² and accounted for 37% of the total land. Meanwhile, in 2014 it occupied 20107km² which represented 45% of the total land and in 2021 it occupied 26416km² and accounted for 60% of the total land area. It can be said that most of the increase in farmlands took place between 2014- 2021. This is because the demand for land for agricultural uses increased as the population increased which affected other land use types, especially the decrease in vegetation in the study area. The increase in farmland agrees with Idowu and Muazu (2010); Edame *et al*., 2011 it is posited that agricultural land increased by 2.18km² with a percentage change of about 28.17%, they attributed the increase in farmland to the adoption of new agricultural practices which made some un-usable land before 2008 usable due to technological advancement. The increase recorded in the percentage area of farmland conformed to the work of Salami *et al*. (1999), who reported that natural vegetation has largely been replaced by perennial and annual crops in many parts of the study area. The changes in LULC during the 37 years, especially the increase in built-up areas, water bodies, and farmland can be attributed to population growth and settlement expansion, these scenarios culminated in the conversion of natural vegetation to farmland. Other human activities such as fuel-wood extraction, sand mining, and quarrying have all contributed to land use changes which equally contributed to the climate variability in the study area. The result also substantiates the finding of Oyinloye (2013) who asserted that the direct relationship between rapid urban growth, agrarian and factors such as the creation of States, Local Governments, and siting of institutions of learning, commercial centers, industrial centers, tourism resorts, and population influx has a basis of land use changes.

### Vulnerability Analysis of Water Stress Areas

The result from Table 3, shows twenty-three (23) LGAs of Kaduna State vulnerability analysis. The indicators selected for the weightier vulnerability model analysis include temperature, rainfall, relative humidity, solar radiation, projected population, and LULC classes. The vulnerability factors were computed to depict the extent of area cover found to either be highly, moderately, less vulnerable, or not vulnerable at all.

**Table 3: Vulnerability areas of the 23 Local Government Areas (Area in Km$^2$)**

| NAME | Highly Vulnerable | Moderately Vulnerable | Less Vulnerable | Not Vulnerable |
|---|---|---|---|---|
| Birnin Gwari | 5857.23 | 335.77 | 0.00 | 0.00 |
| Chikun | 3603.43 | 991.93 | 49.02 | |
| Giwa | 240.67 | 1512.03 | 324.05 | 0.00 |
| Igabi | 3358.38 | 358.44 | 0.00 | 0.00 |
| Ikara | 855.57 | 0.00 | 0.00 | 0.00 |
| Jaba | 0.00 | 0.00 | 319.67 | 47.55 |
| Jema'a | 0.00 | 0.00 | 1657.49 | 0.00 |
| Kachia | 144.10 | 1060.70 | 3021.89 | 399.41 |
| Kaduna North | 72.48 | 0.00 | 0.00 | 0.00 |
| kaduna South | 59.37 | 0.00 | 0.00 | 0.00 |
| Kagarko | 0.00 | 32.92 | 989.74 | 840.51 |
| Kajuru | 1774.65 | 728.59 | 305.04 | 0.00 |
| Kaura | 0.00 | 0.00 | 484.01 | 0.00 |
| Kauru | 354.05 | 863.18 | 959.75 | 286.75 |
| Kubau | 2510.78 | | 0.00 | 0.00 |
| Kudan | 381.12 | 16.10 | 4.38 | 0.00 |
| Lere | 1710.29 | 446.22 | 0.00 | 0.00 |
| Makarfi | 542.45 | | 0.00 | 0.00 |
| Sabon Gari | 153.62 | 63.65 | 47.55 | 0.00 |
| Sanga | 0.00 | 0.00 | 1251.59 | 0.00 |
| Soba | 2238.61 | 0.00 | 0.00 | 0.00 |
| Zango Kataf | 0.00 | 532.54 | 2132.36 | 0.00 |
| Zaria | 235.54 | 49.02 | 16.82 | 0.00 |
| **Total** | **24092.33** | **6991.08** | **11563.36** | **1574.23** |
| **Percentage%** | **54.41** | **15.80** | **26.23** | **3.56** |

**Source: Researcher's Analysis, 2023**

The result of the analysis in Table (3) and Figure (2) revealed that Birnin Gwari LGA located in the Kaduna Central zone is the most highly vulnerable LGA in the study area with 5857.23km² of the area having water stress and 335.77km² moderately vulnerable with a population density (62 persons per km²) and the majority are engaged in agricultural activities KSBS, (2018). The LGA is therefore classified as highly vulnerable in the State (figure 2). The result may be attributed to high temperature, low rainfall, unabated deforestation going on in the LGA, and land use change which affect intervention in water provision by both Local and State Governments (Bogoma dam) thereby contributing to the vulnerability of the LGA. Chikun is the second most vulnerable LGA with a 3603.43km² area highly vulnerable to water stress, 991.93km² is moderately vulnerable and 49.02km² less vulnerable with a population density (of 93 persons per km²) KSBS, (2018). Igabi LGA is the third most vulnerable area with 3358.38km² of the area highly vulnerable to water scarcity and 358.44km² of the area moderately vulnerable with a population density (of 183 persons per km²) of the area. The finding collaborates with Milly *et al.* (2008) and suggests that the wet areas are projected to become wetter and dry areas drier, thus increasing the vulnerability of agricultural and forest-dependent communities in the State whose livelihoods (or incomes) in many cases are sensitive to water availability. Urban water users may be subjected to higher water expenses and residential users may also be required to conserve water. Population growth in these arid and semi-arid regions could also stress water supplies. The impact is likely to become more severe in urban centers than in rural areas.

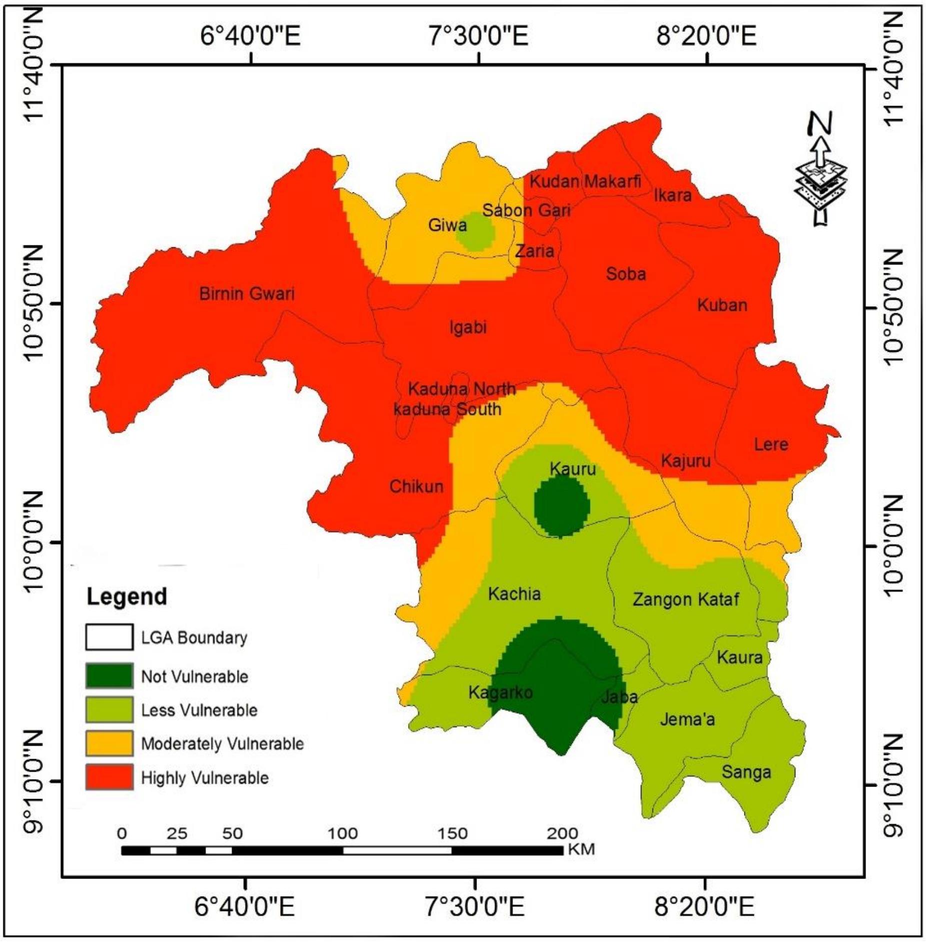


**Figure 2: Map of Vulnerability across the Twenty-three (23) Local Government Areas in Kaduna State**
**Source: Researchers' Analysis, 2023**

Kajuru and Lere LGAs are located at the central zone of the study area and are the fourth most highly vulnerable areas with 1774.65km² and 1710.29km² respectively but 446.22km² moderately vulnerable in Lere LGA. Both LGAs have population densities (66 and 197 persons per km²) respectively.

The result shows that Ikara LGA located at the extreme northern part of the study area is the fifth highly vulnerable area with 855.57km² and population density (180 persons per km²). It is assumed that the higher the population density of an area, the higher the vulnerability to water stress and vice-versa. The socioeconomic characteristics of the people have significantly influenced the level of vulnerability in water resources. Most communities earn their living through farming, logging, fuel wood production, and livestock pasturing. The Sudano-Sahelian zone has been reported to be advancing which is responsible for the loss of vegetation species, arable land, and water stress.

Kubau and Soba LGAs are located in the extreme north-eastern part of the northern zone of the State and sixth most highly vulnerable areas with 2510.76km² and 2238.61km² respectively, with a population density (183, 202 persons per km² for both Kubau and Soba). But Kubau LGA has 728.59km² moderately vulnerable and 305.04km² less vulnerable to water stress as a result of climate variability and change in LULC of the area.

Similarly, Makarfi and Kudan are located in the extreme northern part of the study area which is equally highly vulnerable with 542.45km² and 381.12km² respectively. Both have a population density of (420 and 542 persons per km²). It is attributed to locations in arid or semiarid areas that are affected by droughts and climatic variability, combined with rapid population growth and economic development. In Kudan 16.10km² of the area is moderately vulnerable and 4.38km² is less vulnerable to water stress. This can be attributed to the water retention reservoir (Hunkuyi multipurpose Dam) in the area that increases water availability.

Kauru LGA is located in Kaduna central zone with about 354.05km² of area highly vulnerable, 863.18km² moderately vulnerable, 959.75km² less vulnerable to water stress and about 286.75km² of the total land area in Kauru not vulnerable to water crisis with a population density of (121 persons per km²). The non-vulnerability of water in Kauru is attributed to the water supply from the upper course of river Kaduna.

Giwa LGA is located in the northern part of the study area with 240.67km² of the area highly vulnerable, 1512.03km² of the area moderately vulnerable and 324.05km² of the area less vulnerable. Giwa has a population density of (214 persons per km²).

Zaria and Sabon Gari LGAs are located in the northern part of the study area with 235.54 km² and 153.62km² of the area respectively, highly vulnerable. 49.02km² and 63.65km² are moderately vulnerable areas in the two LGAs and 16.82km² and 47.55km² are areas less vulnerable in the areas. Both Zaria and Sabon Gari LGAs have a high population density of (1568 and 1690 persons per km²). The demand for water to meet the needs of this high population density and water retention in the form of water reservoirs has increased in Zaria and Sabon Gari with the constructions of Kubani Dam, Galma Dam, and Zaria water expansion work to meet the water needs of the areas. The results collaborate with the findings of Farley *et al*. (2011), who point out that vulnerability to climate variability in the water sector may vary by location and the amount of water used, in the vulnerability map of Kaduna State (Figure 2) urbanized areas are more vulnerable to water stress. In addition, they point out that demographic growth exacerbates the impact of climate variability in water supply sectors. It has been pointed out by many studies such as (SanchezGoni and Harrison, 2010; Milly *et al.*, 2005; Evans, 2008) that the joint effect of climate variability and population growth will profoundly affect the availability and quality of water resources in any area.

The Kaduna North and Kaduna South LGAs are located in the Kaduna Central zone and constitute the Kaduna metropolis with high vulnerability of 72.48km² and 59.37km² respectively. Both LGAs have a population density of (6795 and 9098 persons per km²). Despite the effort of the Kaduna State Government in the expansion of Kangimi Dam for water supply to the metropolis, river Kaduna and its tributaries still have water scarcity and some areas within the metropolis are vulnerable to extreme weather events which in tandem with the finding of Ati *et al*, 2007; Abaje *et al*, 2015, which asserted that increase in rainfall totals may pose a significant danger to areas that are prone to flooding as reservoirs could easily overflow leading to loss of lives and properties.

Kachia is located in the southern zone of Kaduna state and is the only LGA with high vulnerability to water stress in the zone. About 144.10km² of the area is highly vulnerable, 1060.70km² is moderately vulnerable, 3021.89km² is less vulnerable and 399.41km² is not vulnerable to water crisis. The LGA has the highest population density in the southern zone of the State with (671 persons per km²) KSBS (2018), but on the other hand, the moderately vulnerable LGAs are Zangon Kataf and Kagarko LGAs with about 532.54km² and 32.92km² of areas respectively. In Zangon kataf about 2132.36km² of the area is less vulnerable while in Kagarko, 989.74km² of the area is less vulnerable and 840.51km² is not vulnerable. Both LGAs have a population density of (187 and 142 persons per km²).

Meanwhile, less vulnerable LGAs are Sanga with a 1251.59km² population density is (161 persons per km²), Kaura with 484.01km² and a population of (418 persons per km²), and Jama'a with 1657.49km ² with a population density is (236 persons per km²) and Jaba with 319.67km² and population density of (414 persons per km²) are less vulnerable to water stress. The result is attributable to high rainfall and the presence of the Gurara dam in the area which resulted in less vulnerability observed. The result is in tandem with the finding of Van Dam (1999) and vulnerability analysis of water scarcity in the State. Whereby areas located within Kaduna's central catchment area such as Chikun, Igabi, and Birnin aware Kaduna North and South indicated a high level of vulnerability to water scarcity, followed by areas located within the Galma catchment areas like Giwa, Ikara, Kudan, Sabon gari, Zaria, Lere and Maikafi and least vulnerable catchment area to water scarcity is Mada catchment area like Sanga, Kaura, Kagarko, Jaba, Jama'a and Zango Kataf. Similarly, the results from the LULC changes in (Table 2) are aligned with Salihu *et al*., (2019) findings, which attributed the water stress in the sudano-sahelian ecological zones to vegetation depletion. However, the Salihu *et al*., (2019), assertion seem to be more believable, but the changes observed are only variations. However, once the vegetation is depleted like in the case of Kaduna State, the local atmosphere is further influenced by increased dust loads. Most modeling efforts led to the conclusion that increased mineral aerosol loads will cool the surface, warm the lower atmosphere, stabilize the atmosphere, and reduce local rainfall which affects surface water availability (Moulin *et al.,* 1997).

The result of the finding is in tandem with the works of Abaje *et. al*, 2014; Abaje *et. al*., 2018, which posited that rainfall in Kaduna State is unevenly distributed as well as water. It also approves the finding of trend analysis which asserted that rainfall decreases from the southern part to the northern part and revealed that the southern part of the State has the highest rate of increase in annual rainfall and water, followed by the northern part, and the least is the central part which includes Kaduna metropolis. The progressive built-up areas in Kaduna Central and the impermeability of the landscape can also have an indirect effect on the hydrological regime. Impermeable surfaces are introduced into the landscape, affecting the natural infiltration of water in the environment which supported the finding of Jandova, *et. al*. (2020), who posited that apart from the construction of roads, the development of cities currently has the greatest impact on the built-up areas where urban development causes multiple water loses. As urban sprawl rises, space for unaffected infiltration and retention is increasingly limited.

Vulnerability impacts of climatic parameters, population, and LULC changes on water availability and quality are likely to threaten sustainability and increase the risk for social and ecological systems. Climate rise would accelerate rainfall and result in faster and earlier runoff. Bare land and rock outcrop areas especially in built-up environments with such runoff would be particularly vulnerable to increased flooding. Generally, flood frequencies are most likely to increase in the higher latitudes and pave surfaces (Urban areas) where the largest increase in rainfall is a primary determinant of runoff, in coastal areas and increased storm surges (Kelkar *et al.,* 2008). In addition, the water sector is exposed to extreme events such as droughts and floods. According to IPCC (2014) reduced rainfall, evapotranspiration as a result of a decrease in vegetation, and more frequent dry spells can bring forth higher frequency and greater intensity of droughts in some areas. Lal *et al.* (2011) point out that, possible limitation on water supply by projected temperature increase in the region becomes more serious if the rain is reduced substantially. They also pointed out that, as regional and seasonal rainfall patterns change due to changes in LULC and rainfall becomes more concentrated in heavy events coupled with paved surfaces and plowing of land for agricultural purposes, floods are going to be more frequent and intense.

The vulnerability of the water sector has been regarded as an extremely sensitive sector to climate variability (Salihu *et al*, 2019). As water availability becomes increasingly stressed with anthropogenic activities, the ability to absorb these stresses coupled with new realities and potential future surprises becomes critical (Engle and Lemos, 2010). Globally, the potential impact of climate variability on water resources has been the subject of analysis for over a decade, and there is evidence that freshwater resources are vulnerable globally (Farley, Tague, and Grant, 2011).

With the positive increase in built-up land and farmland in the study area, adaptive measures to cope with hydrologic fluctuations require the costs of building and managing infrastructure to provide more even and reliable flows. Furthermore, the probability of facing droughts and water stress in Kaduna central and Galma catchment areas and floods remains non-negligible despite the sizeable investments to control flood waters and increase available supplies of water in the areas. Given the infrastructure of towns, climate variability could alter both the frequency and magnitude of large floods.

## CONCLUSION AND RECOMMENDATIONS

Water stress occurs due to excessive abstraction that cannot be balanced by the climate. However, with a good water exploitation monitoring system, and enough weather stations, Kaduna State Water Board (KSWB) should be able to identify specific areas within their jurisdiction exposed to water stress. This will help to implement proactive measures to both save and efficiently distribute water. GIS and Remote Sensing have proven to be vital tools available to KSWB to contribute to these water resource management strategies. The large amount of available water during the rainy season; and crop varieties that can withstand much water should be planted in areas of high rainfall, and government policies related to agriculture and water resources development should be based on the increase in rainfall and water resources trends in Kaduna State. The paper recommended the implementation of water conservation measures which include the creation of wetlands and shelter belts in areas vulnerable to water stress and Remote Sensing and GIS techniques for use in monitoring and management of water stress areas for better water allocation policies in the State.

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