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Research Article

Monitoring Ecosystem Change and Its Impact on Livelihoods in Wamakko Local Government Area of Sokoto State: An Integrated Approach

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ABSTRACT

Wamakko Local Government Area is one of the 23 Local Government Areas of Sokoto State, characterized by a fragile dryland ecosystem. However, the ecosystem in this area is under heavy threats caused by both natural and anthropogenic drivers, a situation that adversely undermines its ability to provide adequate and qualitative goods and services necessary for human survival, environmental protection, and sustainable development. This study assesses ecosystem change and its impacts on livelihoods in Wamakko LGA, Sokoto State, Nigeria. Using an integrated approach combining Remote Sensing, multitemporal Landsat images (2000- 2024), which were used to compute the Normalized Difference Vegetation Index (NDVI), GIS analysis, and field surveys (300 questionnaires, FGD, and KII). The study reveals a significant decline in ecosystem vigor (NDVI decreased from 0.59 to 0.42, ~30%). The degradation is driven by climate variability and population-induced land-use pressures. Livelihood impacts include reduced agricultural productivity, water scarcity, and declining income. Frequent ecosystem monitoring, ecosystem restoration, and sustainable land and water management practices, among others, were recommended to mitigate the situation.

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Ecosystem Change; Anthropogenic drivers; Human Livelihood; Climate Change; Geoinformatics

1 Introduction

There is a very strong link between ecosystem, human livelihood, and climate change, particularly in the developing countries (Jibrillah et al., 2025; Jibrillah & Hamisu, 2022; Jibrillah & Shamaki, 2024; Wang et al., 2022). Healthy ecosystems are fundamental to human livelihoods, well-being, and sustainable development as they provide benefits to the people, such as food, clean water, grazing lands, air, fertile soil, and lots more, collectively referred to as ecosystem goods and services (Tehrani et al., 2023; Jibrillah et al., 2025). An ecosystem is a complex system of plants, animals, and microorganisms, communities, and their associated non-living environment interacting as an ecological unit. Ecosystems could be natural, such as a forest, grassland, a desert, a river ecosystem, or human-managed ecosystems such as agro-ecosystems or rangelands (Jibrillah, Choy, et al., 2018; Jibrillah et al., 2025; Xu & Guo, 2015; Zlinszky et al., 2015). Rapport et al. (1998) defined a healthy ecosystem as "one that is stable and sustainable, maintaining its organisation, autonomy over time, and is resilient to stress".

Human well-being and sustainable development are, to a very large extent, dependent upon the condition of the earth's ecosystem and the goods and services it provides. Ecosystem goods and services provide the foundation for human survival and improved livelihoods as it provides the human population with a variety of goods and services such as food production, provision of clean water, timber production, disease control, climate modification, and air quality regulation, among others (Goroshi et al., 2014; Jibrillah et al., 2019; Jibrillah & Saleh, 2023). However, the global ecosystem is in a state of constant change, which could be positive or negative, depending on the interplay of different drivers responsible for the change (Jibrillah & Hamisu, 2023; Parra, 2022; Primmer & Furman, 2012; Rapport et al., 1998). Changes in the structure and function of ecosystems affect human well-being in many ways. As such, maintaining a healthy ecosystem is thus critical for the survival and sustainable development of the people, particularly the rural poor (Cui et al., 2013; Jibrillah et al., 2019; Jibrillah & Hamisu, 2022).

In line with the global trend, however, the dryland ecosystem of Wamakko Local Government Area in Sokoto State is continuously under heavy threat by the forces of climate change occasioned by both natural and human-induced drivers. This situation becomes even more serious considering the facts that significant proportions of the population in this area depend on economic activities that are climate change sensitive and are directly linked to the ecosystems, such as rain-fed crop cultivation, livestock rearing, fisheries, and forest products extractions. Any negative change to the ecosystems will therefore pose a serious threat to the basic foundation upon which the inhabitants of the area depend for their livelihoods and economic development.

Nevertheless, ecosystems and ecosystem processes in this area are constantly changing in response to both

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natural and anthropogenic drivers such as land degradation, urban expansion, unsustainable farming and fishing practices, and unrestrained fuel wood extractions, among others. Recent climate change and variability are now aggravating these challenges, resulting in the continuous alteration of both the structure and functions of the fragile dryland ecosystem of the area (Abdullahi et al., 2014; Jibrillah, 2018; Jibrillah & Hamisu, 2022; Jibrillah & Saleh, 2023; Vogelmann et al., 2012). Consequently, frequent monitoring and assessment of the state of the ecosystem in this area is essential in order to track changes that could negatively affect the ecosystem and its ability to provide essential goods and services.

However, to achieve this, it will require the integration of many diverse sources of data regarding different properties of the ecosystem, which renders the traditional field survey methods extremely ineffective and time-consuming (Tehrani et al., 2023; Asner et al., 2003; Stoll et al., 2015; Ugoyibo et al., 2021). Integrated and effective ecosystem monitoring and assessment using a combination of field surveys and Geoinformatics will provide a cost-effective, continuous, clear, and deep understanding of how the dryland ecosystem of the study area is responding to threats posed by different direct and indirect drivers, both natural and anthropogenic. In conjunction with field survey techniques, Geoinformatics has known potentials to map various properties of ecosystem, support standardized processing and at the same time, allow for rigorous accuracy assessment and has been widely used to study different components and properties of ecosystem at both global, regional and local scales (Benabou et al., 2022; Dahl, 2006; Jibrillah & Shamaki, 2024; Stoll et al., 2015). This can, to a large extent, help in estimating the ecological and economic effects of direct and indirect drivers of ecosystem change and how they affect the livelihoods and overall sustainable development in the study area, and thus, enable both the individuals and authorities to develop and assess adaptation and mitigation measures.

2 Materials and Methods

2.1 Study Area

The study area is Wamakko Local Government Area of Sokoto State, which, together with the other Local Government Areas such as Sokoto North, Sokoto South, Kware, and Dange-Shuni, constitutes the Sokoto Metropolis. Geographically, the area is located between latitudes 13^0 00′ to $13^0$30′N and longitudes $5^0$00′ to $5^0$30′E. Wamakko shares common boundaries with other Local Government areas in the state, such as Tangaza and Kware to the North, Yabo and Bodinga to the South, Binji, Silame to the West, as well as Sokoto North, Sokoto South, and Dange Shuni to the East (Figure 1). The area is made up of combinations of urban, suburban, and peri-urban landscapes, providing an ideal site for analysing ecosystem dynamics.

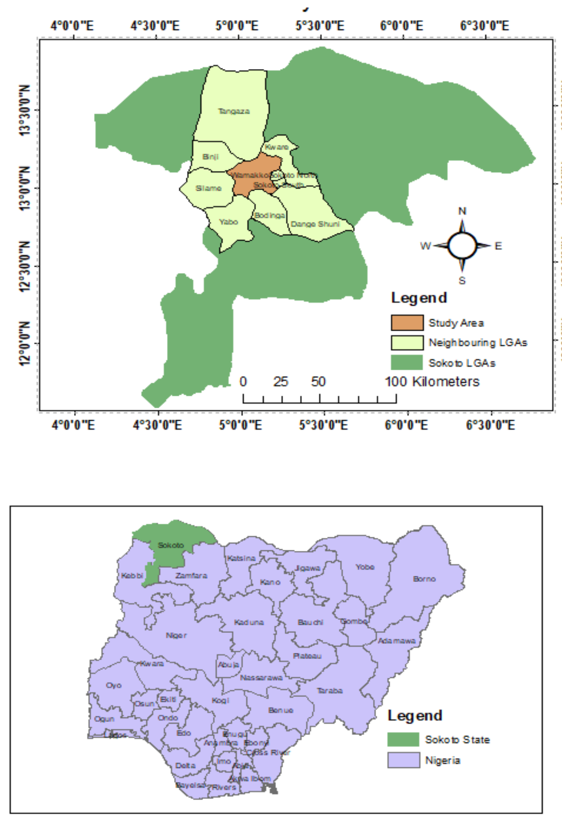

Figure 1: The Study Area.

The state is characterized by a tropical continental climate with a very fragile ecosystem. Temperatures are high throughout the year, while rainfall is low and erratic, lasting for barely more than five months in a year. Average annual rainfall barely exceeds 630 mm while temperatures could be as high as 45^{o}C or even higher, particularly during the months of March, April, and May, which usually record the highest temperatures (Eniolorunda & Jibrillah, 2020; Jibrillah et al., 2019). The area is also characterized by Sudan Savannah type of vegetation dominated by short grasses and shrubs, interspaced by short woody trees, which together provide a vast grazing land for the large population of livestock and wild herbivores in the area. The grasses look green and luxuriant during the rainy season but eventually wither and die during the dry season, leaving the more drought-resistant thorny shrubs, which usually shed their leaves as an adaptation to reduce water loss through transpiration (Eniolorunda & Jibrillah, 2020; Jibrillah et al., 2019). Crop cultivation, animal husbandry, and fishing are the dominant economic activities in the area. However, almost everybody in the area is engaged in one form of non-farming activity or the other, both during the wet and dry seasons, to basically supplement the dwindling income derived from both lowland and upland farming

(Eniolorunda & Jibrillah, 2020; Jibrillah et al., 2019; Jibrillah, Jaafar, et al., 2018).

2.2 Data Sources

Remote Sensing Satellite data (Landsat) provide the basic data for monitoring ecosystem change, while field survey techniques, including questionnaire administration, Focus Group Discussion (FGD), and Key Informant Interview (KII), were used to assess the impacts of the observed changes on human livelihoods in the area. Multi-temporal Landsat data covering the study area spanning from the year 2000 to 2024 were downloaded from the official site of the United States Geological Survey (USGS) via Earth Explorer and processed to produce Normalised Difference Vegetation Index (NDVI) and used as a surrogate for ecosystem vigor due to the strong positive correlation between the two (Filipponi et al., 2021; Jibrillah, 2018; Jibrillah et al., 2019; Jibrillah & Saleh, 2023; Qi et al., 2024). Landsat Images for the years 2000, 2005, 2010, 2015, 2020, and 2024 (Table 1) were used.

Table 1: Remote Sensing (Landsat) Data used

Image (Sensor)	Acquisition Date	Spectral Resolution	Spatial Resolution
Landsat 7 ETM+	05/09/2000	8 Bands	30 Meters
Landsat 7 ETM+	18/09/2005	8 Bands	30 Meters
Landsat 7 ETM+	05/09/2010	8 Bands	30 Meters
Landsat 8 OLI	18/09/2015	11 Bands	30 Meters
Landsat 8 OLI	18/09/2020	11 Bands	30 Meters
Landsat 8 OLI	18/09/2024	11 Bands	30 Meters

The choice of the data was based on the availability of the cloud and scanline error scenes of the study area, while the choice of the month of September was based on the fact that vegetation vigour was at its peak during the period.

2.3 Processing and Analysis of Satellite Data

All processing operations were performed using ArcGIS software Version 10.8. These include clipping of the study area from the larger datasets (Figure 2), computations of Normalised Difference Vegetation Index (NDVI) to use as a surrogate for ecosystem Vigour and monitor change in vegetation cover, as well as Normalised Difference Built-up Index (NDBI), to monitor urban expansion as one of the drivers of ecosystem change in the study area. NDVI is calculated using Red and Near-infrared bands as:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

where NIR represents reflectance value in the Near infrared region of the electromagnetic spectrum and RED represents the reflectance in the red region.

While NDBI is derived using the shortwave infrared band and near infrared band, as:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

where SWIR and NIR represent the reflectance values in the shortwave infrared and near infrared, respectively.

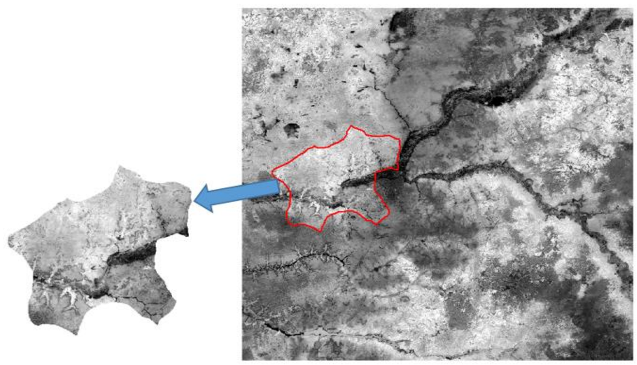

Figure 2: Clipped Study area

2.4 Field Data Collection/Sampling Techniques

To assess the impact of the observed ecosystem change on the livelihood of the inhabitants of the area, a combination of a structured questionnaire, FGD, and KII was used. A combination of stratified and random sampling techniques was used. At the first stage, the major economic activities in the study area that heavily depend on the ecosystem and its services were classified into different strata, namely: farming, animal rearing, and fishing strata. In the second stage, 100 structured questionnaires were administered randomly in each of the strata, giving a total of 300 questionnaires. In addition, FGD and KII were also conducted with some selected officials of the farmers, herders, and fishermen association, and some officials of the ministries of environment, agriculture, and Sokoto Urban and Regional Planning Board in order to triangulate the information obtained from the questionnaires. The result was summarized using simple descriptive statistics such as frequency tables, percentages, pie charts, and bar graphs, while correlation analysis was used to measure the relationships between different variables.

3 Results

3.1 Nature Ecosystem Changes in the Study Area

Changes in the ecosystem could be positive or negative, as well as gradual or abrupt, depending on the interplay of different drivers responsible for the change. However, results from the analyses of remote sensing data signify a gradual but persistent negative change in the ecosystem of the area (Figure 3). The average NDVI values in the area, which were used as a surrogate for vegetation vigour, in the area revealed a steady decline from 0.59 in the year 2000 to 0.42 in 2024, representing a close to 30% decline in less than a 25-year period. This kind of negative change is what Rapport et al. (1994) and Jibrillah et al. (2025) described as "Ecosystem Distress Syndrome (EDS)," which, according to them, is prevalent in all ecosystems, both terrestrial and aquatic ecosystems. They noted that this syndrome undermines the ability of the ecosystem to provide adequate and qualitative goods and services necessary for human livelihood and sustainable development, such as food supply, clean water, air purification, and control of environmental degradations such as floods and desertification. This will in turn have multiple effects on the livelihood of human livelihoods, particularly in areas where the inhabitants largely engage in economic activities that ecosystem dependents, such as in Wamakko Local Government Area.

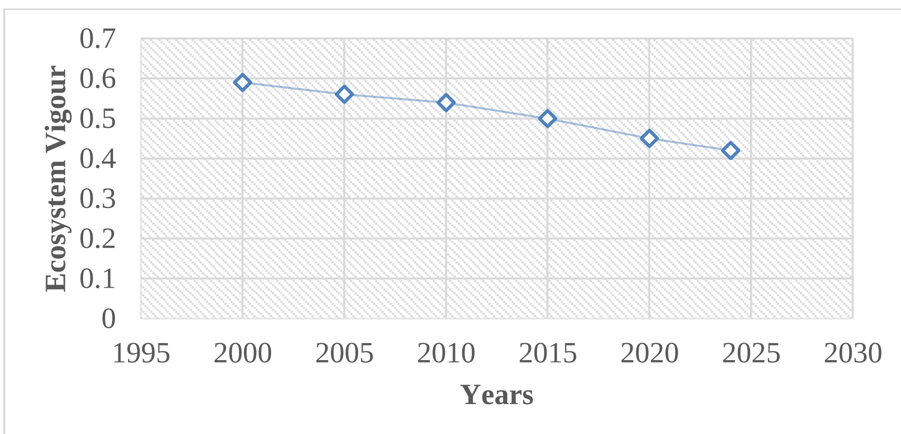

Figure 3: Trend in Ecosystem Vigour in Wamakko LGA

3.2 Causes of Ecosystem Change in the Area.

Many drivers of ecosystem change, both natural and mostly anthropogenic, could be responsible for the observed ecosystem change in the area, such:

3.2.1 Climate

The study area is located in the dryland ecosystem of Northwestern Nigeria, where rainfall is the most important climatic variable determining ecosystem vigour (Health and productivity). Consequently, recent climatic change and variability have had a negative impact on the ecosystem of the area. Rainfall records from the synoptic weather stations with the catchment of the study area revealed a declining trend in the total annual rainfall of the area, which correlated positively with computed ecosystem vigour derived from the analysis of satellite remote sensing data of the area, with a correlation coefficient of 0.94 (Figure 4).

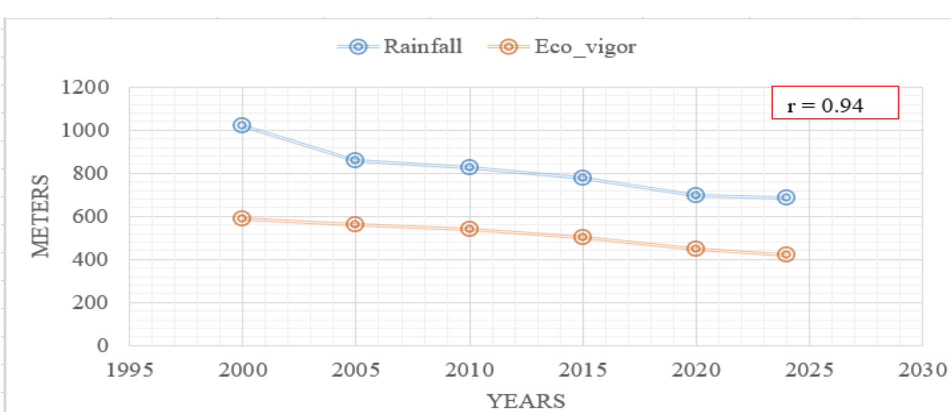

Figure 4: Relationship between Total Annual Rainfall and Ecosystem Vigour

The above figure (Figure 4) depicts a strong positive relationship between the climate of the area (Rainfall) and ecosystem change, as declining rainfall patterns lead to a decline in the ecosystem health and productivity (vigour) of the ecosystem area. This will, in turn, have multiple negative effects on the livelihoods of the inhabitants of the area.

3.2.2 Population Growth

Population increase (growth) and associated anthropogenic activities are yet another active driver causing ecosystem change in the study area. This is because an increase in population size in the area over the years continues to create more demand and consumption of environmental resources for food, residential areas, grazing land, and other urban services and utilities such as roads, schools, hospitals, and commercial centres, all of which are developed to the detriment of vegetation cover, which is the most important component of the ecosystem. Again, as the demand and consumption of environmental resources increase, more waste, both solid, liquid, and gaseous, is generated and thrown into the environment from homes, factories, commercial centres, agricultural fields, and the like. This also aggravates environmental pollution of the land, air, and water bodies, which to a very large extent undermines ecosystem vigour in the area. Recent population projections from the National Population Commission revealed an increasing trend in the total population of the study area from 187,113 persons in 2005 to 309,390 persons in the year 2024, representing over 150% increase. This population increase in the area is a result of both natural increase and massive rural-urban exodus of the people into the area due to escalating insecurity in the neighbouring Local Government areas in the state.

Again, a perfect negative correlation exists between population growth and computed ecosystem vigour in the area, as revealed by Figure 5.

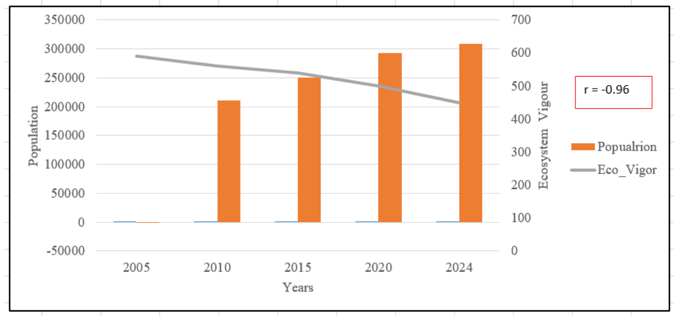

Figure 5: Relationship between Population Growth and Ecosystem Vigour

3.2.3 Impacts of Ecosystem Change on the Livelihoods

The observed ecosystem changes present multiple negative impacts on the livelihoods of the inhabitants of Wamakko Local Government Area. To assess these impacts, however, 300 structured questionnaires were administered to three major groups of people in the area whose major livelihood activities heavily depend on the ecosystem and the goods and services it provides. These major groups include farmers, herders, and fishermen, with 100 questionnaires administered to each of the groups through a combination of stratified and random sampling techniques. The results were also triangulated through FGD and KII, as summarized in Table 2.

Table 2: Impacts of Ecosystem Change on the Livelihoods

Impact	Frequency	Percentage	Ranking
Loss of Vegetation cover	72	24	1st
	63	21	2nd
Declining Food Production	43	14	3rd
Increasing Water Scarcity	31	11	5th
Declining Livelihood and Family Income	35	12	4th
Conflicts over Land and Communal Resources	30	10	6th
Migration	26	8	7th
Total	**300**	**100**	

Although all the respondents were unanimous about the occurrence of all the above impacts in the study area, they were, however, divergent as to which of the above is the most conspicuous and most challenging impact. Loss of vegetation cover is by far the most threatening impact, which also affects all other components of the ecosystem in the area due to the dominant role of vegetation in maintaining ecosystem balance and integrity. A total of 24% of the respondents consider loss of vegetation as the most serious impact of ecosystem change in the area, which is mostly caused by land clearance in response to the demand for residential areas and other urban services created by the rapidly growing population of the area. Another important driver claiming a large chunk of the vegetation in the area is mineral mining of mostly limestone, as the area houses two large cement factories

(Sokoto Cement Factory and BUA Cement Factory), which are actively involved in limestone mining in the area. Analysis of remote sensing data (Figure 6) revealed a heavy loss of vegetation cover in the area from 69,522.30 hectares of land in 2000 to 47,275.16 hectares in 2024, representing over 32% decline in Vegetation cover.

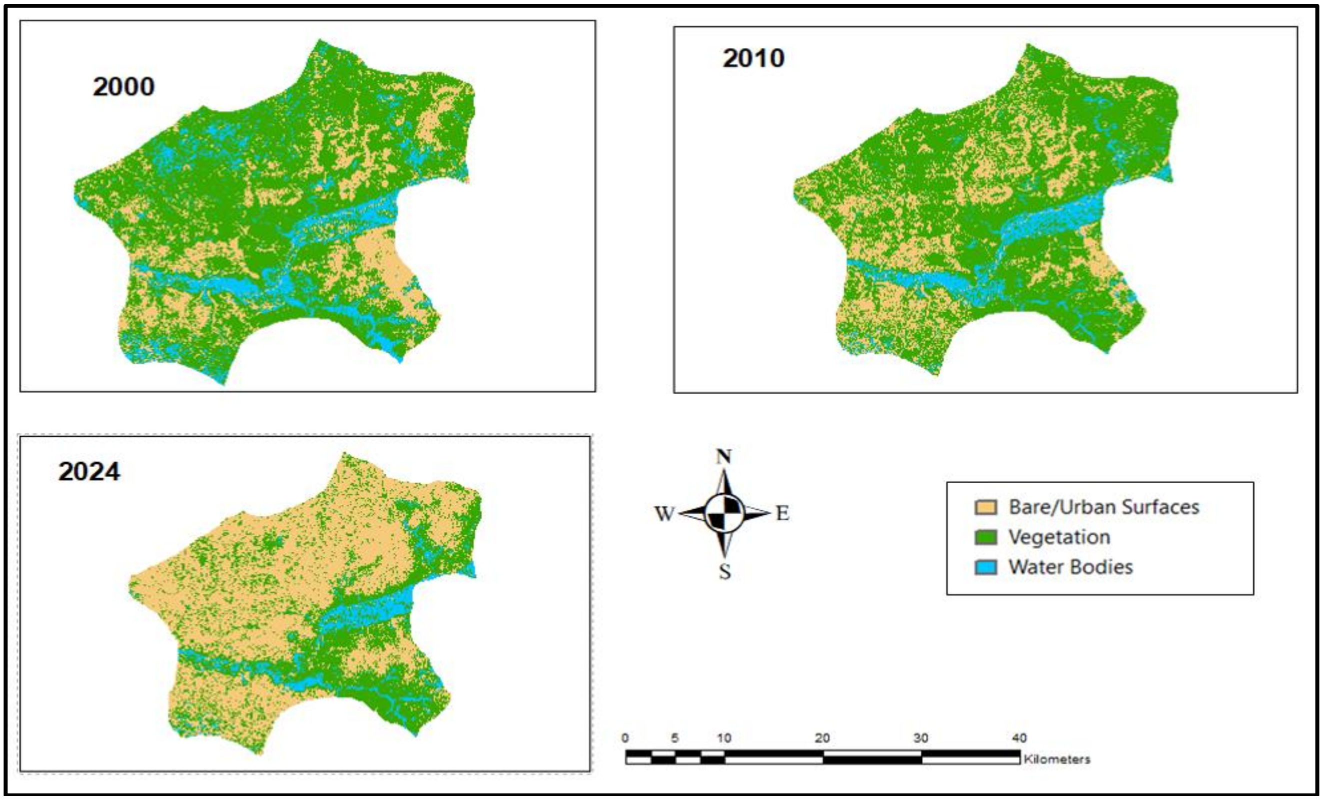

Figure 6: Temporal Change in Vegetation Cover

Destruction of farmlands and grazing areas, which further leads to declining food productions are other serious impact of ecosystem change in the area. Declining rainfall, increasing temperature, and loss of vegetation cover combine to destroy vast expanses of agricultural and grazing areas, thereby creating a serious challenge to food production in the area, which has been on the decline, as explained by the inhabitant of the area through their responses on the questionnaire and during FGD and KII sessions. This further leads to the declining family income and livelihoods among the inhabitants of the area, as most of them largely depend on farming and animal husbandry as their major economic activities. Destruction of farmlands and grazing areas, therefore, created a serious challenge that forces many of them to abandon farming and animal husbandry to migrate to urban centres in search of jobs, thereby compounding the problems bedeviling the urban areas. Increasing water scarcity due to increasing demand by the growing population, as well as low recharge of both surface and ground water sources due to declining rainfall couple with the increasing water loss through evapotranspiration, exacerbated by the recent increase in temperature, is yet another serious impact of ecosystem change in the area with serious consequences to farming, animal rearing, and fishing communities in the study area.

4 Conclusion

Based on the evidence from this research, it is concluded that the ecosystem in this area is under increasing challenges and threats from many drivers, both natural and anthropogenic. The combined impacts of which limit the ability of the ecosystem to provide adequate and qualitative goods and services necessary for sustainable development of the area, a situation generally referred to as "Ecosystem Distress Syndrome (EDS)". This situation presents serious challenges, including threats to food security and sustainable livelihoods for the inhabitants of the area. Improved livelihood and overall sustainable development of the area, therefore, depend to a very large extent on effective management of the ecosystem upon which the majority of the people in the area depend. To achieve these, the following recommendations are put forward.

Regular and effective ecosystem monitoring and assessment, including an efficient system of climate and weather observations, monitoring, and forecasting. This will serve multiple purposes as it will help in tracking the condition of the physical environment and detecting negative changes in the structure and functions of the ecosystem, monitoring the impacts of developmental projects on the ecosystem, as well as assessing the effectiveness of mitigation and adaptation policies and programmes.

Integrated and sustainable land and water management involves all measures that protect soil from erosion, salinization, and other forms of land and water degradation. They include controlling the cultivation of land without replacing its nutrients through manure application and appropriate application of chemical fertilizers, controlling overgrazing through transhumance, which will ensure rational use of rangeland, controlling unsustainable irrigation practices, using traditional water harvesting techniques to store water in the rainy season for use during the dry season, and diverse soil water conservation measures.

Mitigation and adaptation capacities of the farmers, livestock pastoralists, and artisanal fishermen should be strengthened to enable them to address the low productivity resulting from EDS, climate change, and associated challenges. This could be achieved by training and encouraging people to pursue alternative means of livelihood that are less dependent on the environment and climate, and yet provide sustainable income. These could include dry land aquaculture for the production of fish and crustaceans.

In view of the important roles of vegetation in supporting, protecting, and stabilizing the ecosystem, conscious efforts and measures should be put in place by all stakeholders to protect and conserve the vegetation cover in the area. This is necessary to protect soil from wind and water erosion. Properly maintained vegetative cover also prevents loss of ecosystem services during drought episodes, aids biodiversity preservation, and improves carbon sequestration potentials, thereby minimizing greenhouse gas concentration in the atmosphere.

Finally, the state should encourage and provide effective Civic and Environmental Education that emphasizes the appreciation for and interaction with natural and social environment, as well as equip people with the necessary skills required for responsive behaviours, informed decisions, and constructive actions towards the environment. Effective environmental education will rise and strengthen civil society's concern for the environment. This could be provided through training and workshops where environmental problems are addressed through systematic and integrated approaches to climate change and its challenges.

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