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Spatiotemporal Variation of Land Use Pattern and Land Cover Changes in Gidan Kwano Watershed Area in North Central Nigeria

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Abstract

Land Management Systems (LMS) are institutional frameworks complex by the tasks they must achieve, national, cultural, political, and judicial settings and technology. The urbanisation process in Nigeria has increased since the 1960s because of the crude oil boom era and other government-backed industrial initiatives and investments. This study employed the use of both primary and secondary sources of data. Preliminary data comprise methods of land use, types of agricultural activities carried out and the process of working on the land by the farmers within a 10 km radius. The secondary data involved the interactive digital and visual techniques of the Geographical Information system for five seasons, with each having a ten-year interval span within 1975 to 2015. Statistical analysis was carried out with SPSS 2013 and XLSTAT 2015. Five land use and land cover types were observed within the Gidan Kwano watershed, which includes wetlands (WL), water bodies (WB), bare grounds (BG), vegetation (VG), and settlements (SL). The most prevalent landform in the study area during the 1975 period was the vegetative area which was 50% of the total landmass. Thus, the vegetation (VG) covered half of the Gidan Kwano watershed. However, the vegetative area decreased substantially during the study period of 1975 to 2015. It was observed that the vegetation (VG) within the study area had the highest percentage of coverage, of 34%. During the study period, a significant decrease was observed in the WL, WB and VG areas. It was also concluded that due to the built-up places, the infiltration of surface runoff from rainwater would be drastically reduced as most of the sections are paved for construction activities while a section of the study area is covered with rock outcrops and farmlands.

Keywords

Agriculture, Bare Land, Land Use, Settlement, Vegetation and Wetland

1. Introduction

Land is a limited source for which competition intensifies because of increasing population, economic activities etc. [1] [2] [3]. Land Management Systems (LMS) are institutional frameworks complex by the tasks they must achieve, by national, cultural, political, and judicial settings and by technology [4]. Numerous developing and developed countries should set up their LMS dependent on their familiarity of property rights, restrictions, and tasks to manage the relationship between land and people for effective land governance and property rights system due to their fundamental role to the overall process of economic and political development [5] [6].

The urbanisation process in Nigeria has increased since the 1960s because of the crude oil boom era and other government-backed industrial initiatives and investments [7]. Such activities led to population growth in most urban settlements and the movement of people from rural communities to the urban centers where settlement needs are not reached, with slums developing because of unplanned lands without infrastructure. The Turkish Statistical Institute data stated that 75 per cent of the country population lived in rural, and 25 per cent lived in urban areas in the 1950s; the current ratio appears to be the opposite, with 23 per cent and 77 per cent respectively [8]. Complicated construction of infrastructure and technical qualifications has now reached an advanced stage of their economic life. The areas hosting them have brought about social breakdowns due to their failure to adapt to the city's growing and changing dynamics [9].

Since the last century, soil erosion accelerated by human activities has become a severe environmental problem, most especially in developing countries where there are no existing policies to protect the land from excessive usage [10]. It has multiple environmental effects by negatively affecting the water supply, reservoir storage capacity, agricultural productivity, and freshwater ecology of the region [11]. Soil erosion risk varies from place to place depending on the nature of the watershed (topography, shape), the soil characteristics, the local climatic conditions and the land use and management practices [12] [13].

Good land management practice is known to have great importance for soil which is believed to significantly influence soil quality [14] [15]. The most significant factors in soil quality are the physical composition and fertility of the soil [16], whose characteristics depend on the size and stability of soil aggregates, the organic carbon content of the soil and other agents [17].

In a recent review, [18] explained how man's use of soil and natural resources in their quest to face the food demand of the world population approaches the limits of three main constraints: land use, water use, and ability of agriculture to produce crops.

Changes in land use are generally considered one of the most critical factors of global change [19]. The changes had a limited impact which geographically limited the concerns for agricultural development in the last three centuries [20]. Studies worldwide have revealed that there seems to be a similar evolution path in land cover changes, with similar transition processes [21] [22]. As population density increases, periods of ever more intensive agriculture activities succeeded each other [23]. This intensification has fueled the rise in urban demand for economic incentives. This typical pattern of transition processes repeated itself in accelerated or slowed down form, or even modified, in different historical periods or study areas. Studies have confirmed that agriculture has been the leading cause of deforestation in most of the world from prehistoric times to industrialisation [5] [24]. They likewise indicated how from the beginning of industrialisation, this procedure quickened and finished in the second half of the twentieth century, after which the surface area occupied by forests started to increase again in many industrialised nations.

Soil erosion is a significant threat to agricultural sustainability because soil resources are finite on a human time scale [10]. Sustainable agriculture depends, among many other issues, on how efficiently it can use the natural resources, specifically soil and water [25]. This study is aimed at identifying the impact of land-use change on soil erosion within the area and its impact on agricultural productivity.

2. Materials and Methods

2.1. Study Area

Niger State has a total landmass of 76,363 km^2 with twenty-five local government areas, of which Bosso is one. Bosso Local Government Area has a total landmass of 1592 km^2. This local government area houses the study area with a proximity to Minna, the capital of Niger State, located in the north-central region of Nigeria (**Figure 1**). The study area is physiographically divided into alluvial plain, local valleys, and undulating upland, followed by gentle hill slopes. The study area falls within the agro-climatic zone, between 720˚28'E to 730˚37'E longitude and 200˚00'N to 200˚05'N latitude. The area comes under a subtropical, semi-arid climate and receives an average annual rainfall of between 800 mm and 1100 mm. The heaviest rainfall period is experienced from July through to September of each year. The temperature of the study area ranges between 27˚C and 42˚C [26], with the lowest and highest temperature months as December/January and March/April, respectively. The study was performed in the Gidan Kwano area in Bosso Local government area within a radius of 10 km from the Federal University of Technology, Minna, Niger State. The topsoil texture is sandy loam or loam with a medium to high water infiltration rate. Agricultural activities are significant occupations of the residents of the people

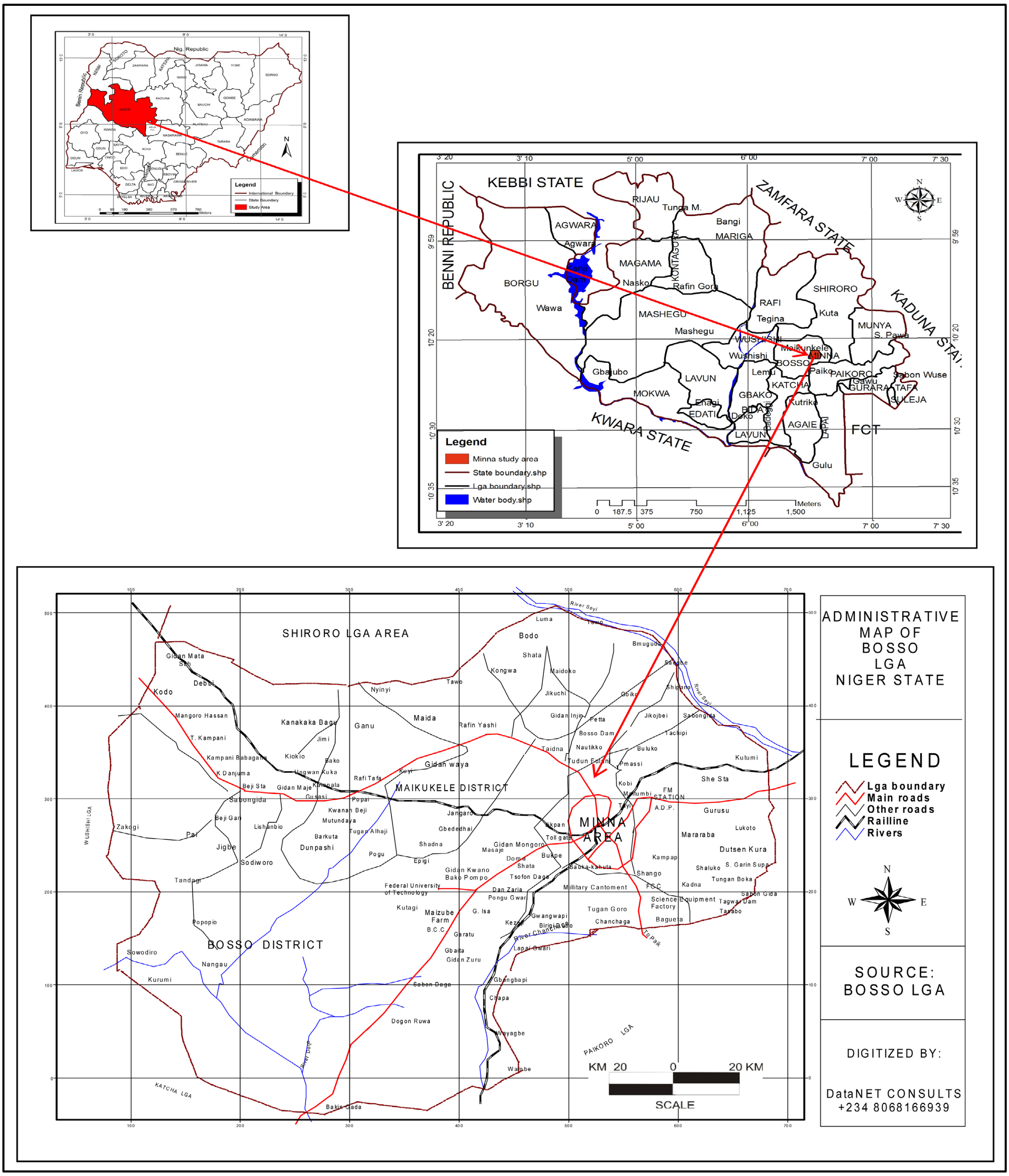


Figure 1. Map of Nigeria showing the extracted map of Niger State and the study location.

staying in the area with very few engaged in livestock farming.

2.2. Primary Data

This study employed the use of a primary source of data collection. Preliminary data comprises methods of land use, types of agricultural activities carried out and the process of working on the land by the farmers within a 10 km radius.

2.3. Secondary Data

The secondary data are presented in Table 1 below.

2.4. Generation of Thematic Maps

The interactive digital and visual techniques of the Geographic Information system was employed to generate the various maps of the watershed at a 1:50,000 scale. The remote sensing satellite data of IRS-1B (LISS-II) for five seasons with each having a ten-year interval of a span of 1975 to 2015 were acquired. The ground truth data were collected and used for preparing thematic maps. Base maps and derived maps were prepared using the collateral and satellite data. The base maps were then converted into digital maps using screen digitiser software used for land use classification.

To obtain accurate land use maps of the study area, a combination of supervised classification with a decision tree approach were utilised. Firstly, guided by images with higher spatial resolution such as Landsat TM, SPOT and Google Earth maps, several training areas were selected. The Landsat series of satellites has the most comprehensive archive of earth observation satellite imagery to date and provides an excellent baseline resource for moderate-resolution land cover change detection studies. A support vector machine was used to classify the satellite images into five LULC types: water body, wetland, vegetation, Settlement (built-up land) and bare ground. Finally, based on a set of rules on attributes such as DEM and EVI (Enhanced Vegetation Index), the LULC was determined based on prior knowledge and existing data. The final land use map distinguished the various categories. The accuracy of classification was evaluated using the 30-m resolution TM images covering the study areas.

2.5. Secondary Data

Analysis was carried out on the Land-use activities in the study area using the post-classification change comparison method, which is considered the exact

Table 1. Secondary data collection process.

Data set	Year	Format	Scale	Source
Topographic map	2020	Digital Vector format	1:50,000	FUT Minna Survey Dept.
Landsat images	1975, 1985, 1995, 2005, 2015	Digital raster	1:50,000	https://www.earthexplorer.usgs.gov
Google earth image	2020	Digital raster		Google earth

process that presents the nature of change [27]. The Stratified random sampling was used to generate test pixels, and accuracy assessment statistics in the form of percentage accuracy was employed to determine the percentage usage of the land within the study area. Accuracy of classification can be considered suitable for a varied urban border from the medium resolution satellite images. Several researchers [28] [29] [30] have employed the use of Maximum Likelihood Classification (MLC) to determine the level of land-use change. The magnitude land-use change for the study areas was determined using Equation (1) while the percentage change was calculated with Equation (2).

$$\text{Magnitude} = \text{Magnitude of the new year} - \text{Magnitude of the previous year} \quad (1)$$

The percentage change (trend) for each of the land-use types was determined using Equation (2).

$$\text{Percentage Change} = \frac{\text{Magnitude of change} \times 100}{\text{Base Year}} \quad (2)$$

2.6. Statistical Analysis

Statistical analysis was carried out with SPSS 2013 (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.) and XLSTAT 2015. Skewness and coefficient of variations were carried out to compare the values between the various land use and land cover patterns during the study period of fifty years. Significant differences were detected based on a probability level of $p < 0.05$.

3. Results and Discussion

Better usage of natural resources stresses progressively more thorough inventories of its constituents and an examination of the changes which must have taken place in the time past to understand the present situation and what the future will look like when projected. In this study, the image processing methodology was discovered to be efficient in producing similar LULC data over time, regardless of the variations in a spatial, spectral and radiometric resolution of the satellite data.

The Gidan Kwano watershed area covers a large part of the study area, one of the significant areas for agricultural activities and the income region for livestock production for the residents of Minna and her immediate environment [31]. Thus, the income of many people in the study area and the immediate environs depends on these lands. Five land use and land cover types were observed within the Gidan Kwano watershed, which include wetlands (WL), water bodies (WB), bare grounds (BG), vegetation (VG), and settlements (SL). The quantification of LULC change for the analysed categories is given in **Figure 2**.

The most prevalent landforms in the study area during the 1975 time period was the vegetative area which was 50% of the total landmass. Thus, the vegetation (VG) covered half of the Gidan Kwano watershed. However, the vegetative area decreased substantially during the study period of 1975 to 2015. This observation is similar to the findings of [32] that compared the spatial and temporal

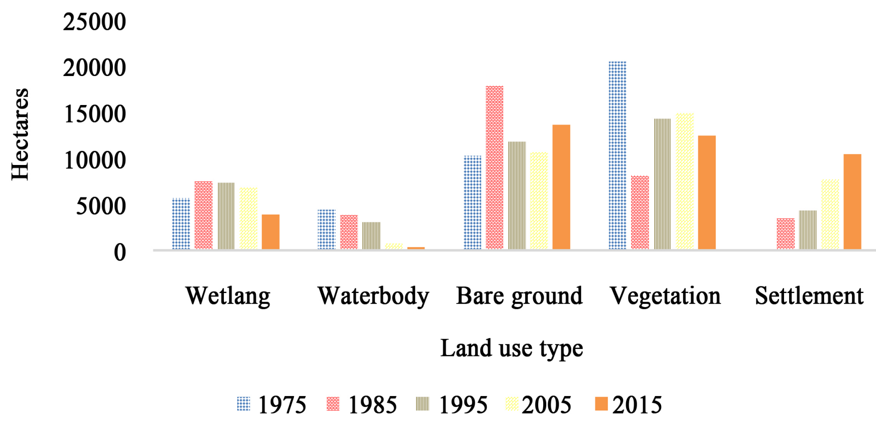
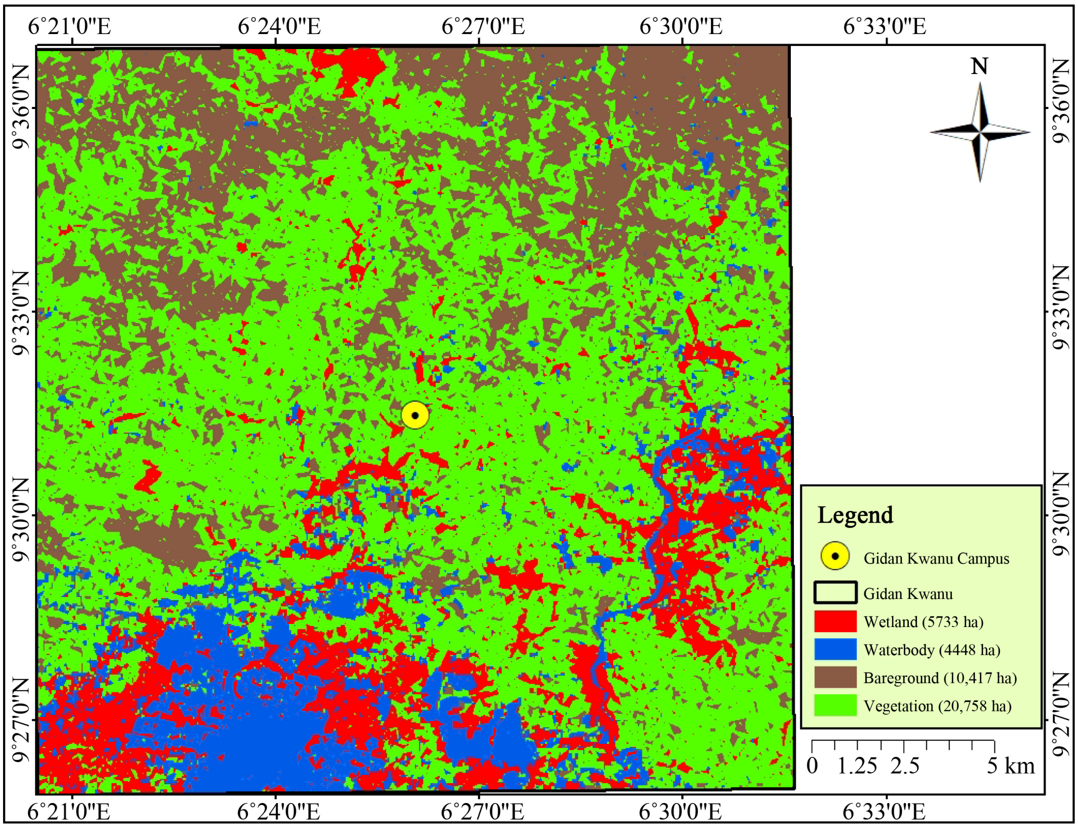


Figure 2. Variability pattern as a function of urbanisation for 50 years.

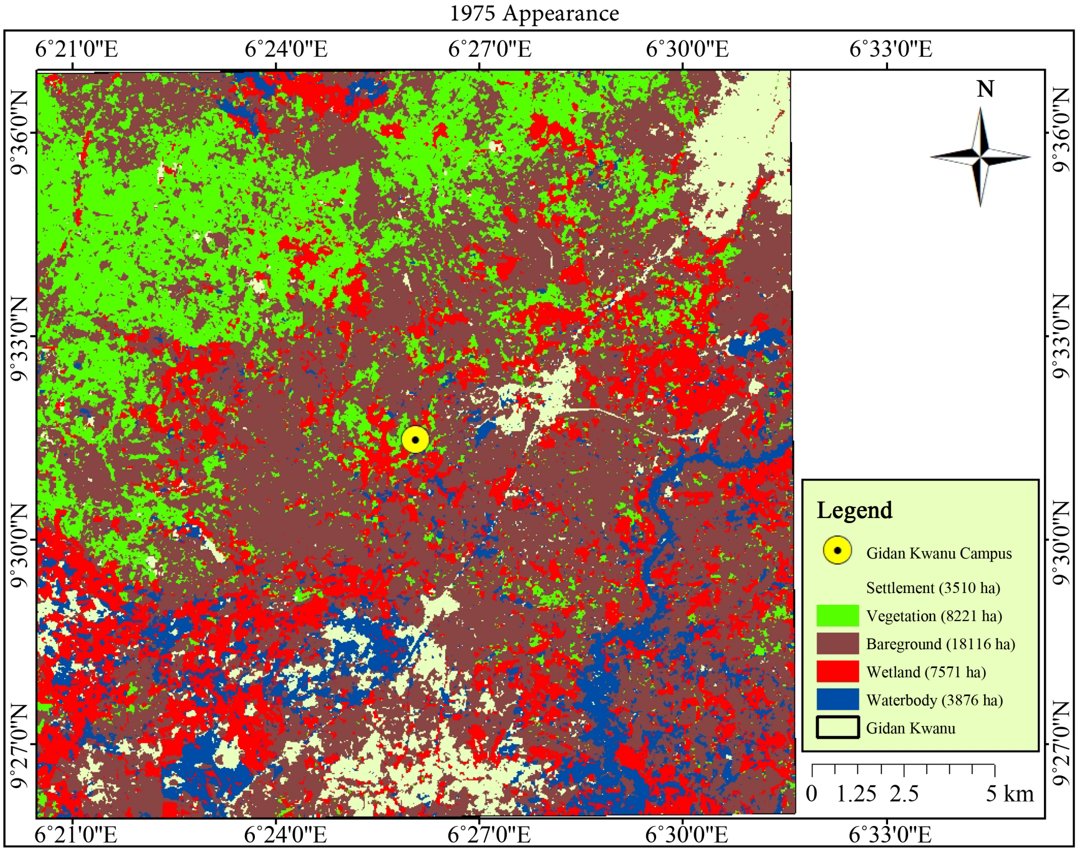
dynamics of urban expansion for some pioneer cities, Guangzhou and Shenzhen from 1975 to 2015 in China with regards to rapid urbanisation. Again, from the study area, BG was observed to be 50% of the cultivated area over the same study period of 1975, which is similar to the findings of [33] and [34] who examined land use/land cover changes, their drivers and implications while contrasting agro-ecological environments of Ethiopia, and land cover change in West Africa over four decades as population pressure increased, respectively. The vegetation and wetlands were used for agricultural purposes, which accounted for the large turnout of agricultural produce within the study period. The combination of the WL, BG and vegetation accounted for 36,908 out of the total landmass of 41,356 hectares of land that most Minna residents preyed upon as farmlands. This value shows clearly that agriculture plays an essential role in the socio-economic development of the watershed. **Figure 3** presents the GIS mappings for the five seasons of the study area. Between 1975 and 1985, it was observed that 0.15% (62 hectares) of land was lost to possible degradation, more farming activities and settlement. The wetland in the year 1985 was observed to have increased by 24%, *i.e.*, from 5733 to 7571 hectares, while the water bodies reduced in size by 12.86%. This could have resulted from the tremendous increase in deforestation and agricultural processes in the study area. For the possible change in climate, an increase in farming activities and settlement were observed for ten years which showed a drop in vegetative section by 60.39%. Subsequently, a gradual pick up of vegetative growth of 43.26% was also observed over the next ten years (ending 1995).

The study area of Gidan Kwano underwent the most significant growth in terms of human settlement and further fragmentation between 1995 and 2015. One of the primary reasons attributed to the expansion in the area of human settlement was the relocation of the Federal University of Technology Minna, and the National Examination Council of Nigeria (NECO) to their permanent sites in Gidan Kwano in the years 2007 and 2008 respectively.

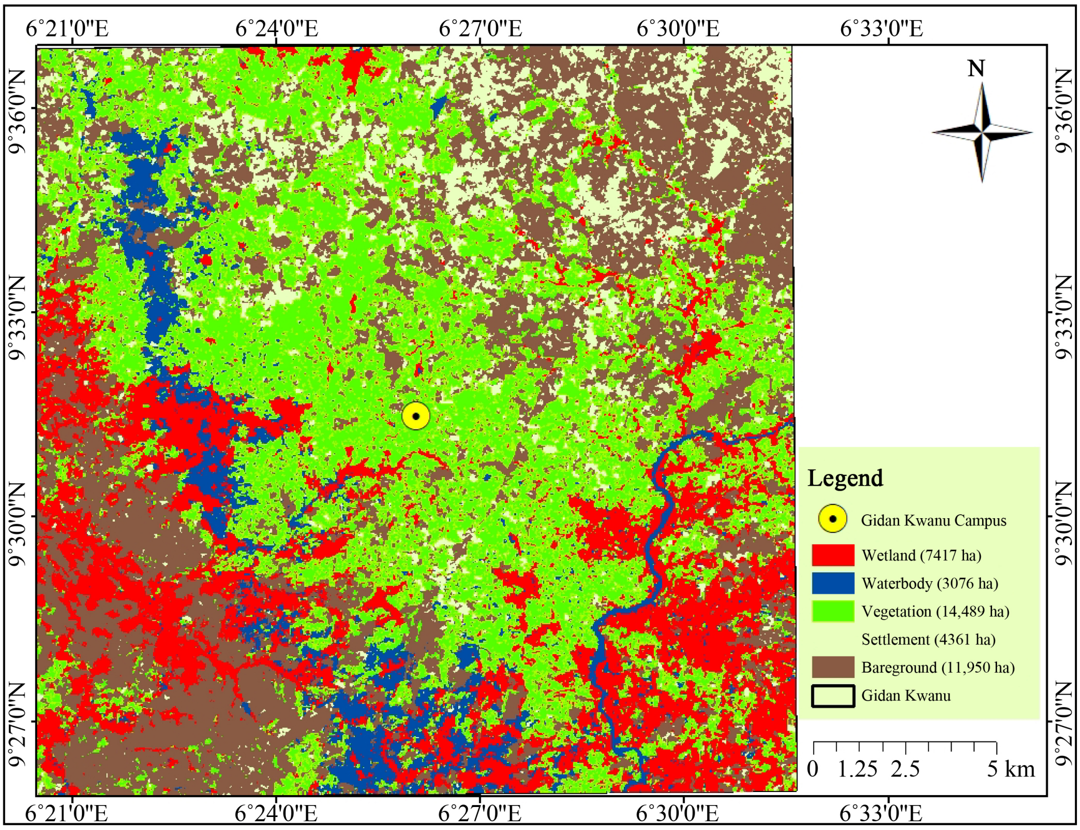
This resulted in the staff of these establishments sourcing for lands for development as residential homes and other business centres, with a strong belief by



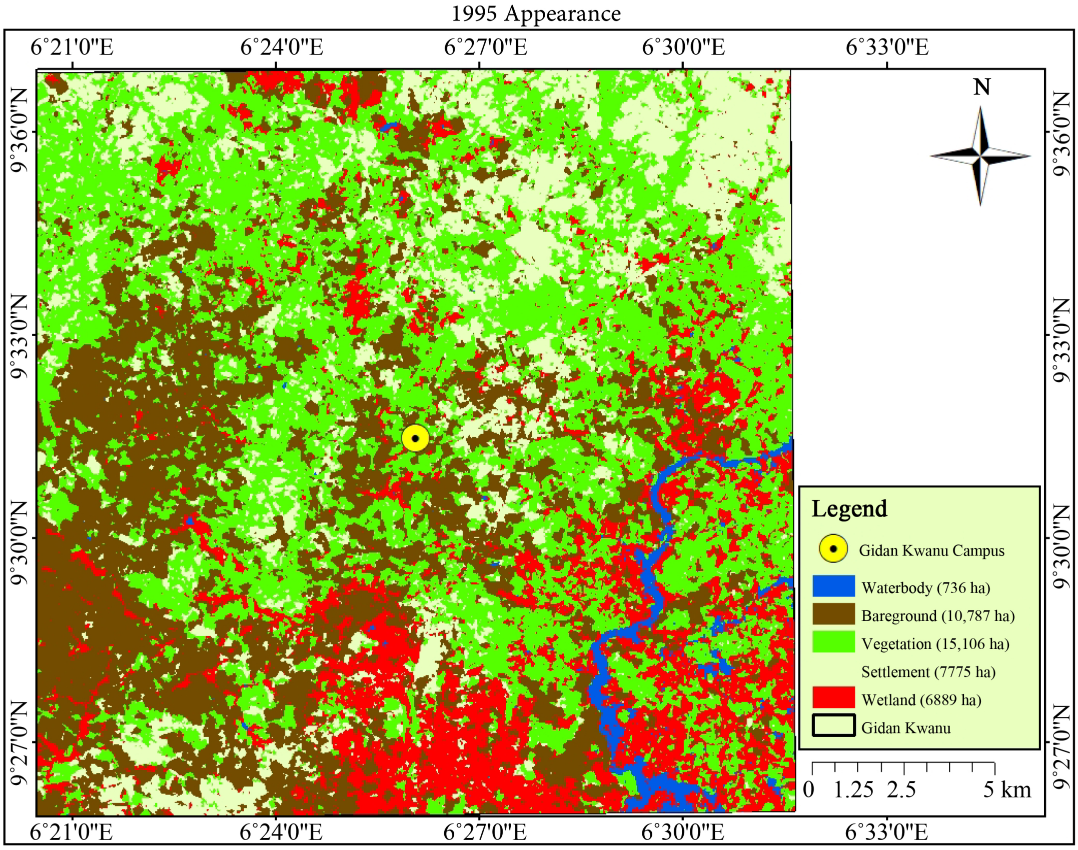
1975 Appearance



1985 Appearance



1995 Appearance



2005 Appearance

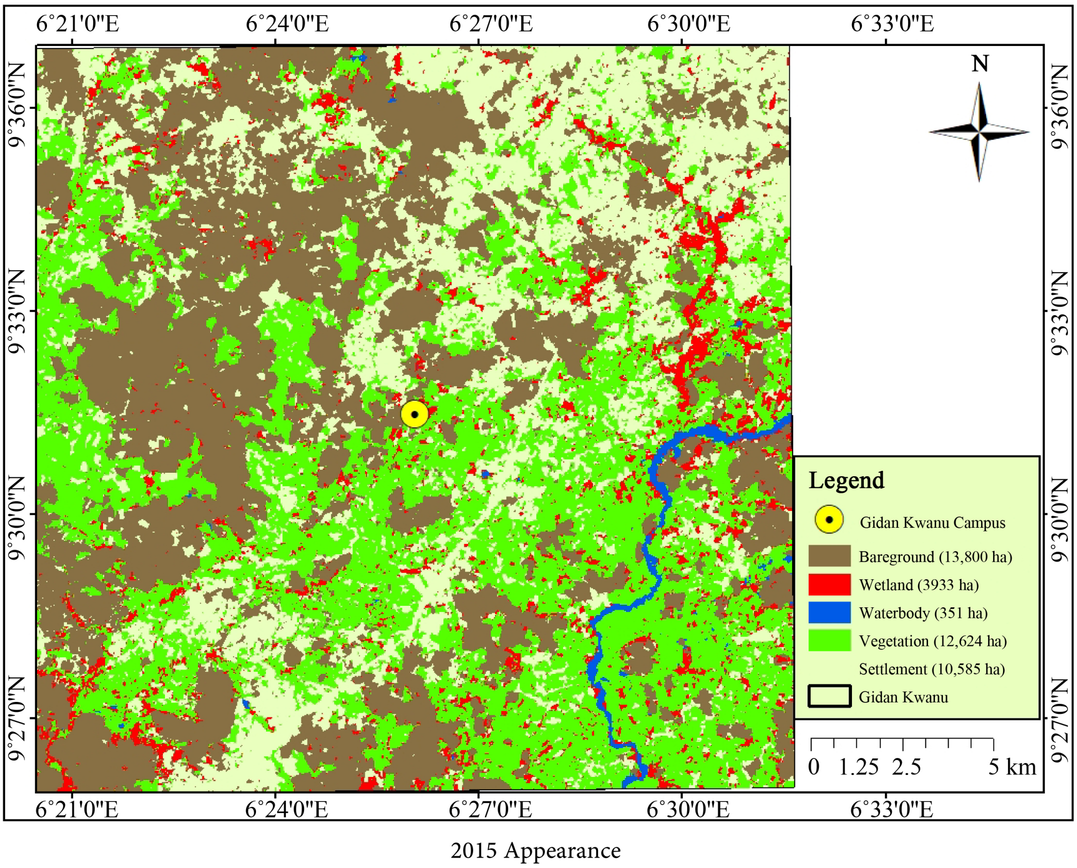


Figure 3. GIS image of the study area

the residents of Minna that wherever students are residents, there are high possibilities of market activities, thus the migration of most commercial activities to the Gidan Kwano watershed. This action affected the various parameters of the study. The wetlands reduced from 5733 to 3933 hectares which is similar to the findings of [35], which looked at assessing and predicting changes in ecosystem service values based on land use/cover change in the Bohai Rim coastal zone of Northern China plain. Also, the vegetative reduction from 20,758 to 12,624 hectares, while the bare land saw an increment from 10,417 to 13,800 hectares. This increment could be linked to the opening of new lands for developmental structures, which will reduce the surface area of the land for infiltration of surface runoff. The observation for this study area is in conformity with the findings of [36]. They predicted the land-cover and land-use change in the urban fringe of Morelia city in Mexico. In their conclusions, they stated that reduction of bare lands and vegetation saw the decrease in agricultural activities, which also affected the end cost of the farm produce, which was observed to be true in the case of the Gidan Kwano watershed.

Similar to new settlements across the world, the new settlement of Gidan Kwano lacked adequate planning, which gave way to improper drainage systems. This is similar to the studies of [37]; and [38] for studies carried out in Mzuzu city, Malawi and Lagos, Nigeria, respectively. Thus, most of the built area is now located on the alluvial plains of the study area occupying the former agricultural land.

The average variability pattern of LULC for the study area is presented in **Figure 4**. It was observed that the vegetation (VG) within the study area had the highest percentage of coverage of 34% which is similar to the works of [39] and [35] for study areas in Sudan and Liaodong Peninsula, the Shandong Peninsula and the North China Plain respectively. The bare ground (BG) which includes rock outcrops had 32% coverage while the settlement area was 13% as at the initial stage of the mapping process. The VG areas included cropped lands and areas where tree crops exist. Such tree crops include palm, Melina, teak and cashew trees.

The magnitude of change during the period of study is presented in **Table 2**. The rate of change within the study areas was observed to be unsystematic in nature. The changes with respect to LULC activities was sinusoidal in nature which is relative to the findings of [39] studied land use/land cover change analysis and its impact on soil properties in the northern part of the Gadarif region, Sudan. A major decrease was observed during the study period in the WL, WB and VG areas. **Table 3** indicates the percentage change in the LULC pattern of the study area. The general pattern of the LULC identified in all the five images

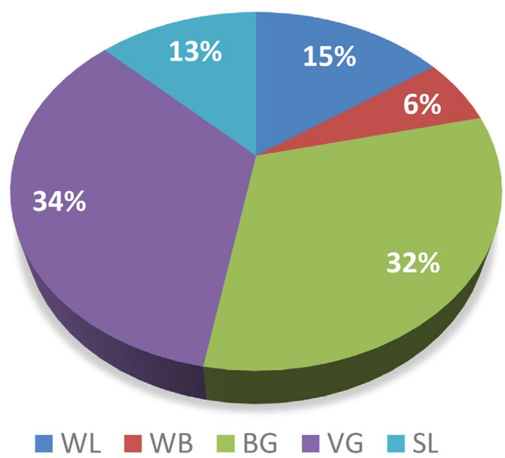


Figure 4. Average variability pattern as a function of urbanisation over a period of 50 years. WL: Wetland, WB: Waterbody, BG: Bare ground, VG: Vegetation, and SL: Settlement.

Table 2. Magnitude of change of land use and land cover.

Land use pattern	Magnitude of change (ha)			
	1985-1975	1995-1985	2005-1995	2015-2005
Wetland (WL)	1838	−154	−528	−2956
Water body (WB)	−572	−800	−2340	−385
Bare ground (BG)	7699	−6166	−1163	3013
Vegetation (VG)	−12,537	6268	617	−2482
Settlement (SL)	3510	851	3414	2810

Table 3. Percentage of change in land use and land cover patterns.

Land use pattern	Percentage of change (%)			
	1985-1975	1995-1985	2005-1995	2015-2005
Wetland (WL)	32.06	−2.03	−7.12	−42.91
Water body (WB)	−12.86	20.64	−76.07	−52.31
Bare ground (BG)	73.91	−34.04	−9.73	27.93
Vegetation (VG)	−60.40	76.24	4.26	−19.66
Settlement (SL)	0.00	24.25	78.28	36.14

covering a period of fifty years were largely dominated by WL, WB, VG, BG and SL areas. A significant increase in the SL and BG was noticed within the 10 km radius of the study area which indicates a high level of deforestation process with more agricultural activities and built-up areas taking place. This is similar to the findings of [40] in Bangladesh where they studied the land use classification and change detection by using multi-temporal remotely sensed imagery.

The observed LULC pattern shows a statistical structural interaction between the various types of land use classification in the study area, the environmental heterogeneity, or both. The calculated statistical interaction exhibits a large-scale variation that may be connected to the kind of activities within the study area. More specifically, the occurrence of these changes is in a close relationship to the settlement and agricultural activities in the area of study. Thus, encouraging interaction between the close by LULC. Expansion of farmlands may not have been possible without good fertile soils, hence necessitating the influence of the covariates on the distribution of LULC. The variability change detection statistics for the five decades of the study area is presented in **Table 4**. It was observed that there was no correlation between WL and WB as a significant level of 0.476 was observed for a 2-tailed Pearson moment correlation. VG and BG were observed to be statistically significant at 0.05 level while SL and WB had a correlation significance of −0.963. **Figure 5** presents the distribution of statistical moments of the first, second and third-order in terms of development patterns in the study area.

Table 4. Pearson moment correlation.

	WL	*WB*	*BG*	*VG*	*SL*
WL	1				
WB	0.476	1			
BG	0.189	0.154	1		
VG	−0.246	0.194	−0.897*	1	
SL	−0.462	−0.963**	0.084	−0.412	1

**Correlation is significant at 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

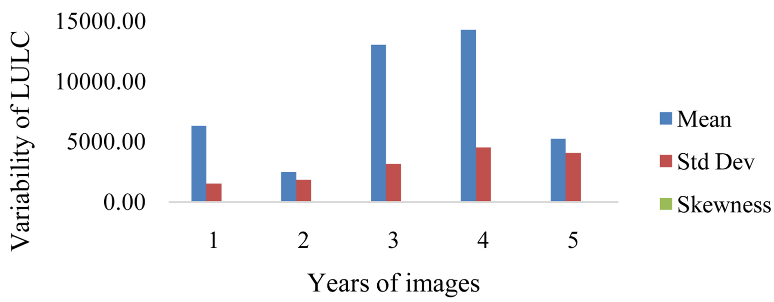


Figure 5. Distribution of statistical moments (First, second and third-order) in terms of development patterns.

4. Conclusion

Based on the LULC analysis of the satellite imageries of the years 1975, 1985, 1995, 2005 and 2015, it was concluded that LULC change varied significantly during the years under study. The results showed that WL, WB, BG, VG, and SL had average variability of 15%, 6%, 32%, 34% and 13% respectively over the study period of 50 years. The results also concluded that the rate of development of the built areas and agricultural activities increased rapidly which is justified by the presence of the permanent site of the Federal University of Technology, Minna. These activities have led to the gradual disappearance of WBs and WLs in the study area. It was also concluded that as a result of the builtup places, the rate of infiltration of surface runoff of rain water will be drastically reduced as most of the sections are paved for construction activities while a section of the study area is covered with rock outcrops and farmlands. The overall classification accuracy achieved for the satellite images ranged within 86 to 92 per cent. In future, if high spatial resolution remote sensing data will be available, then that could lead to higher classification accuracy and subsequently to represent more details of the cultivated and settlement areas.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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