Bima Journal of Science and Technology, Vol. 9(2B) Jul, 2025 ISSN: 2536-6041

E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292

Analysis of the Impact of Climatic Element Variability on Surface Water Degradation in Komadugu Yobe Basin, Nigeria

Babagana Boso[1]* and Ibrahim Abubakar Audu [2]

[1]Department of Geography and Environmental Management, Yobe State University, Damaturu, Nigeria

[2]Department of Environmental and Resources Management, Usmanu Danfodiyo University, Sokoto, Sokoto State.

Corresponding Author: bosobabagana@ysu.edu.ng

ABSTRACT

This study intended to analyses the impact of climatic variability on surface water degradation in Komadugu Yobe Basin, Nigeria. Its aim to examine the water resources degradation of the basin and its aerial extent. Satellite images were officially sourced and downloaded from the United State Geological Survey website. The images were Landsat generated. Image processing and analysis was done under the supervision of GIS laboratory technician. Image interpretation, classification and overlay was done by GIS expert. Images with digital data was constructed with relevant design and presented in form of maps and tables which reflected land cover changes. Surface water which occupies about 3790.545km^2 representing 18% of the total area of the Komadugu Yobe Basin in 1972 was reduced to 584.002km^2 representing a paltry of 3.2% of the total area in 2017. Findings from Key Informant Interview indicated that about 66.5% of the basin communities are farmers engaged in different crop production. Though farming is the dominant economic activity, Fishing and Livestock rearing are the second and third major economic activities in the basin. Climatic variability, particularly, irregular rainfall, declining surface water mainly due to upstream dam construction and climate change are key factors responsible for the surface water degradation. The findings from the study also revealed that decline in surface water and rainfall have resulted in declining food production due to low crop yield, herders and fishermen migration due to none availability of pasture and low fish catch, hence food insecurity at the community level with over 75% of the household became food insecure. The study further reveals that surface water degradation has negative impact on food security of the basin communities. It is recommended that dam re-optimization, awareness creation on water conservation techniques and sustainable agricultural practice, river training (desilting and typha grass clearance in the river bed to improve flow of water for livelihood activities) of the basin would go a long way in addressing water resources degradation of the basin.

Keywords: Climatic element; Variability; Surface Water; Degradation; Yobe Basin.

INTRODUCTION

Freshwater resources across the globe are facing unprecedented pressure. Factors such as rapid population growth, expanding economic activities, decreasing rainfall, and recurring droughts have intensified competition and conflict over this limited resource. Moreover, social inequality, economic exclusion, and the absence of effective poverty reduction programs force impoverished communities to exploit land and forest resources unsustainably, which in turn harms water sources. Inadequate pollution control mechanisms further contribute to the degradation of freshwater systems (Integrated Water Resources Management, 2014). Over the 20th century, the global population has tripled, and currently, around one-third of the world's population lives in regions with moderate to high water stress. At the same time, global water withdrawals have increased sevenfold. This situation is expected to worsen, with two-thirds of the global population projected to face similar water stress levels by 2025 (UNESCO, 2013). Projections suggest that the world will need to feed an additional 2 to 3 billion people within the next 25 years. This poses a significant challenge, as water is becoming a major constraint on food production. Irrigated agriculture already accounts for over 70% of total water withdrawals, which amounts to 90% of the water actually consumed (UNEP/UN-HABITAT, 2010). Even with a modest forecast of 15–20% more irrigation water being needed, serious tensions may arise among competing water users including agriculture, human consumption, and ecological needs. The situation could become more severe if water-scarce nations aim for complete food self-sufficiency instead of relying on food trade essentially importing "virtual water" from water-rich areas (UNEP/UN-HABITAT, 2010).

Nigeria is divided into eight hydrological zones based on its surface water distribution. Major river systems like the Niger and Benue Rivers and their numerous tributaries, along with Lake Chad and Oguta Lake, dominate these regions (Goldface, 2008). Other significant rivers in Nigeria's hydrological landscape include the Gongola, Hadejia, Jama'are, Yobe, Komadugu-Gana, Kaduna, and Zamfara in the north, and the Ogun, Osun, Imo, Cross, and Anambra Rivers in the south. The Komadugu Yobe River falls within Hydrological Area VIII. In Nigeria, water resources have been significantly depleted, largely due to dam construction. This has created complex water transfer cycles both upstream and downstream, as well as between rural and urban regions. Land degradation in upstream catchments mainly driven by poor farmers cultivating marginal lands has led to increased sediment and nutrient loading, thereby reducing both the quality and quantity of downstream water (Sabiths et al., 2024). This issue is particularly evident in the Komadugu Yobe River Basin.

The Komadugu Yobe Basin (KYB) spans over 148,000 square kilometers and supports over 28 million people across six Nigerian states: Plateau, Bauchi, Kano, Jigawa, Yobe, and Borno, based on 2020 census projections. Rapid population growth directly impacts the water availability in the basin. Since the 1940s, the Sahel region has witnessed a 3% annual population increase, leading to significant expansion of cultivated land (Seguin et al., 2004). More than 15 million people in the basin rely directly or indirectly on its water for agriculture, livestock, and fishing. The floodplains of the Komadugu Yobe are especially important for the region's economy and food supply, offering high yields of rice, vegetables, and other crops such as millet, sorghum, and wheat, while also supporting fishing and pastoral livelihoods.

This region represents a densely populated area within a dry climate zone, where the 15 million residents are increasingly reliant on limited water supplies. Between the 1960s and early 1980s, the basin was one of Nigeria's major food-producing areas, supplying large quantities of food and fish to local and southern Nigerian markets. The region also contains two important pastoral corridors—the Hadejia-Nguru Wetlands and the Lake Chad basin—from which livestock are regularly transported to major southern urban centers (HJKYB Trust Fund, 2019). However, surface water in the Komadugu Yobe Basin has deteriorated due to declining rainfall, climate change, and overuse of water without effective conservation. This has negatively impacted the

Bima Journal of Science and Technology, Vol. 9(2B) Jul, 2025 ISSN: 2536-6041

E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292

livelihoods of people in the basin, deepening poverty as water-dependent activities like farming and fishing become less viable (World Resources Institute, 2023). It is against this serious water resources degradation condition that this study was attempted. It is aim to Analyse the Impact of Climatic Variability on Surface Water Degradation in Komadugu Yobe Basin, Yobe State, Nigeria.

MATERIALS AND METHODS

Location of the Study Area

The Komadugu Yobe Basin (KYB) is located between latitude 10° 13’ 12.81” N and 13° 46’ 48.47” N and longitude 07° 49’ 17.83” E and 14° 39’ 25.43” E. The Komadugu Yobe Basin covers a total area of about 148,000 km^2 in northern Nigeria (95% of basin area) and south east Niger (5%) see figure 1. The basin is drained by two main river sub-systems. The first sub-system, the Yobe River, is formed by the Hadejia and Jama’are tributaries, which create the Hadejia Nguru Floodplain at their juncture. The second sub-system is the Komadugu Gana (or Misau) River. Historically, it is a tributary of the Yobe River. The hydrological boundaries of the basin traverse the states of Plateau, Bauchi, Kano, Jigawa, Yobe and Borno States respectively (Hadejia, 2016).

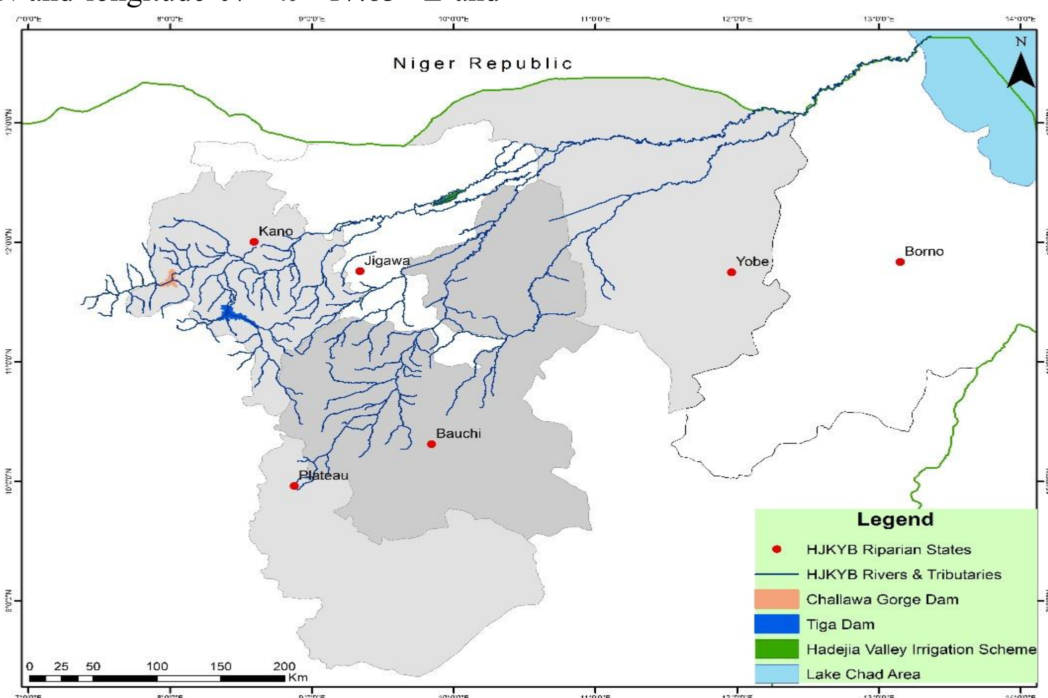


Figure 1: Map of Komadugu Yobe River Basin.

Source: Enhanced from Muhammad et al (2006)

Data Collection Method

The research is a multi-disciplinary one, which uses both descriptive and analytical approach of environmental studies. Data collected includes data from remote sensing and ground truth data, climatic data particularly rainfall, temperature and river discharge.

Data Collection

The data for this study were obtained from primary and secondary sources.

Primary data: The Key Informant Interview involved seven people namely; the heads of upland and irrigation farmers, the head of fishermen, head of herders group, head of women farmers group, community and religious leaders. The rationale behind the interview is to elucidates information that was not captured in the community survey questionnaire such as observe changes in the livelihood activities of the basin community, negative impact of dam construction on the livelihoods of the community, when the community faces food shortages, the period the community begin to experience decline in crop production, period the community face food shortages among others. All the participants were met and interviewed face to face in their respective domains.

Secondary data: The data on land cover was obtained from remote sensing images. The data was obtained in collaboration with Geographic Information System (GIS) laboratory of the Department of Geography and Environmental Management, Yobe State University. Two (2) images were officially sourced and downloaded from United State Geological Survey website (https://earthexplorer.usgs.gov/) for 1970 and 2017. The images were Landsat generated. Image processing and analysis was done under the supervision of GIS technician. Image interpretation, classification and overlay was done by GIS expert. Two images with digital data was constructed with relevant design and presented in form of maps and tables which reflected land cover.

Landsat images covering the period 1972 and 2017 were specifically selected from those available based on quality. Two different epochs (1972 and 2017) were selected. These images were also selected to provide image capture dates out of growing seasons (rainy seasons) so as to remove seasonal effects (Table 1). As seasonal plants/crop field could potentially affect the quality of the image classification. The main temporal period selected for examination was April, and December period. Therefore, all the above dates for acquiring the imageries fall outside the growing season (rainy seasons) of the study region. The study region experiences dry season's period from late October to late May (Naibbi et al, 2014).

Resampled Resolution

Rainfall, temperature and river discharge data were also collected from Nigerian Meteorological Service Agency (NiMet) field offices in Nguru and Potiskum towns Water Resources Engineering and Construction Agency (WRECA), Kano, and Hadejia, Jama'are Komadugu Yobe Basin Trust Fund (HJKYB-TF) Damaturu respectively. Data on rainfall, temperature and river discharge pattern and trend were presented in form of line graph using excel. Other secondary data were also collected through consulting relevant books; records from River Basin Development Authorities (RBDAs), and ministries of Environment, Water Resources and Agriculture of the riparian States as well as water resources based Non-Governmental Organization, Komadugu Yobe Basin Wetlands Development Initiatives (KYB-WDI) Hadejia, Jigawa State.

Data Analysis

Satellite imageries for the year 1972 and 2017 was obtained, classified and interpreted to determine the aerial extent of water resources degradation of the basin. Geographic Information System (GIS) was also employed to digitize the satellite imageries of the basin for classification and results were presented in form of GIS maps and tables. Time series and trend analysis were also used to determine temperature, rainfall amount and river discharge in the study area.

Bima Journal of Science and Technology, Vol. 9(2B) Jul, 2025 ISSN: 2536-6041
E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292

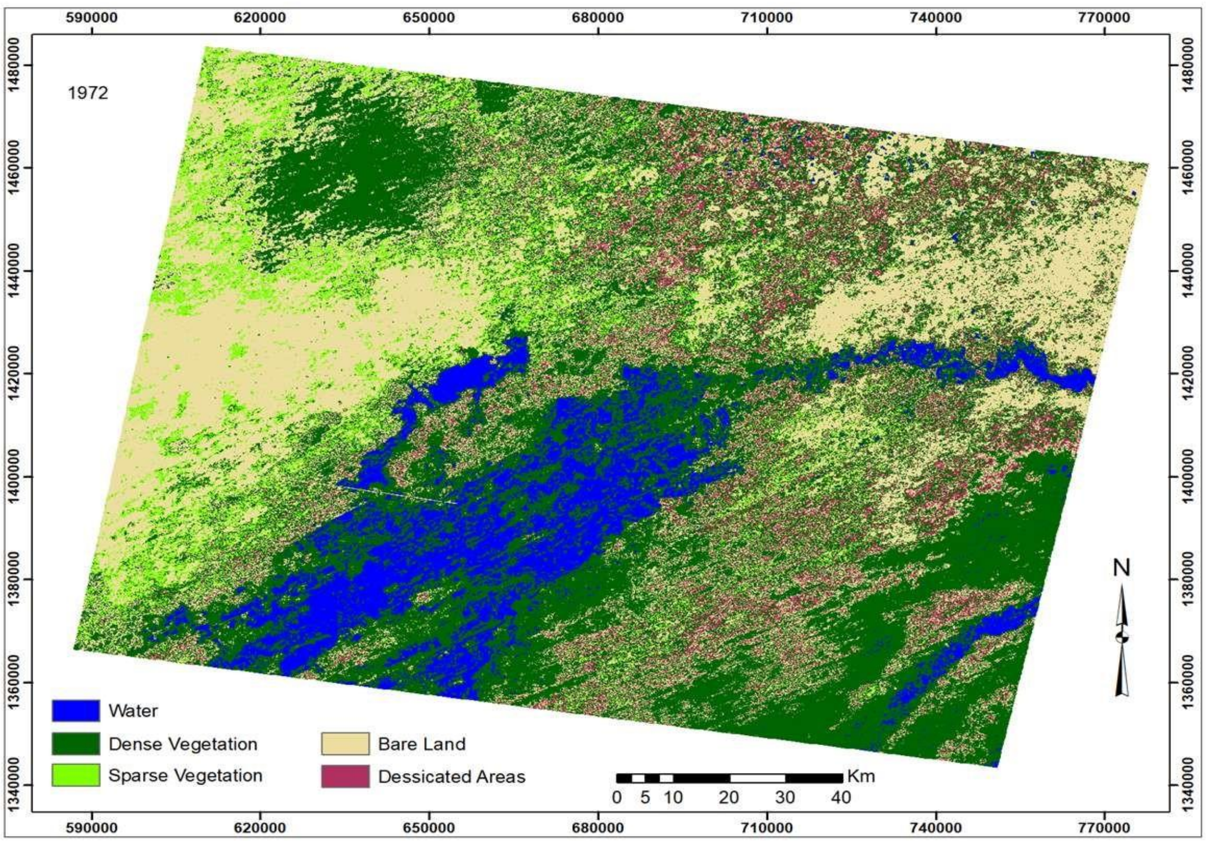
Table 1: The Characteristics of the Satellite Imageries Used in the Study

Datasets	Acquisition date	Path	Row	Bands	Resolution (m)
Landsat - MSS 1	1972/11/04	201	51	1-4	60(30)*
Landsat -7 (ETM+7)	2017-10-16	187	51	1-8	30

RESULTS AND DISCUSSION

Land Cover (LC) in 1972

The land cover changes of the basin in table 1 indicates that water occupies about 18% of the basin area. While, 11.4%, of the area is desiccated area as at 1972. Map of the spatial distribution of the basin LC of 1972 confirmed that.

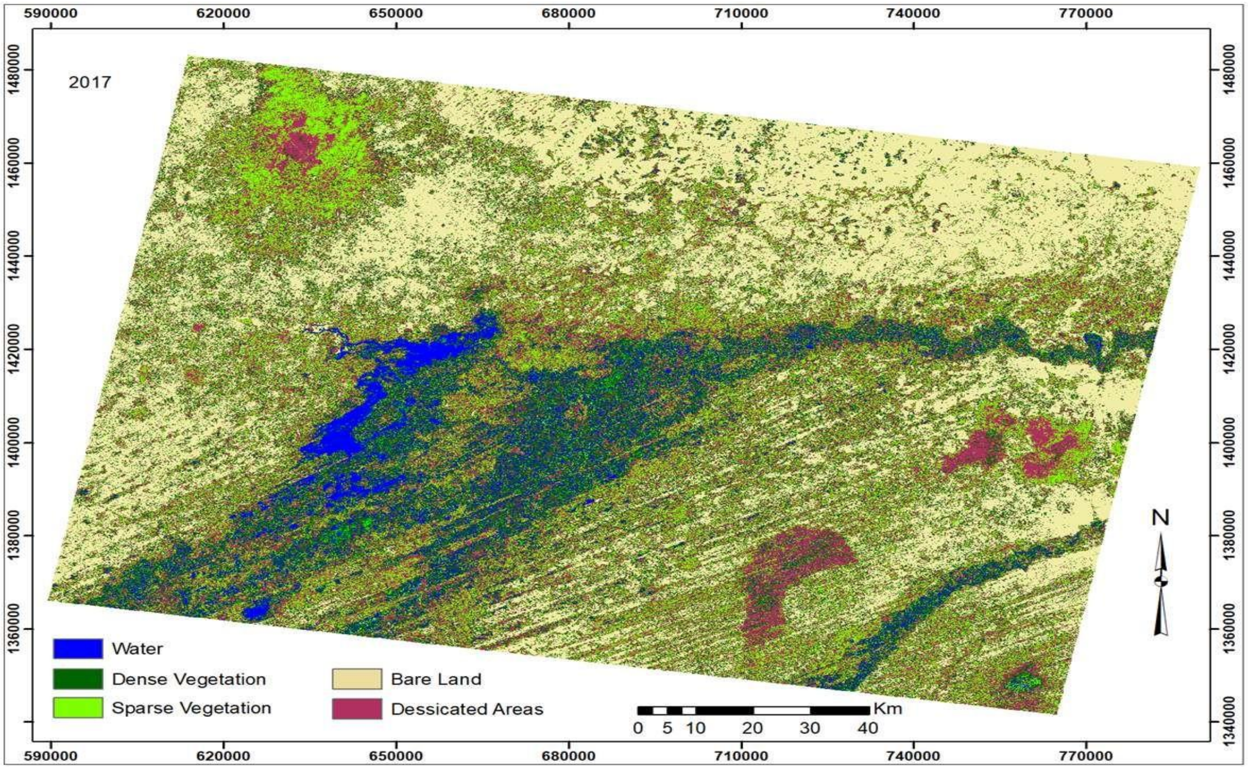


Map of Basin Land Cover in 1972; Source: United State Geological Survey (https://earthexplorer.usgs.gov).

Land Use Land Cover in 2017

In 2017, there is a further reduction of surface water to 3.2% compare to what was obtainable in the year 1972 which was 18%. While desiccated areas increased from 11.2% in 1972 to 29% in 2017. The year 2017 LULC map of the basin reflected the changes.

E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292



Map of Basin Land Cover in 2017; Source: United State Geological Survey (https://earthexplorer.usgs.gov).

Table 1: Area and Percentage of Land Cover Classes for the Period 1972 and 2017.

Land cover type	Area in KM^2 (1972)	Area (%)	Area in KM^2 (2017)	Area (%)
Water	3790.55	18	584.002	3.2
Desiccated	937.639	4.4	5467.15	29

Table 2: Change Magnitude of Land Cover Classes for 1972 and 2017.

Land Cover Class	1972 (Km^2)	2017 (Km^2)
Water	-363.2	-2104.43
Desiccated areas	1626.57	3175.44

Table 2 shows change magnitude of the basin surface water resources from 1972 to 2017. The surface water resource decreased to -2104.43 square kilometer in 1972 to -363.2 square kilometer in 2017. While desiccated area of the basin is 1626.57 square kilometer in 1972 but reduced to 3175.44 in 2017.

Table 3: Trends of the LULC in 1972 and 2017.

Land Cover Class	1972	2017
Water	-38.42	-23.17
Desiccated Areas	46.45	40.92

Bima Journal of Science and Technology, Vol. 9(2B) Jul, 2025 ISSN: 2536-6041
E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292

Table 3 shows trends of the land use land cover of the basin from 1972-2017. Surface water indicated a serious downward trend of -38.42% in 1972 which decreased to -23.17% in 2017. While desiccated areas shows a downward trend from 46.45 to 40.92% in 2017 respectively.

Table 4: Annual Rate of Change of the LC in 1972 and 2017.

Land Cover Class	1972-1986 (14)	2000-2017 (17)
Water	-5.37	-3.93
Desiccated Areas	6.5	6.95

The annual change rate of the basin natural resources as presented in table 4 above shows a dramatic change in the surface water resources of the basin had occurred between the period 1972 and 2017. Within that period, surface water of the basin declined by -5.37% but an increase was recorded in 2017 where the surface water grew to -3.93%. Again, desiccated areas of the basin increased from 6.5% of the basin area in 1972 to 6.95% in 2017.

Climatic Elements Pattern and Trend in the Study Area

Temperature

The distribution of yearly average temperature as shown in figure 2 of Komadugu Yobe River was obtained from Nigerian Meteorological Agency (Nimet) reflects homogeneity in the average annual temperature with some slight rise and fall in some years within the same period (1980-2017). Annual average low temperature was experienced in 1992 and 2014.

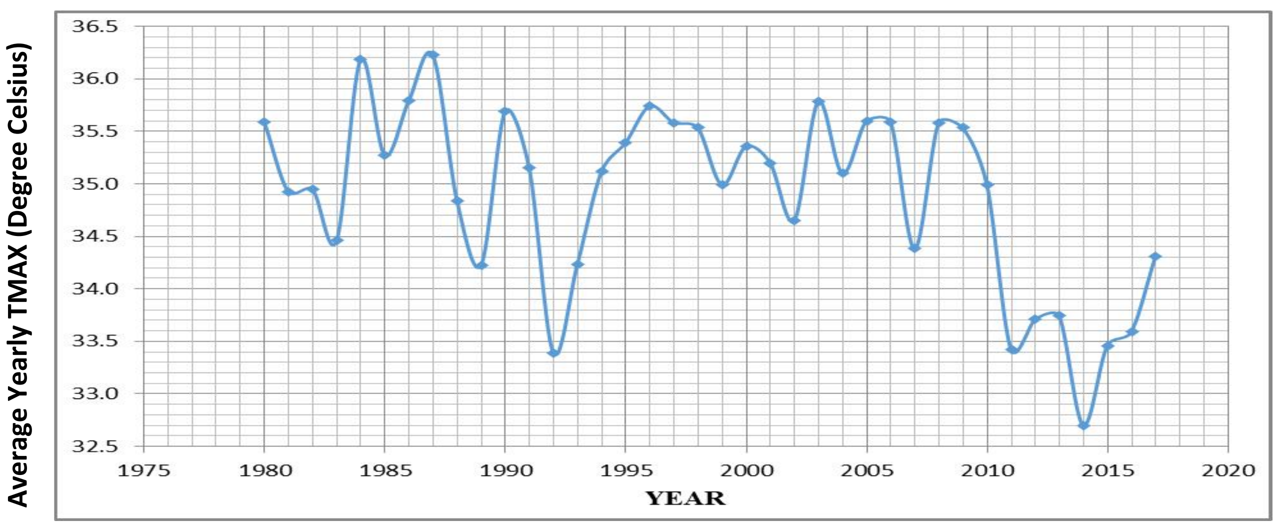


Figure 2: Yearly average Temperature of the basin from 1980-2017. Source: NiMet 2018.

Annual Rainfall of the Basin

The Komadugu Yobe River Basin rainfall regimes from 1970-2017 indicated that the actual rainfall from 1970, 1974, 1975, and 1979 is beyond normal, so also 1997, 2012, 2015, 2016, and 2017 respectively. The deviation of rainfall from normal is observed to have occurred from 1972 up to 2014.

Bima Journal of Science and Technology, Vol. 9(2B) Jul, 2025 ISSN: 2536-6041

E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292

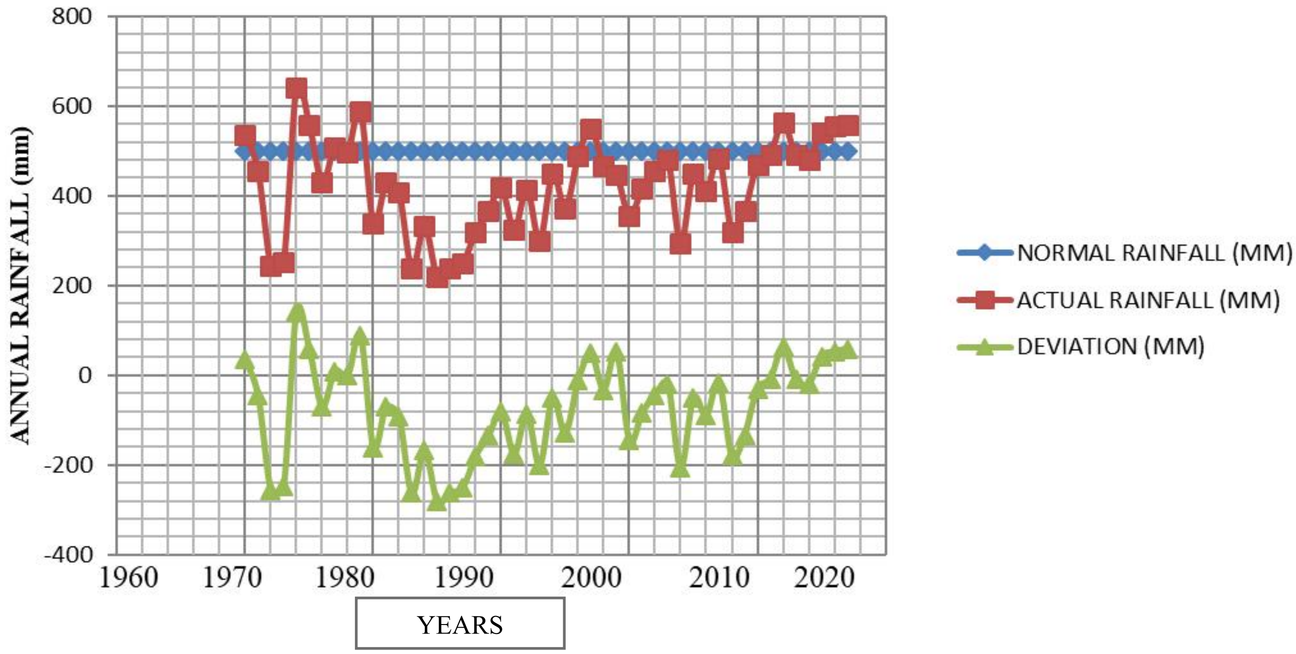


Figure 3: Deviation of rainfall from normal (1970-2017) in the Basin, **Source: NiMet, 2018.**

Rivers Discharge Pattern

Figure 4 shows that precipitation patterns mostly dictate the hydrological regime of rivers in the Komadugu Yobe basin. Between 2008-2017, there is progressive decrease in the annual rainfall and river discharge pattern in the basin. Except in the year 2009 and 2011 were high river discharge was recorded. The satellite image of the basin is in agreement with the decade decline in rainfall of the basin as shown in the 2017 land cover (LC) image of the basin.

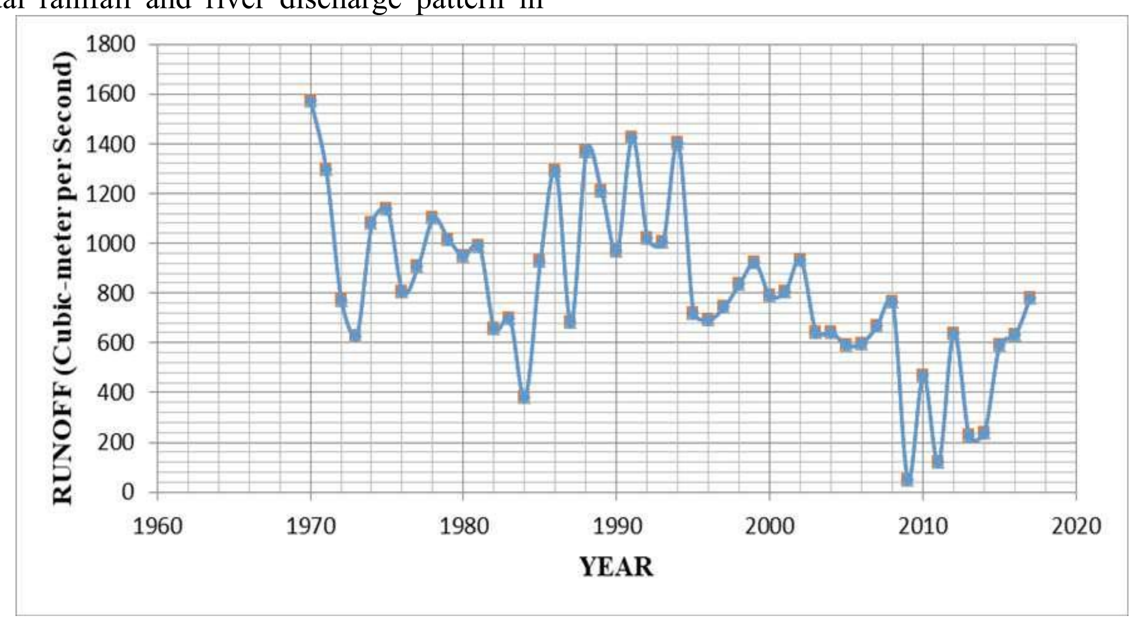


Figure 4: Yearly runoff in the Yobe river at Gashua bridge, 1970-2017, Source: WRECA, 2018.

Mean Annual Run-off in the Yobe River Basin

The pattern of river discharge over the basin reflects the balance between rainfall and losses due to evaporation and infiltration. The highest rainfall occurs in the upper reaches of both the Hadejia and Jama'are sub-system. This is reflected in the relatively high run off rates at Chiromawa and Bunga bridge in the upper reaches of Komadugu Yobe river. In the middle reaches, run off per unit area is less, although total run off volumes are greater than at the upstream stations at Wudil and Katagum in the upper reaches. In the lower reaches losses are extremely high and both run off rates and actual volume decreases as one move downstream around Gashua. Flows in the Marma channel are lost to the Hadejia System by evaporation and infiltration in the area around Nguru lakes. This water does not reach Gashua town.

Table 5: Summary of Mean Annual Runoff in the River Yobe basin.

River	Location	Catchment area (km^2)	Mean annual runoff					
			Pre-Tiga Dam			Post-Tiga Dam		
			Mm^3	mm	Period	Mm^3	mm	Period
Upper Hadejia								
Challawa	Challawa Bridge Chiromawa	6,890	657	95	1964-73	618.5	90	1974-90
Kano	Wudil	6.975	1,077	154	1964-73	674	97	1974-90
Hadejia		16, 380	1,915	117	1964-73	1,164	91	1974-90
Lower Hadejia								
Gaya	Chai Chai	1,710	85.5	50	1964-73	35.4	21	1974-90
Hadejia	Hadejia	30,430	718.1	24	1964-73	522.4	17	1974-90
Kafin Hausa	Kafin Hausa	30,430	-	-		92.4	3	1974-90
Marma Channel								
	Likori	-	-	-		264	-	1974-90
Jama'are								
Jama'are	Bunga Bridge	7,980	2,061	258	1964-73	1,477	185	1974-90
Jama'are	Faggo	9,840	2,524	257	1964-72	-	-	-
Jama'are	Katagum	15,000	-	-	-	1,691	113	1974-90
Yobe								
Yobe	Gashua	62,150	1,397	22	1964-73	952	15	1974-90

Source: WRECA, 2018

DISCUSSION

Climatic Elements Pattern in the Area of Study

The distribution of yearly average temperature of the Komadugu Yobe Basin from 1980-2017 as obtained at the Nigerian Meteorological Agency (NIMET), Nguru station reflects homogeneity in the average annual temperature with some slight rise and falls of temperature in some years within the time period. The period of average low temperature was recorded in 1992 and 2014. Different studies (Walther, B. A, 2016 and Sabitha, N. M., 2024) have investigated how changing precipitation patterns have affected the hydrological regimes of river basins. The results from figures 3 show that precipitation patterns in most cases dictate the hydrological regime of river basins. The Komadugu Yobe River Basin rainfall regimes from 1970-2017 indicated that the actual rainfall from 1970, 1974, 1975 and 1979 is beyond normal so also 1997, 2012, 2015, 2016 and 2017 respectively. The decline in the rainfall from normal (deviation) is observed to have occurred from 1972 up to 2014. The Komadugu Yobe River Basin is currently facing a conflicting balance between effectively benefiting from the available water resources and a reduction in the damages caused by the developmental projects.

The Hadejia River sub-basin of the Komadugu Yobe Basin which is a major contributor to the Lake Chad had been subjected to tremendous exploitation of its surface water resources through the construction of several dams particularly Tiga and Challawa dams as well as large scale irrigation schemes (Kano River Irrigation Project and Hadejia Valley Irrigation Project). There has been a decline in the occurrence of rainfall-dependent seasonal flooding which plays a vital role in maintaining and preserving the ecological system of the basin wetlands (Hadejia-Nguru Wetlands). This has negatively affected the practice of both flood and recession farming in the wetland region and over the entire basin. The drought episodes of the 70s and 80s account for the basin's climatic variability and these drought periods were characterized by considerably below average rainfall. These episodes subsequently shifted the average isohyets in the early 1970s and particularly the 1980s southwards. As a result of this spatial overall discrepancy, there is often some temporal irregularity of rainfall in the basin. This study agrees with the work of Jimoh, (2006) which stated that drought of the 1970s and 1980s coupled with uncoordinated water resources management and the increasing population has led to the degradation of the water resources of the basin.

The Komadugu-Yobe River floodplain is a significant landmark for the economy and livelihood of the basin communities due to its high yield in rice, vegetables, other cereals and cash crops. In addition to the production of millet, sorghum, rice, wheat and vegetables, the wetlands sustain fishing and livestock rearing practices. These activities are dependent on rainfall variability and flood cycles, yet Hadejia-Nguru wetlands alone provided the livelihood of about 1.2 million people (HJKYB-TF, 2019). Historically, agriculture is the life wire of the Komadugu Yobe basin communities, a sub set of Lake Chad, and it is driven by population growth and increased demand for food availability.

Rivers Discharge Pattern

It is difficult to detect any evidence of the regulating effect of Tiga dam as there is no discernible change in either peak discharges or run off in the dry season. After the dam construction in 1974, the discharge pattern is undulating signifying that there is no sharp decline in the run off of the Yobe River, rather the river discharge is fluctuating, meaning it increase in volume and sometimes it decreases. The highest discharge of 1500 cubic meter per second was obtained in 1970, that is before the construction of the Tiga dam and the lowest river discharge was recorded in 2009. Table (5) shows the summary of the data presented for the periods before and after the impounding of Tiga reservoir which began in 1970 wet season.

The pattern of runoff over the basin reflects the balance between rainfall and losses due to evaporation and infiltration. The highest rainfall occurs in the upper reaches of both the Hadejia and Jama'are sub-system. This is reflected in the relatively high run off rates at Chiromawa and Bunga bridge. In the middle reaches, run off per unit area is less, although total run off volumes are greater than at the upstream stations (Wudil and Katagum). In the lower reaches losses are extremely high and both run off rates and actual volume decreases as one move downstream (Gashua). Flows in the Marma channel (Likori) are lost to the Hadejia System by evaporation and infiltration in the area around Nguru lakes. This water does not reach Gashua. The fundamental question to any allocation of water resources throughout the Yobe River basin is: What are the relative contribution of the Hadejia and Jama'are rivers to the total flow in the Yobe River at Gashua?

In the Hadejia River Basin, study estimated that an average annual run off of 1360Mm^3 at Gashua, approximately 45% originated in the Hadejia basin with the remaining 55% coming from the Jama'are basin. This estimate of the contribution made by the Hadejia river was too high for the period they were considering and much too high. This is because the construction of Tiga dam has altered the hydrological regime downstream of the dam. The reduction in high floods led to the silting up and blocking of some channels, particularly in wetland areas. This increase the likelihood of overbank flooding which gives rise to greater loses due to infiltration and evaporation. The downstream basin communities also suffer from water loses due to high evaporation rate and siltation (WRECA, 2018).

CONCLUSION

The community livelihood security is mainly dependent on agriculture, based on rain fed or irrigation. This community livelihood security is affected negatively by many factors which is reflected on the decline in production. Factors, such as rainfall variability, reduced river flow and construction of dam are the major cause of surface water degradation leading to production decline, especially, the downstream areas suffer from more dry condition. On the contrary, the upstream areas suffer from flooding. The decline in surface water resources as reflected in the 1974-2017 rainfall record has reduced the community ability for production. The findings from this study revealed that there is water resources degradation within the study area which is caused by various factors, key amongst them are; Population increase, rainfall variability, dam constructions at the upper reaches of the basin which resulted in desiccation of the rivers downstream. Evidence from different satellite imageries revealed that there is serious water resources degradation in the basin. Diminishing surface water and forest resources may be attributed to increasing human needs and climatic variability. Agriculture is the major livelihood activities in the study area. Based on the findings of the study, the following measures are recommended to reverse the increasing water resources degradation; Monitoring of water should be included in the Strategic Action Plan of the basin.

River training of the entire river systems should be undertaken to allow free flow of water to all users at the mid- stream and downstream communities to boost agricultural production. Educational campaigns and awareness creation should be intensified among different resource users to raise awareness on economic implications of water resource degradation in the area. On the other hand, there is a need for establishing institutions and organizations to empower resource users in other source of income generating activities to reduce pressure on the land and water resources of the basin. Loss of buffer, role of aquifers, loss of agriculture land, desertification, reduced recharge due to climate change in places, desertification, out-migration, land abandonment, food insecurity, extreme poverty, intensification of conflicts is to be frontally addressed by government and other support agencies to reverse all the listed risk factors.

REFERENCES

Akurugu BA, Obuobie E, Yidana SM, Stisen S, Seidenfaden IK, Chegbeleh LP (2022). Groundwater resources assessment in the Densu Basin: A review. Journal of Hydrology: Regional Studies 40:101017.

Arthur A (2023). GWCL blames water shortage in parts of Accra on challenges at Weija plant.

Asante EA, Ababio S, Boadu KB (2017). The use of indigenous cultural practices by the Ashantis for the conservation of forests in Ghana. Sage Open 7(1):2158244016687611.

Chiroma, M. J, Kazaure, Y.D., Karaye, Y.B. and Gashua, A.J. (2006). Water Management Issues in the Hadejia-Jama'are-Komadugu-Yobe Basin: DFID-JWL and Stakeholders Experience in Information Sharing, Reaching Consensus and Physical Interventions. DFID-Joint Wetlands Livelihoods Project (JWL), Nigeria.

European Environment Agency, (2021). River basin. Available at: https://www.eea.europa.eu/archived/archived-content-water topic/wise-help-centre/glossary-definitions/river-basin

Fernando, S., Vasco, M., and Abdulkalam, M.Z (2019). A mapping Framework to Characterize Land Use in the Sudan Sahel Region from Dense Stacks of Landsat Data. MDPI Journal of Remote Sensing, Vol.1 Issue 6. 10.3390/rs11060648.

Gawne B, Capon SJ, Hale J, Brooks SS, Campbell C, Stewardson MJ, Grace MR, Stoffels RJ, Guarino F, Everingham P (2018). Different conceptualizations of river basins to inform management of environmental flows. Frontiers in Environmental Science 6:111. Ghana Statistical Service (GSS) (2021). Population and Housing Census: Population of Regions and Districts. Ghana Statistical Service.

Goldface-Irokalibe, I. J. (2008). Water Management in Federal and Federal–Type Countries: Nigerian Perspectives.

GWP, (2002b). Effective Water Governance How IWRM will contribute to achieving the MDGs. Technical Committee (TEC) Technical Policy Brief Paper No. 4. Global Water Partnership, Stockholm, Sweden.

GWP, (2004). Catalyzing Change: A handbook for Developing Water Resources Management IWRM and Water Efficiency Strategies. Prepared by Technical Committee with support from Norway's Ministry of Foreign Affairs.

GWP, (2012). Water in the Green Economy. Global Water Partnership Perspectives Paper.

Stockholm, Sweden. *www.gwptoolbox.org*

Hadejia, I.A. (2016). Functional Gaps and Overlaps in the Implementation of Integrated Water Resources Management of the Hadejia Jama'are Komadugu Yobe Basin. Unpublished PhD thesis submitted to the Department of Geography, Bayero University Kano, Kano State 2016.

HJKYB-TF, (2019). Brief to Local Government Chairmen on the HJKY Basin. HJKYB-TF 6 KM Potiskum Road, Damaturu, Yobe State, Nigeria.

IWRM (2014) Global Water Partnership Technical Advisory Committee Paper no. 4

Jaramillo F, Åhlén I, Luna G De (2022). Causes and consequences of recent degradation of the Magdalena River basin, Colombia pp. 451- 465.

Jimoh, S. O., (2006). Sustaining the role of Non-Timber Forest Products in Rural Poverty Reduction and Household Food Security in Nigeria. Journal of Fisheries International Vol. 1(2) April, 2006; p. 276.

Owusu PA, Asumadu-Sarkodie S, Ameyo P (2016). A review of Ghana's water resource management and the future prospect. Cogent Engineering 3(1):1164275.

Ofosu SA, Adjei KA, Odai, SN (2020). Ecological vulnerability of the Densu river Basin due to land use change and climate variability. Cogent Engineering 7(1):1735714.

Pegram G (2013). River basin planning: principles, procedures and approaches for strategic basin planning. UNESCO.

Sampson LE, Agyemang OO (2020). Quality of raw water from Ghana's reservoirs: a case of Weija reservoir. Journal of Environment and Earth Science 10:1e13.

Sabith, N.M., Santosh (2024). Estimation of Potential Impact of Land Use Change on Sedimentation Yield from a Small Tropical Watershed Using the TREX Erosion Model. https://doi.org/10.1002//ldr.5398

Seckler, D. and Amarasinghe, U. (2000). Water supply and demand, 1995 to 2025: water scarcity and major issues. In: World water supply and demand [online]. Colombo, Sri Lanka: International Water Management Institute. http://www.lk.iwmi.org/pubs/WWVisn/ WWSDHtml.htm. [Accessed 1 July, 2019].

Seguin, B., Baculat, B., Baret, F., Brisson, N., Huard, F. and Ruget, F. (2004). An overview of the consequences of the Summer 2003 for agriculture in France. P335-336 ESA (ed.) VIII ESA congress: European agriculture in a global context. Copenhagen, 11-15 July 2004.

Shrestha S (2015). Assessment of Bagmati river encroachment through application of GIS and remote sensing. Pokhara University p 10.

Stockholm International Peace Research Institute. (2011). *SIPRI Yearbook 2011: Armaments, Disarmament and International Security*. Oxford University Press.

UNEP and UN Habitat (2010): Sick Water: The Central Role of Wastewater Management in Sustainable Development, UNEP and UN Habitat, Nairobi.

Sunday CE, Vera CCE (2018). Examining information and communication technology (ICT) adoption in SMEs: A dynamic capabilities approach. Journal of Enterprise Information Management 31(2):338-356.

UNESCO (2009). International Hydrological Programme (IHP), (2009). Introduction to the IWRM Guidelines at River Basin Level – Part 1: Principles.

UNESCO (2013): UN World Water Development Report, UNESCO, Paris.

Walther, B. A (2016). A Review of Recent Ecological Changes in the Sahel.

E-ISSN: 3115-4662 DOI: 10.64290/bima.v9i2B.1292

African Journal of Ecology Vol. 54 Issue 3. https://.doi.org/10.1111/lage 12350. Pp 268-280

Wantzen KM (2023). River Culture: Living with the River, Loving the River, Taking Care of the River. Blue Papers 2:1.

WRECA (Water Resources Engineering and Construction Agency). Annual Report 2018

WRI (World Resources Institute) (2000). A Guide to World Resources 2000–2001: People and Ecosystems: The Fraying Web of Life. Washington D.C. (USA): World Resources Institute.

WRI (World Resources Institute, 2023). People, Nature and Climate. Annual Report, 2023.