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Urban Green Spaces in Bamako and Sikasso, Mali: Land Use Changes and Perceptions

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Abstract: Increasing land use and land cover change and climate change have considerable impacts on urban green spaces and their ecosystem services. These impacts result in a loss of urban green space and particularly weaken the climate resilience of urban populations. Landsat imagery data from 1990 to 2020 were used to track the spatio-temporal dynamics of urban sprawl and its influence on the loss of urban green space in Bamako and Sikasso in Mali. Furthermore, a survey of local stakeholders was conducted to capture the perceptions of the status of urban green space. The results of the land use/land cover analysis of the cities between 1990 and 2020 showed that most of the vegetation classes, mainly urban green spaces, have been converted into built-up and bare land in both cities during the last 30 years. In Bamako, built-up land has risen from 5421 hectares in 1990 to 13,350 hectares in 2020, and in Sikasso, from 929 hectares in 1990 to 2213 hectares in 2020. Respondents mentioned street trees as the prevalent type of urban green spaces in both cities (20% of the respondents in Bamako and 24% in Sikasso). In addition, the majority of respondents perceived urban green spaces in Sikasso as having a good status and in Bamako as having a good or moderate status. This study recommends improving the number and quality of urban green spaces, which are crucial for the provision of ecosystem services and for the resilience of cities against climate change.

Keywords: public space; green area; ecosystems services; land cover; urbanization; Africa

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1. Introduction

Increasingly, the Earth's surface and human well-being are being affected by urbanization and climate change, creating a number of challenges for urban planning [1]. Climate change is seen as one of the main emerging issues that cities are facing. Indeed, it is described as one of the greatest challenges of our time, with negative effects compromising the ability of all countries to achieve sustainable development. For example, vegetation, phenology, and biodiversity in urban areas are directly affected when air temperature rises [2]. Green spaces need to be integrated into urban planning, particularly in low- and lower-middle-income countries where the pace of urbanization is expected to be fastest to achieve sustainable urban growth [3]. Urbanization is a global phenomenon and is especially accelerating in the Global South. According to the United Nations (UN 2018), 68% of the world population is projected to live in urban areas by 2050 [4–6]. With urbanization, increasing challenges also occur regarding social and environmental justice [7–11], climate resilience [10,11], and other aspects of sustainability.

The Sustainable Development Goals (SDGs) should contribute to the reduction in serious imbalances or the prevention of emerging social, economic, or ecological problems. SDG 11 makes statements regarding sustainable cities and communities [9]. Target 11.7: "by 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities" [12]. Therefore, the expansion of green spaces is among the targets of the SDGs in order to provide more people equitable access. Green spaces provide many social, economic, and environmental benefits. By buffering negative environmental effects, urban vegetation makes an essential contribution to resilient cities [13–16]. Therefore, green spaces can be considered as nature-based solutions [17–22], and can support other SDG targets, e.g., reducing the risk of flooding events (Target 11.5) by faster water infiltration than sealed areas or by improving the air quality in cities (Target 11.6).

According to the classification of ecosystem services provided by the International Common Classification of Ecosystem Services (CICES), urban ecosystem services provided by urban green spaces are (a) provisioning services, such as food and fuelwood; (b) regulating and maintenance services, such as water, climate, or soil erosion regulation; and (c) cultural services, such as recreational, spiritual, or religious services [23–25]. However, urbanization, and especially urban sprawl, lead to the reduction in green spaces in urban areas and, therefore, related ecosystem services. This causal cascade will also negatively affect the resilience of cities and its urban population [21,26,27].

Green spaces are considered to be areas covered with vegetation of any kind (such as trees, urban gardens, grassland, and bushes). These green spaces allow water to infiltrate through the soil and vegetation, filtering some of the sediments and pollutants before reaching the underlying water table [28,29]. Green spaces enrich the city's existing character, improve environmental conditions, promote outdoor recreational spaces and active lifestyles, and protect biodiversity by creating wildlife habitats [4].

Urban adaptation to climate change will improve if more emphasis is laid on ecosystem-based adaptation. In terms of adaptation and mitigation, green infrastructure, in particular, can have co-benefits [30]. The positive effects of urban vegetation have been demonstrated via the attenuation of high local temperatures through shading and evapotranspiration, as well as reduction in the effects of strong winds [31–34]. The effect on the microclimate by planting of vegetation, particularly trees in streets and market gardens, is significant since its interaction with urban morphology and weather conditions affects air quality in different ways [10,31]. Furthermore, the ability of vegetation to retain water is an important element of flood prevention that can reduce peak flows [35]. According to several studies, urban green spaces also contribute to carbon storage [36–38]. Recent studies have highlighted the importance of revitalizing urban green areas and linking fragments of green space with ecological corridors to improve biodiversity and the dispersal of species in the urban landscape [39–41,41–48].

As we have outlined, the contribution of urban green spaces is an important sustainable and climate-resilient issue. Green spaces should be especially integrated in city planning where urbanization is a challenge and where livelihood dependencies on ecosystem services are high [49]. Bamako and Sikasso are the largest cities in Mali that are confronted with land use change and climate change. Many people are affected by the negative effects and, therefore, urban green spaces and ecosystem services are highly relevant for adaption and mitigation.

Green spaces in Bamako and Sikasso differ in their extent. In Bamako, the green area is allocated by the municipality according to the distribution plan approved by the Urban Planning Department in cooperation with the municipality. Thus, the total area of green spaces in the municipality of Bamako is 1439 hectares [50], the largest of which is in Municipality 1, since it has the classified forest of "Koulouba", which occupies a very large area. In Sikasso, the total area of green spaces is approximately 828.49 hectares, of which the inland settlement area comprises two types of classified forest: Zamblara (60 ha) and Kaboïla (410 ha) [51]. These forests lack maintenance and development.

The main aim of our study was to assess changes in land use, its spatial impact on the loss of green space, and the perception of green spaces in Bamako and Sikasso. The specific research questions were as follows:

- How has urban land use changed between 1990 and 2020 in Bamako and Sikasso?
- What types of green spaces have been identified?
- How do local representatives in Bamako and Sikasso view urban green spaces?

A spatial analysis was chosen to identify changes in land use, and a quantitative analysis was conducted through surveys with local stakeholders to identify the types of green spaces and determine the perceived status of urban green spaces.

2. Materials and Methods

2.1. Study Area

The Republic of Mali is a sub-Saharan country in West Africa (Figure 1). Having a size of more than 1,241,238 square kilometers, Mali is a landlocked country with a tropical climate [52]. The district of Bamako is located south of the Koulikoro, at 12°36′07″ north latitude and 7°59′44″ west longitude. Bamako district is separated by the Niger River, and to the north by Mount Manding, and in the South by the Tienkoulou reliefs [53]. Sikasso city is located in the southern part of Mali at 11°19′03″ north latitude and 5°39′59″ west longitude. In Bamako, the wet season lasts from May to October and the dry season runs from November to April. The climate is dry tropical Sudanese with an annual rainfall between 600 mm and 1000 mm. Sikasso has a Sudano-Guinean climate with annual rainfall between 900 and 1200 mm with a dry season in winter and a wet season in summer [54].

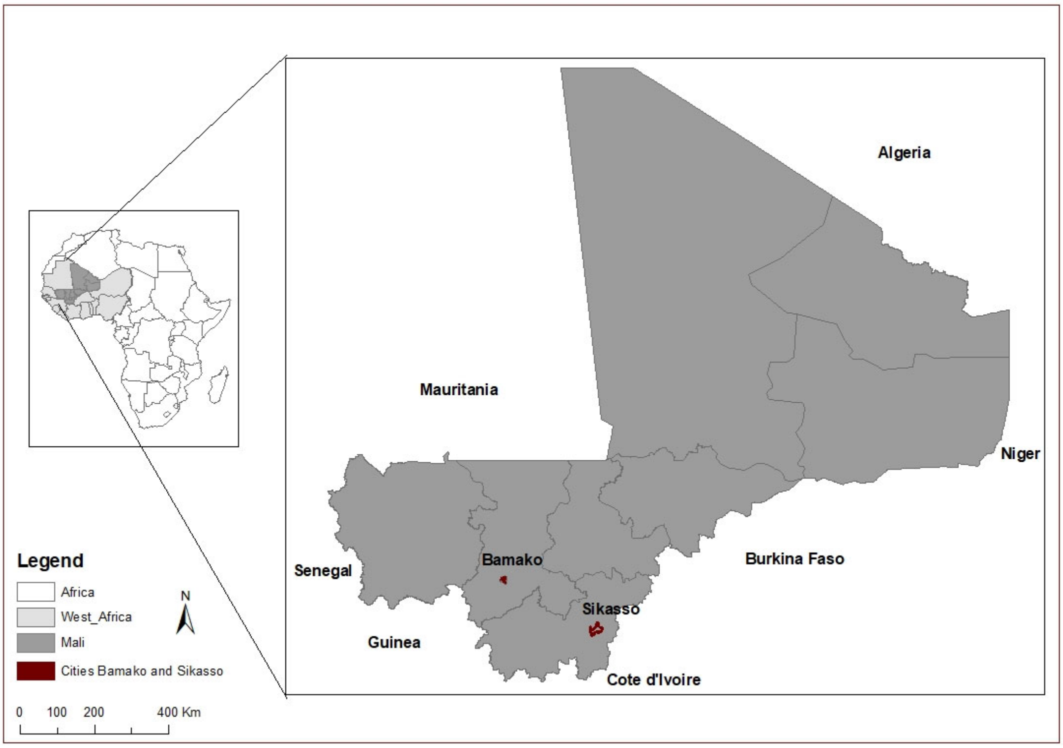

Figure 1. Location of Bamako and Sikasso cities in Mali (M. FOMBA, 2023, ArcGIS 10.8).

The population of Mali is 20,250,833 and 67% of its population was estimated to be below the age of 25 in 2020. According to the latest census, Bamako has a maximum area of 267 square kilometers with 3,337,122 inhabitants and a population density of 1115 people per square kilometer [55]. Bamako, the capital, is the dominant city economically with 16.47% of the population [56]. Sikasso's city has a population of approx. 386,262 and it is the second largest town in Mali [57]. In Bamako, about one-third of the population lives below the poverty line. In both cities, households have low levels of education and are forced to fend for themselves on a day-to-day basis, seeking opportunities as unskilled laborers and/or earning modest income from street vending and petty trade. The upper classes include skilled workers and paid employees, who benefit from higher daily or monthly wages and more predictable and stable sources of income [58].

Excessive pressure on natural resources has caused degradation of soil and plants, structurally reducing subsistence farming and exacerbating poverty. Degradation also causes the expansion of desert-like characteristics [59]. Any policy aimed at combating land use change and climate change requires a strategy that should include the maintenance and restoration of ecosystems.

According to [53,60], neighborhoods ("Communes"; see Appendix A Figure A1) in Bamako were affected in 2013 by changes in the use of public spaces, including green spaces, where Commune IV (33%) was the most affected, while 32% of Communes V and VI were affected. There is no legal procedure for changing the use of space in Mali's urban planning. However, this phenomenon occurs repeatedly, sometimes leading to conflicts between residents and the agencies responsible for managing these areas. In order to protect these areas, the government has enacted protection regulations aimed at classifying some of them, although these regulations are not effective for the protection of these areas [60].

The city of Sikasso and its surrounding areas have serious environmental concerns even though natural resource development is controlled by nature conservation services. These environmental concerns include deforestation, bushfires, and erosion [51]. However, it should be noted that all villages of the commune have groves and individual or collective plantations [51,61]. The total area of the plantation is approximately 142.06 hectares.

2.2. Methods

This study included a spatial analysis and a survey. The first part focused on GIS and remote sensing data processing, using satellite data to analyze land use, land cover changes, and their spatial influence on urban green spaces (Section 2.2.1). The second part was based on a survey and data analysis regarding the perception of urban green spaces (Section 2.2.2).

The survey allowed the development of a database that includes the location of green spaces in the communes of Bamako and Sikasso, and the type of green space according to the vegetation cover based on the typology described by [62–66]. Figure 2 shows the methodological process.

2.2.1. Geographical Information System and Remote Sensing

Data Collection

Satellite data covered the years 1990, 2000, 2010, and 2020. Data from the sensors Landsat 5 Enhanced Thematic Mapper (ETM) acquired in 1990 and 2010, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) acquired in 2000, and Landsat 8 Operational Land Imager (OLI) acquired in 2020 were downloaded from the Global Visualization Viewer (GLOVIS; https://glovis.usgs.gov/app; accessed on 3 December 2020) data portal distributed by the United States Geological Survey (USGS). The study areas of Bamako and Sikasso are covered by the Landsat Path 199 and 197 and the Rows 51 and 52, respectively. Landsat data are part of the medium-resolution (30 m) satellite dataset every 16 days, allowing for the observation of green spaces in urban areas. Therefore, remote sensing helped to determine the spatial distribution and characteristics of green spaces. The selection criteria for the Landsat images were (i) the acquisition date in the regional dry season which lasts from November to April and (ii) cloud cover below 10%, but as low as possible (see details in Table 1).

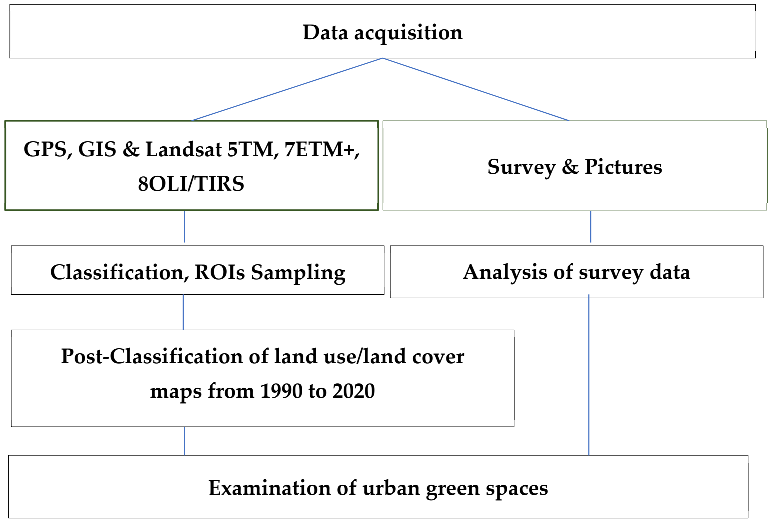

Figure 2. Methodological process of this study. GIS = Geographical Information System, GPS = Global Positioning System, ROI = Region of Interest.

Table 1. Spatial data used to analyze land use and land cover changes between 1990 and 2020 in Bamako and Sikasso. The table contents are sorted according to the years.

City	Satellite	Sensor	Resolution (m)	Number of Bands	Cloud Cover (%)	Data Acquired (dd/mm/yy)
Bamako	Landsat 5	TM	30	7	0.00	22 March 1990
	Landsat 7	ETM+	30	8	0.00	17 March 2000
	Landsat 5	TM	30	7	5.00	16 November 2010
	Landsat 8	OLI	30	11	5.18	16 March 2020
Sikasso	Landsat 5	TM	30	7	0.00	13 December 1990
	Landsat 7	ETM+	30	8	4.00	15 January 2000
	Landsat 5	TM	30	7	2.00	18 November 2010
	Landsat 8	OLI	30	11	0.19	15 December 2020

Image Pre-Processing

The L5 TM, L7 ETM+, and L8 OLI images were processed before analysis using Envi (Version 4.7). The purpose of pre-processing satellite images prior to change detection is to directly associate the biophysical phenomena on the ground with the acquired data. In image classification, the main objective is to place the set of pixels in an image into the land use/land cover (LULC) classes in order to derive useful thematic information based on the reflectance characteristics of the different LULC types [67]. Training samples were selected for each of the predetermined land use types by delineating polygons around representative sites. For the identification of the different levels of vegetation growth and the separation of the different vegetation shades, the infrared color composites NIR (4), SWIR (5), and red (3) were used. For the identification of built-up areas and bare land, the shortwave infrared (7), near infrared (4), and red (2) color composites were used, which are sensitive to changes in moisture content [67]. Different color composites were used to improve the visualization of the different objects on the imagery. Ground truth data for urban green spaces classes were recorded in the form of reference points collected using the geographic positioning system (GPS) for the analysis of Landsat images, which were used for the classification of images and evaluation of the overall accuracy of the classification results [67]. Cultivated land, open space, high (trees), medium (vegetables), and low (grass, flowers) vegetation, and water constitute the delineated land use categories, as shown in Table 2.

Table 2. Land use/land cover classes and their descriptions for the supervised classification.

N	Land Use/Cover	Description
1	Bare Land	An abandoned and often eroded area without vegetation cover as a result of soil degradation and its usage as unpaved road.
2	Built-Up Area	An area covered with commercial, residential, industrial and transport infrastructure and buildings in urban areas.
3	Farmland	An area used specifically for agriculture (food crops: maize, green beans, beans, cassava, and mangoes). Cereal crops are prohibited in the cities for security reasons, but are still cultivated.
4	High Vegetation	An area occupied by sparse trees and shrubs.
5	Medium Vegetation	An area occupied by small-scale market gardens in cities.
6	Low Vegetation	An area covered by grass, lawns, or flowers in public and private spaces.
7	Water Body	An area covered by water, either along the river or riverbed, or by artificial dams or haphazard constructions, temporarily filled dams and ponds.

LULC Mapping and Its Accuracy Assessment

Remote sensing methods are developed to automatically delineate LULC classes and to ensure that accuracy is maintained through the design of several techniques and tools [68]. The land surface coverage analyses were conducted using the information shown in Table 1. The supervised maximum likelihood classification algorithm was applied to the Landsat images to discriminate the selected LULC classes (Table 2).

2.2.2. Survey with Local Stakeholders

A socio-economic survey of the population in both cities was conducted. It involved analyzing the effects of urban green spaces and their ecosystem services (ES) on sustainability and climate change resilience. Thus, looking at the various urban green spaces and the socio-cultural knowledge of the indigenous populations, the administrative authorities, and certain technical services.

The survey was divided into four sections: 1. Socio-demographic characteristics of the respondent; 2. Characteristics and perception of the status of urban green spaces and their ES provided; 3. Urbanization, changing urban planning strategies, and social, physical, and environmental benefits; and 4. Relationship and motivation to use green spaces providing ES. This paper focuses on part 2. The selected questions can be found in Appendix C.

In order to acquire the population's perception regarding the status and changes in urban green space, in the survey we questioned farmers and owners of private green spaces, students and citizens, and administrative authorities and providers of technical services (agriculture, water, and forest) from Bamako and Sikasso (Table 3). We used the formula of Dagnelie (1998) to identify the sample size [69]. The targeted sample size was 384 respondents in each city. In total, 754 people were questioned in the survey, including 370 people (of the 384 planned) for Bamako and 384 people in Sikasso, in order to determine people's perceptions of green spaces. Most of the respondents in both cities were male—78% in Bamako and 71% in Sikasso; their age ranged from 20 to 70 years, with an average age of 31. Males had, on average, a higher educational level in both cities.

Questions were posed to respondents using the Kobo toolbox [70,71] in Bambara (a local language) and in French, and interviews lasted, on average, approximately 35 min per person. In Bamako, the majority of participants (51%) were students and citizens, 41% were farmers and private owners of green areas, and 8% were administrative bodies and technical services. In Sikasso, the majority of participants (52%) were farmers and private owners of green areas, 35% were students and citizens, and 13% were administrative authorities and some technical services.

Table 3. Sample description of Bamako and Sikasso.

City	Representatives of the Respective Stakeholder Group	Specification of Representatives	Number of Respondents
Bamako	Farmers and private owners of green spaces	Left the Niger river (60 people) and right the Niger river (90 people)	150
	Local population	Students and other citizens	190
	Administrative authorities and technical services	Institute of Rural Economy (IER), Health, Water and Forests, Municipality, Urbanism, School and Institute	30
Sikasso	Farmers and private owners of green spaces	Sanoubougou, Hamdallaye, Lafiabougou, 4 Ponts, Medine, Lafiabougou	200
	Local population	Students and other citizens	134
	Administrative authorities and technical services	Governorate, Regional Direction of Agriculture (DRA), Health, IER, Water and Forests, Municipality, Urbanism, School and Institute	50
Total			754

Questions that were used in this study were related to the types of green spaces close to the locality of the respondent and the perception of green spaces regarding the sustainability in their respective community (see Appendix C for the extract of the survey template). The survey was conducted by university students and graduates (agronomists and geographers) who had received preliminary training in the concept of green spaces and the provided ecosystem services, based on the definition and CICES of different types of green spaces.

In addition, field visits made it possible to identify green spaces by geolocation (GPS) and to identify several types of green space by photography. Table 4 shows the criteria established to determine local people's perception of the status of urban green spaces in the two cities. Thus, the types of green spaces listed in Appendix D were explained to respondents during the survey so that they could understand the choice of these different categories and their relevance to their area.

Table 4. Perception of the status of urban green space in Bamako and Sikasso.

Criteria	Perceptions
Many different ecosystem services are provided in high quality	Excellent
Several ecosystem services are provided in medium quality	Good
Several ecosystem services are provided in low quality	Moderate
Only a few ecosystem services are provided and in low quality	Poor

2.2.3. Classification of Local Green Spaces

The types of urban green space types were manually classified. Information on green spaces was extracted using visual interpretation taking into account the boundary and type of each parcel, as well as location, size, shape, and spatial relationships with neighbors. In addition, field visits were conducted every two months for six months in Bamako and Sikasso in order to identify the main types of green space and the variability of the different land use categories. On this basis, we identified sampling points to indicate the urban green space type as a classification of the main terrestrial vegetation (e.g., trees, farmland) [72]. Photos were taken in streets, public and private spaces, market gardening areas, along the Niger River in Bamako, and along the watershed in Sikasso. The survey allowed the development of a database that includes the location of green spaces in the communes of Bamako and Sikasso, and the type of green space according to the vegetation cover based on the typology described by [62–66]. Based on the survey and fieldwork investigation as shown by the selected Schemes 1–3, and the master plan for urbanization, it was possible to locate all public spaces occupied by vegetation [48]. The green spaces in both cities were divided into nine categories: street trees, grass, private garden, public garden, protected urban forest, urban park, market garden, roadside tree group, and greenery of river banks.

Scheme 1. Street trees and front of houses in Bamako and Sikasso (Photos: M. FOMBA, 2021–2022), and Mali National Park (public green space) in Bamako (Photos: O. A. TRAORE, 2020).

Scheme 2. Public Park of the Faculty of Science and Technology (FST) of the University of Bamako, opposite the Campus Numérique Francophone (CNF), roadside tree group, and grassland occupying the space between the faculty and the tarred road, Mali (Photos: M. FOMBA, 2021).

Scheme 3. Market gardens and greenery of river banks in Bamako (Photos: M. FOMBA, 2022).

Descriptions of the selected photos:

- Scheme 1: This includes vegetation on facades and around boundary walls, as well as trees in urban parks.
- Scheme 2: This is considered to be vegetation in public spaces and along roads, as well as trees in rows and meadows.
- Scheme 3: Areas occupied by market gardens as well as vegetation along the river and water points in towns.

2.2.4. Statistical Processing

For the LULC classification, random points were selected per city, for each land cover class, in order to assess the accuracy of each class. The data were then analyzed with application systems such as Envi 4.7 and ArcGIS 10.8, to improve the visualization of the different objects on the imagery, using different color composites. Supervised image classification with the maximum likelihood classification algorithm was applied for the

LULC classification of Landsat images from 1990 to 2020. The matrix was obtained by comparing the classification data with the field verification data (reference data). The estimated quality of the classification is indicated by the Kappa coefficient. We calculated the percentage cover for each land use and cover class for different periods from 1990 to 2020. For the survey, data from the Kobo toolbox were transferred to an Excel file and then analyzed using R-Studio. Descriptive statistics were used for the analysis.

3. Results

3.1. Land Use/Land Cover Maps and Its Accuracy Assessment

The results of the LULC classification showed that the overall classification accuracy values of 1990, 2000, 2010, and 2020 were relatively high (Appendix B, Tables A1 and A2). The total area of interest is 24,556 hectares in Bamako and 4534 hectares in Sikasso. It becomes directly visible that the urban area was increasing for both study sites during the analyzed time period (see Table 5 and Figures 3 and 4). The built-up area of Bamako more than doubled from 5421 hectares in 1990 to 13,350 hectares in 2020. Similarly, large changes are shown for Sikasso, where the built-up area increased from 929 hectares in 1990 to 2213 hectares in 2020. The share of the total area of built-up area increased in Sikasso from 20.5% in 1990 (approx. 22.08% in Bamako in 1990) to 48.8% in 2020 (approx. 54.37% in Bamako in 2020). At the same time, vegetation decreased in both cities. Specifically, low vegetation decreased in Bamako from 6432 hectares in 1990 (26.19% of the total area) to 3708 hectares in 2020 (15.10% of the total area). High vegetation (trees and shrubs) decreased in Sikasso from 975 hectares in 1990 (21.5% of the total area) to 228 hectares in 2020 (5.0% of the total area). Farmland decreased in Bamako while it increased in Sikasso from 1990 (280 hectares) to 2000 (790 hectares) and 2010 (656 hectares), but decreased again to 339 hectares in 2020.

Table 5. Land use/land cover (LULC) changes between 1990 and 2020 in Bamako and Sikasso in hectares (ha) and share of the total area under investigation (%). Please see Table 2 for the definition of LULC classes.

LULC Class	Area (ha) 1990	Share of the Total (%)	Area (ha) 2000	Share of the Total (%)	Area (ha) 2010	Share of the Total (%)	Area (ha) 2020	Share of the Total (%)
BAMAKO								
Bare Land	4742	19.31	3797	15.46	2775	11.30	3617	14.73
Built-up Area	5421	22.08	10,496	42.74	10,902	44.40	13,350	54.37
Farmland	3691	15.03	1587	6.46	1623	6.61	1370	5.58
High Vegetation	531	2.16	756	3.08	486	1.98	492	2.00
Medium Vegetation	2325	9.47	2257	9.19	1994	8.12	710	2.89
Low Vegetation	6432	26.19	4293	17.48	5006	20.39	3708	15.10
Water Body	1414	5.76	1370	5.58	1770	7.21	1309	5.33
Total	24,556	100	24,556	100	24,556	100	24,556	100
SIKASSO								
Bare Land	1385	30.55	178	3.93	730	16.10	1243	27.42
Built-up Area	929	20.49	1940	42.79	1974	43.54	2213	48.81
Farmland	280	6.18	790	17.42	656	14.47	339	7.48
High Vegetation	975	21.50	223	4.92	83	1.83	228	5.03
Medium Vegetation	199	4.39	408	9.00	219	4.83	54	1.19
Low Vegetation	749	16.52	971	21.42	823	18.15	422	9.31
Water Body	17	0.37	25	0.55	49	1.08	35	0.77
Total	4534	100	4534	100	4534	100	4534	100

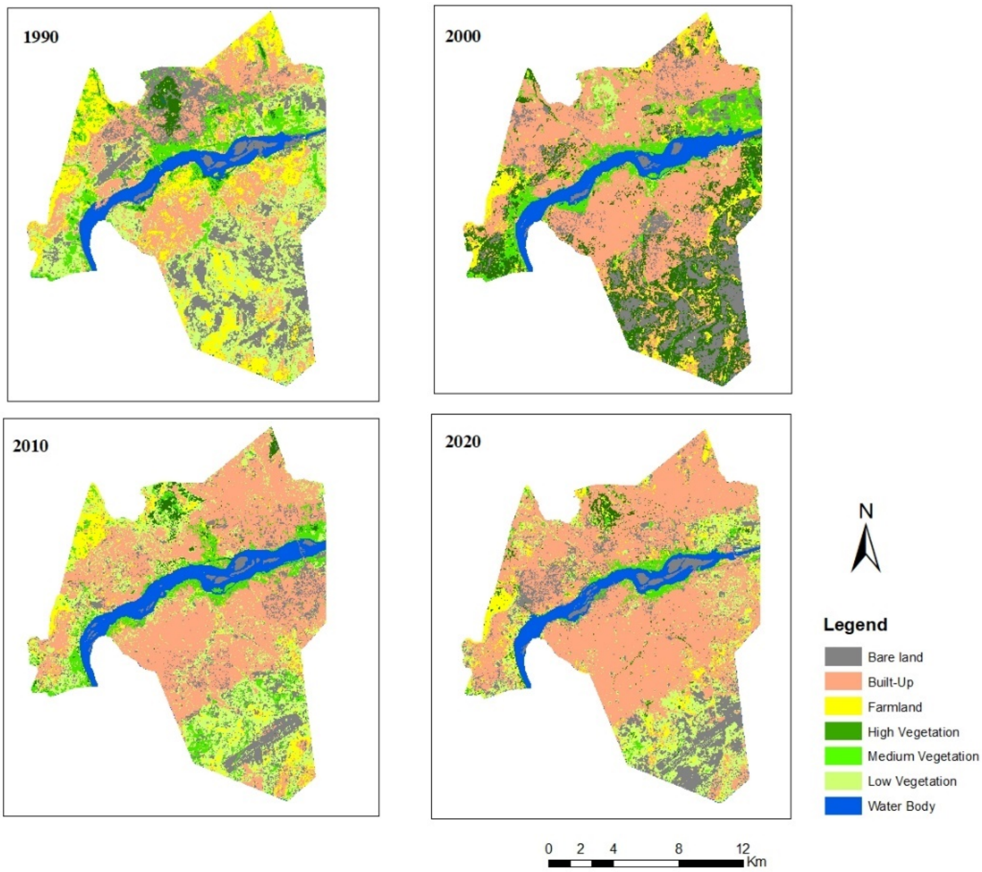

Figure 3. Land use and land cover change in Bamako from 1990 to 2020 (ArcGIS version 10.8).

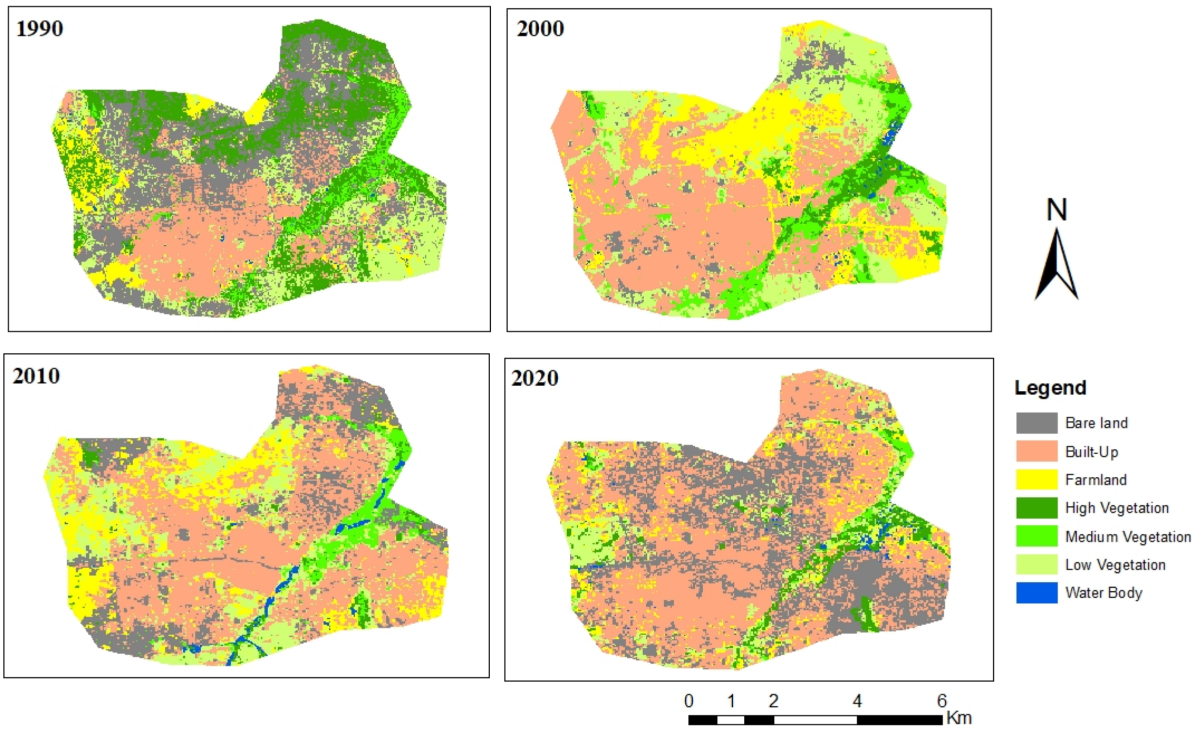

Figure 4. Land use and land cover change in Sikasso from 1990 to 2020 (ArcGIS version 10.8).

3.2. Perception of Urban Green Spaces by Local Stakeholders

Nine types of green spaces were identified (Table 6). Street trees were most often mentioned as being close to the locality of the respondents (Figure 5; 20% in Bamako and 24% in Sikasso), followed by the roadside trees group, with 16% in Bamako and 18% in Sikasso. Public and private gardens were mentioned, with 16% in Bamako and 6% and 8% in Sikasso, respectively. Market gardens were mentioned by 10% of the respondents in Bamako and by 14% of the respondents in Sikasso as being close to the respondents' locality. The greenery of river banks was mentioned by 5% in Bamako and 11% of the respondents in Sikasso as being close to the respondents' locality.

Table 6. Definition of types of urban green spaces.

Green Space	Definition
Streets trees	These trees are usually planted linearly and regularly along streets for decoration and shade.
Grassland	Is an area of herbaceous plants.
Private garden	This is an urban or country green space belonging to private property.
Public garden	This is a place accessible for the public with flowers and trees. They are most commonly found near boulevards and monuments in cities.
Protected urban forest	These are reserved areas in cities, protected by communities and used for cultural and traditional purposes.
Urban park	This is a public space with walking paths, open fields, sports facilities such as football fields, and playground for children.
Market garden	This is a small farm that grows vegetables and fruits; mainly for selling.
Roadside tree group	A tree or group of trees for specific care operations. These are trees planted at specific points along the street to protect the edges from water erosion and ongoing degradation.
Greenery of river banks	Planted trees along the banks of the river.

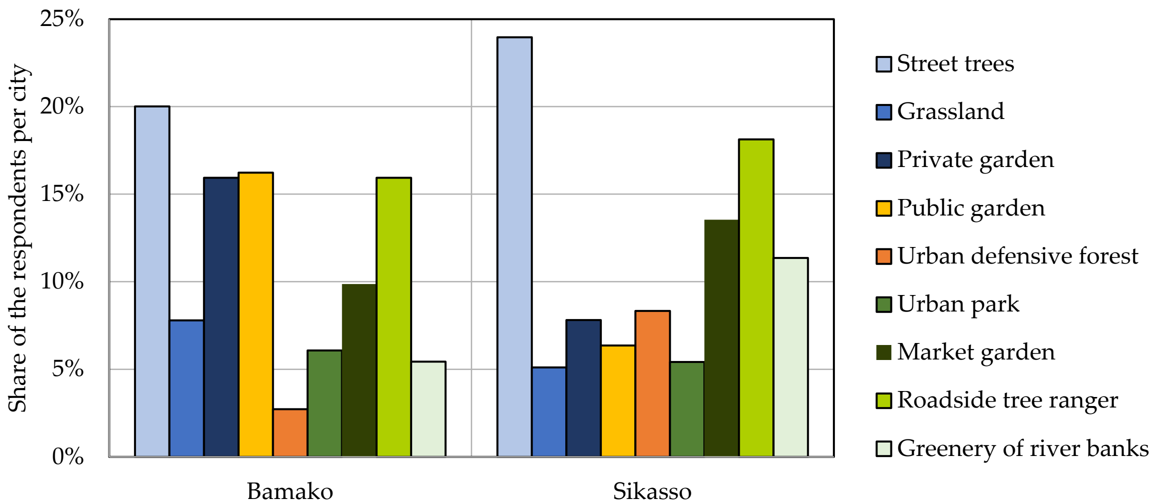

Figure 5. Types of urban green spaces close to respondents' locality in Bamako (n = 370) and Sikasso (n = 384).

The majority of the respondents in Bamako perceive the status of urban green space as being "good" or "moderate" (42% for each), while in Sikasso, the majority of the respondents (72%) perceive the status of urban green space as being "good" (Figure 6).

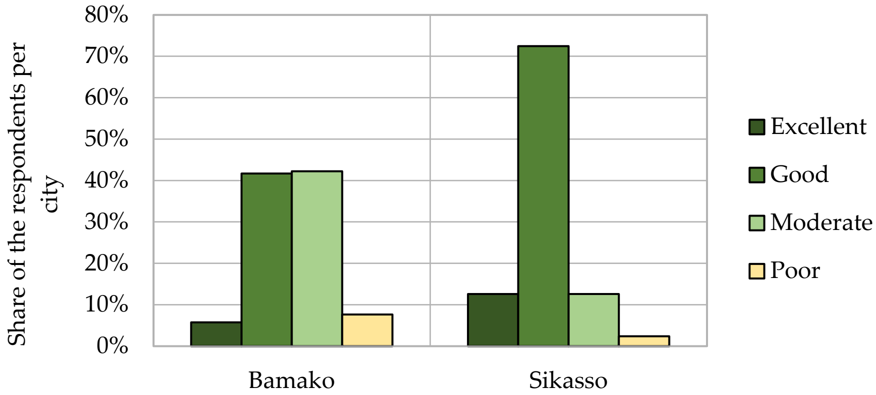

Figure 6. Perception of the status of urban green space in Bamako (n = 370) and Sikasso (n = 384) related to the sustainability of the respective respondents' community.

4. Discussion

4.1. Land Use/Land Cover Maps and Its Accuracy Assessment

There were significant conversions from all vegetation cover categories to built-up, bare land, and farmland between 1990 and 2020 in both cities, as confirmed by [54,58,67,73]. The decrease in urban green space was mainly due to the expansion in built-up areas, confirmed by [74], and was probably attributed to population growth [75]. Mali's towns and cities are growing rapidly, which reflects the trend towards the growing urbanization of the countries in the Global South. Bamako stands out from the country's other cities, with a population ten times greater than that of Mali's second largest city, Sikasso [76]. With over 2 million inhabitants and a population growth rate of approximately 5.4% in inhabitants per year, Bamako is one of the fastest growing cities in the world [60,76]. In response to this growth, the Mali government has delegated responsibility for urban management to decentralized institutions, supported by technical services. The emergence of new political players in urban management created a conflict between general interests and individual approaches to land management [77].

The results of our land use analysis corroborate the research work of Dembele et al. [60], in which nearly 1600 areas in Bamako were identified, mapped, and described. Thus, the research of Dembele et al. [60] shows that the legal instruments classified by decree of the President of the Republic no longer protect the public space, due to the fact that between 10% and 50% of the classified spaces have changed their uses.

A study conducted by Diana et al. [78] of the urban structure and spatial dynamics in Bamako estimated the area of vegetated space at 918.7 ha. However, it was revealed that vegetated areas are different from green areas, with the latter containing green areas open to the public. This surface area in relation to the population of Bamako in 1996 was 8.75 m^2, which is far from the 15 m^2 of vegetated areas per inhabitant envisaged by the master plan for the year 2000 [73,78]. The urban master plan of the city of Sikasso stipulates the following: develop and maintain existing green spaces and create more green spaces in cities; encourage people to regenerate natural species, especially large trees that are disappearing or have disappeared; and the creation of collective and individual groves. Indeed, "Grand Bamako 2030" is a strategy of planning with action points or management priorities to be achieved by 2030.

4.2. Perception of Urban Green Spaces by Local Stakeholders

The main types of green spaces encountered by the respondents of both cities in their locality were street trees and roadside tree groups, while private and public gardens reached especially a high level in Bamako. Due to the fact that trees play an important role in Malian culture, new housing developments are being built, first with roads and buildings, and then with trees that are usually planted very late, so that they also mature very late [76]. Every year, locals in every city in Mali are encouraged to volunteer to plant street trees, especially during the national winter reforestation campaign every August. Reforestation is one of the alternatives that can improve people's quality of life, especially after the destruction of forested areas around major cities. As part of the national strategy for adapting the forestry sector to the impacts of climate change in Mali, 17 strategic adaptation areas have been identified, including strategies based on reforestation. Strategy 4 recommends the implementation of plantations (leveling, enrichment, shade, green areas, reception parks, shrub areas, orchards, hedges, windbreaks, etc.) [79]. The ESIA (Environmental and Social Impact Assessment) report also recommends that the 1st and 4th municipal authorities work together to create green spaces, and that the Bamako Regional Government compensates for plant losses along the main tarmac route and creates green spaces in public areas [80]. Overall, there is no strategic plan for afforestation in and around cities, whereas trees are planted everywhere in the zone of the real estate agency ("Agence de Cessions Immobilières", ACI), created in 2000 by a real estate agency that took green spaces into account in its development plan and in certain colonial-era developments and boulevards [76].

Even though urban green spaces are decreasing in both cities, the perception of the existing urban green spaces by the respondents was rather good. In Bamako, the share of the perception of "moderate" status of urban green spaces was higher, potentially reflecting the higher pressure on urban green spaces in Bamako. Indeed, the Plan for Management and Urban Planning of Bamako and Surrounding Areas was established in 1979 and approved by Decree No. 111PGRN ("Projet de Gouvernance des Ressources Naturelles") on April 1, 1981, for a period of thirty years (1981–2010). It was revised in 1990 and 1995 [76]. However, no five-yearly periodicity has been observed as planned, and so it is essential to continue with the five-yearly adaptation of the plan in order to contribute to improving the development and urban planning of Mali's cities. Further research is needed to explore the relation between perceptions of the local population and current land use changes.

In addition to the green spaces envisioned in the urban planning and development master plan, specific communities in the city of Bamako are working with the urban planning administration to develop new green spaces and improve existing ones in the future [76]. For example, in Commune III (see Appendix A for the map), there is a green space project initiated by the Youth Association with technical support from the Higher School of Engineering, Architecture and Urbanism (ESIAU). The mission was funded as part of the Bamako Urban Planning Directorate's Action Plan for Preconfigured Units [76]. However, this task was part of a process of urban reflection initiated at the Urban Development Forum in 2010 and the International Urban Project Management Workshop held in 2011 under the theme "The New Center of the Bamako Metropolis", which is an operational strategy to implement the Bamako Metropolis new center. More recently, various urban planning and development projects were conducted as part of "Grand Bamako 2030", giving priority to projects that can have a significant leverage effect on the functioning of the metropolis, the participation of private actors and residents, and the attractiveness of the city. Indeed, most studies on urban green spaces have been carried out in developed countries and the results confirm the positive impact of green spaces in the provision of ecosystem services, the well-being of populations, the mitigation of climate change, and the strategic and sustainable planning of the cities [81–84]. It is therefore also crucial to promote green spaces and their ecosystem services in the cities of Bamako and Sikasso, making them sustainable and resilient to climate change.

In Sikasso, the approach based on the terms of reference and the advice of the consultants indicated that the protection and extension of the existing green areas is part of the green area measures, in particular the planned development of 200 hectares around the slaughterhouse and the cattle market along the "Tata" (a swamp) Marigot; tree planting and green belt protection along detour roads; creation and/or reinforcement of forests; green safety belts in industrial and oil areas, arterial road edges, public squares, and former cemeteries; and sealing of abandoned quarries, swamps, and dikes [51]. The consultants, the URBATEC/Atelier 21 consortium, developed the urban master planning approach in a document consisting of two main parts: (i) the assessment/consensus aims to diagnose all issues related to the development of the city of Sikasso, including housing, large commercial areas, roads and various networks, and large facilities; and (ii) the program report includes 20 years of development recommendations, summary cost estimates, implementation strategies, and recommendations [51].

5. Conclusions

The results of the LULC analysis between 1990 and 2020 showed that most of the natural vegetation has decreased in both cities and have been converted into built-up area, farmland, and bare land. The most common urban green space mentioned was street trees in both cities, followed by roadside tree groups. The built-up area increased in Bamako between 1990 and 2020 from 22.08% to 54.37%, and in Sikasso from 20.49% to 48.81%, while vegetation decreased in both cities.

In contrast to the decrease in urban green spaces, the perception of the status of urban green spaces by the respondents was rather positive. Pressure on urban green spaces will probably further increase due to population growth. These results can be used by policy-makers in sustainable city planning to address climate issues through specific mitigation and resilience actions. The authors recommend the following: (i) promotion of sustainable land use systems, such as urban green spaces, which are crucial for the provision of ecosystem services and the resilience of cities to climate change; and (ii) helping urban planners to take into account the public perception of the benefits of urban green spaces for a sustainable city. Therefore, the elaboration of new measures or the enforcement of existing measures are needed to maintain and improve urban green spaces in Bamako and Sikasso.

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Appendix A. Map of Bamako and Sikasso

This map of the study area shows the location of Bamako, Koulikoro region, right in the center of the Kati ring. This configuration is undoubtedly reminiscent of its special legal status. Bamako is in the heart of Kati Cercle.

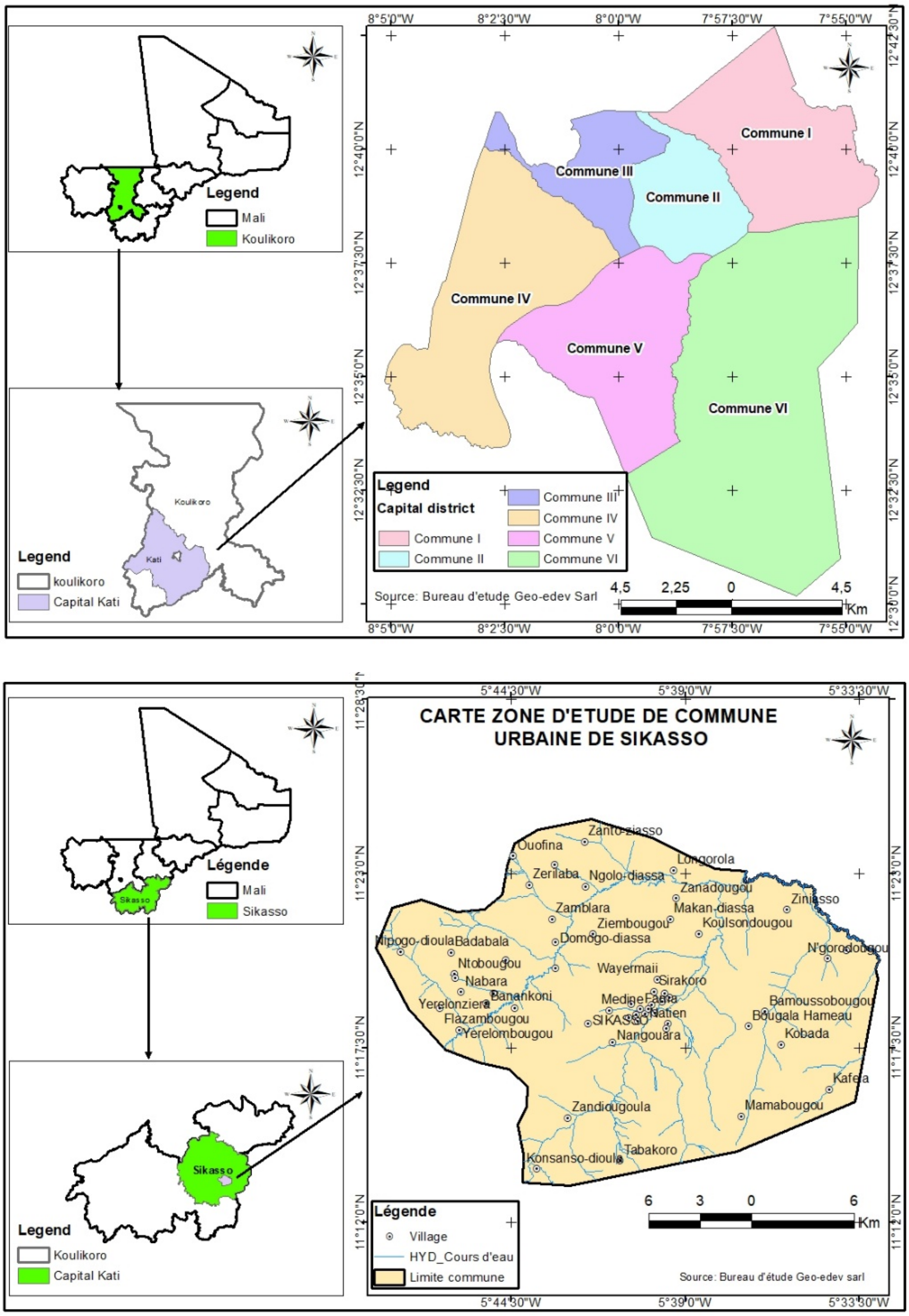

Figure A1. Study area of Bamako in above and Sikasso at the bottom.

Appendix B. Accuracy Assessment of Land Use and Land Cover in Bamako and Sikasso from 1990 to 2020

Table A1. Accuracy assessment of land use/cover in Bamako in 1990, 2000, 2010 and 2020.

Years	Overall Accuracy (%)	Kappa Coefficient (%)
1990	84.81	82.26
2000	90.00	88.17
2010	98.68	93.98
2020	99.17	99.02

Table A2. Accuracy assessment of land use/cover in Bamako in 1990, 2000, 2010 and 2020.

Years	Overall Accuracy (%)	Kappa Coefficient (%)
1990	97.92	93.43
2000	98.42	98.14
2010	98.02	97.65
2020	96.96	96.43

Appendix C. Extract of the Survey Template to Identify the Perceived Characteristics and Types of Green Spaces

Only the relevant questions Q10 and Q16 for this paper from the questionnaire template are shown.

N°	QUESTIONS	ANSWER
...	...	
Q.10	What types of green spaces exist in your locality? *1 = Market gardens; 2 = Roadside tree group; 3 = Protected urban forest; 4 = Urban park; 5 = Public garden; 6 = Private garden; 7 = Street trees; 8 = Grassland; 9 = Greenery of river banks.*	
...	...	
Q.16	What is your perception of the status of urban green space related to sustainability and ecosystem services in your community? *1 = Excellent; 2 = Good; 3 = Moderate; 4 = Poor*	

Appendix D. Types of Urban Green Spaces Mentioned by Respondents

Types of Urban Green Spaces Close to Respondents	Number of Respondents in Bamako	Number of Respondents in Sikasso
Street trees	75	91
Grassland	28	21
Private Garden	58	29
Public Garden	61	22
Protected urban forest	10	33
Urban Park	24	21
Market Garden	36	52
Roadside Tree group	58	71
Greenery of river banks	20	44
TOTAL	370	384

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