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Effects of climate change on some selected geomorphosites and geo-heritage resources in Northeastern Nigeria: A case study and comparative analysis

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ABSTRACT

This study assessed and compared the effects of climate change on some selected geomorphosites and geo-heritage resources in Northeastern Nigeria. The objectives of this study are to examine the impact of climate change on some selected geomorphosites and geo-heritage resources and to determine their level of degradation. M-GAM was conducted with 50 respondents in each of the six states of the region, making a total of 300 participants. Focus Group Discussions (FGD) and in-depth interviews were conducted with the special people such as Heads of Tourism Centers, Conservators of National Parks, Traditional leaders and Heads of Fishermen. The study revealed that climate change significantly impacts geomophosite and geo-heritage resources, with heavy rainfall and high temperatures as the major causes. Each selected geomorphosites and geo-heritage resource is under ecological and socio-economic stress, with one category experiencing effects of similar or different magnitude to one another. The study concludes that the ecological diversity of Mandara Mountain is less directly affected by floods compared to that of Daba-Gajere. Ibi River and Sukur Cultural Landscape are also affected by the impacts of climate change through change in species distributions, loss and low productivity. The study recommended that the State ministry of Environment & Climate change and state tourism centres should enforce laws against excessive exploitation of resources and reduce climate change effects on them. This should be done through raising awareness among local communities about the danger of degradation of resources such as; quarrying, overfishing and poaching and against causes of climate change such as; bush burning, deforestation and emission of fossil fuels to prevent future occurrences of a rise in temperature.

1. INTRODUCTION

Landform degradation is the alteration or loss of land-surface features and functions through water and wind erosion, gullying, sediment movement, vegetation loss, soil compaction, mining, road construction and poorly managed farming or grazing. Sparse vegetation, long dry periods and intense rainfall can expose soils to erosion; overgrazing, fuel wood collection and cultivation of fragile slopes may intensify it. Outcomes include topsoil loss, expanding gullies, mobile dunes, reservoir sedimentation and declining productivity. Climate change and human pressures commonly interact (Roy et al., 2024). Semi-arid examples include rock outcrops, inselberg, dunes, fossil sites, river terraces, badlands, caves and distinctive erosional landforms. They preserve evidence of Earth history and may support education and geo-tourism. Current threats include quarrying and mining, vandalism, unregulated tourism, urban expansion, weak legal protection and incomplete inventories. Intense rainfall, flash floods, heat and weathering can also damage vulnerable sites; climate risk remains underrepresented in some geo-heritage risk-assessment approaches (Geo-heritage Degradation Risk Assessment, 2024; Global strategies for protecting geo-heritage, 2025). Climate vulnerability is the potential for people, ecosystems and infrastructure to be harmed by climate hazards, shaped by exposure, sensitivity and adaptive capacity. Semi-arid areas face drought, heat waves, rainfall variability, intense storms, flash floods and water scarcity. These hazards affect rain-fed farming, livestock, drinking water, health, biodiversity and household income (UNCCD, 2024).

Experiments have shown that climate change induces ecosystem changes and is particularly likely to push ecosystems across thresholds (Nancy *et al.,* 2013). Warming-induced shifts in species composition have been broadly observed in grassland ecosystems. Warming has been reported to drive woody invasion of high-latitude, herb-dominated ecosystems (Yang, Wu and Liu, 2011). High temperatures could lead to several increases in the energy requirement of lake trout (Salvelinussnomaycush). It also increases the frequency of toxic algal outbreaks and their toxicity to other animals (Birjees, Humaira, Niamat, Nissar and Ali, 2020). Temperature also affects the morphology of aquatic animals, as it causes decreases in body size at a given developmental stage in over 90% of them. Studies indicate that a 2^0 c rise in air temperature will drastically skew sex ratio, and a 40^0 c rise would virtually eliminate all male turtles from the population. Most of the endemic fish go extinct due to increased warming. Climate change directly and indirectly affects freshwater ecosystems and communities (Birjees *et al,,* 2020). Additionally, inland freshwater fisheries at higher elevations are likely to be affected by lower availability of oxygen due to rise in surface air temperature. Climate change has the potential to substantially alter fish breeding habitat, food supply for fish and ultimately the abundance of freshwater fish population (Chersich *et al.,* 2015). Furthermore, temperature increases of 2^0 c in wetlands and forests could result in the loss of ecosystems and biodiversity, which is bad for human development and the poor who depend most heavily on ecosystem services (Chersich *et al.,* 2015).

Climate change is rapidly being recognized as a serious threat to the sustainability of geo-morphosite and geo-heritage through geo-tourism and eco-tourism systems such as ecosystems, local communities, and the economy (Yu *et al*., 2009). National parks and wilderness zones in forest and woodland areas may face higher fire risk and subsequent closures, preventing recreational access. Native ecosystems that currently act as tourist

attractions may be invaded by weeds, feral animals, or plant and animal pathogens and may become less attractive as a consequence (Plamen and Milana, 2008; Ralf, 2011). High precipitation supports vegetation growth on geomorphosites and geo-heritage areas (Arens, Slings, Geelen and Vander, 2007). However, when temperature exceeds the average temperature of the warmest months, the growing conditions of the vegetation in geomorphosite and geo-heritage areas worsen (Jullius *et al.,* 2020).

In Africa, the impacts of climate change on the ecological and social values of geo-morphosites and geo-heritage areas, which play a vital role in geo-tourism activities is of great concern (Smart, 2011). In Northern Nigeria, geological, geomorphological, fluvial and other geo-heritage features like; hills, sand dune, river banks, mountains and landscapes are affected by climatic events such as; storms, drought, high temperature, heavy rainfall etc (Orga & Kaugama, 2022). A study conducted by Ijeoma and Aiyeloja, (2009) on the impact of climate change in Jos, Plateau State, Nigeria revealed that climate change can destabilize ecosystems, reduce tourism patronage, cause shifts in tourism destinations, death and migration of wildlife species, flooding of eco-destinations etc. Study revealed that 90.2% of respondents believed climate change impacts geo-tourism resources in Northern Nigeria. The nature of climatic impacts to geo-tourism resources is through destruction and disturbance of natural resources in the affected areas, such as landscape, rock formations, sand dunes, beaches and other geo-heritage features, due to heavy rainfall, high temperature, poor soil condition, and desertification, making geo-tourism resources highly vulnerable to being affected and destroyed. Mambila Plateau was reported to be affected by storms and heavy rainfall. A lot of geo-tourism features like; landscapes and valleys were also destroyed in Bauchi State. Climatic events are damaging the aesthetic beauty of geo-tourism features. Landscape and other geo-heritage features are affected by deterioration of the topographical surface of the earth due to geomorphological action and other climate change impacts (Orga & Kaugama, 2022).

2. Methodology

2.1: Brief Description of the Study Area

North Eastern Nigeria extends from latitudes 6 28^0 N to 13 44^0 N and longitude 8 44^0 E to 14 38 ″ E. The landmass of the region is calculated to be 272,395 km^2 which is 29.45% of the total area of Nigeria landmass, and has a population of 18,984,299 persons according to the 2006 Nigerian population census (Mayomi and Yelwa, 2014). The present North Eastern Nigeria comprises six of the thirty- six states in the country which are; Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe as shown in Figure 1 (Dada *et al.,* 2007; Mayomi and Yelwa, 2014; Hassan *et al.*, 2017).

Mean annual rainfall is less than 500mm in the northeast, although there are considerable spatial and annual variations to the long-term mean. The region experiences consistently high temperatures throughout the year (Adelana *et al.,* 2008). Mean temperature range between 25.9 at Bauchi to 28.3 at Yola (Hassan *et al.*, 2017; Jalo, 2015; Ladan, 2018). The North-eastern region of Nigeria is a featureless plain, gently sloping east and north-eastward toward Lake Chad (Mayomi and Yelwa, 2014). Udo (1982) classified the relief of this region into highlands and plains. The highland area is mountainous, especially the Mandara

Mountains (1200-1500 m), the Atlantika (1200m), the Shebsi (1800m) and the Biu hills (Udo, 1982). The soils in area are generally sandy at the top, compact at depth, with often hard pans. Aeolian deposits from the Sahara Desert form a substantial part of the soils. The mixing of the subsoil in these deposits has given rise to clay subsoil, which is found in some parts of the area (Ladan, 2018).

The vegetation in this region is the poorest of the savannas. It forms a transition zone between the savannah and the desert. Few trees are present, such as thorny acacia, scattered gum Arabic trees, and date palms are available. The Sahel Savannah is found in the extreme northeast, where mean annual rainfall is less than 650mm and the season is longer than eight months. Vegetation cover is mainly short, tussocky grass. The most important tree is the acacia. Tall trees are to be found in the seasonally flooded areas around Lake Chad (Ologe, (nd) & (Mayomi and Yelwa, 2014). Many rivers and streams that flow through the study area are seasonal. Most of them, on the way to Lake Chad, flow into marshy areas and disappear by evapotranspiration before reaching the lake (Manko, 2020).

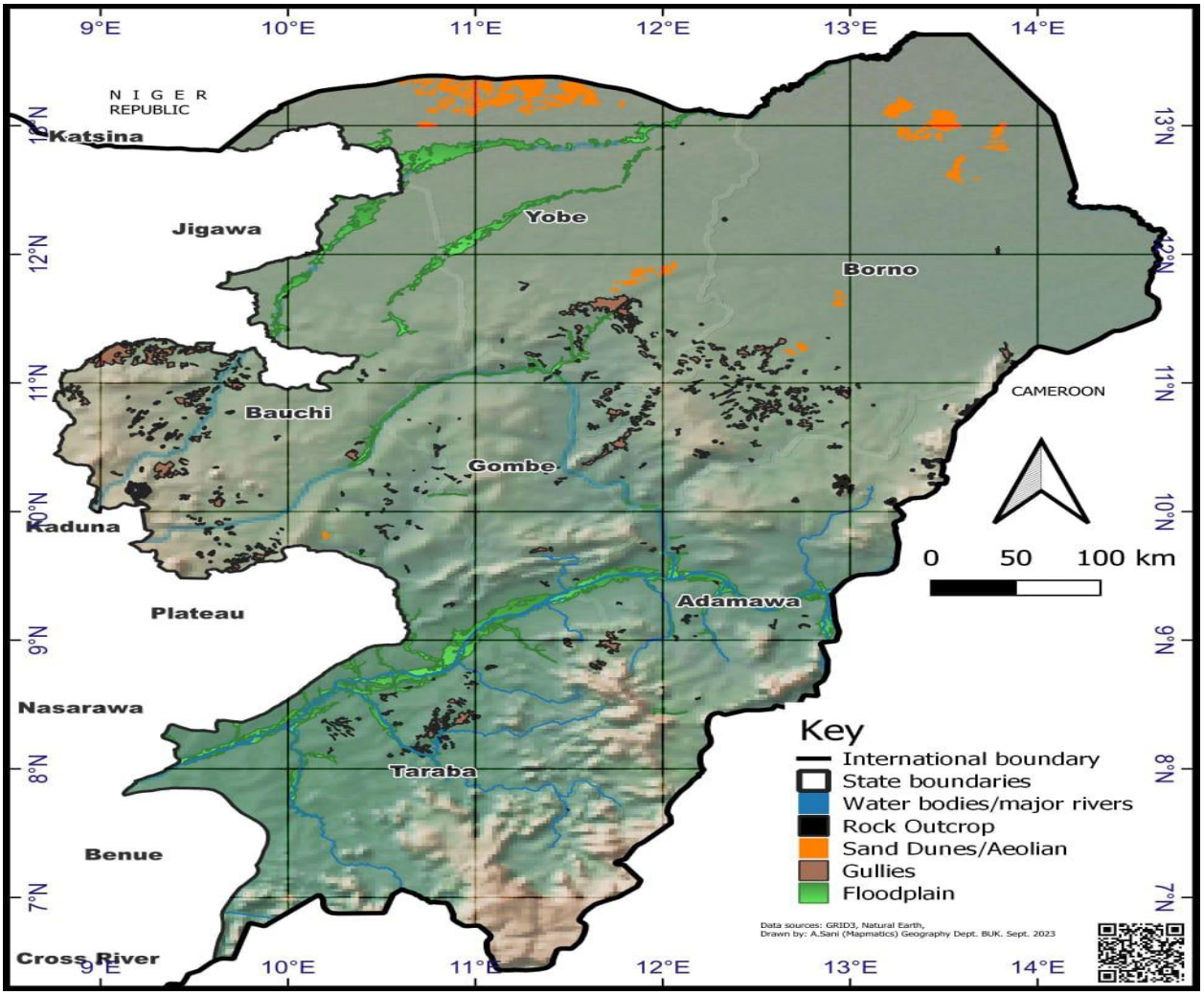


Figure 1: Physical Map of Northeastern Nigeria

Source: GIS Lab BUK, 2025

Northeastern Nigeria has an abundance of hills, mangroves, caves, cultural heritage, rivers and lakes, wildlife, zoos, historical sites etc. These attractive tourist products and destinations are classified into two main categories namely: Natural Features and

Cultural/Historic Attractions. The natural Attractions include; Lake Chad Sanctuary, Yankari National Park, Wikki Warm Spring, Manbila Plateau, Hot Spring at Lamale, Three Sisters Rocks at Sorg, Jangani Mountain range of Ganye, Rolling Uplands of Muri. The cultural/historic attractions are; Kukas Tombs, Rabeh Fort at Dikwa, Shira Rock Painting, Keffin Madaki Historic Monument etc.

2.2 Types and Sources of Data

The study employed both primary and secondary data. Primary data were collected from individual respondents quantitatively using the Modified Geomorphosites Assessment Model (M-GAM). Qualitative data were also collected from respondents through Focus Group Discussions (FGDs). In-depth Interviews, Key Informant Interviews (KIIs), and the M-GAM observation checklist were used to collect qualitative and quantitative data. Also, climatic data were collected from *Nimet,* as it is a relevant agency responsible for gathering, recording, and interpreting climatic data.

2.3 Population and Sample Size

An inventory of all areas of geomorphosites and geo-heritage sites in Northeastern Nigeria was conducted, with sites listed and graded based on their types, uses, potentialities, and ecological and social values, using sampling and data collection. The study population comprises male and female inhabitants of the sites with experience and knowledge of the impacts of climate change on ecological values in Northeastern Nigeria. The total of five hundred and sixty-nine (569) identified potential geomorphosites and geo-heritage sites were used to form the population. A sample was drawn from the total of 569 identified sites. The age range of respondents was 20 years and above. The second category of respondents comprises key informants, such as Forest Guards and Traditional Leaders, and officials from relevant agencies, such as Heads of tourism centers, on the impact of climate change on the ecological values of geomorphosites and geo-heritage sites.

The following sample sizes were purposely selected for the study.

a) Key Informant Interviews (KII) was conducted with two (2) participants in each of the thirty-six (36) sampled areas, making seventy-two (72) KII participants (table 1).
b) In-depth interviews were conducted with three (3) participants in the thirty-six (36) sampled areas, making the total number of one hundred and eight (108) in-depth interview participants for the study.
c) Focus Group Discussions (FGD) was conducted in twelve (12) sampled areas with participants ranging from eight to twelve (8-12) members (Table 1). People aged 60 years and above were identified for FGDs and sampled for in-depth interviews, as they are a group likely to have experience of climatic seasons (30 years & above) and might have acquired climatic knowledge from their parents and grandparents (another 30 years).
d) Observation was conducted on some of the 36 sampled areas to observe and record the nature of Geomorphosites and geo-heritage areas. Features of interest were also captured or snapped using devices for illustration and further discussion.
e) M-GAM was used to collect the opinions of fifty (50) respondents in each of the six (6) states of Northeastern Nigeria, making the total number of three hundred (300) M-GAM respondents for the study.

Table 1: Methods, Characteristics of Respondents, and Data Collected

S/N	Instrument	Types of Respondent	Characteristic of Respondent	Number of Respondents	Some Places Conducted
1	KII	Traditional leaders, *Nimet,* Head of tourism centres.	Specialists based on position. 15 years' Work experience	2 participants in each of the 36 sampled sites, making 72	Wukari, Maiduguri, Fika, Machina, Daba-Masara,
2	FGD	Inhabitants of the nearest settlement to the sample sites who have knowledge and experience of the impacts	Male participants, 60 years and above, same language and social status	8 to 12 participants in the nearest settlements of the 12 sampled sites.	Gashua, Billiri, Wukari, Maiduguri, Fika, Machina, Daba-Masara, Dadin-Kowa, Baga, Mandara, Donga
3	M-GAM	Inhabitants of the nearest settlement with knowledge and experience of the sites.	20y and above, male and female respondents.	50 respondents from each of six states, for a total of 300.	Yola, Ibi, Ningi, Bauchi, Nguru, Gombe, Mambila, Gashua, Billiri, Maiduguri, Fika, Daba-Masara, Baga, Mandara, Donga, Dabar-Wanzam
4	In-depth Interview	Aged people, experienced and knowledgeable local communities	60 years and above, male and female. All tribes and all social statuses	3 participants from each of the 36 sampled areas, for a total of 108 participants.	Machina, Maiduguri, Fika, Baga, Bauchi, Donga, Dabar-Wanzam, Wukari
5	Climatic Data	*Nimet*	Rainfall and temperature data of Northeastern Nigeria	40 years of climatic information	Nguru, Yola, Bauchi, Maiduguri, Potiskum, Gombe.

2.4 Sampling Technique

The sampling techniques employed in selecting the participants were as follows:

i. Purposive sampling was used proportionally in selecting the sampled areas and respondents in the various sampled sites to conduct FGD. However, only participants who shared similar characteristics, being male, speaking the same language, and having relatively balanced social status, were selected to conduct the FGD.

ii. Key Informants Interview (KII) participants, like Traditional Leaders, Forest Guards, representatives of Head of tourism centers representatives of Conservators of various national parks and game reserves, etc., were purposely selected because only participants with knowledge and experience of the impact of climate change on ecological and social values of geomorphosites and geo-heritage areas were required to respond to the KII checklist.

iii. In-depth interview participants and M-GAM respondents were purposively selected to provide information, as only participants/inhabitants who reside close to the study sites were required to respond to the M-GAM. Lastly, purposive sampling was used to identify geomorphosites and geo-heritage areas; and to identify their ecological values and categories of features or sites of interest. This is because only relevant features, activities, or values serve the purpose of the M-GAM assessment in the study. Therefore, the standard form and sheet were designed and used.

2.5 Instruments and Procedure for Data Collection

a) Focus Group Discussions (FGDs)

As explained earlier two types of FGDs were used in this study. The first one was in the form of a dual moderator focus group to avoid been distracted as in the case of single moderator which ensured all questions were answered. The other was a respondent-moderated focus group, which limited unintentional bias. This also gave community members room to conduct the FGD in areas not accessible to the researcher. In conducting FGDs with the

nearest settlements of the local communities, the discussion was conducted in the language of the local communities; the moderators asked the prepared questions and ensured that all questions were answered; the note-taker recorded key issues and other factors that might influence the interpretation of data collected. A recording device was used to record the discussions.

b) Key Informants Interview (KIIs)

Key Informants Interview (KIIs) were conducted with special people (based on special position) to supplement and backup the responses collected using other methods of data collection such as M-GAM form, FGD and In-depth interview. KIIs were conducted with Officials and community leaders, such as representatives of head tourism centres, to identify the impacts of climate change on sites/features, the most common impacts, their nature and severity, and the most affected sites. The KII was conducted with community leaders and Forest Guards to identify the types and nature of ecological values of geo-morphosites and geo-heritage areas (Table, 1).

c) In-depth interview

In-depth interview formed part of the instruments for data collection in this study. In-depth interviews were conducted with Local Communities (experienced people) to find out the ecological values of geomorphosites and geo-heritage areas, as well as impacts of climate change on the sites. Special preference was given to aged people (60 years and above) to collect data on climatic changes and their impact on the study sites (Table, 1).

d) Modified Geomorphosites Assessment Model (M-GAM)

The Geo-site Assessment Model GAM consists of two key indicators: main values and additional values, which are further divided into 12 and 15 indicators, respectively, each individually marked from 0.00 to 1.00. This division is made due to two general kinds of value; main values are mostly generated by the geo-sites natural characteristics and additional values, which are mostly human-induced and generated by modifications for their use by visitors. The main value (MV) comprises three groups of indicators; scientific/educational (VSE), scenic/aesthetical (VSA), and protection (VPr). The additional values (AV) are divided into two groups of indicators: functional (VFn) and touristic value (VTr). Vujucic et, al (2011) use the Geo-site Assessment Model in their preliminary geo-site assessment model (GAM) and its application on Fruska Gora mountain, a potential geo-tourism destination of Serbia (Vujucic et, al., 2011).

M-GAM has two values namely main values and additional values which are further subdivided as follows: Main values (MV), Protection (VPr), Additional values (AV), Functional Values (VFn), Touristic values (VTr). It also has 28 sub-indicators including: scientific/educational, scenic, accessibility, protection, vulnerability tourism infrastructures, and tour guide service Tomić and Božić, (2014). They further use it in the assessment of Lazar Canyon (Tomic and Bozic, 2014). Kubalíková & Kirchner, (2015) proposed a Modified Geo-site Assessment Model (M-GAM) which considers an assessment of the added values such as ecological, cultural, historic, archaeological, artistic, religious value of a site, aesthetic, landscape and scenic value etc (Kubalíková & Kirchner, 2015). Jonathan and Elisa (2021) evaluated the ecological value of geomorphosites based on two groups of numeric criteria: criteria for assessing the interest of the plant community and

criteria for determining the influence of geomorphological processes on vegetation based on the morphodynamics index ranging from 0 to 9 (Jonathan and Elisa, 2021).

Table 2. Criteria in Geomorphosite Assessment Method

Scientific value criteria	Additional value	Management criteria
Rarity	Cultural	Accessibility
Representativeness	Ecological	Visibility
Integrity	Aesthetic	Vulnerability
Diversity		
Scientific knowledge		

Source: Adopted from Pereira & Pereira, 2010

This study uses the modified geo-site assessment model M-GAM using the following criteria: additional value and management value. The additional values include cultural value, ecological value and aesthetic values. The management values include vulnerability and accessibility, as shown in Table 2 of the Criteria in Geo-morphosite Assessment Method adopted from Pereira & Pereira, 2010. The indicators used include: IrV Irrigation Value, FiV Fishing Value, BreV Breeding Value, HabV Habitat Value, ConV Consumption Value, EdcV Educational Value, ReaV Recreational Value, SndV Sand mining Value, SacV Bird sanctuary Value, SpV Spiritual Value, ComV Commuting Value, TrV geo-tourism Value. Other indicators used in the assessment of climate change include: loss of biodiversity, habitat degradation and changes, migration & extinction of species, loss of heritage sites/resources and loss of socio-economic activities, changes in livelihood sources, decline in local business and unemployment. The assessment method was adopted from Pereira & Pereira (2010 as: 0 = nil | 1 = very low | 2 = low | 3 = moderate | 4 = high | 5 = very high, as shown in Table 3 of the criteria for assessment of potential geomorphosites. Another assessment method was adopted from Pereira & Pereira (2010 for climate change vulnerability: 1 – low; 2 – medium; 3 – high.

Table 3. Criteria for Assessment of Potential Geomorphosite

Criteria		Assessment
Geo-morphological intrinsic value (IV)	Scientific (Sc)	2 – low; 3 – medium; 4 – high; 5 – very high
	Other geomorphological values (Ogv) Ecological (Ec) Cultural (Cul) Aesthetic (Ae)	0 – nil; 1 - very low; 2 – low; 3 – medium; 4 – high; 5 – very high
Potential use (PU)	Accessibility (Ac) Visibility (Vi) Use of other natural or cultural values (Oth)	1 - very difficult; 2 - difficult; 3 - medium; 4 - easy/good; 5 - very easy/very good
Need for protection (NP)	Deterioration (De) Vulnerability (Vu)	1 – low; 2 – medium; 3 – high

Source: Adopted from periera & Pereira, 2010

2.6 Data Analysis

The data collected using M-GAM were analyzed using descriptive statistics, with frequencies and percentages. The results were presented graphically, including a pie chart and tables (as indicated in Table 4). However, the qualitative data collected through FGD, KII, and in-depth interviews were analyzed using inscriptional means of qualitative data analysis, such as analytic strategy, successive approximation, and figures. Climatic data collected from *Nimet* were analysed using means and percentages.

Table 4: Forms of Data and Methods of Data Analysis

S/N	Instrument	Data	Method of Analysis	Presentation of Results
1	FGD	Qualitative	Summarizing pattern and relationship, analytic strategy, and successive approximation. Percentage and frequency in quantitative analysis.	Narration, discussion, and reporting. Table, percentage, and pie chart
2	KII	Qualitative (special position)	Analytic strategy (social correlation)	Narration, discussion, and reporting
3	In-depth Interview	Qualitative (well-experienced persons)	Successive approximation (moving forward and backwards), analytic comparison	Narration, discussion, and reporting.
4	M-GAM	Quantitative (M-GAM questionnaire)	Percentage and frequency, Pictorial images.	Tables, percentages, and pie charts
5	Climatic Data	Qualitative data	Mann-Kendall trend test analysis.	Figures, tables, and graphs.

3. Effects of Climate Change on Ecological and Social Values of Some Selected Geo-Morphosite and Geo-Heritage Resources

This section provides case studies on the effects of climate change on ecological and social values of the following geo-morphosites and geo-heritage resources in Northeastern Nigeria: Hadejia-Nguru Wetlands, River Ibi, Mandara Mountain, Daba-Gajere Island, Babban Gwani Palace, Dutsen Mamaki Mysterious Rock and Sukur Cultural Landscape.

a) Hadejia-Nguru Wetlands

The Hadejia-Nguru Wetlands are one of the prominent geomorphosites and geo-heritage resources in Northeastern Nigeria. It is a large saturated land area with riparian vegetation and ecological diversity extending in part of Yobe state straddling the border of Jigawa state. Hence, it is located within the extreme border of Nguru in Yobe State and Birniwa in Jigawa state. Climate change is having profound effects on the Hadejia-Nguru wetlands affecting ecological diversity and the natural environment with consequences on socio-cultural activities and sources of livelihood of the local communities. The findings of the study revealed that reduced rainfall, drought, increased & high temperatures are causing continuous shrinkage and retreat of the wetland. Typhoon grasses, overexploitation and poor management also contributed to shrinkage and retreat. These are affecting the ecological diversity of the wetland most especially indigenous aquatic species, riparian vegetation and even terrestrial species that depend on wetlands for water consumption, food, habitat and more. This finding is in consonanance with that of Birjees *et al.,* 2020 who asserted that climate change has greatly impacted the ecology of rivers affecting their breeding period's reproduction, and resulting in extinctions of species. Also changes in water level have a stronger effect on river fishes than changes in temperature. As the floodplains dry up due to

the end of the rainy season, members of the "whitefish" guild move back to the main river channel (Birjees *et al.,* 2020).

Community leaders revealed that the wetland is experiencing decline and shrinkage, affecting many aquatic and terrestrial animal's that are dependent on the wetland resources. FGD participant opined that "some species had migrated, gone extinct or faced death due to changes in the physical composition of the wetlands and declines in resource availability caused by climate change… … Floods usually affect Tilapia fish due to their fragility. Though most of the time flood comes along with some benefit as new fishes are being introduced into the water body…"

Another FGD participant opined that Hadejia-Nguru wetland has reduced to more than half compared to the last 50 years. However, another FGD participant disputed this assertion. In-depth interview participant revealed that change of rainfall pattern and decreasing water availability is reducing the quantity of aquatic products derived from the wetland. This is especially evident in the decline in the quantity of fish catches by fishermen in recent years compared to the last 40 years or so. This supports the findings of Arrens *et al.,* 2007 who find out that changes in these ecosystems could have major negative effects on freshwater supplies, fisheries, biodiversity, and tourism. They added that one way climate change could affect freshwater biodiversity is by altering the carbon-to-nitrogen (C:N) ratio in riparian vegetation (Arrens *et al.,* 2007). Birjees *et al.* (2020) also revealed that rare species may get lost if the ephemeral wetlands especially in arid regions dry up (Birjees *et al.,* 2020). On the other hand, the Head of the Farmers Association revealed that "changing rainfall pattern is reducing irrigation potentialities… declined and change in rainfall grossly affect farming activities and causes decline in crop productivity… …pastoralist are affected by decline in productivity and grasses that support grazing activities".

Declines in the quantity of fish and other aquatic products, reductions in farm productivity derived from irrigation farming and shortages of grasses and fodder resources used by herdsmen for grazing are cumulatively causing reductions in economic activities, sources of livelihood and other socio-economic activities, which increase poverty and food insecurity. This causes displacement, migration and conflict over resources, making communities more susceptible to recruitment into armed groups like Boko Haram and ISWAP. This is increasing security challenges in part of the area. Head of fishermen revealed that fishing catches have seriously declined due to shallow waters and receding. A community leader narrated that "shrinkage of wetland has led to significant loss of ecological habitat causing migration, poor productivity and death of biodiversity… …the wetland is witnessing decline in fish population and other aquatic species, directly or indirectly affecting the livelihoods of the immediate local communities that depend on the resources as sources of income".

This finding is similar to that of Stefano *et al.* (2019) who find out that climate change results in net specie decline due to fall in juvenile emergence, growth and survival. They added that the release of warm water in winter from dams shows a massive decline of invertebrates for tens of kilometers downstream and overall river warming would be expected to have a similar effect (Stefano *et al.,* 2019).

Findings revealed that ecological degradation of wetlands due to climate change has led to declines in fish and wildlife populations, including rabbits, birds, jackals, hyenas, antelope,

and many more. This finding is in support of Daufresne and Boët (2007) who observed an increase related to global warming in total abundance and in proportions of warm-water species and size structure changes in fish communities (Daufresne and Boët, 2007). This indicates that ecological degradation of the site due to climate change exacerbates socio-economic problems that affect fishing, grazing and geo-tourism, which have serious repercussions on immediate local communities through effects on sources of livelihood and other socio-cultural activities.

b) River Ibi

River Ibi is a naturally flowing large body of water with varied riparian vegetation, ecological diversity and socio-cultural and economic uses such as commuting, trading, fishing and irrigation. Climate change is affecting the river's ecological and social values. It was revealed that reduced rainfall and increased evaporation due to a rise in temperature are affecting water levels and altering flow patterns. This affects the life of aquatic species that depend on the sites as habitat and sources of food. This is in relation to the finding of Wilhelm and Adrian, 2008 who revealed that climate change impacted freshwater ecosystems physiology and life history (Wilhelm and Adrian, 2008). This is because changes in the quality and quantity of the water lead to a decline in productivity of aquatic species, and this affects ecosystem services causing loss of biodiversity. A KII participant revealed that changes in river flow due to heavy rainfall and other climatic or environmental causes can destroy aquatic species' habitats. Head of tourism center revealed that "...changes in water condition impacted food availability and food webs in the river ecosystem, which causes stress among aquatic species, making them vulnerable for decline, death, loss and extinction... ...This affects productivity and future sustainability of aquatic species with economic repercussions on local communities that depend on fishes and aquatic products as sources of livelihood...

On the other hand, FGD participants revealed that heavy rainfall brings a positive impact to aquatic species, because new wetted areas create new breeding habitat, especially for fish and other amphibians. Also, erosion from intense rainfall dumps sediments that serve as nutrients for algae and cyanobacteria that support aquatic food webs. This is an indication that climate change has associated positive impacts on aquatic species and benefits for local communities, as they gain more fish resources and irrigation area from the new wetted areas created by new water.

KII revealed that sudden temperature drops and turbidity stress aquatic species like catfish and tilapia fishes. FGD participant revealed that heavy rainfall associated with floods causes some flood-tolerant plant especially typher grasses that colonize new areas altering riparian vegetation structure. Though, it increases genetic diversity it is of less significance. Another FGD participant revealed that "floods and heavy rainfall with high flow velocities erode river banks and sometimes wipe out nest and burrows of some species especially birds that are living close to the area. This leads to population decline and local extinction".

KII revealed that high temperatures affect tilapia fishes causing stress, reduced growth and sometime death. This is due to the fact that tilapia fish need more oxygen, but warm water holds less dissolved oxygen. The head of the tourism centre revealed that toxic algae thrive in warm temperatures, producing toxins that harm fish and other aquatic species. Floods

facilitate the spread of invasive species that out compete native species for habitat and other resources. Also change in water temperature, flow and quality affect fish population impacting the livelihood of people dependent on fishing activities as sources of income. Increase evaporation affects agricultural productivity derived from irrigation. This is impacting food security and income of local community.

It can be deduced from the above findings that climate change affects the ecological values of River Ibi through changes in the population of fish and other aquatic species. It also affects riparian vegetation and wildlife that depend on the river for survival; it altered nutrient cycles and water quality that subsequently affect the ecosystem. Findings revealed that changes in water flow, quality and quantity impact socio-cultural activities, especially tourism and fishing. This affects the social life of people living in the area because it leads to a decline in activities such as; trading, food and beverage, accommodation and hotel services, transportation and many more. Also, increased flooding can lead to displacement and migration of people living close to the area.

c) Mandara Mountain

Mandara Mountain is one of the historical sites with a volcanic cone peak with a distinct cone shape in Mandara of Borno state; it has long historical background, cultural settlement, socio-economic activities and varied ecological diversity and micro-organism. Climate change exert significant positive and negative impacts on the Mandara Mountain. Findings revealed that heavy rainfall can benefit plant growth around the mountain areas. However, excessive water can lead to root rot. The Head of the Tourism center revealed that heavy rainfall causes erosion and landslide leading to habitat destruction and biodiversity loss. Community leader revealed that heavy rainfall and undercutting is causing biodiversity loss around the mountain areas leading to disruption of ecosystem, decline productivity and habitat loss. This finding is in consonant with that of Karma et.al 2010 & Kohler and Maselli 2012 who find out that places where climatic change may lead to warmer and drier conditions, mountain vegetation is expected to suffer as a result of increased evapotranspiration (Karma et.al 2010; Kohler and Maselli, 2012)

FGD participant revealed that heavy rainfall replenishes water sources around the mountain benefitting ecological species dependent on it. Heavy rainfall brings nutrient-rich sediment from atop of it, enhancing soil fertility and promoting vegetation growth in the surrounding area. This is an indication that climate change has positive impacts to biodiversity and ecosystem; supporting growth and development of species which enhance tourism appeal, livelihood source and other socio-economic activities.

In-depth interview participant revealed that heavy rainfall led to flood, destruct habitat, decline in species population and reduced productivity. This is affecting wellbeing and sustainability of species and micro-organism living in the site. This finding is in relation to that of Monique Fort, 2015 and Monique, 2021 who stated that mountain environments are “fragile”, they can be damaged by many factors such as deforestation, overgrazing by livestock, cultivation on marginal soils, and progression of urbanization, all of which may result in a rapid degradation of biodiversity and water resources, and an increase in natural hazards, hence putting adjacent populations at risk (Monique Fort, 2015; Monique, 2021). Head of tourism center opined that “heavy rainfall led to increased sedimentation and

nutrient run-off around the mountains directly or indirectly affecting ecological diversity... ...high temperature is affecting vegetation cover and physiology of plant species and other terrestrial animals around the mountain. Due to this some species migrate to cooler, higher altitude and face local extinction".

The study indicates that wildlife species living on the mountain are vulnerable to habitat shift. In-depth interview participant expressed that high temperature stress wildlife species, affecting their reproduction and survival rates. This destabilizes ecosystem and affect food webs. FGD participant revealed that high temperature dries out soils, reduce fertility, microbial activities and nutrient availability. This is an indication that high temperature at the mountainous area affects ecosystem productivity, availability and sustainability due to its effects on ecological diversity.

On the other hand, finding indicate that alteration to the mountain's ecosystem reduce tourism appeal, affect local businesses and sources of employment such as; guide and accommodation services, transportation service, trading, restaurant and more. Also, the mountain holds significant socio-cultural values for local communities. Therefore, any changes to ecological values and physical nature of the sites erode those values. Additionally, change in physical nature and structure of the mountain is affecting recreational values of the site such as; hiking and sightseeing.

d) Daba-Gajere Island

Daba-Gajere is one of the well-known *tumbu* (island) extending for 3.5Km^2 located at Chad Basin in Kukawa local Government area of Borno State. Climate change is affecting the ecological diversity and social values of the islands. Finding revealed that rising sea level and increased storm surge is causing erosion of the island's coastal habitat affecting riparian vegetation and other aquatic habitat leading to decline of productivity, migration and death. Also, heavy rainfall and storms damage ecosystem around the Island through death and loss of aquatic species leading to loss of biodiversity and ecosystem services. An FGD participant revealed that heavy rainfall replenishes fresh water sources of the island, benefiting plants and animals adapted to the Daba-Gajere Island (*tumbu*). Heavy rainfall also brings nutrient-sediments, enhancing soil fertility of the islands which support crops and vegetation growth as well as increases productivity.

On the other hand, a farmer living at the islands revealed that heavy rainfall and storm cause flooding and destruction of building on the island leading to erosion and habitat loss affecting ecosystem's productivity and sustainability. Community leader revealed that unique biodiversity species of the island are vulnerable to climate change due to limited space and isolation of the site. Therefore, any change in micro-climate exerts significant effects to ecological resources. An FGD participant opined that change of water volume and flow pattern affect fish productivity, population and quality with subsequent effect on sources of livelihood of fishermen dependent on fishing. This finding is in consonant with that of Karma *et al.,* 2010 & Chersich *et al.,* 2015 who revealed that fisheries and fish production are sensitive to changes in climate and are currently at risk from overfishing, diminishing spawning areas, and extensive pollution. Both crops and livestock will be affected by increased incidence of alien/invasive pests and diseases (Karma *et al.,* 2010; Chersich *et al.,*

2015). This causes poverty, stress and migration. The worst part of it is that it results in our youth joining arm group such as Boko Haram and ISWAP.

FGD participant revealed that alteration of ecological diversity of the island (*tumbu)* ecosystem couple with growing insecurity; reduce tourism appeal, affecting local business activities and employment opportunities. This is because tourist arrival supports trading; restaurant and beverage services. These findings revealed that the island (*tumbu)* hold cultural significance and recreational activities like sightseeing and swimming. Therefore, any erosion of the integrity of the site (*tumbu)* results to decline in socio-cultural and recreational activities. Also, heavy rainfall causes flood and erosion of the part of the site (*tumbu)* resulting to displacement and migration of local inhabitant causing stress, disruption of cultural activities and economic loses.

e) Babban Gwani Palace

Babban-Gwani palace is one of the prominent and very old historical geo-heritage. A palace standing firm for more than 158years, with significant historical and cultural attachment located in Ganjiwa area of Bauchi state. The findings revealed that climate change affect the structural integrity of some part of the site due to warm temperature and increase humidity level which causes structural damage to the building through; cracking, decay of wood and stone materials. This is because increase humidity level has accelerated mold growth which damages the site. FGD participant revealed that heavy rainfall directly erodes the sites damage buildings and its surrounding landscape.

Head of the Tourism Centre revealed that climate change alters the local climate, which affects the ecosystem, causing biodiversity loss and other ecological effects on species that depend on specific conditions around the sites. It also causes loss of habitat for species nesting in the sites. FGD participant revealed that "heavy rainfall and erosion is affecting the stability of structural landscape and wall of the site… …when heavy rainfall, high temperature, flood or erosion cause damage to the site like erode of cultural value and integrity of the site, there will be less community cohesion as the site is consider as place of geo-historical value".

Therefore, climatic event altered traditional practice usually observe in the site and affect socio-cultural life of the community. The finding also indicates that damage to heritage site reduce tourism appeal, affecting local economic growth through loss or decline in guide service, accommodation and hotel service, transportation service, restaurant service, trading and more. Though only few local communities depend on those activities as sources of livelihood. Also, in some cases cost of reinforcing the damage cause by effects of climate change to the site is an issue of concern because the resources could be diverted from other priorities to ensure sustainability of the geo-heritage sites. This hinders timely development of other sectors and priorities.

f) Dutsen Mamaki Mysterious Rock

Dutsen Mamaki (Mysterious Rock) is one of the well-known mysterious geo-heritage sites that hold significant ecological species and socio-economic benefits. It is a scenic rock outcrops arranged in geo-metrical shape with distinct cone shape of geological antecedents located at Billiri of Gombe state. It possesses ecological diversity of both plant and animal

species and as well have significant cultural, historical and mysterious attachment. Finding revealed that excessive heavy rainfall, high temperature, humidity, flood and erosion exert significant impacts to Dutsen Mamaki rock formation. It was found out that heavy rainfall led to erosion which wear away the rock surface and that cause fragmentation and further break-off of the sites. Thermal expansions cause expansion of rocks which cause cracking or further breaking. Though, the rocks are cut and arrange in geo-metrical shape by nature. This might reduce tourism appeal and socio-economic activities associated with tourism activities such as; guide service, accommodation, trading and others.

KII participant revealed that chemical reaction between rock and water causes weakening of the rock structure. Also, humid condition promotes biological growth which contributed to rock degradation. Heavy rainfall facilitates transportation of sediment and debris impacting surrounding landscape of the rock outcrops. It can further destabilize the landscape that lead to rock falls. This finding is consistent with EEA-JRC-WHO 2008 & Olumuyiwa and Masengo (2017), who find that soil ecology, such as microbes, plants, and animals, is affected by climate change, and the repercussions indirectly affect the entire ecosystem (EEA-JRC-WHO, 2008; Olumuyiwa and Masengo, 2017). Head of tourism center revealed that moist condition as a result of heavy rainfall and humidity promotes microbial growth contributing to nutrient cycles that support ecosystem and biodiversity through microbial activities. Though, it can also alter microbial community composition impacting ecosystem function.

g) Sukur Cultural Landscape

Sukur Cultural landscape is a panoramic view site located in Sukur Village of Adamawa state. It is a historical socio-cultural site with cultural landscape, mysterious architectural typology, terrace farming and historical cemetery that support the existence of cultural and ecological values. Study found out that the resources and the socio-cultural and economic activities derived from the site are vulnerable to the impacts of climate change. This is because finding revealed that heavy rainfall around the landscape lead to excessive leaching that wash away nutrient and causes surface water pollution. This is considered of significant socio-economic effects due to the facts that local communities are using part of the site for terrace farming. Therefore, losses of nutrient affect plant growth and reduce crops productivity. Sometime the inhabitant and animals are using surface water for consumption. Hence, if polluted result to health problem to both human being and animal species. FGD participant narrated that “high rainfall intensity cause soil erosion damaging the physical landscape of the site affecting its integrity… …increase rainfall led to flood which impact plants and animals’ species affecting wellbeing of ecosystem… …flood affect day to day activities of the local communities through damage to the sites and terrace farmland. This reduces tourism appeal and cause effects to sources of livelihood”.

An in-depth interview participant narrated that heat stress is affecting plant and animal species within the landscape due to an increase in regional temperature. This is altering species composition, productivity, growth and development as well as future sustainability. This indicated that climate change is affecting ecological values of the panoramic view resources around Sukur cultural landscape. Therefore, measure should be taken to prevent

effect of climate change on the resources for their effective utilization, management and sustainability.

Community leader revealed that flood and erosion damage the structure and integrity of the Sukur landscape affecting cultural heritage potential and the Sukur Architectural Typology of the stony made settlement. These historical buildings are one of the significant geo-heritage views that the landscape holds. Therefore, it degradation means reduction in tourism appeal, which affect transportation, guide and restaurant service. FGD participant revealed that sometime heavy rainfall and flood lead to erosion that damage crops at lower level of terrace farmland of the landscape which affect agricultural productivity and food security. The repercussions affect local production, cause hunger, and lead to job losses, which affect the sources of livelihood of the local community inhabiting the cultural landscape.

4. Comparison of Climate Change Effects on Ecological and Social Values of Some Geo-Morphosite and Geo-Heritage Resources

This provides a comparison between one site and another on the effects of climate change on ecological and social values of Daba-Gajere Island versus Mandara Mountain and Ibi River versus Sukur Cultural Landscape geo-morphosites and geo-heritage.

a) Daba-Gajere Island Verses Mandara Mountain

Erosion and flooding destruct aquatic habitat threaten ecosystem productivity and sustainability as well as affect socio-economic activities like fishing, irrigation, trading and geo-tourism at Daba-Gajere Island. Whereas ecological diversity of Mandara Mountain is less directly impacted by flood compared to ecological species at Daba-Gajere. Though, it causes decline in tourism appeal and local extinction of affected ecosystem. Rising temperature led to change in vegetation cover, affect aquatic species especially Tilapia fish at Daba-Gajere Island. While high temperature is causing cracking and exfoliation at Mandara Mountain, it also affects plant and animal physiology affecting sustainability of mountain ecosystem. Both sites are facing ecological stress and decline in socio-economic activities like geo-tourism, accommodation, hotel and restaurants services and more.

Heavy rainfall at Daba-Gajere Island leads to flooding and erosion, while low or no rainfall can cause drought, both of which can have positive and negative impacts on aquatic species and sources of livelihood. Whereas heavy rainfall causes landslide and mass wasting at Mandara Mountain affecting mountain ecosystem and tourism appeal with repercussion on socio-economic development.

Both ecological and social values of Island geo-morphosite and Mandara Mountain geo-heritage are vulnerable to the impacts of climate change including high temperature, heavy rainfall, flood, erosion and other. Some of the ecosystems at Daba-Gajere Island are fragile and vulnerable to effect of climate change. In comparison, ecosystems at Mandara Mountain are less affected by the effects of climate change because some ecosystems are adapted to harsh conditions; however, it affects species productivity and distribution. Local communities of both Daba-Gajere Island and Mandara Mountain are affected by the effects of climate change through fishing and irrigation (for Daba-Gajere) and geo-tourism for both geo-heritage site affecting sources of livelihood and earning such as: trading, guide service, accommodation and hotel services, restaurant services and others.

b) Ibi River Verses Sukur Cultural Landscape

Ibi River hold an aquatic ecosystem while Sukur Cultural Landscape possessed a terrestrial ecosystem with varied socio-cultural significance. Both the sites are vulnerable to the impacts of climate change of change in precipitation pattern, temperature, flood and heavy rainfall which impact aquatic ecosystem through destruction of habitat. Whereas flood affect agricultural productivity at Sukur cultural landscape through upland flow that off root plant on the terrace farmland. This has impacts on both aquatic species and crop productivity.

At Ibi River, climate change alters species distributions and affects aquatic and riparian vegetation, whereas at the Sukur Cultural Landscape it alters vegetation patterns and affects ecosystem services. Also, increase flood damage aquatic habitat at Ibi River affecting fish and other aquatic species with repercussion on fishing, trading and other socio-economic activities. Whereas flood and erosion damage Sukur Cultural Heritage Site, disturbed ecosystem living in the site and affect socio-economic activities like geo-tourism, cultural activities and more.

Local communities' reliant on Ibi River for food and other sources of livelihood are more vulnerable to the effects of climate change whereas local communities reliant on Sukur Cultural Heritage are only affected by the effects of climate change through hindrance to cultural practices and livelihood sources.

5. CONCLUSION

Climate change exerts significant impacts on geo-morphosite and geo-heritage resources with heavy rainfall and high temperatures as the major causes. This is due to change in rainfall pattern and temperature anomalies. It has brought severe and far-reaching effects to the ecological values of the resources in the region. The social effects are disruption of cultural activities & values, loss of geo-heritage sites, and loss of economic activities. Each geo-morphosites and geo-heritage resources is under ecological and socio-economic stress with one category experiencing effects in similar or different magnitude to one another. Erosion and flood destruct aquatic habitat, threaten ecosystem productivity and sustainability as well as affect socio-economic activities like; fishing and irrigation. Rising temperature led to change in vegetation cover, affect aquatic species especially Tilapia fish. While it causes cracking and exfoliation as well as affect plant and animal physiology at Mountain Ecosystem.

6. RECOMMENDATION

This study recommends that:

I. State Ministry of Environment & Climate Change and state tourism centres should enforce laws against excessive exploitation of geomorphosites and geo-heritage resources to avoid migration and/or extinction of species living in the sites. This is because some ecological diversity was reported to be extinct or to have migrated from their original ecological habitat.

II. Government institutions and non-governmental organization should make effort to reduce climate change effects on the resources. This should be done by raising awareness among local communities about the dangers of resource degradation, such as quarrying, overfishing, and poaching.

III. Government institution in collaboration with non-governmental organization should involve in awareness against causes of climate change such as; bush burning, deforestation, emission of fossil fuel and others to prevent future occurrences of rise in temperature. These are among the climatic variables that have direct impacts to ecological and social values of the resources.

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