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Land Use and Land Cover Changes in Niamey Municipality from 1981 to 2021 in Flood Context

Hassane Bassirou[1,]*, Masamaéya D.-T. Gnazou[2], Ibrah Seidou Sanda[3], Ambe Emmanuel Cheo[4], Ibrahim Pouye[5]

Abstract

The increase in population leads to a need for housing and agricultural land. As a result, some areas are being modified to meet these needs. In addition, rapid growth combined with the negative impacts of climate change observed in recent decades, plays an important role in land use changes. This study examines land use changes in Niamey, Niger, from 1981 to 2021. To detect land use changes, a geographic information system is used. Data processing and analysis were carried out using ENVI 4.5 and Arc GIS 10.4.1 software. The results show that land cover changes in Niamey are caused by land use and it was noted that the average changes of shallow areas, irrigated agricultural areas, and agricultural land during the period 1981–2021 are estimated at 71479, 675554.5, 34572542, and 132208440 m^2 respectively, which means that human activities through housing areas and agriculture are the main causes of land cover changes. In contrast, the waterhole, the Sahelian short grass savannah, and the steppe show a negative rate of -287416, -39583425, and -8669576 m^2 respectively. Human overexploitation of land has an impact on vegetation and water resources. This situation is exacerbated by the impacts of climate change such as drought and desertification. This study provides valuable information for land use planning and management, especially in the context of climate change mitigation and sustainable development in the region.

***Author for Correspondence**
Hassane Bassirou
E-mail: hassanebassirou@yahoo.fr

[1,5]Ph.D. Scholar, West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL), Graduate Research Program on Climate Change and Disaster Risk Management, University of Lomé, 01 BP 1515 Lomé 01, Togo
[2]Professor, Department of Geology, Faculty of Sciences, University of Lomé, BP: 1515 Lomé, Togo
[3]Professor, Regional Centre AGRHYMET/CILSS, 425 Boulevard de l'Université, Rive Droite, BP: 11011 Niamey, Niger
[4]Ph.D., Department of Environmental Vulnerability and Ecosystem Services Section, Institute of Environmental and Human Security, United Nations University, Platz der Vereinten Nationen 1, 53113 Bonn, Germany
[5]Researcher, West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL) Graduate Research Program on Climate Change and Disaster Risk Management, Université de Lomé. Togo Lomé, 01 BP 1515 Lomé 01, Togo

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INTRODUCTION

In a study, the causes of land use land cover change are attributed to deforestation, rangeland modifications, agricultural intensification, and urbanization. High rates of deforestation within a country are most commonly linked to population growth and poverty, shifting cultivation in large tracts of forests [1]. The misconception that follows is that most deforestation occurs by the push of population growth and poverty to invade, slash, and burn the forest along the roads [2]. Rangelands defined as the presence of grass and trees used by grazers or browsers, and encompass vegetation types ranging from complete grass cover, through woodlands with as much as 80% canopy cover, to pastures within dense forests, are affected by human activities which are commonly a functional part of them, and reducing or eliminating human use will trigger significant changes. Temperate and tropical rangelands are both highly dynamic and also resilient, moving through multiple vegetation states, either as successional sequences or by shifting chaotically in response to the random interplay of human and biophysical drivers [3].

Agricultural intensification defined as higher levels of inputs and increased output of cultivated or reared products per unit area and time, increased the world's food production. Such achievements are viewed skeptically by observers contemplating the future of non-irrigated agriculture in the tropical world where intensification may be considered environmentally untenable, owing to special biophysical constraints and socio-economic conditions that inhibit farmers' access to input factors. Rapidly developing land scarcity may trigger an increase in cropping frequency unmatched by appropriate changes in inputs or management, resulting in a stressed system with stagnating or declining output, abandoned Landesque capital such as terraces, irrigation, and land degradation. Defined as a landscape transformation process, urbanization is manifested by spatial expansion relative to human development. In reality, urbanization affects land change through the transformation of urban-rural linkages. Urbanization in the less-developed world outbids all other uses for land adjacent to the city, including prime croplands. Cities attract a significant proportion of the rural population by way of permanent and circulatory migration, and the wages earned in the city are often remitted by migrants to rural homelands, in some cases transforming the use of croplands and creating remittance landscapes. Perhaps most importantly, this urbanization changes ways of life ultimately associated with demographic transitions, increasing expectations about consumption, and potentially a weakened understanding of production and consumption relationships noted for the well-developed world [2–9].

The causes of land use land cover change to deforestation, rangeland modifications, agricultural intensification, and urbanization, A study, stated that the causes of the change of landscape attributed to five main categories of driving forces: social, political, technological, natural, and cultural. The economy is the main source of the socioeconomic driving factors. Particularly potent forces are the market economy, globalization, and the effects of World Trade Organization (WTO) agreements. Political programs, laws, and policies consider socioeconomic requirements, hence there is a close relationship between the two. However, technology has also significantly changed the environment. The different effects of railroads and highways on settlement patterns are striking examples. Landscape change is anticipated to be significantly accelerated by information technology. Natural disturbances can be swift or delayed acting, and site factors are stable in the near term but changing in the long run. Global change is currently the main slow-moving natural disturbance. Avalanches, mudslides, and storms are examples of swift-moving natural disasters that can have a significant impact on areas and landscapes. Furthermore, because culture shapes landscapes, which in turn immunizes culture, culture surely makes a lasting impression on landscapes [10–17].

land use change resulting from human land use is a major source and driver of global environmental change. Human action is changing the Earth's environment at unprecedented rates, magnitudes, and spatial scales. The immediate human sources of these changes lie in two groups of production and consumption activities. The first is global industrial metabolism, for example, the flow of energy and materials through the processes of resource extraction, processing, use, and disposal in the industrial sector of the global economy. The second is the change in land use and land cover on a global scale. There are five main categories of driving forces for a landscape: social, political, technological, natural, and cultural. The economy is the main source of the socioeconomic driving factors. Particularly potent forces are the market economy, globalization, and the effects of World Trade Organization (WTO) agreements. Political programs, laws, and policies consider socioeconomic requirements, hence there is a close relationship between the two. However, technology has also significantly changed the environment. The different effects of railroads and highways on settlement patterns are striking examples. Landscape change is anticipated to be significantly accelerated by information technology. Natural disturbances can be swift or delayed acting, and site factors are stable in the near term but changing in the long run. Global change is currently the main slow-moving natural disturbance. Avalanches, mudslides, and storms are examples of swift-moving natural disasters that can have a significant impact on areas and landscapes. Furthermore, because culture shapes landscapes, which in turn immunizes culture, culture surely makes a lasting impression on landscapes [18–26].

In Africa, particularly in the Sahel region, it is often described as the hotspot of global environmental change. This is due to demographic change, intensive human activities, and recurrent severe droughts in the 1970s and 1980s. These environmental disturbances have led to land degradation and have threatened vegetation growth and food security on this continent with these changes to human activities. In addition, in the Sahel particularly in Niger, the cause of the land changes is the expansion of agriculture and the dynamics and sustainability of the human-environmental systems depend heavily on land management. Niger has one of the fastest rates of population increase in West Africa, with an annual growth rate of 4.0%. The most notable change in Niger's landscapes has been the expansion of agriculture, which is being driven by the country's rapid population increase and rising food consumption. Consequently, land use and land cover change over time. In this study, we investigate the dynamics of land use and land cover between 1981 and 2021. Eight land cover units were considered: Shallow, Irrigated agriculture, Settlements, water body, Sahelian short grass savanna, steppe, rocky land, and agricultural land [27–31].

STUDY AREA

Niamey, the capital of Niger, has an area of 255 square kilometers and is located between latitudes 13°28′ and 13°35′ North and 2°03′ and 2°10′ East. The city is located on an alluvial plain on the right bank of the Niger River and a plateau overlooking the left bank of the river. Niamey has experienced spectacular demographic and spatial growth since the colonial conquest and especially since independence until today. In 1930, the city had only 1,640 inhabitants, 11,790 in 1952, and eight years later (1960) 33,816, a growth rate of 12%. This enormous growth continued between 1960 and 1972, tripling the population to 108,000. From 1972 onwards, the population explosion was even more rapid than in the previous period. The population quadrupled in 16 years, from 108,000 to 398,265, an annual increase of 18,141 people, including about 12,000 immigrants. Today, the city has a population of over 700,000 (Motcho 2004). Its territorial expansion has been equally rapid: in 1970, Niamey covered 1,367 ha; two years later, 2,347 ha; in 1977, 4,400 ha; in 1988, 4,848 ha. In 2004, the city covers 10,384 ha and extends on both banks of the Niger River.

According to the 2012 general population and housing census, the Niamey region has 1,026,848 inhabitants. This represents 6% of the country's population. This population is essentially urban. Indeed, 856,527 inhabitants, or 91.1% of the population, live in urban areas. The intercensal growth rate decreased slightly from 4.5% in 2001 to 3.3%. In 2018, the population was estimated at 1,203,766 inhabitants with 598,488 males and 605,278 women, and an annual growth rate of 4.5%. This demographic flow creates a high human concentration that has negative effects on the social and environmental spheres, including issues with waste management, housing, the availability of clean drinking water throughout the city, and health. The plateau of the left bank and the plain of the right bank constitute the two fundamental elements of the relief of the region of Niamey. The average altitude of the plateau on the left bank is around 250 m. Overlooking a drop of 20 to 25 m, this plateau occupies the largest urbanized space. The plain on the right bank is the zone par excellence for urban and peri-urban market gardening. With an average altitude of 125 m, this plain extends over several kilometers. We also note the presence of fossil dunes from the arid periods of the Quaternary. The dunes form at the level of the plateaus' sandy covers or longitudinal dune cords in an East-West direction. Niamey has a Sahelo-Sudanian climate characterized by a short rainy season (June to September) and a long dry season (October to May). There are also two types of wind: The harmattan, a hot and dry wind, which blows from North-East to South-West from September to May, and the monsoon, a cool and humid wind that blows from West to East from June to October. The analysis of the region's rainfall data shows an irregularity in the evolution of the annual accumulations recorded from 2010 to 2019 with, however, a slight stability between 2013 and 2016. During this decade, the year 2017 was the rainiest with an annual total of 833.2 mm. It experienced a vertiginous drop in 2018 with 442.4 mm and a slight increase in 2019. Overall, 2011 was the least wet year with an annual total of 359.8 mm.

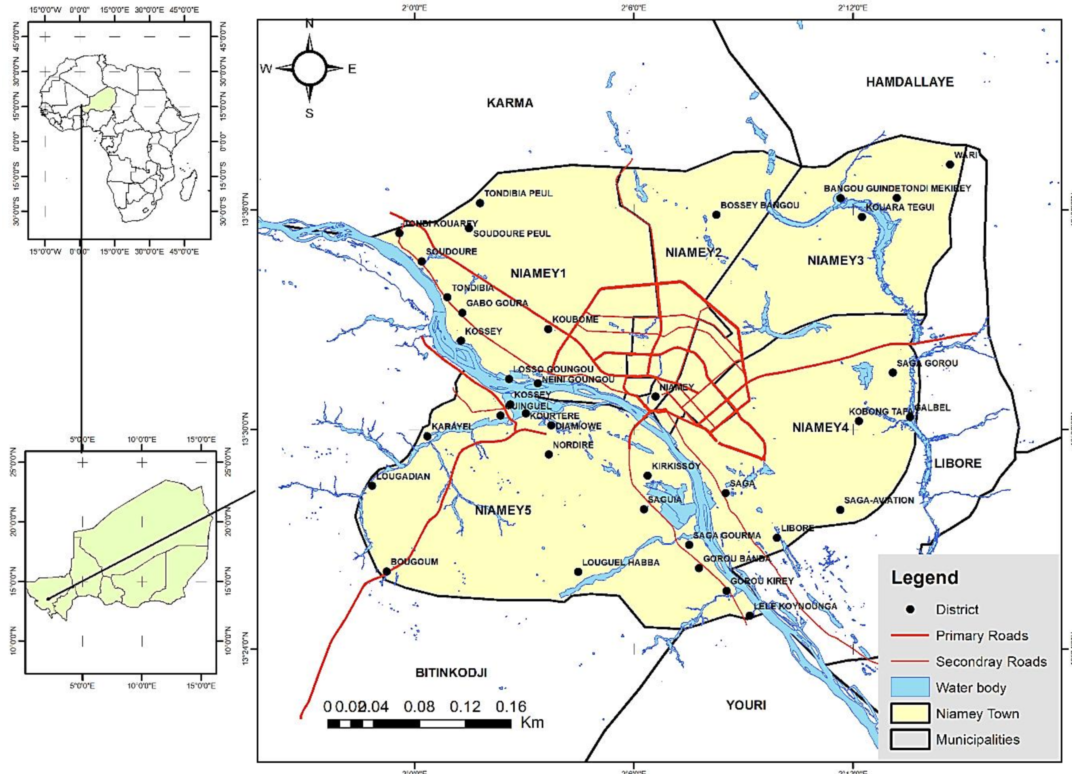

Figure 1. Location map of the study area.

Three main vegetation types, including fallow savanna, crop fields on sandy soils, and tiger bush on lateritic plateaus, make up the extremely fragmented vegetation cover. Pearl millet grown in rainy conditions dominates the agricultural production system. Because it relies on rainfall for both agriculture and livestock, the region is particularly susceptible to climate change (Figure 1).

In terms of pedology, there are three types of soil in the project area. These include in particular: Soils of the ironclad plateaus, which are very degraded and offer no agricultural possibilities due to their depth and their permeability and especially their extreme aridity; Sandy-textured soils including tropical ferruginous soils of sandy valleys; and hydromorphic soils located in the Niger River valley. They are reserved for off-season crops and are home to most of the capital's orchards because of their fertility and the irrigation possibilities offered by the river. With regard to surface water, the network of the Niamey region consists of a single watercourse, the Niger River with a maximum flow of 2340 m^3/second crossing this administrative entity over a length of more than 15 km. (INS, 2016). However, the river is experiencing a disruption of its regime and a drop in its flow due to the phenomena of silting and sedimentation due to water erosion. The existence of some permanent and semi-permanent ponds is noted. The only artificial reservoir is the Goudel sill, built to store a capacity of 3,000,000 m^3 to support the water supply of the city of Niamey. However, during the development of the drinking water supply master plan for the city of Niamey (2017), a bathymetric study carried out at the level of the Goudel water reservoir showed that the current capacity is 800 000 m^3 (representing 7 days of production), which indicates significant silting up of the dam. This is what led SPEN to proceed in an artisanal way to raise the Goudel dike by adding sandbags over nearly 75 cm, thus increasing the capacity of the reservoir to reach 1,400,000 m^3. i.e. an autonomy of 15 days of pumping in the event of a total stoppage of the flow of the river (SPEN, 2021).

MATERIALS AND METHODS

Data Source

To determine the Land use land cover changes, primary (Landsat images) and secondary data (Regional and communal division boundary of Niger) are used. For primary data, **t**he Landsat TM, ETM+, and OL_TIRS multi-resolution satellite data for five distinct Landsat images of the years 1981, 1991, 2001, 2011, and 2021 are the primary data used in this study. These images are used to determine the land cover units. The satellite, sensor, path, row, number of bands, and date of capture are used to determine these images. These Landsat images were downloaded from the USGS (United States Geological Survey http://earthexplorer.usgs.gov/) of the City of Niamey [1].

Regarding the secondary data **(**the regional and communal division boundary of Niger**)** from the National Geographic Institute of Niger (IGNN) are used for mapping land use land cover changes in the study area (Table 1).

Table 1. Landsat images' information (1981, 1991, 2001, 2011, and 2021) of Niamey municipality.

Primary data					
Satellite	**Sensor**	**Path/Row**	**Band number**	**Resolution**	**Acquisition date**
Landsat 5	TM	189/49	7	30 m	1981
Landsat 5	TM	189/49	7	30 m	1991
Landsat 7	ETM+	189/49	8	30 m	2001
Landsat 7	ETM+	189/49	8	30 m	2011
Landsat 8	OLI_TIRS	187/48	11	30 m	2021
Secondary data					
Data		**Format**		**Scale**	**Source**
Regional and communal division boundary of Niger		Shapefile		1/110,000	IGNN

Source: U.S. Geological Survey (2023). EarthExplorer. [online] available from: https://earthexplorer.usgs.gov/

Methodology

In this study, Geographic Information System is used to determine the land use land cover change from 1981 to 2021. Data processing and analysis were employed through the software ENVI 4.5 and Arc GIS 10.4.1. The following flowchart resumes all processes that we used in this study.

Images Processing

Since the satellite images acquired were already geo-referenced and geocoded, they were processed directly. In the ENVI software, this processing was carried out according to the following steps.

Band Composites and the Study Area Delimitation

This grouping is carried out by the "Layer stacking" operation. It is essential because it makes it possible to group the bands (which are most often individual at acquisition) to better carry out the manipulations to come. After the grouping, the study area was extracted using the 'Spatial Subset' tool from the 'Basic tools' menu of the 'Resize data' submenu of the ENVI software.

Contrast Enhancement, Band Composites, and Visual Interpretation

The visual quality of the images used was improved by contrast enhancement using the 'linear' method. This enhancement allows a clear thematic identification. The analysis of the spectral signatures of the different land cover entities is very important for the choice of the TM, ETM+, and OLI channels of the Landsat scenes and the visual interpretation of the images.

About the color composite, the combination of three (03) spectral bands of the image was done. It is a color display of the scene for the identification of the different land use units. Color composition techniques consist of displaying each spectral band in one of the display planes making up the color screen. The display planes are the three primary colors: red, green, and blue listed in composition order. The following composite bands are used:

- Composition 4-3-2 was used for the TM and ETM+ image;
- Composition 7-4-3 was used for the OLI-TIRS image.

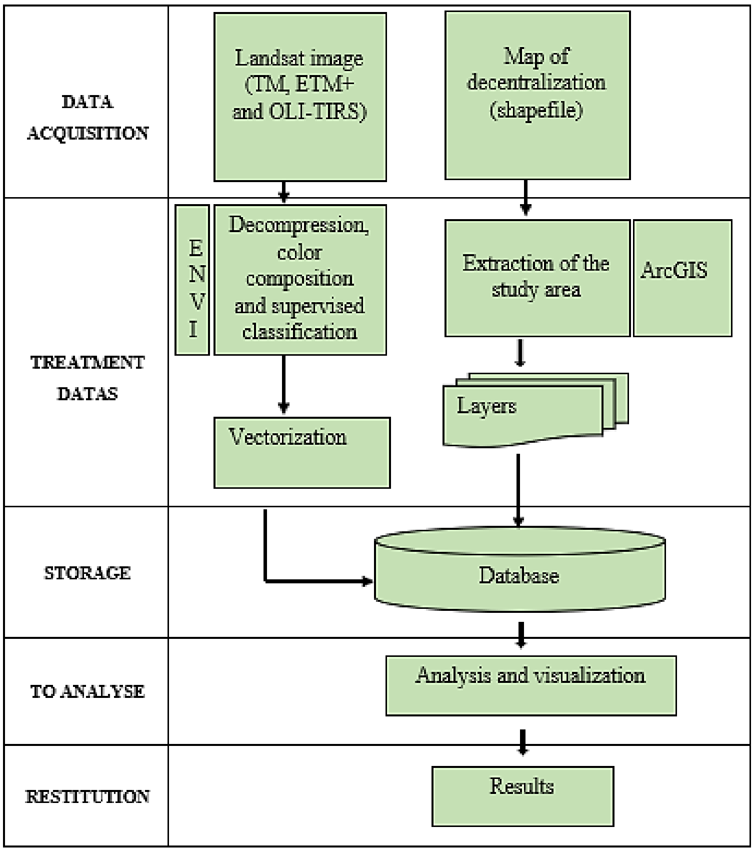

Figure 2. Flowchart showing the methodology adopted in this study.

Regarding visual interpretation, it is a process of extracting useful information by inspection, identification, and recognition of objects present on satellite images by simple observation. This technique requires a good knowledge of the zone of interest, which supposes the perfect recognition of the object so that the latter will be assigned an identity on the image. The keys to interpretation are the shape, size, texture, shade, pattern, and location have made it possible to identify the following land occupation units: Shallow, Irrigated agriculture, Settlements, Water body, Sahelian short grass savanna, Steppe, Rocky land, Agricultural land (Figure 2).

Supervised Classification

This is the image segmentation stage, i.e., the automatic grouping of pixels by theme of interest by means of the definition of training sites and the use of a grouping.

It is based on a classification system consisting of the definition of all the classes before carrying out the classification. The classification took place in ENVI 4.5 in four essential phases which are:

- The definition of the legend of the ROI (Region of Interest): to do this, a combination was made with the composition in false color;
- The description of the different classes;
- The choice of training plots (or regions) to be assigned to each ROI;
- The choice of the classification algorithm: the classifier which gave the best results is that of the maximum likelihood for the scenes of 1981, 1991, 2001, 2011, and 2021.

Validation

The classification is validated by the confusion matrix which is a statistical tool for detecting confusion between classes based on a ground truth. It can be characterized either from field readings or by using the test areas entered (hence the importance of the quality of these test areas if this matrix is to make sense). Ideally, the definition of the areas which will be used for the validation of a supervised classification must be done randomly so as not to truncate the validation. The comparison between the classified or “predicted” land cover and the photo-interpreted land cover is made by constructing and discussing a confusion matrix (or contingency table).

The confusion matrix is characterized by a classification quality indicator: the kappa. The kappa index expresses the proportional reduction of the error obtained by a classification, compared to the error obtained by a completely random classification.

It is expressed from the matrix of confusion.

Post Classification

This is the stage of refining and smoothing the classification before transforming raster classes into polygons. Without further clarification, the Sieve (elimination of isolated pixels) and Clump (homogenization of classes) tools of ENVI will be used, which will allow us to obtain a fairly smooth and low-noise image.

Vectorization

Vectorization is the transition from a raster image (where the information is contained in pixels) to vector data (the information is contained in point, line, and polygon-type entities). As part of this project, the classified images were vectorized in the ENVI 4.5 environment using the 'Classification to Vector' tool. They were then exported in ArcGIS Shapefile (.shp) format to facilitate proper manipulation and presentation of the information. In the ArcGIS environment, the vector file was dissolved by theme (Dissolve) and cut according to the boundaries of the rural commune of Dan Kassari and Guéchémé.

RESULTS

The following resumed the different land cover unit changes for the years 1981, 1991, 2001, 2011, and 2021 (Table 2).

Table 2. Land use land cover in Niamey municipality from 1981 to 2021.

	Area (m^2)				
Land cover units	***1981***	***1991***	***2001***	***2011***	***2021***
Shallow	21531354	21559006.56	21572614.78	21776882.85	21817271.85
Irrigated agriculture	12548819	14858948.36	15251036.68	15251036.68	15251036.67
Settlements	68884466	75922567.05	96795522.09	149032496	207174635.2
Waterbody	21602265	21722869.89	22032902.18	19995390.66	20452601.58
Sahelian short grass savanna	160574258	146232854.6	137251449	29834483.84	2240560.414
Steppe	80609385	73163688.69	55345451.19	45809327.01	45931079.22
Rocky land	42425684	42425683.55	42425683.55	42425683.55	42425683.55
Agricultural land	152580510	164871120.3	170082079.5	236631438.3	205463870.5
Total	560756738.9	560756738.9	560756738.9	560756738.9	560756738.9

The following is about the change’s detection of the different land cover units changes from 1981 to 2021 (Table 3).

Table 3. Detecting changes in land use units at ten-year intervals from 1981 to 2021.

Land cover units	**Net Loss/Gain (m^2)**				**Average changes**
	1981–1991	***1991–2001***	***2001–2011***	***2011–2021***	
Shallow	27652.07252	13608.22271	204268.0693	40389.00375	71479.34207
Irrigated agriculture	2310129.724	392088.3175	0	-0.007370001	675554.5085

Settlements	7038101.478	20872955.04	52236973.92	58142139.14	34572542.39
Waterbody	120605.2165	310032.2842	-2037511.52	457210.9265	-287415.7732
Sahelian short grass savanna	-14341403	-8981405.578	-107416965.1	-27593923.43	-39583424.28
Steppe	-7445695.915	-17818237.5	-9536124.185	121752.2097	-8669576.348
Rocky land	0	0	0	0	0
Agricultural land	12290610.43	5210959.209	66549358.85	-31167567.84	13220840.16

Source: Landsat 4 at IGNN

These results show that the average changes of shallow, irrigated agriculture settlements and agricultural land during the period 1981–2021 are estimated at 71479, 675554.5, 34572542, and 132208440 m^2 respectively. Whereas, the water body, Sahelian short grass savanna, and steppe record negative rates with -287416, -39583425, and -8669576 m^2, respectively.

Land Cover Units in 1981

Human settlements made up the largest land use category in 1981, taking up around 68.9 million square meters, or 12.3% of the total area. This shows that Niamey was a heavily urbanized area, with both residential and commercial structures occupying a sizable amount of the land. Regarding agricultural land, it should be mentioned that agricultural operations occupy more than 152.6 million square meters or almost 27.2% of the total area. 15.2 million square meters are used for irrigation in agriculture. This suggests that agriculture, both irrigated and rain-fed agriculture, is a significant land use in Niamey. It should be noted that the Sahelian short-grass savannah and steppe made up a sizeable amount of the overall area, with the Sahelian short-grass savannah accounting for around 28.6% of the total area and the steppe for about 14.4% (Figure 3).

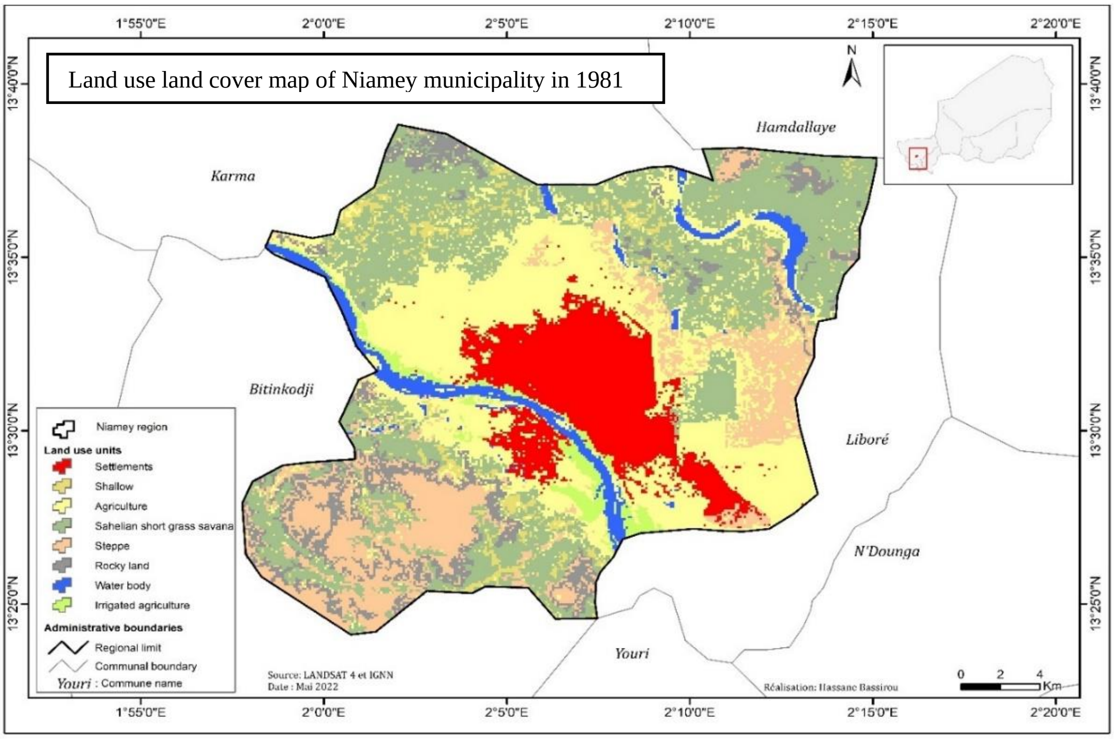

Figure 3. Land use land cover changes in Niamey municipality in 1981.

These types of land use are common in the Sahel region, which is distinguished by a dry environment and little vegetation. The fact that the water bodies category made up around 3.8% of the total area suggests that Niamey has abundant water resources (River Niger). 7.6% of the total area was made up of rocky ground, indicating that some portions of Niamey are not suitable for building or agriculture due to their rocky character. The land use pattern generally indicates that Niamey was largely urbanized in 1981, with a sizeable amount of the areas being devoted to housing and agriculture. Significant savannah and Sahelian short grass steppe areas, as well as rocky terrain and water bodies, may also be seen in Niamey.

Land Cover Units in 1991

In 1991, the largest land use category was human settlements, which accounted for about 75.9 million square meters, or 13.5% of the total area. This demonstrates how densely populated Niamey was, with both residential and commercial constructions taking up a large portion of the land. It should be noted that agricultural enterprises use more than 164.9 million square meters of land, or over 29.4% of the total area, for their operations. Agriculture uses irrigation on 14.8 million square meters (Figure 4).

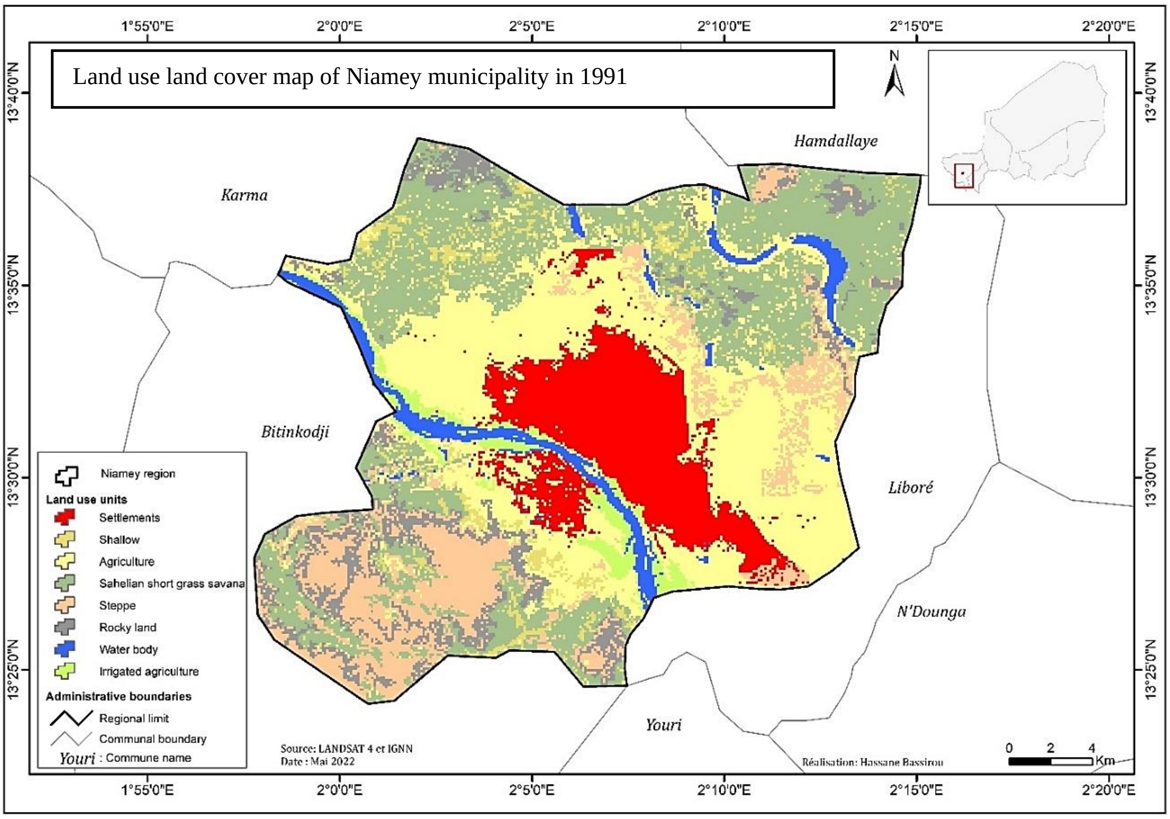

Figure 4. Land use land cover changes in Niamey municipality in 1991.

This shows that Niamey has a substantial amount of irrigated and rain-fed farmland. It should be noted that the Sahelian short-grass savannah and steppe made up a sizable portion of the total area, with the steppe accounting for around 13.1% and the Sahelian short-grass savannah for approximately 26.1%. In the Sahel region, which is defined by a dry climate and sparse vegetation, certain types of land use are typical. Niamey has a lot of water resources, including the River Niger, as evidenced by the fact that the water bodies category accounted for about 3.9% of the total area. Rocks made up 7.6% of the total area, showing that some areas of Niamey are not suitable for construction or agriculture due to their rocky nature. According to the overall land use pattern, Niamey was primarily urbanized in 1991, with a sizable portion of the region being set aside for housing and agriculture. Niamey also has sizable savannah and Sahelian short grass steppe areas, as well as rocky terrain and water bodies.

Land Cover Units in 2001

Human settlements made up the largest land use category in 2001, making up around 96.8 million square meters, or 17.3% of the total area (Figure 5).

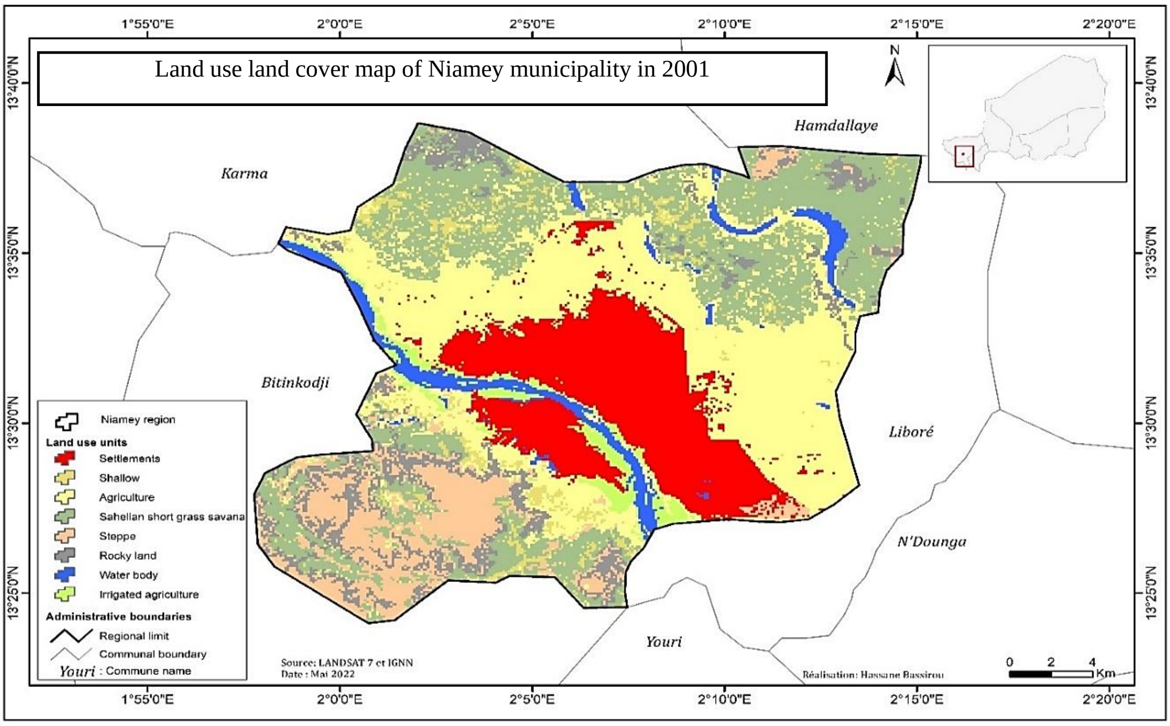

Figure 5. Land use land cover changes in Niamey municipality in 2001.

This illustrates how crowded Niamey was, with both domestic and commercial structures occupying a large amount of the landscape. It should be noted that both the steppe and the Sahelian short grass savannah occupied a sizeable amount of the total area, with the steppe making up roughly 9.9% and the Sahelian short grass savannah about 24.5%. Some types of land use are characteristic of the Sahel region, which is characterized by a dry environment and scant vegetation. 7.6% of the total area was made up of rocks, demonstrating that some regions of Niamey are not suited for cultivation or development due to their rocky character. The fact that the water bodies category made up around 3.9% of the total area indicates that Niamey has a lot of water resources, especially the River Niger. It should be emphasized that more than 170.1 million square meters, or more than 30.3% of the total area, are used by agricultural firms for their operations. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. Niamey was predominantly urbanized in 2001, with a sizeable amount of the area designated for housing and agriculture, according to the general land use pattern. Along with vast regions of the savannah and Sahelian short grass steppe, Niamey also includes rocky terrain and bodies of water.

Land Cover Units in 2011

It should be emphasized that in 2011, agriculture accounted for the largest land use category, with businesses using more than 236.6 million square meters of land, or more than 42.2% of the total area, for their activities. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. Approximately 149 million square meters, or 26.6% of the total area, fell under the category of settlement. This illustrates how crowded Niamey was, with both domestic and commercial structures occupying a large amount of the landscape. It is important to note that the steppe and Sahelian short grass savannah made up a significant amount of the total area, with the steppe accounting for roughly 8.2% and the Sahelian short grass savannah for roughly 5.3%. Some types of land use are characteristic of the Sahel region, which is characterized by a dry environment and scant vegetation.

The fact that the water bodies category made up around 3.6% of the total area indicates that Niamey has a lot of water resources, especially the River Niger. A low depth of groundwater is likely present in some regions of Niamey given that shallow areas make up about 3.9% of the overall area. 7.6% of the total area was made up of rocks, demonstrating that some regions of Niamey are not suited for cultivation or development due to their rocky character. In 2011, Niamey was distinguished by a predominance of agricultural land, with a sizeable share of the territory being set aside for agriculture, according to the general land use pattern (Figure 6).

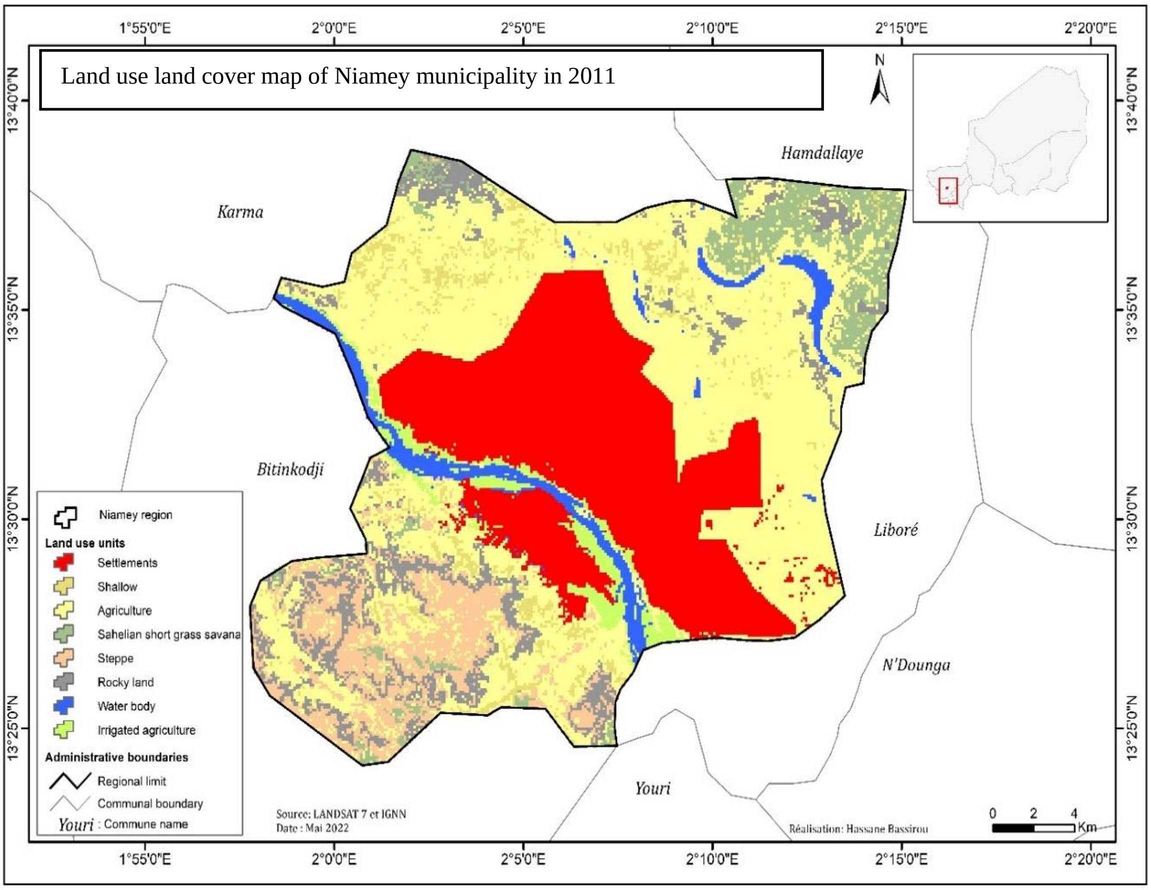

Figure 6. Land use land cover changes in Niamey municipality in 2011.

Land Cover Units in 2021

In 2021, the greatest land use type was human settlements, which accounted for almost 207 million square meters, or 37% of the total area. This demonstrates how densely populated Niamey was, with both residential and commercial constructions taking up a large portion of the land. It should be noted that agricultural enterprises use more than 205.5 million square meters of land, or over 37% of the total area, for their operations. Agriculture uses irrigation on 15.3 million square meters.

This shows that Niamey has a substantial amount of irrigated and rain-fed farmland. It should be noted that the Sahelian short grass savannah and steppe made up a considerable portion of the total land, with the steppe accounting for around 8.2% and 0.4%, respectively. In the Sahel region, which is defined by a dry climate and sparse vegetation, certain types of land use are typical. Niamey likely has a lot of water resources (River Niger), as the water bodies category accounted for about 3.6% of the total area. A low depth of groundwater is likely present in some regions of the study area given that shallow areas make up about 3.8% of the overall area. Rocks made up 7.6% of the total area, showing that some areas of Niamey are not suitable for construction or agriculture due to their rocky nature. Overall, the findings point to a predominance of urban areas and agricultural land in the research region, with lesser amounts of the steppe, rocky terrain, water bodies, shallow areas, and Sahelian short grass savanna in 2021 (Figure 7).

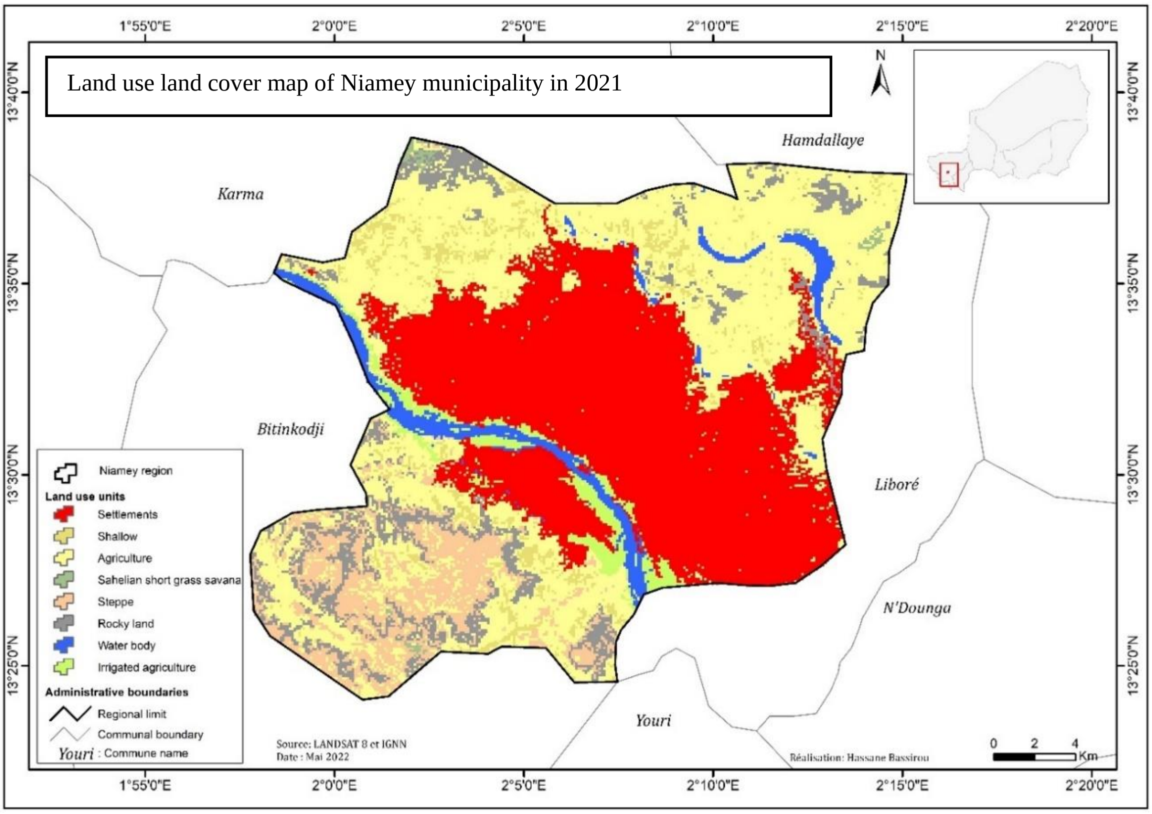

Figure 7. Land use land cover changes in Niamey municipality in 2021.

DISCUSSION

The land cover units were classified into eight units: Cultivation area, Steppe, Sahelian savannah, Rocky terrain, Body of water, Dwellings, Shallows, and Irrigated crops. These units are characterized by changes over the period 1981–2021 and are characterized by positive and negative changes. In terms of settlements, the changes in areas occupied by habitations made up the largest land use category in 1981, taking up around 68.9 million square meters, or 12.3% of the total area. This shows that Niamey was a heavily urbanized area, with both residential and commercial structures occupying a sizable amount of the land. In 1991, settlements, which accounted for about 75.9 million square meters, or 13.5% of the total area shows an increase. In 2001, human settlements made up the largest land use category, making up around 96.8 million square meters, or 17.3% of the total area. In 2021, approximately 149 million square meters, or 26.6% of the total area, fell under the category of settlement. The greatest land use type was human settlements, which accounted for almost 207 million square meters, or 37% of the total area. This demonstrates how densely populated Niamey was, with both residential and commercial constructions taking up a large portion of the land.

Regarding the agricultural land changes during the period 1981–2021, an increase in land used for agricultural activities is noted. In Niamey, in 1981, it should be mentioned that agricultural operations occupy more than 152.6 million square meters or almost 27.2% of the total area. 15.2 million square meters are used for irrigation in agriculture. This suggests that agriculture, both irrigated and rain-fed agriculture, is a significant land use in Niamey. In 1991, the areas occupied by agricultural activities used more than 164.9 million square meters of land, or over 29.4% of the total area, for their operations. Whereas irrigated agriculture shows a decrease estimated at 14.8 million square meters. In 2001, it is noted that more than 170.1 million square meters, or more than 30.3% of the total area, is used by agricultural firms for their operations. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. In 2011, agriculture accounted for the largest land use category, with businesses using more than 236.6 million square meters of land, or more than 42.2% of the total area, for their activities. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. In 2021, Niamey was distinguished by a predominance of agricultural land, with a sizeable share of the territory being set aside for agriculture, according to the general land use pattern. It should be noted that agricultural enterprises use more than 205.5 million square meters of land, or over 37% of the total area, for their operations. Agriculture uses irrigation on 15.3 million square meters. This shows that Niamey has a substantial amount of irrigated and rain-fed farmland. From 1981 to 2021, the portion of land occupied by agriculture shows an increased trend. This situation can be explained by the fact that, with population growth, lands around the city are employed by agricultural activities (Figure 8).

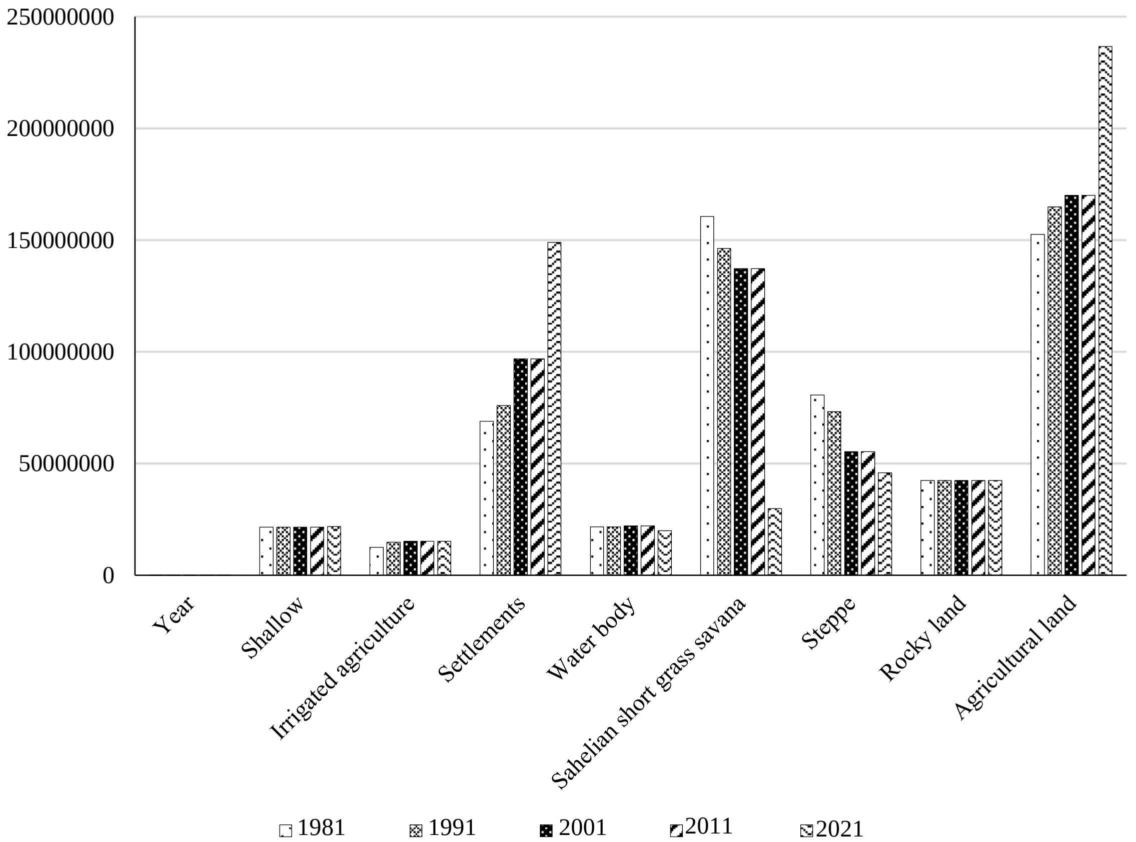

Figure 8. Land cover unit changes from 1981 to 2021 of the Niamey municipality.

Land use has cumulatively transformed land cover on a global scale. The consequences have been significant not only for land cover, particularly vegetation cover but also for climate, atmospheric composition, biodiversity, soil conditions, and water and sediment flows. These types of impacts are generated both by modification involving changes in vegetation cover and conversion of vegetation cover to another, e.g., from forest to grassland by clearing for grazing [29].

However, in a study [19], it is widely acknowledged that rainfall affects vegetation differences in the Sahel. According to several studies [5, 11–15, 19], local NDVI trends might not be fully explained by local causal factors like changes in land use. The shift in vegetation can be explained by a variety of non-anthropogenic factors, such as the intra-annual distribution of rainfall events, humidity, or temperature, according to Rishmawi and Prince (2016) [25]. Therefore, distinguishing between changes in biomass caused by the climate and changes caused by other variables, both anthropogenic and natural, is crucial for describing the primary forces behind vegetation dynamics [17, 19, 21]. In addition, Mather and Needle (2000) argued that population growth and poverty are the two factors most frequently associated with high rates of deforestation within a nation, with shifting cultivation occupying large areas of forest [20]. However, Allen and Barnes (1985) stated that it would be a mistake to say that poverty and population growth are the reasons for deforestation [2, 18].

In Niamey, it is noted that the Sahelian short grass savannah and steppe represent a significant share of the total area, with the Sahelian short grass savannah representing about 28.6% of the total area and the steppe about 14.4% in 1981. In 1991, it should be noted that the Sahelian short grass savannah and the steppe represented a significant share of the total area, with the steppe representing about 13.1% and the Sahelian short grass savannah about 26.1%. In the Sahel region, which is characterized by a dry climate and sparse vegetation, certain land use types are typical. In 2001, the steppe accounted for about 9.9%, and the Sahelian short grass savannah for about 24.5%. In 2011, steppe accounted for about 8.2% and short grass Sahelian savannah about 5.3%. In 2021, the Sahelian short-grass savannah and steppe represented a considerable share of the total land area, with the steppe accounting for about 8.2% and 0.4%, respectively. Certain land use types are characteristic of the Sahel region, which is characterized by a dry environment and scarce vegetation. It is important to note that the steppe and the Sahelian short-grass savannah represented a significant share of the total area during the period 1981–2021. However, it is important to note that a decreasing trend for the Sahelian short grass savannah and steppe is observed during the period 1981–2021 (Figure 9). This can be explained by the fact that during this period human activities through urbanization and agricultural activities show an increasing trend in Niamey.

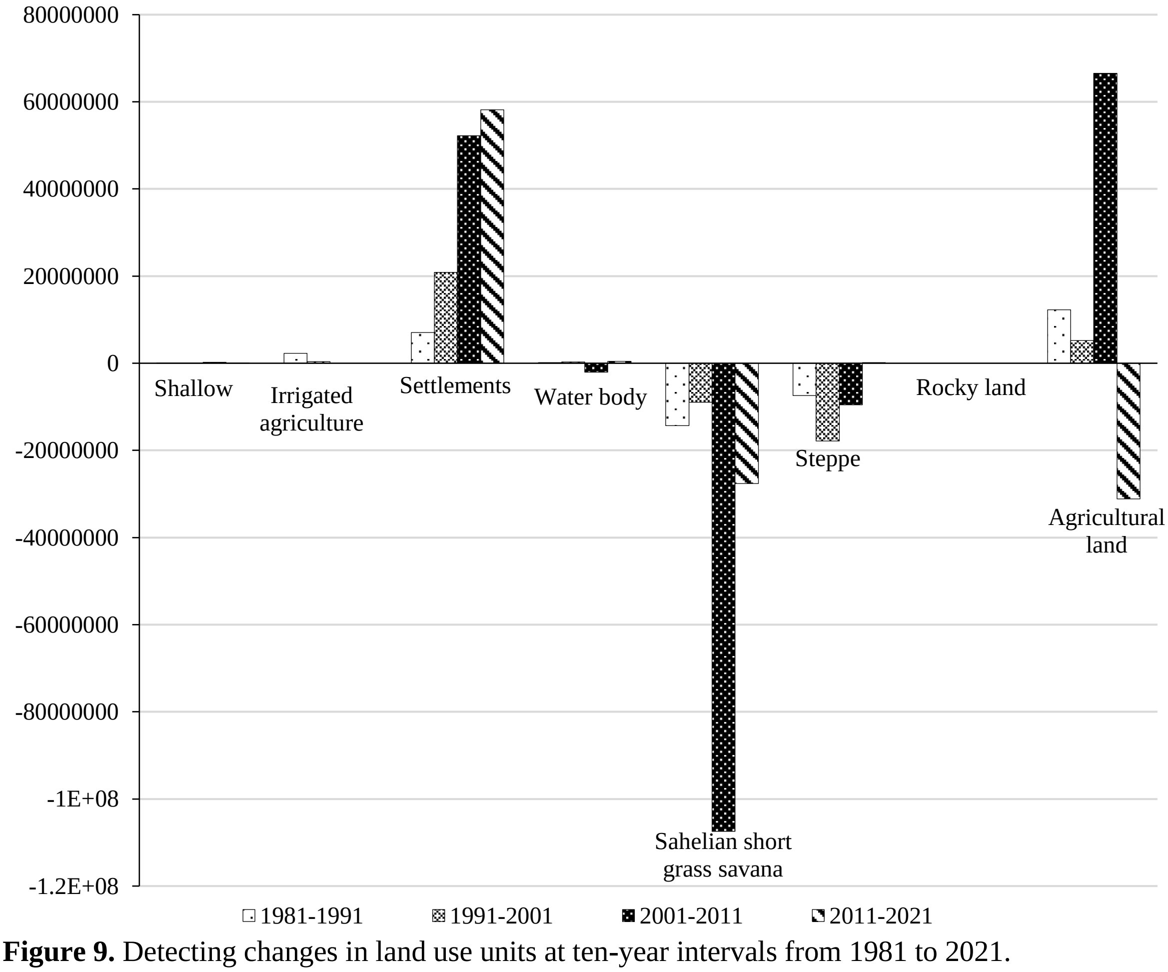

Figure 9. Detecting changes in land use units at ten-year intervals from 1981 to 2021.

According to the general land-use plan, Niamey was largely urbanized in 2011 and 2021, with a significant share of areas devoted to housing and agriculture. Large areas of savannah and Sahelian short grass steppe, as well as rocky terrain and water bodies, can also be observed in Niamey. Overall, the results indicate a predominance of urban areas and agricultural land in the research region, with lesser amounts of steppe, rocky terrain, water bodies, shallow areas, and Sahelian short grass savannah in 2021. Niamey has many water resources, including the River Niger, as evidenced by the fact that the water body category represents about 3.9% of the total area. Shallow groundwater is present in some areas of Niamey as the shallow areas that do not exceed 3.9% of the total area and 7.6% of the total area were rocky soils, indicating that some parts of Niamey are not suitable for construction or agriculture due to their rocky nature during the period 1981–2021 appendix.

CONCLUSION

In summary, the changes in land use in Niamey over the period 1981–2021 are generally due not only to human factors throughout the settlement and agricultural activities but also climatic factors with changes in climatic parameters such as rainfall and temperature. These two main facts (settlements and agricultural activities) are driven by the availability of water sources and the suitability of soil for agricultural activities. The findings prove that land use is the primary driver of land cover changes in Niamey. It was noted that, between 1981 and 2021, the average changes in shallow areas, irrigated agricultural areas, and agricultural land were estimated to be 71479, 675554.5, 34572542, and 132208440 m^2, respectively. This indicates that human activities related to urbanization and agriculture are the primary drivers of land cover changes. The Sahelian short grass savannah, the steppe, and the waterhole, on the other hand, all exhibit negative rates of -287416, -39583425, and -8669576 m^2, respectively. Overuse of the land by humans affects the vegetation and water supply. The effects of climate change, such as desertification and drought, worsen this problem (Appendix).

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APPENDIX

Table A1. Confusion matrix of the classified TM 1981 image.

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	190	0	4	0	0	0	0	0	194	0.99	0.01
PE	0	235	0	0	0	0	0	0	235	1	0
CZ	0	0	200	0	5	0	0	0	205	0.96	0.03
BF	7	0	0	330	0	0	0	0	337	0.99	0.02
H.A.B.	0	0	8	0	357	0	0	0	365	0.98	0.02
THIS	0	0	1	0	2	260	0	0	263	0.99	0.01
TR	2	0	0	10	10	0	236	0	260	0.90	0.1
SS	0	0	2	0	0	0	0	216	217	0.99	0.01
Total	197	235	214	340	374	260	236	216	2072		
LCI	0.96	1	0.96	0.95	0.95	1	1	1			
EO	0.03	0	0.05	0.03	0.05	0	0	0			
Kappa index											
IPT	96.04										

***Legend**: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah; EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index.*

Table A2. Confusion matrix of the classified TM 1991 image.

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	195	0	1	0	0	0	0	0	196	0.99	0.01
PE	0	230	0	0	0	0	0	0	230	1	0
CZ	0	0	210	0	5	0	0	0	215	0.97	0.03
BF	3	0	0	339	0	0	0	0	342	0.99	0.01
H.A.B.	0	0	7	0	357	0	0	0	364	0.98	0.02
THIS	0	0	2	0	2	264	0	0	268	0.98	0.02
TR	2	0	0	12	10	0	236	0	260	0.90	0.1
SS	0	0	1	0	0	0	0	216	217	0.99	0.01
Total	200	230	221	351	374	264	236	216	2092		
LCI	0.97	1	0.95	0.96	0.95	1	1	1			
EO	0.03	0	0.05	0.04	0.05	0	0	0			
Kappa index											
IPT	97.84										

***Legend**: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah; EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index.*

Table A3. Confusion matrix of the classified Landsat ETM+ 2001 image.

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	195	0	1	0	0	1	0	0	197	0.98	0.01
PE	0	230	0	0	0	0	0	0	230	1	0
CZ	0	0	210	0	10	0	0	0	220	0.95	0.03
BF	3	0	0	339	0	0	0	0	342	0.99	0.01
H.A.B.	0	0	7	0	357	0	10	0	374	0.97	0.02
THIS	0	0	2	0	2	264	0	0	268	0.98	0.02
TR	2	0	0	12	20	0	236	0	260	0.90	0.1
SS	0	0	1	0	0	0	0	216	217	0.99	0.01
Total	200	230	221	351	389	265	246	216	2118		
LCI	0.97	1	0.95	0.96	0.95	0.99	0.99	1			

EO	0.03	0	0.05	0.04	0.05	0	0	0
Kappa index								
IPT	97.02							

Legend: *PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah; EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index.*

Table A4. Confusion matrix of the classified Landsat ETM+ 2011 image.

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	284	0	15	0	0	0	1	0	300	0.94	0.06
PE	0	683	0	0	0	0	0	0	683	1	0
CZ	15	0	331	0	0	0	0	0	346	0.95	0.05
BF	0	0	0	373	0	0	0	0	373	1	0
H.A.B.	0	0	0	0	533	0	0	0	533	1	0
THIS	0	0	0	45	21	237	0	0	303	0.78	0.22
TR	0	0	0	0	0	0	185	0	185	1	0
SS	2	0	0	0	0	0	0	122	124	0.98	0.02
Total	301	683	346	418	554	237	186	122	2847		
LCI	0.94	1	0.95	0.89	0.96	1	0.99	1			
EO	0.06	0	0.05	0.11	0.04	0	0.01	0			
Kappa index											
IPT	96.52										

Legend: *PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah; EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index*.

Table A5. Confusion matrix of the classified Landsat OLI-TIRS 2021 image.

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	OC
Steppe	386	0	0	0	0	0	1	0	387	0.99	0.01
PE	0	459	0	0	0	0	0	12	471	0.97	0.03
CZ	9	0	223	0	28	0	0	0	260	0.85	0.15
BF	0	0	0	757	0	2	0	0	759	0.99	0.01
H.A.B.	0	0	40	0	997	0	0	0	1037	0.96	0.04
THIS	0	0	149	0	4	253	0	0	406	0.62	0.38
TR	239	0	0	0	0	0	233	0	472	0.49	0.51
SS	0	0	5	0	0	0	0	196	201	0.97	0.03
Total	634	459	417	757	1029	255	234	208	3993		
LCI	0.60	1	0.53	1	0.96	0.99	0.99	0.94			
EO	0.40	0	0.47	0	0.04	0.01	0.01	0.06			
Kappa index											
IPT	87.75										

Legend: *PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah; EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index*.

