GREEN SPACES DEVELOPMENT AND THEIR CONTRIBUTIONS TO SUSTAINABLE CLIMATE CHANGE RESILIENCE OF BAMAKO AND SIKASSO CITIES IN MALI

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PhD/SPS/FT/2019/11125

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OCTOBER, 2024

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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN CLIMATE CHANGE AND HUMAN HABITAT

OCTOBER, 2024

DECLARATION

I hereby declare that this thesis titled: ***"Green Spaces development and their contribution to Sustainable Climate Change Resilience of Bamako and Sikasso Cities in Mali"*** is a collection of my original research work and it has not been presented for any other qualification anywhere**.** Information from other sources (published or unpublished) has been duly acknowledged.

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Signature & Date

CERTIFICATION

The thesis titled "Green Spaces Development and Their Contribution to Sustainable Climate Change Resilience of Bamako and Sikasso Cities in Mali" by FOMBA, Mohamed (PhD/SPS/FT/2019/11125) meets the regulations governing the degree of PhD of the Federal University of Technology, Minna, and it is approved for its contribution to the scientific knowledge and literary presentation.

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Dean of Postgraduate School Signature & Date

DEDICATION

This work is dedicated to the glory of Allah and my wife Boussourata Boubacar MAÏGA for her fidelity, quiet times, and shared ideals. It is the outcome of continuous and unwavering devotion.

In my devotional periods, I always say this prayer in remembrance of my father, posthumously: "O my Lord, have mercy on him all as he raised me as a child." Qur'an, S 17, V 24.

ACKNOWLEDGEMENTS

This study is, the outcome of an alliance between WASCAL, FUTMINNA, and Martin Luther University Halle-Wittenberg, Halle, Germany. I use this opportunity to express my deep gratitude and appreciation to everyone that I benefited from, including the assistance that made the process of preparing for my study and dissertation go smoothly. Many people helped me with this research, which was sponsored by the German Federal Ministry of Education and Research (BMBF). My most sincere thanks goes to my supervisors, Prof. Mrs. Zinash D. Osunde, my major supervisor, who provided me with valuable scientific instruction and crucial documentation about the guidelines of PGS, despite her varied activities; Dr. Souleymane S. Traore, my co-supervisor, who agreed to supervise the work at the internship site and provided astute design ideas that undoubtedly raised the document's scientific calibre; and Prof. Dr. Habil. Christine Fürst, my Germany supervisor, who invited me to a highly rewarding scientific stop in Germany and provided me with numerous suggestions and crucial documents that greatly supported this work with high-level contributions for published papers in the MDPI Journal, I say thank you. Likewise, I appreciate Dr. Janina Kleemann for her availability, invaluable documentation, and multiple scientific contributions to this project, such as my published paper in the MDPI Journal and various presentations at conferences and internal defense. I would like to thank Professor Appollonia Aimiosino Okhimamhe, the director of the WASCAL CC&HH programme, for accepting me into the project and for all of her help from the moment I developed the study proposal and her administrative assistance until I completed writing of the thesis, The Deputy Director Dr. Emmanuel Umaru, Dr. Mrs. Saratu Ibrahim, the former Deputy Director, and all the staff of the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), especially Dr. Mrs. Mary Odekunle, Mrs. Lucy Peter, Engineer Raphael Agboola, Dr. Mrs. Julia Eichie,

M. Yahaya Abdulrahaman, Dr. Isaiah Sule, M. Wakila, M. Ayuba and others for always being problem solvers. I wish to also acknowledge Prof. Dukiya Jaiye, my internal examiner for his high-level contribution and availability; the entire team at WASCAL ACCRA and the computer centre in Ouagadougou, who went above and beyond to make my stay at WASCAL enjoyable and those who have provided me with crucial support in gathering and documenting satellite, meteorological, and survey data when I've been on the ground. I say a big thank you. My sincere gratitude goes out to Dr. Yacouba Diallo, the director of the CC&Agriculture programme, for his availability, to the entire Mali-Meteo agency staff, to the IER in Sotuba's agroclimatology unit for providing the climatic data used in this study, and to the Sikasso town hall and regional urban planning department for hosting the investigators while they were in the town. I would also like to express my sincere gratitude to Mr. Lucas Dombrowka and the members of the research group of the Institute of Geosciences and Geography, Department of Sustainable Landscape Development, Martin Luther University Halle-Wittenberg, Halle for their support and encouragement. In addition, I would like to thank Ibrahim Laouali, Boubacar Doumbia, Doukoro Diarra, Modou Pouye, and Ibrahim Laouali for their availability and scientific interactions. My sincere gratitude goes out to the late Yacouba Kone, Mory Sylla, and Alkassoum Barka, the Regional Directors of Agriculture in Sikasso, who supported me throughout my training, as well as to all the interviewers for their assistance in gathering data. In particular, I would like to thank the head of the GIS (Geometric Information System) section, Dr. Cheick Hamalla Diakite. My deepest gratitude goes out to my entire family for their unwavering love and support throughout the study period that at times felt like it would last a lifetime. In particular, I would like to thank my mother Fatoumata Sissoko, my wife Boussourata Boubacar Maïga, my kids, and all my children (Fodiè Kane, Korotoumou M Fomba, Laïbatou M Fomba, Souraka dit Aliou M Fomba, Noureen Ibrahim M Fomba, Ousmane Yassir M Fomba). Along with my Malian colleagues in other WASCAL programme: Aboubacar Doumbia, Doukoro Diarra, Mahamadou Maïga, Makan Garba Diarisso, Mohamed Fofana, Mohamed Sidibe, Nagale dit Mohamed Sanogo, and Youssouf Bolozogola, I would also like to convey my appreciation to all other WASCAL students and all of my colleagues in the CC&HH programme who were there for me during the programme: Abdoul Moumouni Sithou, Alexis Akakpo, Audrey Tohoun, Femi Asonibare, Ibrahim Mamadou, Jerry Asaana, Konko Yao, Okeleye Sunday Opeyemi, Richard Adade, Valentine Ouedraogo, and all my friends numerous to mention.

ABSTRACT

Urban green spaces (UGS) play an essential role in providing urban ecosystem services and creating a livable environment for urban residents. Increasing land use, 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. In order to assess urban green spaces and their ecosystem services provided in Bamako and Sikasso, as well as their planning approach design for sustainable land use system and climate change resilience of Bamako and Sikasso. This study made use of remote sensing, Google Earth, Landsat imagery data from 1990 to 2020, climatic data (from Mali-méteo), and structured questionnaires for household surveys. From 1990 until 2020, remote sensing data and images were extracted from Landsat photos. Standardised Precipitation Index (SPI), Standardised Precipitation Evapotranspiration Index (SPEI), Mann-Kendal test, and non-parametric test were used to evaluate the spatiotemporal dynamical changes in climate variables (rainfall, minimum and maximum temperatures) between 1990 and 2020. Descriptive statistics were used to examine all semi-structured interviews in order to ascertain how the public views green areas and the ecosystem services they offer. In addition, a climatic analysis was carried out using rainfall and temperature data from 1990 to 2020 in order to evaluate the climate variability and its effects on urban green spaces according to the population's perception. A maximum likelihood classification was applied for the classification of LULCs. The results of the LULC analysis showed that most of the natural vegetation has decreased in both cities and has been converted into built-up areas, farmland, and bare land. 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. The results of the survey indicate that the majority of respondents have a strong relationship (social cohesion) with green spaces (96.13%) and attribute a good status to green spaces in Sikasso (64.59%). Rainfall in the two cities is statistically insignificant; however, seasonal minimum temperatures in Bamako City differ statistically significantly ($p=0.0001$, $R2=0.4027$). The seasonal minimum temperature ($p=0.0001$, $R2=0.476$) and seasonal maximum temperature ($p=0.0001$, $R2=0.6448$) in Sikasso differ statistically significantly due to climate change and entropic activities. Bamako city has higher temperature than Sikasso because Sikasso is located in the humid and sub-humid zones, with high vegetation density while Bamako is located in the Sudanese climate zone. The highest values for ecosystem services in both cities are provisioning services. These results can be used to set up some policies on urban green spaces management and development, and solve some climate issues in cities in order to improve sustainable cities and climate change resilience, through green spaces and ecosystems services provided. However, the promotion of UGS, perceived by the population as an appropriate way to reduce climate change in cities, are necessaries. In order to provide ecosystem services that increase Mali's cities' resistance to climate change, this study suggests safeguarding, preserving, and improving urban green spaces.

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

AEDD	Environment and Sustainable Development Agency
AIVF	Association of French City Engineers
AKDN	Aga Khan Development Network
AKTC	Aga Khan Trust for Culture
BL	Bare land
BU	Built-Up
CA	Cellular Automaton
CICES	Common International Classification of Ecosystem Services
CO_2	Carbon dioxide
DNSI	National Directorate of Statistics and Informatics
ES	Ecosystem Services
EPA	Environmental Protection Agency
ETM	Enhaced Thematic Mapper
FAO	Food and Agriculture Organisation
FL	Farmland
GIS	Geographic Information System
GISCAME	(GIS = Geographic Information System, CA = Cellular Automaton, ME = Multi-criteria Evaluation)
GLOVIS	Global Visualisation Viewer
GPS	Geographic Positioning System
HV	High Vegetation
IER	Institute of Rural Economy
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC	Intergovernmental Panel on Climate Change
LULC	Land Use and Land Cover
LV	Low Vegetation
ME	Multi-criteria-Evaluation
MV	Medium Vegetation
NDBI	Normalized Difference Building Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
OLI	Operational Land Imager
PGS	Public Green Spaces
Popul	Population
SDG	Sustainable Development Goals
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
Temp	Temperature
UGS	Urban Green Spaces
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNWCED	United Nations World Commission on Environment and Development
U.S	United State
WB	Water Body
WWF	World Wildlife Fund

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background to the Study

Any area with vegetation of any kind, including grass, bushes, trees, and vegetable crops, is referred to as a green space. Water can percolate through the flora and soil in these green spaces, removing some of the pollutants and silt before it reaches the water table underneath (Benefits and Benefits, 2019). The vegetation, phenology, and biodiversity of urban forests are directly impacted by rising air temperatures (Choi *et al.*, 2012). According to the UN cited by Prud'homme (2018), 68% of people on Earth are expected to live in cities by 2050, and as a result of urbanisation, there will be fewer green spaces, changing the way land is used spatially (Prud'homme, 2018).

Emphasizing ecosystem-based adaptation, green infrastructure, and the utilisation of natural systems for carbon sequestration in metropolitan areas, we can speed urban adaption. Green infrastructure in particular can provide co-benefits in terms of adaptation and mitigation (Bazaz *et al.*, 2018). Urbanisation and climate change are having an increasing impact on the earth's surface and worldwide urban health, which presents a variety of issues for urban planning (Kabisch and Bosch, 2017). Humans are becoming a more urban species as a result of the global phenomena of urbanisation; this shift occurs quite quickly when one considers how long humans have been associated with a much more natural environment. One of the most important concerns that cities are dealing with right now is climate change. The ramifications of this issue put every country's ability to achieve sustainable development in jeopardy, making it one of the most important contemporary issues.

According to recent studies, reviving green urban areas and connecting scattered green spaces to ecological corridors are critical to improving biodiversity and the distribution of animal species in urban environments. Human health and climate change adaptation are positively impacted by green spaces. One of the most important methods of preventing floods and reducing peak flows is the retention of water by vegetation (https://climate-adapt.eea.europa.eu/metadata/adaptation-options/green-spaces-and-corridors-in-urban-areas).

Given how commonplace urbanisation is, the significance of urban green areas in reducing the consequences of climate change has been emphasized on a global scale. The sustainable development goals address this issue, and numerous studies have shown how important sustainable urban planning is to creating more livable cities. According to Çinar *et al.,* (2018), the landscape design method is the most advantageous, sustainable, and natural way to create green areas. Although much of the early innovation in ecosystem services and green infrastructure focused on addressing water shortages or floods, the importance of adapting to climate change is becoming more widely acknowledged. Green spaces are helpful for both absorbing precipitation and reducing excessive heat.

Urban forests and trees benefit cities by offering shade, evaporative cooling, rainwater interception, storage and, and infiltration services. Due to the fast and frequently uncontrolled growth of cities in low- and middle-income nations, a substantially smaller percentage of the Urbanized land remains as parks and other green areas (Revi *et al.,* 2015). One of the most pressing difficulties facing cities today is climate change, which has been called one of the biggest challenges of our time. Its negative repercussions could make it impossible for any nation to achieve sustainable development (UN, 2016).

Efforts to avert climate change would intensify competition for the resources needed for agriculture, as it directly affects agricultural systems and food security. Scientists have tracked changes in Africa's climate over the past century, with records indicating a rise in heat across the continent. It is already recognized that climate change will negatively affect Africa. Climate change is affecting the well-being of terrestrial and marine ecosystems, as well as the food security and general health of many of the most vulnerable individuals in the region (IPCC, 2014). In addition, climate change has a major effect on the urban environment. The primary effects of climate change in urban areas are rising air temperatures (such as during heat waves), poorer air quality and higher ozone concentrations, and excessive precipitation (Kabisch and Bosch, 2017).

Urban adaptation choices can be expanded through the development of green areas in a context-appropriate manner, the preservation of ecosystem services, and the creation of nature-based solutions. Thus, at least some of the decision to keep global warming to 1.5°C rests on how feasible urban initiatives and policies are. Experienced cities and regions will act as role models for cities preparing for and planning for these system transitions, having successfully navigated some of them (Bazaz *et al.*, 2018).

West Africa is one of the most urbanising regions of Africa, where temperatures are much greater than in the nearby rural areas. Attention must be focused on the urban heat island that arises when hard surfaces replace vegetative areas throughout the urbanisation process (Amani-beni *et al.*, 2019). Furthermore, in the upcoming decades, climate forecasting models project a notable rise in temperature, a decline in precipitation, and an amplification of extreme weather events (droughts, floods) in Mali (AEDD, 2011). The primary factors contributing to the loss of green spaces are urbanisation and modifications in the spatial organisation of urban land use. In urban settings, phenology, biodiversity, and forest vegetation are all directly impacted by rising air temperatures (Choi *et al.*, 2012). Due to their contributions to water absorption and infiltration, which lower runoff rates, green spaces and permeable surfaces are requisite in urban environments (Benefits and Benefits, 2019). Furthermore, green areas in cities are useful for reducing excessive heat and absorbing precipitation (Benefits and Benefits, 2019). Therefore, increasing forest cover to reduce the urban heat island remains a viable proposal (Revi *et al.*, 2015).

The Quito Declaration on Cities and Sustainable Human Settlements from October 17 – 20, 2016, will make urbanisation one of the main drivers of transformation in the 21st century. It is also evident that climate change impacts are felt in cities, which must now be designed or reconstructed to be resilient. This is very important because the interactions of socio-economic and cultural activities and environmental and humanitarian impacts are increasingly concentrated in cities, posing enormous sustainability challenges that affect natural resources, basic services, housing, food security, infrastructure, health, education, and especially decent jobs (Dubbeling *etal.*, 2019). Green spaces and other nature-based solutions provide creative ways to improve urban surroundings, build community resilience, and encourage sustainable lifestyles, which in turn improve the health and well-being of urban people (World Health Organisation, 2017). According to Anguluri and Narayanan (2017), urban green space is therefore essential to urban planning, which can play a significant role in the sustainable development of cities. In addition, they contribute more to the decrease of urban heat and offer numerous additional advantages that are social, physical, and environmental.

Urban green spaces are important for sustainability and citizens' well-being in increasingly urbanized societies (Contesse *et al.*, 2017). Indeed, these green spaces vary in size depending on the quality of the environment and other aspects. However, maintaining the livelihoods of low-income dwellers in cities and peri-urban areas in developing countries for many years has been possible through the practice of urban agriculture. The increased availability of fresh crops, particularly vegetables, and the contribution to food security and sustainable livelihoods are benefits that arise from urban agriculture and are often underestimated and undervalued.

The design of quality public or private spaces, where nature and especially plants find their place, integrates the new models of a sustainable city with the realisation of green infrastructure such as parks, gardens, interstitial spaces, and trees (Osseni *et al.*, 2015). Thus, thinking of more sustainable and resilient cities requires the contribution of urban green spaces that must ensure food security, the well-being of populations, and the environment. Urban gardening and tree planting have long supported the low-income urban and peri-urban residents of emerging nations (Addo, 2010). Urban green spaces serve a variety of purposes and offer a several advantages that are crucial for raising urban residents' quality of life. Green areas foster connections between humans and the natural world (Bilgili and Gökyer, 2012).

The United Arab Emirates had the greatest ecological footprint per person in 2006, according to a World Wildlife Fund (WWF) report, partly as a result of its carbon emissions. Indeed, there have been notable double increases in the population and the number of cars on the roads using fossil fuels. It transformed from a small and poor fishing village and trading port to a city with the densest collection of skyscrapers and the third busiest airport. Its shift towards sustainability received a boost from the leadership that decreed that by 2050, the city will receive 75% of its energy from clean sources. According to Robert Kunzig, the southern outskirts of Dubai are today a large tract of land dedicated to a 'sustainable city' where waste and water are recycled and green energy is generated; driverless metro trains carry more passengers than the cars; and a giant solar power plant exists in the desert aimed at producing the cheapest and cleanest electricity on Earth (Kunzig, 2017).

Additionally, there are numerous national parks and tree-lined roadways in Dubai, evidence of green-spaces in the desert. Certain studies claim that urban green spaces are a form of nature-based solutions that use the services that urban ecosystems provide to alleviate the problems caused by urbanisation and climate change. (Kabisch and Bosch, 2017). The United Nations has set forth the Sustainable Development Goals (SDGs), which state that by 2030, all countries should strive for inclusive and sustainable urban development that reduces inequality and meets the needs of all populations (Shi *et al.*, 2020). That is why the topic of urban green spaces is essential to climate resilience and sustainability. In sub-Saharan cities, where forty percent of households are urban farmers, many are already green. Vegetables and fruit trees are grown by millions of urban Africans in their gardens for family consumption and also for sale. There are an estimated 7,500 households in Dakar that grow their vegetables in micro-gardens. Home gardening is practiced by 700,000 urban dwellers in Malawi to meet their food needs in order to earn additional income. Low-income urban gardeners in Zambia earn $230 per year from sales (FAO, 2012).

Bertrand *et al.* (2020) combined case studies on African cities and discovered that urban areas were growing at a rate of five hundred hectares per year, displacing natural and agricultural land cover (Bertrand *et al.* 2020). For instance, Kumasi, a city in Ghana, has an atmosphere that can hold between 168 and 1,737 tonnes of CO_2 per acre (Nero *et al.*, 2020).

It was discovered that Kumasi's poor condition of green space is primarily the result of underlying factors like institutional inefficiencies, a lack of community participation, a lack of priority given to green spaces by the city authorities, a poor maintenance culture, and uncooperative attitudes of the general public towards the preservation of such spaces (Adjei Mensah, 2016). For instance, Kumasi's overall bad state of urban green spaces and the underlying causes of this situation offer some lessons for other African cities where data indicate that green spaces are seriously threatened. One of these lessons is that all development plans should prioritize green places. The general public's lack of cooperation in managing green spaces is another aspect that needs a lot of attention. Local government agencies can address this by organising community seminars and workshops as part of their educational programme to inform people about the value of green areas and the necessity of preserving them. Green space design, implementation, and administration should involve a larger range of stakeholders, including the business sector, the general public, and city authorities. Additionally, this will encourage these organisations to actively participate in the preservation of green areas by making them feel like a part of the management process (Adjei Mensah, 2016).

The government of Mali responded to the establishment of a 103-hectare section within a larger 2,100-hectare protected forest reserve, which constitutes a significant green belt in the otherwise parched country, by defining the boundaries of Mali's National Park. The government asked the Aga Khan Trust for Culture (AKTC) to concentrate on the 103 hectares of the park, the large semi-circular canyon of protected forest beneath the terraced outcrops of the Koulouba Plateau between the Presidential Palace Complex and the National Museum, as part of the public-private partnership (Complex, 2010). The zoo and botanical garden, located in the city's upper and lower areas, respectively, are considered to be two of Bamako's most important institutions. However, their vast expanse of land-which includes severely demarcated residential areas and even some houses presents organisational and technical challenges due to the anarchy villages that the municipality exploits there (Sidibe, 1993). As a result, neither their treatment nor their biological goals are the same among people. While urbanites seldom find time to unwind in green areas, it is usual, even customary, for people to gather beneath the canopy of trees situated either inside or outside the concession. The majority of family life occurs in this area (Sidibe, 1993).

Large areas of green space in the tropics disappear annually, which may be explained by a mix of human activity and natural processes. The landscape has changed mostly as a result of population expansion. Urbanisation brought on by sustained population expansion has drastically altered the loss of biodiversity worldwide, particularly in Bamako, and resulted in major environmental issues such as pollution (Diallo and Zhengyu, 2018). After Bamako, Sikasso is regarded as the second-largest city. The study concentrated on green areas, particularly parks and market gardens, which should enhance urban living conditions, food security, air quality, rainwater infiltration, and other factors. New strategies are needed for successful adaptation and mitigation of the negative consequences of climate change and urbanisation if we are to maximize the prospects for enhancing the sustainability of all urban residents, regardless of socioeconomic class, gender, cultural background, or age. (Kabisch and Bosch, 2017).

1.2. Statement of the Research Problem

The African Humid Period (AHP), a humid phase across North Africa which peaked between 9,000 and 6,000 years ago, highlights the significant impact of Earth's orbital changes on climate, exemplified by the Sahara's transformation into a green landscape. This period shows that even gradual climate forces can result in rapid changes, affecting water availability and human sustainability with the attendant impact on green spaces. North African paleoclimate and archeological evidence emphasize water's crucial role in cultural development, paving the way for complex urban civilizations (deMenocal, 2001; Kuper and Kröpalin, 2006), which include major cities such as Bamako and Sikasso, in the Sahelian country called Mali.

In more recent times, increased warming in cities is driven by an increase in climate change and urbanisation, especially during heat waves (Shukla *et al.*, 2019). In Africa, urban green spaces are being destroyed at an alarming rate, with a small proportion of the land mass having vegetated surfaces in many urban areas (Mensah, 2014). Indeed, the destruction of vegetated surfaces in the urbanisation process is at the origin of urban heat islands. (Amani-beni *et al.,* 2019). In all the big cities of the world, there is a significant amount of resource consumption and a far greater environmental impact. However, cities must help support and enrich human communities in their bio-regions by keeping some of the natural or rural land. (Panagopoulos *et al.,* 2018).

Sub-Saharan Africa's urban population will grow by 6.9 % per year by 2025, compared with 3.1 % of the region's total population (Lam *et al.*, 2019; United Nations and Africa, 2006). There is therefore a need to produce enough food to meet the projected demand and sustain it under the increasing impact of global climate change (Addo, 2010). Cities in South Africa and the North African region are the greenest major urban areas on the continent. The only city in sub-Saharan Africa (excluding South Africa) to fall into the "above average" category is Accra, the capital of Ghana (FAO, 2011).

According to the yearly rate of change from 2015 to 2020, Mali's urban population is 43.9% of the country's total population, indicating an urbanisation rate of 4.86% (People and society, 2020). Moreover, projections by the National Directorate of Statistics and Informatics (DNSI) show a rapid growth in Mali's urban population, which will almost double as a proportion of the country's total population between 1998 and 2024, rising from 26.7% to 47.5 (Farvacque-vitkovic and Eghoff, 2007). Indeed, the development of the Mali National Park in Bamako was carried out within the framework of a public-private partnership between the Government of Mali and the Aga Khan Trust for Culture (AKTC). An important part of the AKDN's work was the creation of parks and gardens with the objective of using green spaces to positively stimulate socio-economic and cultural change, as well as the expression of ethical notions and the presence of beauty in the built environment. However, Mali National Park in Bamako minimize the influence of man and his companions on the green areas of Bamako through gaps, uprooting of plants, animal attacks, ...

In addition to the dangers posed by man and his goods, today green spaces are unfortunately made up of domestic waste, domestic sewage, and various animal carcasses (MATP, 2006; Sidibe, 1993). Out of ignorance or contempt, city dwellers often confuse green spaces with areas where human and animal waste is disposed of (Sidibe, 1993).

However, in improving the quality and sustainability of the environment, urban green spaces (wooded and market gardening as agricultural areas) are attracting more attention than before because of their crucial role. Therefore, it is crucial to provide a wide range of services and improve social, ecological, and cultural values, with the most crucial being the improvement of landscape aesthetics, outdoor leisure, noise reduction, and cooling efficiency (Li *et al.*, 2018). Thus, factors influencing climate change that affect ecosystem functions include temperature, precipitation patterns, evaporation, soil moisture, vegetation growth rate, and air quality (Panagopoulos *et al*., 2018).

However, in response to increasing urbanisation and the resulting demand for food in cities, the urban green space and urban agriculture sectors need to grow in these cities, regardless of the often unfavorable political and policy environment. Even though Mali has green spaces and agricultural areas in these urban areas, especially in Bamako and Sikasso cities, climate change and rapid urbanisation that impact the well-being of urban populations are major problems that persist. Hence the need for this study on': green spaces development and their contribution to sustainable climate change resilience of Bamako and Sikasso cities in Mali.

Consequently; this work should answer the follower questions in the selected cities in Mali:

i. What are the spatial changes and the characteristics of Urban Green Spaces types in Bamako and Sikasso?
ii. What impact do urbanisation and climate change have on designated green spaces and the Ecosystem Services (ES) they provide?
iii. What planning strategies could be created to enhance UGS's ES and climate change resilience?
iv. How are green spaces in Sikasso and Bamako used in terms of land use, as well as the condition of the ecosystem services they offer?

The following hypothesis is considered for this study:

i. Ho, there is no statistically significant relationship between urban green space development dynamics and urban temperature in the two cities.

1.3. Aim and Objectives

This study is aimed at assessing urban green spaces and their ecosystem services provided, in order to design planning approach for sustainable land use system and climate change resilience in Bamako and Sikasso cities.

The specific objectives of this study are to:

i. Evaluate the spatial changes and the characteristics of the different types of Urban Green Spaces (UGS) in Bamako and Sikasso cities;
ii. Examine the impact of urban green space and ecosystem service distribution dynamics on climate change resilience.
iii. Compare urban green spaces and their ecosystem services in the study areas.
iv. Determine the availability and quality of green spaces in the study areas.
v. Examine the implications of the existing green spaces on the resilience cities.

1.4. Justification for the Study

Unlike most African countries south of the Sahara, where cities date from colonisation, urbanisation is not a new phenomenon in Mali. Thus, Mali has a very ancient urban history and culture, and these historic cities were either capitals of the great mediaeval empires or more often commercial, religious, and cultural centres (Diana *et al.*, 2003). According to a report by Mali's Ministry of Housing and Urban Development, a new urban development plan is to be drawn up for the cities, especially Bamako, the Malian capital, and its surroundings. This measure is intended to meet the development objectives pursued following the implementation of the urban planning and development plan, revised in 1990 and 1995 (Dembele, 2017).

This new urban planning tool must imperatively take into account a system of sustainable land use as well as several development issues, notably the development of the Niger River easements in the District of Bamako, the liberation and development of the riverbed, and the development of a new waterway. Bamako District and the water points in the city of Sikasso, the release and development of natural drains to reduce flooding, and other social housing programmes. Ensuring urban mobility and providing sufficient equipment and infrastructure are essential for bolstering cities' resilience against climate change (L'Urbanisme, 2005). The result of this study is expected to contribute towards improving the performance of professionals in the relevant Ministries such as Ministry of Urban Planning and Housing, Ministry of the Environment, Ministry of Agriculture, and Environmental Agency for Sustainable Development (AEDD), different municipalities and others.

Sikasso and Bamako in Mali are interesting cities with particular status in the country. They promote entrepreneurship and increase economic development through employment opportunities, public services, and food security. Support for urban carbon sequestration comes from policies to expand green spaces and urban carbon sinks (Mohamed *et al.,* 2014). In terms of global warming and air pollution, trees and crop capture CO_2 thanks, thus urban agriculture reduces net CO_2 emissions (Skar *et al.*, 2020) and contributes to reducing the microclimate in cities. The analysis of these locations and the roles played by practitioners, planners, and decision-makers suggests that urban agriculture could contribute to the growth of urban green areas. However, political mechanisms must allow citizens or public organisations to maintain private spaces (Contesse *et al.*, 2017).

Policies that prioritize urban green spaces can contribute to the restoration of degraded lands, human well-being, food security, and mitigation and adaptation to climate change (high confidence). In certain mitigating situations, they can even help with these goals (low confidence). This study aims to enhance policymakers' and urban planners' abilities, particularly in Mali, to formulate effective sustainable development policies and strategic plans for urban resilience against climate change. By engaging the ministries in charge of housing and urban planning, land tenure, rural development, and civil society organisations, national and international partners, the research emphasizes the importance of Urban Green Spaces (UGS) in improving quality of life of citizen. It highlights the dual benefits of water-river parks in mitigating flood risks and urban farms in ensuring food security.

Urban market gardening areas and green spaces constitute a significant policy element that obligates scientists to do high-level research on the many forms of green spaces in urban areas and their contributions to the sustainability of cities in the face of climate change. The high heat in Mali is not entirely unrelated to the horizontal expansion of the cities. Indeed, public and private green spaces, trees in the streets, in front of houses, and on the sides of roads must be consider to make Bamako and Sikasso cities sustainable and resilient to climate change. This is why green spaces in cities deserve special attention from the policymakers to allow people to benefit from the ecosystem services provided (Diana *et al.*, 2003).

In terms of improving the microclimate, urban agriculture can contribute to the comfort of citizens if it is appropriately planned and integrated into urban design. Nonetheless, green areas surrounding homes and apartment complexes, as well as abandoned city blocks, enhance the physical climate. This improvement in the physical climate is due to vegetation that can contribute to increased humidity, lower temperatures, and the introduction of more pleasant smells into the city. Also, it helps to capture dust and gases from polluted air by depositing and capturing them through the foliage of plants and trees, as well as through the soil, breaking wind and intercepting solar radiation, creating shade, and protecting areas. Different criteria are used to categorize urban open spaces and green areas, including their size, intended use, intended function, and geographic location (Bilgili and Gökyer, 2012). Urban green spaces help cities become more resilient by reducing the effects of abrupt shocks like heat waves and storms (Kendal *et al.*, 2016).

The substantial benefits offered to human well-being in urban areas are provided by urban ecosystem services. Thus, the answer to the unhealthful environmental growth of big urban areas is given. UA can help preserve natural places in spite of growing land costs by supporting the intensive production of perishable goods like fruits and vegetables, depending on the ecological conditions and the local environment. Sustainability in Green Spaces City has been the demonstration that nature and humans past, present, and future can coexist and have symbiotic interactions (LugoSantiago, 2020).

Urban agriculture, if properly planned and integrated into urban design, can improve the microclimate and enhance citizens' comfort. Green areas around homes, apartment complexes, and abandoned city blocks improve the physical climate by increasing humidity, lowering temperatures, and introducing pleasant smells. Vegetation also captures dust and pollutants, breaks wind, intercepts solar radiation, creates shade, and offers protection. Urban open spaces and green areas are categorized by size, use, function, and location (Bilgili and Gökyer, 2012). They help cities become more resilient to heat waves and storms (Kendal *et al.,* 2016).

Urban ecosystem services significantly benefit human well-being, addressing the unhealthful environmental growth of large urban areas. Urban agriculture supports the intensive production of perishable goods like fruits and vegetables, helping preserve natural spaces despite rising land costs. Therefore, the outcome of this study would contribute to body of knowledge. It still needs more investigation to fully grasp how green spaces support resilience to climate change and sustainability. Also, the identification of what is effective for different cities depends on the degree of urbanisation. However, strategies for planning and safeguarding urban green spaces, market gardening and other green spaces are included in the housing and urban master plans. Addressing problems at the level of the urban landscape is essential, taking into account the geographical distribution of urban green spaces in line with the goals and master plans of individual cities.

Public green spaces (PGS) are a significant factor in development decisions due to their advantages for recreation and mental health. Most of the developed country research on PGS casts doubt on PGS's potential function in light of the rapid urbanisation occurring in underdeveloped nations. To appropriately incorporate green spaces into urban infrastructure and small-scale agriculture, urban planners must ascertain whether people in developing nations place a higher priority on the existence of green spaces. Before incorporating green spaces into urban infrastructure and small-scale agriculture, urban planners must ascertain whether people in developing nations place a higher value on their presence (Elizabeth Babalola, 2013). To guarantee population comfort and mitigate the urban heat island effect, urban green spaces (UGS) are a suitable strategy.

Sustainable land use practices are therefore essential, especially in light of the ecological services that these green spaces offer. Sustainable land use practices are therefore essential, especially in light of the ecological services that these green spaces offer. Without a doubt, this study on urban green spaces and their role in resilience and sustainability will improve the quality of life in urban areas and empower city dwellers to take responsibility for it.

1.5. The Study Area

1.5.1. The geographical location

The study was conducted in two urban cities in Mali which are located in the northern hemisphere of sub-Saharan West Africa country, crossed by the Niger River or Djoliba (in Mandingo), which is the third largest river on the continent after the Nile and Congo river. Mali is a landlocked nation covering more than 1,241,238 square kilometers and has a tropical climate ((AEDD), 2011). Situated on the Niger River, the biggest river in West Africa, is the capital city of Mali, Bamako (Diana *et al.*, 2003). On the other hand, Bamako district, the capital of the Mali republic, is situated in the southwest of the nation. 50.14% of the nation's urban population lives in the Bamako district. Sikasso (11.82%), Koulikoro (11.27%), Segou (9.81%), Cais (5.79%), Mopti (5.22%), Gao (3.15%), Timbuktu (2.08%), and Kidal (0.72%) are the other districts in order of population density (MATP, 2006). Sikasso, the second-largest city in the nation, is roughly eight times less populous than Bamako alone.

The report of the Ministry of Land Use Planning and Population on the National Land Use Planning Policy shows that there is a huge imbalance between Bamako and other metropolitan areas in Mali, not only in terms of population (the trend of large population growth in the past decade), But also population-specific issues related to the roles each place is developing or intends to develop (MATP, 2006).

The Bamako District located in southern Mali is further divided into six municipalities. The two halves of the Bamako District are separated by the Niger River and are situated at 7°59'W and 12°40'N. The north bank is situated on the alluvial plain where the east and west ends converge, between the Niger River and the Mandine Mountains. With Senou Airport and reliefs from Tiankoulou to Niger, the southern shore spans more than 12,000 hectares (Dembele, 2017; Renzong *et al.,* 2018).

Sikasso is the third administrative region of Mali and the second largest city in terms of economy and population after Bamako. It is situated in Mali's southern region between 10° 49 and 12° 18 of north latitude and between 5° and 6° 35 of west longitude (Figure 1.1). The waterways in the central districts are not yet developed and continue to serve as natural outlets, resulting in frequent flooding. Considered a crossroads city, it is located 41km from the Burkina Faso border and 100km from the Ivory Coast border. It forms the Burkinabe city of Bobo-Dioulasso and the Ivorian city of Korhogo, a commercial and strategic triangle, SIKOBO (Chitou, 2015).

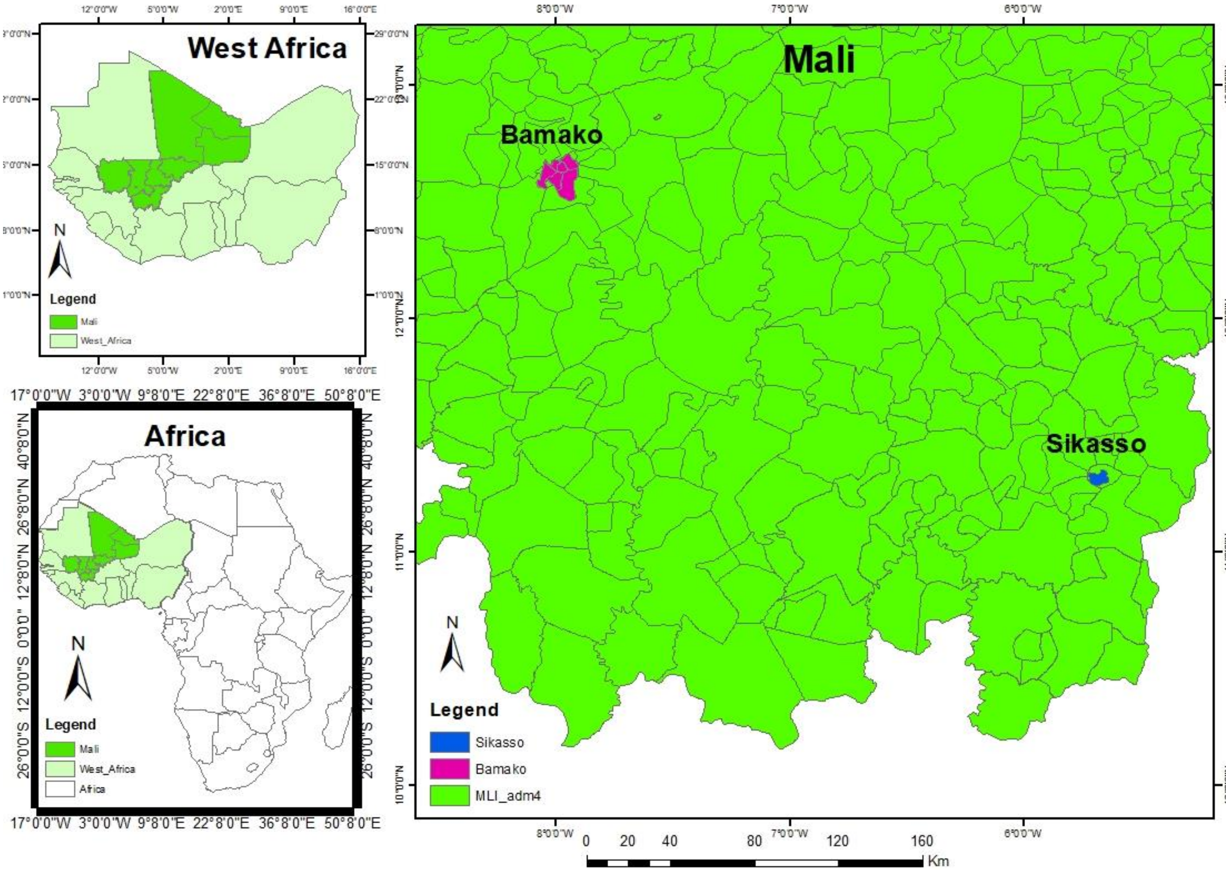


Figure 1. 1: The Locations of Mali's cities of Bamako and Sikasso (M. FOMBA, 2023, ArcGIS 10.8).

1.5.2. The study area description

1.5.2.1. Climate of study area

Bamako is entirely located in the Sudanese climate zone, which by definition is a hot region (always over 18°C). However, it is located on the largest river in West Africa, the Niger River. The main characteristic of the Sudanese climate is the alternation of two seasons. A protracted dry season and a June through September wet season. The dry season includes a short cool season (December to February) and a long hot season with sometimes very high extremes (over 38°C) (Diana *et al.,* 2003). November through April is Bamako's dry season; May through October is its rainy season. The degree of dependence on livestock and the use of arable land is explained by the level of rainfall.

Indeed, rainfall levels range from very low in the extreme northern desert (receiving less than 200 mm of rainfall per year) to between 1,000 and 1,300 mm per year in the more lush southern areas (World Bank, 2015).

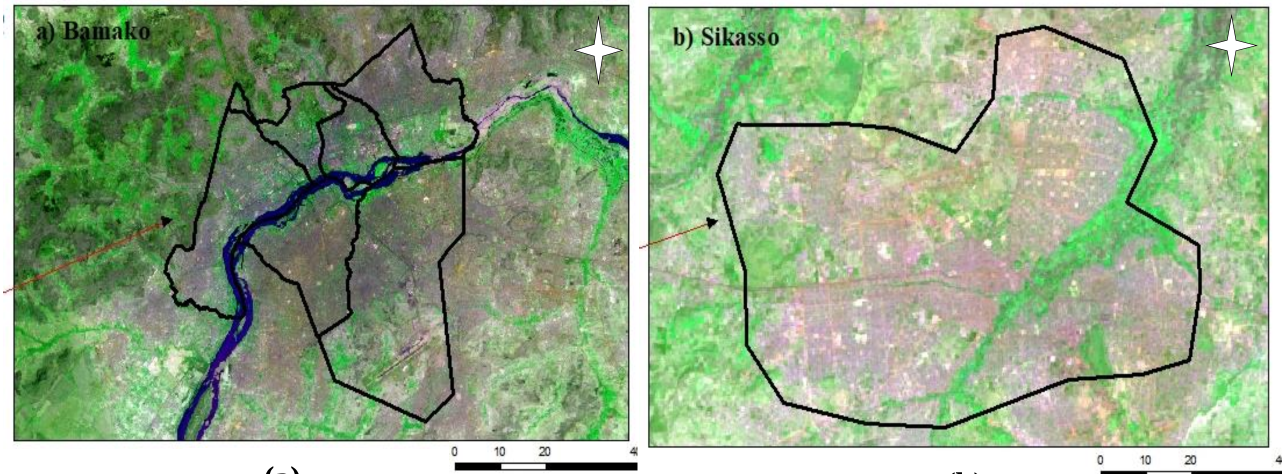
The Sikasso region is the only one that extends exclusively in the humid and sub-humid zones, between the 750 mm isohyets in the north and 1400 mm in the south. It is characterized by several zones such as the humid Sudanian zone and the Guinean zone. It experiences three distinct seasons: a hot dry season from February to April, a dry season from November to January, and a six-month rainy season from May to October. The waterways in the central districts are not yet developed and continue to serve as natural outlets, giving rise to frequent flooding (Chitou, 2015). The average annual temperature is 27°C between April and May and an average of 24°C between December and January.

1.5.2.2. Vegetation, drainage and soils

Vegetation is patchy overall in the study areas, with some scattered patches of trees and shrubs (Figure 1.2). There are also trees and furrows along the roadside, as well as small market gardens within the towns and along waterholes and rivers. Numerous plant species were identified in the study areas, including local species *(Bombax costatum, Parkia biglobosa, Borassus aethiopium, Acacia spp, etc. néré, baobab, borassus palm, doum palm, desert date palm, Spondias momi, etc.*) and trees planted on green spaces, roadsides, carres, riverside marketing sites (*mango, banana, orange, lemon and papaya trees*) and stadiums (sports grounds, monuments, etc.) (M'Baye *et al.,* 2016).

Various species are also found on the banks of the Niger River, along the Dianéguéla site in Bamako and the "Kotorni" site in Sikasso. In addition to Guiera senegalensis, many local protected species are present on the banks of the river at the Sotuba site. The above-mentioned local species are partially or totally protected by Malian forestry regulations.

Herbaceous species include: *Cenchrus biflorus, Amorphophallus aphyllus, Cynodon dactylon, Andropogon spp, Crotalaria spp,* etc. Aquatic plants are found on the river banks, including water hyacinth and freshwater lettuce (characteristic of water pollution) (M'Baye *et al.,* 2016). The types of soil in Bamako are: depressions made of clay, loam, sandy loam, gravelly soil, and clayey loam (Bakker *et al.,* 1998). The types of soil in Sikasso are: sandy soils; clay-sandy soils; gravelly soils and clay soils which are encountered in the lowlands (GEDD-SARL, 2018).



(a) **(b)**

Figure 1. 2: Maps of Bamako (a) and Sikasso (b).

1.5.2.3. Population and socio-economic activities

Mali has a population of 22,395,485 people, of which 47.2% are under the age of 15, an average age of 21.4, and an annual population growth rate of 3.3%, according to the report of the Fifth General Census of Population and Housing (RGPH5). Bamako has a population density of 1115 people per square kilometre, with a maximum size of 267 square kilometres and 3,337,122 residents, according to the most recent census (Keita *et al.,* 2020), Bamako's population density is 1115 persons per square kilometer, with a maximum area of 267 square kilometers and 3,337,122 inhabitants, as per the most recent census. Bamako is the biggest city with 16, 47% of the total population of Mali (World Bank, 2015).

The population of Sikasso's cercle is 817,254 with 49.4% of men against 50.6% of women. Based on projections, this population was expected to reached 929,292 inhabitants in 2016 (International Alert, 2020). However, the town of Sikasso in 2020 had a population of nearly 386,262 inhabitant and is the second largest town in Mali (Nationale, 2017).

1.5.2.4. Urbanisation trend in the study

Like most developing countries, Mali has not escaped a population boom. At a compound annual growth rate of 3.6% in 2009, Mali's population will double in 20 years. Much of this population growth has been concentrated in cities, where the urban population increased from 1,076,829 in 1976 to 3,274,727 in 2009 (16.8% to 22.5% urbanisation) (Dembele, 2022). In 2009, the number of cities with at least 20,000 inhabitants was 25. The capital, Bamako, is at the centre of this population growth, accounting for 55.3% of Mali's urban population (Dembele, 2022; Dnsi, 2001; Ouane and Bandiougou, 2012).

No country or continent is immune to urbanisation, regardless of its level of development. This is a global phenomenon and does not occur in the same way on different continents. Nowadays, with a 50% urbanisation rate, more than half of the world's population resides in cities (Dembele, 2017). By 2030, according to United Nations projections, the proportion will be just over 60% (UNDESA, 2015). As mentioned above, the rapid increase in the population of the cities of Bamako and Sikasso has been accompanied by a strong consumption of space, leading to urban sprawl with consequences such as the proliferation of precarious neighborhoods, inadequate or non-existent infrastructure and sanitation systems, an increase in commuting, the destruction of ecosystems, and increased pollution.

In actuality, Bamako city has had an urban planning and development plan since 1981, similar to other cities in and surrounding Mali. It was amended in 1990 and 1995, but its implementation hasn't allowed it to achieve its development goals (URBATEC, 2006). To address the growth and preservation of green spaces in towns and cities, a new master plan for town planning is desperately needed. Indeed, in Bamako and the eight regional capitals (Ségou, Sikasso, Mopti, Kayes, Timbuktu, Gao, Koulikoro, and Kidal), Urban Development Plans (PAU) were created and updated during the project's startup phase of urban planning and development plan. Although these documents are a great tool for decision-making, they haven't been used much, maybe because of a lack of funding and available space locally (Farvacque-vitkovic and Eghoff, 2007).

1.5.2.5. Socio-economic activities

Most people in Bamako are under 20 years old, and approximately one-third of the population lives below the poverty line. Access to essential services is limited, and unemployment is high. Agropastoral and agricultural practices put the delicate ecosystems' balance in jeopardy and speed up the spread of the desert (ALPHALOG, 2001). Agriculture is the main economic activity in Sikasso, and it is the most agriculturally successful zone in the country. The main crops produced are maize, millet, sorghum, rice, and cotton (Sidibe, 2018).

Families with low levels of education are left to fend for themselves daily in both cities, looking for work as unskilled labor or making meagre ends meet through street selling and small-scale trading (Lecumberri *et al.*, 2015). Skilled workers and salaried employees are part of the upper classes; they gain from greater daily or monthly earnings as well as more reliable and steady sources of income (Lecumberri *et al.*, 2015).

1.6. Scope and Limitations

1.6.1. Scope

(a) Time Boundary: This research is focused on green spaces that are recognized for their valuable contribution to the environment and social and human well-being between 1990 and 2020. Thirty years of satellite imagery from 1990 to 2020, thirty years of temperature and precipitation data from 1990 to 2020, and survey data from 2021 were all used in this study. The time frame of 1990 to 2020 was selected to study climate change, analyse distribution patterns, and look at how urban green areas contribute to long-term resilience to climate change. According to Diana *et al.,* (2003), the spatial dynamics and planning policies that explain environmental changes in the city of Bamako are an impossible compromise. Consequently, planning policies are at the root of landscapes and their dynamics. Urban planning documents are essential tools for the development of urban space. Their role, based on a certain number of basic analyses, is to anticipate the future and plan the rational organisation of land for a more or less distant future. By using satellite image processing, changes in land use and types of green space in the two cities of Bamako and Sikasso were found. Climate variables are used to identify trends in both dry and wet locations.

(b) Space Boundary: The capital city of Bamako and the southern city of Sikasso were specifically chosen from among the cities in Mali. Due to their large land areas, dense population, and plenty of open spaces, Bamako and Sikasso, which are located in central and southern Mali, respectively, were chosen (Fomba *et al.,* 2024). This research on green spaces and their contributions to urban sustainability and resilience focuses on examining the size, spatial distribution, and ecosystem services provided, the most important of which is agriculture, which accounts for 63.2% of all jobs in Mali (World Bank, 2015).

(c) Content Boundary: This study covers all green spaces of any kind, like parks, gardens, and crops (market gardening), as well as the ecosystem services provided by green spaces. As with SPI and SPEI, precipitation and temperature are the climate variables used to determine trends.

1.6.2. Limitations

This study used Landsat images for change detection analysis. The green spaces seen in March are truly green spaces, whereas during the rainy season, everything becomes almost green because of the rain. However, the satellite imagery database for March was not of acceptable quality for specific periods between 1990 and 2020. This had an impact on how accurately land cover change was estimated. This affects the accuracy of land cover change estimates because the actual green area during this period is clearly evident. During the rainy season, most undeveloped areas (bare surfaces) grow green due to the humidity caused by the rain. Apart from the protected Koulouba forest and the Bamako national park, which features a few (insignificant) artificial trees, the majority of the green spaces in the two cities are actually artificial.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Conceptual Framework

Urban green spaces (UGS), an essential component of a healthy built environment, have neighborhoods benefits beyond environmental, social, and economic ones (Bardhan *et al.,* 2016). This conceptual framework on urban green spaces was adapted from Zhang *et al.,* 2017. The overview discussed in this section emphasises how urbanisation, urban green spaces (forest and agricultural areas), sustainability, and climate change resistance are all influenced by the interplay of various factors. These difficulties must be acknowledged in urban green space research and specifically addressed in the study technique. The range of potential causative factors for sustainability and climate change resilience (dependent variable) and the interactions between factors that might make it challenging to pinpoint the precise causal pathways between exposure to USG (independent variable) and ecosystem services (ES) are usefully illustrated by a framework.

The contribution or perception of urban green space and ecosystem services as an independent variable consists of the supply and exposure to urban green space; the mediator and moderator represent the causality that may alter the strength of the relationship; the green space response indicates the contribution to the independent variable that takes into account the sustainable outcome; the spatial scale refers to the spatial context of the Urban Green Space - Climate Change Resilience relationship (Figure 2.1), which shows the conceptual framework of our study.

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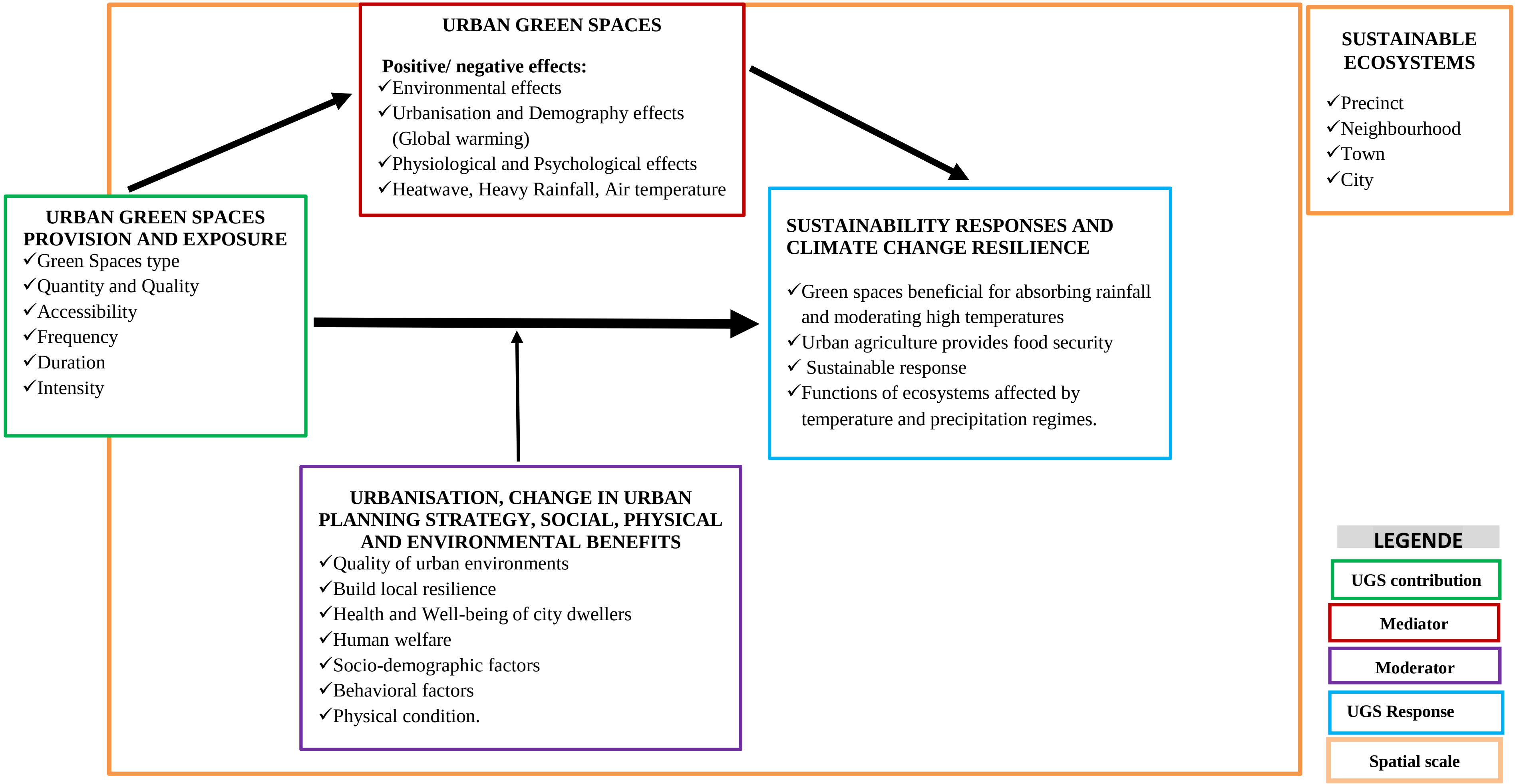


Figure 2. 1: Conceptual Framework of Urban Green Spaces and their Contribution to Sustainable Climate Change Resilience adapted from Zhang *et al.* (2017).

2.1.1. Urbanisation and climate change resilience

2.1.1.1. Urbanisation

A third of people in Bamako are considered to be impoverished, and most of them are under the age of twenty. Both access to essential services and unemployment are high. The delicate ecosystems' balance is endangered by agricultural and agropastoral practices, which also promote the spread of the desert (du Toit *et al.*, 2018; Pauleit *et al.*, 2018). Three times as many as the 400 million urban dwellers on the continent now (Nations and Settlements, 2019), Three times as many as the 400 million urban dwellers on the continent now (United Nations, 2015), are to be accomplished, Bamako and Sikasso cities will need to prepare for and handle a fast urban population increase.

This can be problematic because estimates currently indicate that less than one million people live in small and medium-sized cities in Africa, which are typically extremely impoverished settlements with the least social, institutional, and political capacity to handle future population growth (Donnermeyer *et al.*, 2013; du Toit *et al.*, 2018). These cities are expected to account for nearly three-quarters of Africa's population growth. Since cities offer the required density of people, goods, infrastructure, and services, urbanisation frequently precedes economic growth. Urbanisation, however, is linked to economic contraction as opposed to growth (du Toit *et al.*, 2018).

Urbanisation rates in cities like Bamako and Sikasso are concerning, and changes in land use have had a detrimental effect on ecosystem services. These growing cities have had a substantial impact on land-use patterns, which has complicated effects on social structure and environmental function. Numerous ecosystem services have decreased or perhaps disappeared as a result of the significant surface structure changes brought about by urbanisation. Despite this, Africa is rapidly urbanising, which will put tremendous pressure on the availability of affordable housing in the ensuing decades (UN-Habitat, 2011).

It is also the world's most rural region because African governments have not taken the initiative to recognise and plan for urbanisation. As a result, unplanned, informal slums have spread throughout African cities and are currently home to a sizeable and increasing percentage of the population. Many studies have shown that, especially in urban areas, it is not impossible to increase the availability of cheap housing in Africa to address the issue of slums. Understanding the impact of urbanisation on ecosystem services for sustainable regional development is of major global importance. The ability of the sustainable environment to supply is central to the emerging idea of ecosystem services (Zhang *et al.,* 2022).

With two million inhabitants (Table 2.1), Mali's capital city, Bamako, has a tense and segmented land market within which strong management competition is developing. Due to colonial legal rules and the principle of subdivision, the administrative supply of building plots remains central, while at the same time interweaving "new" allocations and "urban catch-up" regularizations on a fine scale (Bertrand, 2020).

Table 2. 1: Population and Density of Bamako and Sikasso from 1990 to 2020

Years	POPULATION		DENSITY	
	Bamako	Sikasso	Bamako	Sikasso
1990	746382	87897	219.7425	2795.438202
2000	1141913	149693	374.2325	4276.827715
2010	1885545	240442	601.105	7061.966292
2020	2617686	386262	965.655	9804.067416

Sources: World Population Prospects revised in 2022 (Prud'homme, 2018)

2.1.1.2. Climate change

As a result of variations in the amount of solar radiation that reaches the planet and interactions between the atmosphere, ocean, and land, climate change is a normal component of the Earth's natural variability (Locatelli, 2018). The serious threat that climate change poses to humanity is a fact that is only getting worse. Short- and long-term issues like droughts, floods, storms, sea surface temperature rise, glacier melting, and more will result from this. The supply of food and water, the spread of diseases like malaria, migration from rural to urban areas, and other socioeconomic problems will all be impacted by these events.

Climate change has emerged as a significant national, regional, and global concern that impacts both industrialized and developing nations. Due to increasingly unpredictable weather patterns, eroding coastlines, pest infestations, and the development of water-borne illnesses, climate change is having a detrimental impact on people's lives in developing nations in Africa and Asia. As a non-parametric, non-dimensional trend analysis technique, the Mann-Kendall test is employed because the SPI and SPEI rely on threshold values of +2 and -2 to identify periods of wet and dry conditions.

Rural populations find it difficult to work on farms due to unpredictable rainfall and recurrent droughts; as a result, they are forced to relocate from rural communities to metropolitan regions in quest of greener pastures (Belinda and Asfaw, 2011). The Intergovernmental Panel on Climate Change summarises current knowledge about climate change observation and prediction in its periodic status reports. The periodic assessment reports of the Intergovernmental Panel on Climate Change (IPCC) demonstrate that human activity is impacting the Earth's climate. Consequently, since the first IPCC report was released in 1990, scientific knowledge has grown, and policymakers have implemented it at the international, national, and subnational levels (Locatelli, 2015, 2018; Mohamed *et al.*, 2014).

According to Locatelli, (2018), the Kyoto Protocol in 1997 places more emphasis on mitigation than adaptation, and the United Nations Framework Convention on Climate Change (UNFCCC), which was founded in 1992, is one of the most significant climate change projects. Mitigation and adaptation are the two approaches to coping with climate change (Figure 2.2). Africa is among the most susceptible continents overall, according to the most recent assessment of IPCC (Lwasa and Seto, 2022), because of its high risk and limited potential for adaptation. The principal conclusions of the West Africa report are as follows: In terrestrial Africa, there is more evidence of warming compatible with anthropogenic climate change, even if there are still significant gaps in the available data. West African temperatures by the end of the twenty-first century are predicted by global climate models to be 3 to 6 °C higher than the baseline in the late twentieth century, based on emission scenarios (Yaro and Hesselberg, 2016). According to Mohamed *et al.*, (2014), the climate of West Africa is among the most changeable in the world during intra-seasonal to decadal periods.

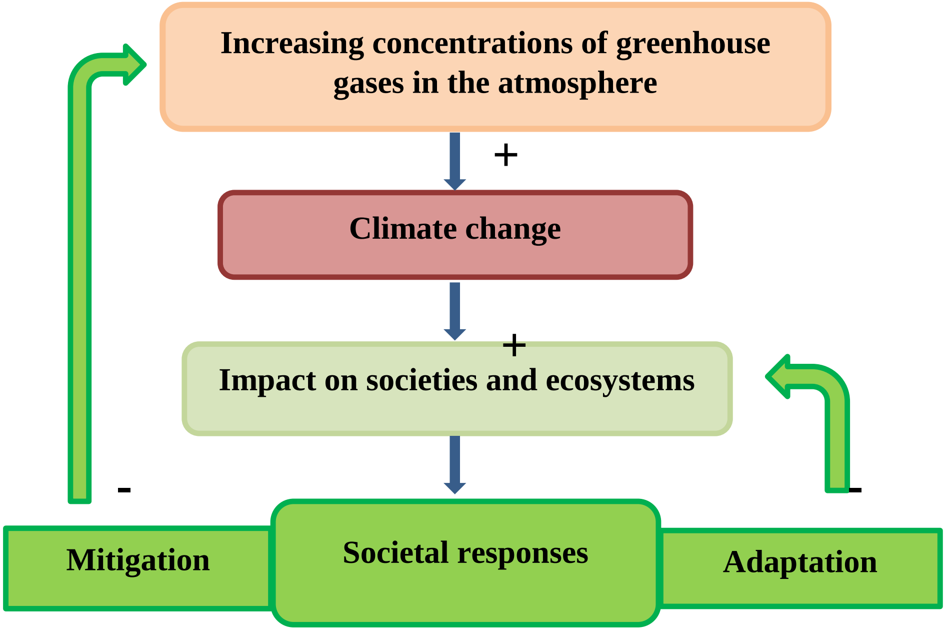


Figure 2. 2: The Difference between Climate Change Mitigation and Adaptation

2.1.2. Urban green spaces and ecosystem services

2.1.2.1. Urban green spaces

Multiple ecosystem services that urban green spaces offer can be advantageous to city people. For instance, UGS offers recreational services, reduces the effects of urban heat islands, and eliminates air pollution. Furthermore, UGS has been linked to a number of advantageous health outcomes. Living close to UGS, in particular, has been linked to increased self-reported health outcomes, a lower chance of death, and decreased levels of anxiety and sadness, according to earlier research (Agyekum, 2022; Huang and Xu, 2022).

Thus, UGS is associated with urban residents' human well-being, either directly or indirectly, as a crucial component of the urban ecosystem (Figure 2.3). UGS mapping and quantification have drawn a lot of interest in recent decades since decision-makers in sustainable land management need to know the availability or quantity of UGS and its spatial patterns (Huang and Xu, 2022). Play areas, outdoor sports areas, parks and gardens, agriculture, gardening, cemeteries, education, institutions, personal gardens, and recreational green spaces are just a few examples of the various uses and entry points that urban green spaces can serve. From a place for kite flying, herbs, different kinds of play areas, and tennis to supplying wild food and firewood, urban green spaces can serve a variety of purposes. Some even have urban green spaces with forests where rainfall can seep into the earth (Kabisch, 2015b; Vargas-Hernández, Pallagst, and Hammer, 2018).

Due to historical periods and the convenience of the designers, some designed urban green space landscapes have historical and cultural value, such as functional green spaces, plant collections, archaeological relics, and so on. Urban green spaces also ensure a better quality of life by fulfilling appropriate functions (Kiplagat *et al.,* 2022; Vargas-Hernández, Pallagst, and Zdunek-Wielgołaska, 2018). Cities and urban quality of life gain from green spaces because they:

i. Achieve favourable health, social, and environmental results;
ii. Improve the social and environmental quality of underprivileged areas;
iii. Make cities more pleasant and livable;
iv. And contributes to a positive perception of the city/city’s brand or identity (For instance, more than one-eighth of Singapore's surface area is made up of verdant green fields. Thus, it's never too far to locate a green area where you may take in the scenery).

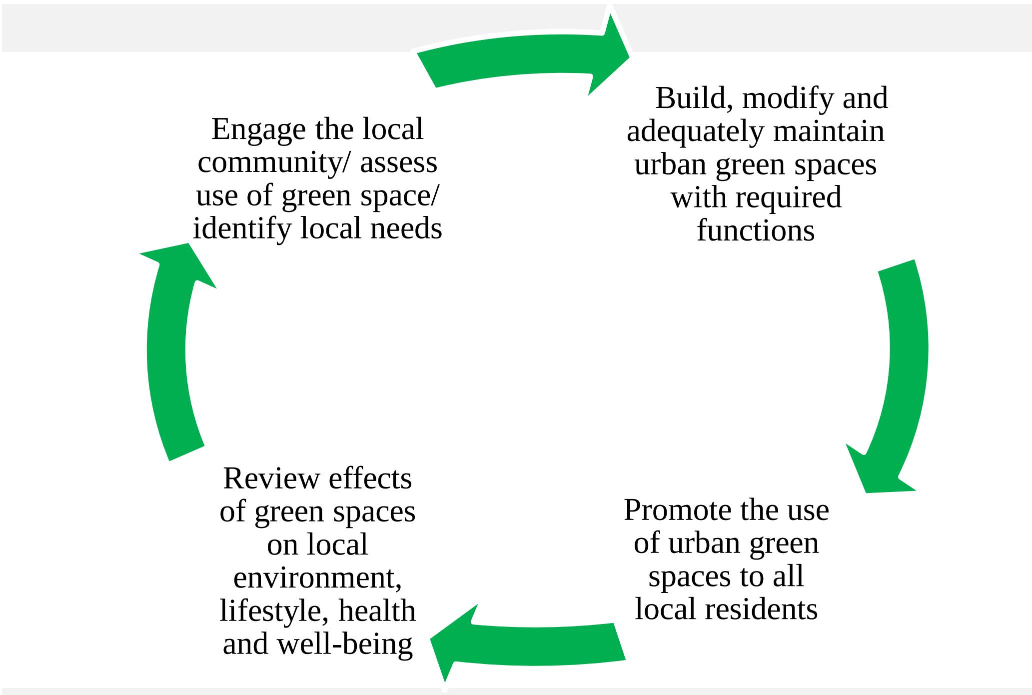


Figure 2. 3: Green Space Action Cycle from (World Health Organisation, 2017).

Plants intercept airborne particles that are carried by rain and eventually fall to the ground. A healthy tree can trap 7,000 particles per litre of air. A mature tree can capture up to 20 kilogrammes of dust each year. According to surveys in one city (ASTERES, 2016), the concentration of particles in the air can be more than three times lower on streets with trees than on streets without. Also, by absorbing and retaining CO_2 throughout their lives, trees mitigate the process of global warming. A small tree of 8 to 15 centimetres in diameter can sequester 16 kilogrammes of CO_2 per year, and a large mature tree can sequester 360 kilogrammes. Up to 5,4 tonnes of CO_2, the same amount as the emissions of an Airbus A320 going 600 kilometres, can be retained by an 80-year-old rosewood tree that is 30 metres tall (ASTERES, 2016). In 1995, the Association of French City Engineers (AIVF) recognized the existence of 13 types of green space (Bougé, 2009), which have been grouped into the following 5 classes:

i. Parks, squares and green spaces adjacent to commercial and industrial activities;

ii. Green spaces along roads, natural landscaped areas;

iii. Green spaces in residential communities, public buildings with surrounding green spaces, care facilities and other social and educational institutions;

iv. Green spaces in stadiums, sports centres, cemeteries, campsites, reception areas and holiday villages;

v. Allotment gardens and horticultural establishments (municipal greenhouses, horticultural colleges, etc.).

2.1.2.2. Ecosystem services

Plant, animal, and microbiological communities function as dynamic complexes called ecosystems that interact with inanimate objects as a single functioning unit (Reid, 2005). The advantages ecosystems provide to humans are known as ecosystem services. Ecosystems provide numerous benefits to humans. All of these advantages are referred to as ecosystem services. Waste breakdown and the provision of clean water are two common ecosystem services (Locatelli, 2015, 2018; Mohamed *et al.,* 2014). The dependence of human well-being and economic prosperity on natural systems is referred to as ecosystem goods and services. The link between changes in environmental systems and concurrent changes in human well-being is currently of interest to both ecology and economics (Locatelli, 2018; Reid, 2005).

The advantages that people get from ecosystem processes or functions are known as ecosystem services. Providing food and water, regulating the climate and controlling diseases, maintaining the cycling of nutrients, and providing recreational opportunities are a few of these cultural services. Depending on the temporal dynamics and geographic explicitness of the research, studies on the interaction between services can be classified as either dynamic, static, spatial, or non-spatial. To include ecosystem services in public and commercial sector decision-making, a number of decision support systems have been created (Zhang *et al.,* 2022). What the Millennium Ecosystem Assessment report defines as "the benefits that people derive from ecosystems" is ecosystem services (Locatelli, 2018; Rozas *et al.*, 2022). Published in 2005, this was a seminal work; nevertheless, in order to improve ES mapping and assessment, a number of scientists have revisited definitions and categories today. There are various classifications for ES (Haines-Young and Potschin, 2018; Rozas *et al.*, 2022). Rozas *et al.*, 2022 show that the idea needs to be approached from both an economic and political standpoint, in addition to a scientific one. Today is Ecosystem Services' Common International Classification Day (CICES). CICES's hierarchical taxonomic structure (section, department, group, class, and class type) is one of its strongest points. The Ecosystem Services and Biodiversity International Science-Policy Platform, or IPBES, has identified 18 categories of ecosystem services and has a strong relationship with these categories (Beckmann-Wübbelt *et al.*, 2021; Rozas *et al.*, 2022).

Furthermore, as Figure 2.4 illustrates, three types of ecosystem services promote human welfare directly: those that supply resources like food and fuelwood; those that control resources like water, climate, or soil erosion; and those that are cultural in nature, such as recreation, spirituality, or religion (Locatelli, 2018; Reid, 2005; Siddiqui, 2019). Nonetheless, ecosystem services are defined as the contributions that ecosystems contribute to human well-being in accordance with the framework and scope of the Common International Classification of Ecosystem Services (CICES), including the original and updated versions of CICES (Haines-Young and Potschin-Young, 2018). Moreover, CICES concentrates on the "final" products of ecosystems and aims to pinpoint the elements and characteristics of ecological systems that humans can benefit from. The three types of ecosystem service groups that were the subject of this study were cultural, regulating and maintaining, and provisioning services (Haines-Young and Potschin-Young, 2018).

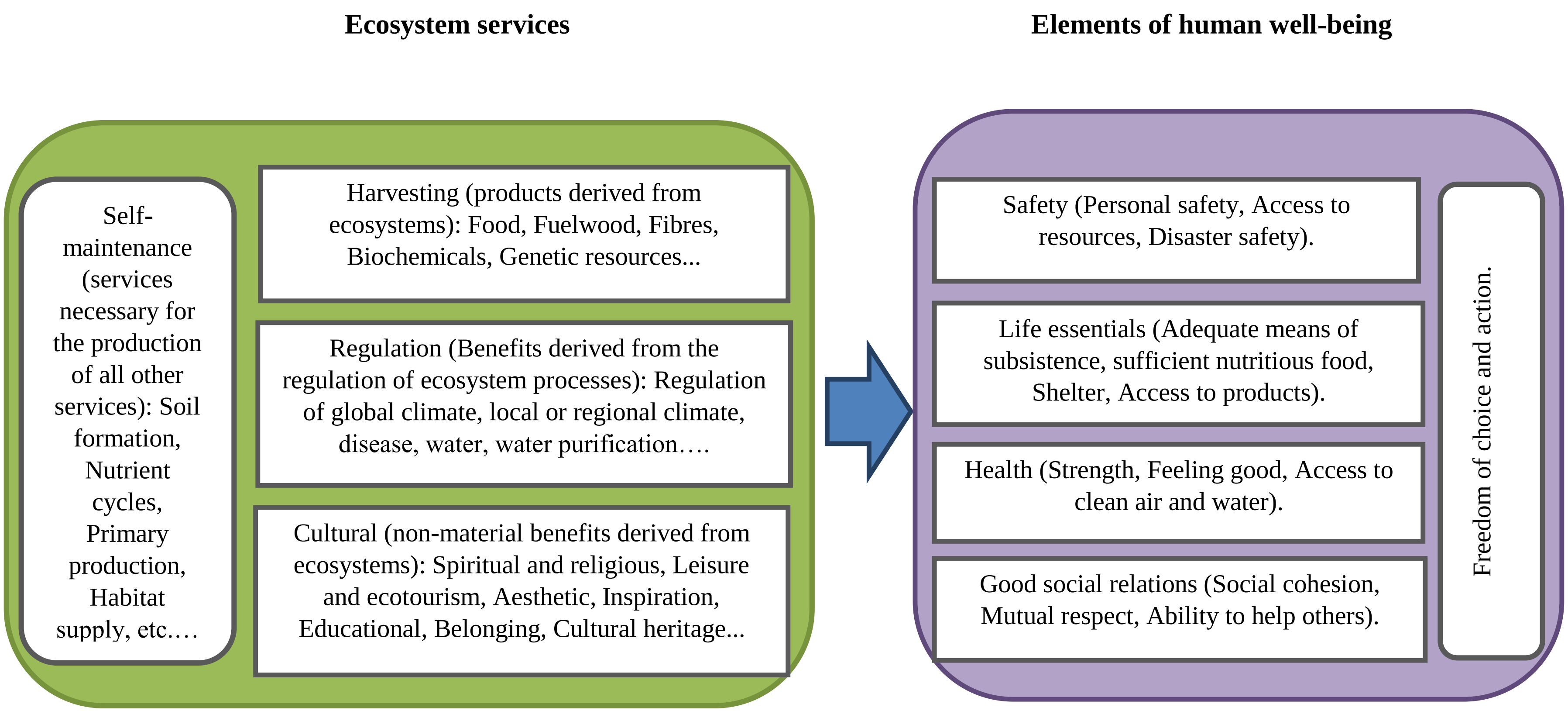


Figure 2. 4: Examples of Ecosystem Services and their Links to Human Well-being, according to MEA (Locatelli, 2018; Reid, 2005; Siddiqui, 2019)

2.1.3. Urban planning strategy and sustainable land use system

Due to high consumption densities and a large population of impoverished people, urban regions usually demand the most work but also provide the highest potential for returns when incorporating local food systems into planning (Lovell, 2010). Due to their large-scale viewpoint, planners can be crucial in the design of urban environments. They can incorporate communal gardens and other urban agricultural elements, safeguard these characteristics with suitable zoning, and even control the amount of land required per capita. Farmers markets, farm-to-agency programmes, and local food networks that link farmers with processors, restaurants, grocery shops, and direct-to-consumer shopping can also be taken into account by urban planners.

Given the accessibility of residents, transport systems for disposing of waste and distributing food present another potential for urban development (Lovell, 2010). Human progress and well-being rely critically on better management to ensure the preservation and sustainable use of the planet's ecosystems in sustainable development (Reid, 2005). The 1987 United Nations World Commission on Environment and Development study, also known as the Brundtland study, provides the concept of sustainable development that is most commonly quoted. A procedure that "meets the needs of the present without compromising future generations" is known as sustainable development. Four governments and institutions are increasingly recognizing that it is impossible to separate economic development concerns from environmental concerns. A broad perspective to understand the factors behind poverty and international inequality is for example, poverty which is both a major cause and a major (“Handb. Engag. Sustain.,” 2020).

In short, sustainability means using natural resources in a way that doesn't damage them. In its most practical form, sustainability is about understanding the links between the environment, society and the economy. Sustainability is founded on the straightforward idea that everything humans require for survival and well-being depends, either directly or indirectly, on our natural environment, according to the U.S. Environmental Protection Agency (EPA). The conditions that allow people to live in peace with the environment and satisfy the social, economic, and other demands of both the present and the future are created and maintained by sustainability ("Handb. Engag. Sustain.," 2020; Vargas-Hernández, Pallagst, and Hammer, 2018).

The need for ecosystem services like food and drinking water is growing, but human activity is making it harder for many ecosystems to supply this demand. Often, sound policy and management interventions can reverse the degradation of ecosystems and improve their contribution to human well-being (Reid, 2005). Thus, knowing when and how to intervene is important for understanding the ecological and social systems involved. The ability of urban planners, who are in a unique position to fully realize urban agriculture's potential as a multipurpose and sustainable land use, is made possible by the coordination of efforts across several disciplines (Lovell, 2010; Wheeler *et al.*, 2015). Specific planning solutions are presented in Table 1 (Appendix 1) to support the diverse functions offered by urban agriculture operations.

2.2. Theoretical Framework

Garden cities are often viewed as ideas that are mostly concerned with the environment and urban planning, having less to do with other structural notions or paradigms and more to do with concerns about the spatial integration of different components of social life. These include, to name a few, municipal institutions and transport infrastructure, agriculture, housing, industry (in the sense of manufacturing activities), and trade. A garden city is a metropolitan area of a size that supports socially and environmentally responsible living, as well as industry and healthy living. In 1898, Ebenezer Howard

(1850–1928) published Tomorrow, which contained his original concept for the green city (Abdel-Rahman, 2016; Howard, 1902, 1928). Most people agree that the concepts of a peaceful path to real reform mainly concern the environment and urban planning. It was revised in 1902, 1946, and 1965 and renamed "Garden Cities of Tomorrow." Its objective is to ensure a harmonious existence between humans and their natural environment. In addition to the establishment of physical space, scientists today recognise that environmental and social systems such as schools, transport, housing, employment, and health requirements must be taken into account in cities (Howard, 1902).

This study is based on UGS, sustainable ecosystem concepts in urban areas, and climate change resilience. Urban areas are considered economic, social, and cultural centres, also the most difficult areas to analyse by remote sensing due to the great spatial and spectral diversity of surface materials (Gulcin and Akpınar, 2018). Each form of green space was determined by first recognizing it and then thoroughly analysing the unique circumstances of the cities of Sikasso and Bamako using the Garden City concept. Indeed, it focused on the characteristics of green spaces that are certainly visible on the remote sensing image (supervised classification), including colour, tone, shape, position, size, and texture (Hang and Ang, 2019).

2.3. Review of Previous Studies

Several studies show that urban green spaces and agriculture helps to mitigate the net emission of carbon dioxide (CO_2), one of the gases that causes global warming, from a variety of urban activities. Our research adds to our understanding of the dynamics of sustainable cities and the role played by green spaces. Urban vegetation has been shown to have beneficial impacts on evapotranspiration, shade, and wind blockage on cold, windy days, which help to mitigate high local temperatures, but putting greenery, especially trees, in market gardens and streets is important because it can have a variety of effects on air quality depending on how it interacts with the weather and urban architecture (Rui *et al*., 2019). Urban buildings and vehicle traffic are the primary causes of air pollution and the heat island effect in urban settings, which are currently regarded as two major issues (Vieira *et al.,* 2018). Urban vegetation in particular has numerous social, economic, and ecological advantages in addition to having a localized impact on the urban climate. Urban climates can thus be considered microclimates resulting from the combined effects of buildings and human activities that can have a significant effect on the thermal energy dynamics of a city (Coronel *et al.,* 2015).

The seasonal fluctuations of the urban thermal environment and the cooling impacts of green spaces on the urban microclimate can be highlighted thanks to the analysis of the primary Normalized components (Chang *et al*., 2020; Rui *et al*., 2019; Yin *et al*., 2019; X. Y. Li and Kuang, 2019; Agnihotri *et al.,* 2018; Xu *et al.,* 2018; Huang and Yang, 2017; Casalegno *et al.,* 2017; Nor *et al.,* 2014; Choi *et al.,* 2012). Climate change increases the difference in exceptionally hot nights between rural and urban areas, simulating warming and extreme heat events caused by urbanisation and increased energy consumption as being as significant as the impact of doubling CO_2 in some locations (Mccarthy *et al.,* 2010). The contribution of GIS in the management of public spaces in the district of Bamako was carried out with the aim of improving the management of green spaces while ensuring a follow-up in more or less real time through the coupling between the geographical and technological databases (Dembele, 2017; Dembele *et al.,* 2016). According to this study, around 10 to 50 percent of classified places change their use, demonstrating that the legal mechanism of categorization by presidential decree no longer safeguards public spaces (Dembele *et al.,* 2016). Explanatory factors and repercussions of urban sprawl in Bamako (Diallo *et al.,* 2020).

Additionally, this study uses data from remote sensing (Landsat) to investigate changes in land use and land cover in Bamako and the surrounding areas between 1972 and 2018. The preservation and extension of the city of Sikasso's current green areas are part of the green area measures, which also include planting trees in the vicinity of industrial and hydrocarbon areas, creating green spaces and their growth in settlements, and developing green space surrounding slaughterhouses and cattle markets along marigots, "Tata," and protective dykes (URBATEC, 2006). Therefore, it is planned to create 200 hectares of green space in the city of Sikasso as follows: greenbelt protection along ring roads, forests to be built or reinforced, industrial and oil and gas zone safety greenbelts, edges of major arterial roads, public squares, pagodas, old cemeteries and quarries that are no longer in use, marigots, and embankments used for waterproofing (URBATEC, 2006).

The data from industrialized countries predominates when it comes to the benefits of urban green spaces for population health, reducing the effects of climate change, offering ecosystem services, and promoting the sustainable and strategic development of cities like Bamako and Sikasso. The current state of the aforementioned green space speaks in many ways to the consideration that the people of the cities of Bamako and Sikasso have for trees. In light of this, it is crucial to remember that Bamako residents do not view green areas and trees especially family trees and trees in public spaces in the same way. Research clearly shows that we need nature around us. Our streets need trees, our gardens need plants, and our balconies need flowers. They need nature as our permanent neighbor. As humans, we have a responsibility to protect the natural environment in our cities. In return, the benefits to our environment and health will be enormous.

2.4. Examples from Other Regions/Countries

Dubai was the most improbable green metropolis in the world to aspire to have the lightest ecological footprint ten years ago, while having one of the greatest ecological footprints of any city worldwide (Kunzig, 2017). Dubai was a small and poor fishing village with a commercial port. One of the first countries to adopt green architecture and sustainable urban planning initiatives was Singapore. In 2005, it introduced the Green Mark certification scheme, which has a vision of moving Singapore's construction sector towards more environmentally friendly buildings. For example, the target is for at least 80% of Singapore's buildings to be green by 2030. A 10-year green cities programmes has been initiated as part of the strategy to green the urban landscape to make cities sustainable and livable (Sikora *et al.,* 2021a).

The United States has the ten greenest cities. To determine which communities were the greenest overall, tests were also conducted for walkability, car ownership, parks, and trash. Many environmental decisions are personal, even though your location can affect how you affect the environment (e.g., your commute's duration, your capacity to walk, recycling facilities, etc.). But the following authors have conducted numerous research on urban agriculture and green spaces: Dubbeling *et al.*, 2019; Verheij, 2019; Yin *et al.*, 2019; Pervaiz *et al.*, 2019; Rozalija Cvejić, Klemen Eler, Marina Pintar, Špela Železnikar (UL, Slovenia), Dagmar Haase, Nadja Kabisch, 2015; Huang and Yang, 2017; Kechebour, 2015; Green, 2009. Despite these studies, few studies are carried out in Africa on urban agriculture as urban green spaces. In addition to food security, urban agriculture has other health benefits, including increased variety and consumption of fresh fruits and vegetables, which improve nutrition, exercise, and stress reduction (Chandia, 2020).

According to Kabisch and Bosch, (2017), "nature-based solutions" refers to urban green areas that utilise urban ecosystem services as a means of providing mitigation and adaptation strategies for the issues of urbanisation and climate change. Remember that by seeking to address the needs of various populations by 2030, the UN Sustainable

Development Goals (SDGs) reduce inequality while promoting inclusive and sustainable urban development in all nations (Shi *et al.,* 2020). However, as more and more people move to our cities and regional centres, the corresponding infrastructure must also be in place. Less green space may result from the construction of additional residences and buildings.

However, neglecting green space can have detrimental effects on our cities and their citizens. Urban areas with green spaces can reduce the consequences of climate change, keep our cities cooler, enhance air quality, and benefit people's health and minds. Most crucially, there are no restrictions on how urban creative designers can incorporate greenery into urban design; they can utilise rooftop gardens, community gardens, street trees, living walls, and apartment planters, among other things. The process of planning, implementing, and guaranteeing that there is enough green space in the urban environment is referred to as "urban greening." The contribution of urban green spaces in this context has become an important issue of sustainability and resilience to climate change.

2.5. The Overview and Key Issues of the Study:

They show in the literature some studies, which are Nature and Challenges of Urban Green Spaces in Africa by Mensah (2014), GIS and urban green spaces management by Osseni *et al*. (2015), but not more information about urban green space effects on climate change resilience and sustainability in West Africa cities. However, climate change and increased climate variability affect human society in the 21st century (Mutegi *et al.,* 2018), and the most important global concern is the management of land, which has unfavourable impacts on urban green spaces, agricultural production, food security, and the environment. Reducing the likelihood of being overweight by providing adapted spaces that encourage physical activity is a necessity of urban green spaces and their contribution to the sustainable climate change resilience of West African cities (Klompmaker *et al.,* 2018). Thus, these green spaces help improve the effects of sudden shocks such as heat waves and storms.

All over the world, due to a strong urbanisation process and rapid change in cities, green spaces are considered lungs. They improve city people' health and general well-being (Sikora *et al.*, 2021a). By defining green spaces as urban land partially or totally covered by grass, trees, shrubs, or other vegetation, they can also consider them a global priority on the political agenda of cities. In general, urban areas are densely populated with heavy constructions that support modern facilities, such as transport and commercial buildings (Alusi *et al.*, 2011; Haughton and Hunter, 2017; Sikora *et al.*, 2021a; Simon *et al.*, 2017).

However, the amount of public and green space in the cities of Bamako and Sikasso is considered to be one of the indicators for measuring Sustainable Development Goals (SDG 11) (Antunes *et al.,* 2021; Sikora *et al.,* 2021a, 2021b). Indeed, the cities do not meet the minimum accepted standard of 45%, of which 30% is for streets and 15% for green spaces. Only 15% of land is allocated to streets on average, especially in the planning of new areas in planned cities. This percentage is 2% for unplanned areas (Antunes *et al.,* 2021; Sikora *et al.*, 2021a). An unhealthy urban living environment is thus created without green spaces, while cities are at the origin of decarbonisation programme leading to low carbon emissions while changing the way cities are planned as the first step towards carbon mitigation and climate resilience (Antunes *et al.,* 2021; Sikora *et al.,* 2021a).

The scarcity, notorious degradation, and almost total indifference of Bamako residents and municipalities to green spaces prior to March 1991 largely reflected the state of the green spaces (Sidibe, 1993). Based on field research, this trend of green spaces in Bamako is similar to that of Sikasso and confirmed in the Sikasso city plan document (URBATEC, 2006). While it has survived in many run-down counties with a new transition period and new greenfield policies launched by Republican authorities, the issue remains urgent and fraught (Sidibe, 1993).

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Description of Materials

In this study, which aim at assessing the contribution of green spaces to sustainable climate change resilience, the cities of Bamako and Sikasso were used as the study area. They combined spatial and non-spatial data from primary and secondary sources using a creative mixed methods technique. The data from remote sensing, climate (rainfall and temperatures), ecological, and expert knowledge were included. In fact, the socioeconomic and cultural surveys of the populace surrounding urban green spaces entail determining urban green space design techniques from a predetermined control point.

3.1.1. Spatial data

Urban green spaces were observed using the medium resolution (30 m) satellite data set. In fact, as in urban green space studies, remote sensing can assist in determining the spatial distribution and characteristics of green areas. Climate variability can be ascertained by the use of meteorological data, such as rainfall and minimum and maximum temperatures. The Geographic Positioning System (GPS) is used to gather reference locations, which serve as the major source of ground truth data for the urban green space classes. These data are used to validate the outcomes of the Landsat image analysis conducted between 1990 and 2020 in order to facilitate image classification and evaluate the overall precision of the classification outcomes (Cheruto *et al.,* 2016).

This study was implemented by the Geographic Information System, Cellular Automation, Multi criteria Evaluation (GISCAME) software platform, which is based on three methodological approaches (Geographic Information System, Modified Cellular

Automata, and Multi-criteria Evaluation Approach) and used satellite images from March. GISCAME is a toolkit or software that allows for the simulation, visualisation and evaluation of land use change. As such, it can be used to include information on the types and characteristics of urbanisation and green spaces, such as climatic or topographical data, in the effect analysis (Arnold *et al.*, 2018). For this reason, GISCAME, an application that assesses, maps, and green spaces utilising information on mixed urban green spaces (trees and agricultural areas), was employed in this study. In addition, GISCAME is the result of long-standing collaboration, continuous development, and the integration of the latest scientific results. The software design considers the landscape as an integrative level for interactions between different types of land use and users and landscape-related ecosystem processes that require the provision of landscape-related ecosystem services.

This study therefore used Google Earth Pro to digitalize the urban green spaces of Sikasso and Bamako in mixed urban green spaces and agricultural areas with ArcGIS composite bands from Landsat data. When they have a single band raster and we add them to our display, the default value is that they are displayed as black and white images (Mapping and Imagery, 2020). A number of elements contribute to Landsat's performance, such as its array of sensors with spectral bands appropriate for monitoring Earth, its functional spatial resolution, and its thorough coverage of the surface (both in terms of sweep width and revisit length). All Landsat satellites are positioned in near-polar, sun-synchronous orbits with morning crossing periods at the equator in order to maximize lighting conditions.

3.1.2. Non-spatial data

The creation of a database with the locations of green spaces in the communes of Sikasso and Bamako, together with the kind of green space based on vegetation cover according to the typology outlined by (Henri Kabanyegeye *et al.*, 2020; Kong *et al.*, 2014; Kong and Nakagoshi, 2006; Mensah, 2014; Sambieni *et al.*, 2018), was made possible by non-spatial data collection focused on the survey with local stakeholders. According to images, fieldwork reports, interviews, and the master plan for urbanisation (Dembele, 2017), there are numerous categories into which the green spaces in both cities can be categorized as following: street trees, grass, private gardens, public gardens, urban defensive forests, urban parks, market gardens, roadside tree rangers, and riverbank vegetation.

3.2. Description of Methods of Data Collection

Integrating survey data on green areas through spatial variation analysis with historical data that is already available, such as satellite photography (Figure 3.1) is advantageous. The study was also conducted using the following software: Envi and ArcGIS for satellite imagery; Excel, XLSTAT, and R-Studio for analyzing climate variables and survey data; and Phyton to identify possible correlations between certain parameters, such as land use and land cover classes, precipitation, temperature, NDVI, NDBI, NDWI, and demographic data. Scenario maps were created using the GISCAME software platform and Google Earth Pro software.

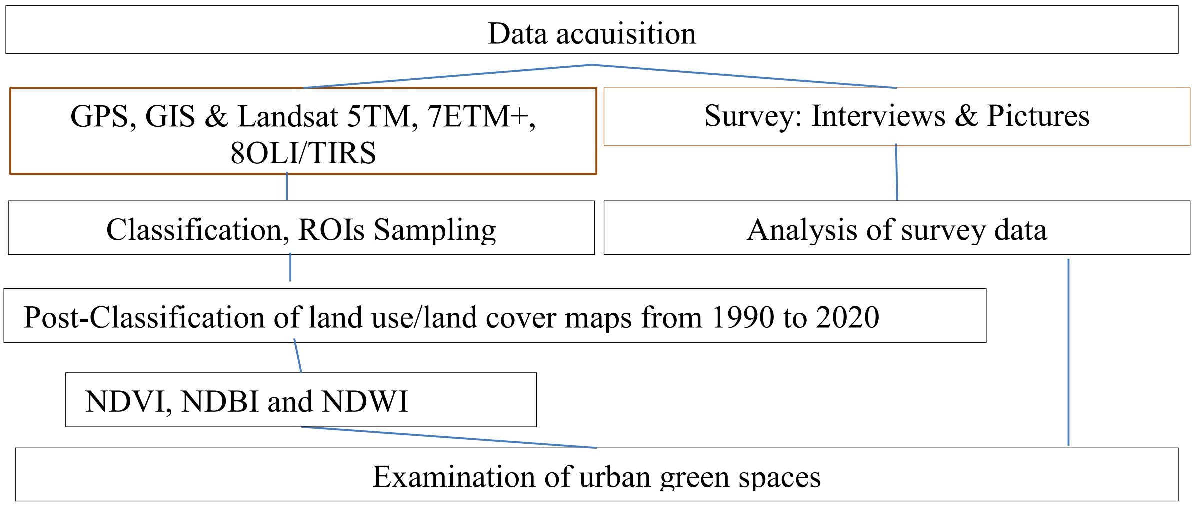


Figure 3. 1: **Methodological Workflow for Changes and Perceptions of Urban Green Spaces in Bamako and Sikasso, Mali**

3.2.1. Evaluation of the spatial repartition and the characteristics of types of green spaces change in Sikasso and Bamako cities.

Multi-temporal satellite imagery from the years 1990 and 2020 was acquired along with other satellite data. In this study, medium resolution satellite images of the cities of Bamako (UTM 29, Path 199, and Row 51) and Sikasso (UTM 30, Path 197, and Row 52) were collected using the satellites Landsat 5 Enhaced Thematic Mapper (ETM) acquired in 1990 and 2000, Landsat 7 Enhaced Thematic Mapper (ETM+) acquired in 2000, and Landsat 8 Operational Land Imager (OLI) acquired in 2020. Every 16 days, Landsat data are added to the medium resolution (30 m) satellite data set, which makes it possible to observe urban green spaces.

The spatial model and temporal variation of land use and cover based on NDVI were used in the green spaces of the cities of Sikasso and Bamako (Li *et al*., 2015). These images were downloaded from the USGS website science data hub. The indicators using the visible and near infrared bands of the electromagnetic spectrum were NDVI, NDBI and NDWI, incorporating more statistical data, model results, expert reports, and empirical knowledge.

Data on land use and green space served as the study areas' geographical foundation. Thus, the features and spatial distribution of green spaces were ascertained with the aid of remote sensing. The two main criteria that were established were reduction of cloud cover and temporal coverage (see Table 3.1 for specifics).

Table 3. 1: Data used in this Study.

City	Platform	Sensor	Resolution (m)	Nº of bands	Cloud cover	Data acquired (dd/mm/yy)
Bamako	Landsat 4	TM	30	7	0.00	22/03/1990
	Landsat 7	ETM+	30	8	0.00	17/03/2000
	Landsat 5	TM	30	7	5.00	16/11/2010
	Landsat 8	OLI	30	11	5.18	16/03/2020
Sikasso	Landsat 5	TM	30	7	0.00	13/12/1990
	Landsat 7	ETM+	30	8	4.00	15/01/2000
	Landsat 5	TM	30	7	2.00	18/11/2010
	Landsat 8	OLI	30	11	0.19	15/12/2020

Source: Author's fieldwork (2022)

3.2.2. Analysis of the effects of green spaces identified on sustainability and climate change resilience and their ecosystem services

a) Interviews with regional participants

Following a socioeconomic and cultural survey of the people in Bamako and Sikasso, an analysis of the effects of Urban Green Spaces (UGS) and their Ecosystem Services (ES) on sustainable climate change resilience was carried out. Interview questions were created for the various urban green spaces, indigenous peoples' sociocultural knowledge, governmental authorities, and some technical services. The questionnaire was therefore divided into the following four sections:

i. The respondent's socio-demographic characteristics;

ii. Green space perception and characteristics;

iii. Urbanisation, shifting urban planning strategies, social, physical, and environmental benefits;

iv. And the relationship and motivation to use green spaces that provide ecosystem services as provisioning; regulation and maintenance and cultural services.

Every segment was completed in the towns of Bamako and Sikasso, involving farmers, private landowners of green spaces, indigenous people and their communities, government officials, and some technical services (forest, water, and agriculture, among other things).

In Mali the observed and projected demographic trends suggest that the age structure of the Malian population (and therefore the dependency ratio) is not likely to change significantly over the next few decades, mainly because of the dynamics of fertility and life expectancy. The proportion of young people in the population rose significantly between 1960 and 2020. The weight of young people aged between 5 and 20 increased from 34% in 1960 to 40.31% in 2020 (UNFPA, 2020). Thus, the weight of young people aged over 20 in 2020 is estimated at 59.69% and can be attributed to respondents.

Therefore, by using the formula of Dagnelie (Gbémavo *et al*., 2014) and the Sample Size Formula (https://www.indikit.net/methodology-calculator), the total sample size in each city was $N = \frac{Z^2pq}{e^2}$; Z is the value of the random statistic found in the tables at 95%, which is 1.96; p is the proportion of people able to respond to questions; q is the $1 - p$ and e is, the desired level of precision, which is 0.05. Indeed, N is around 380 people in each city.

However, they conducted interviews with citizens, private property owners of green spaces, administrative officials, and technical service providers (forest, agriculture, and water) from Bamako and Sikasso to learn about the population's perception of the state and changes in urban green space (Table 3.3). This set of stakeholders were the first choice of the study due to their availability and prompt response to our inquiries.

Table 3. 2: Description of Respondent in Bamako and Sikasso

City	Members of the relevant stakeholder group	Representatives' specifications	Respondent's number	Total population of respondents
Bamako	Farmers and individual green space owners	Niger River located on the (left: 60 and right: 90).	150	370
	Local population	Citizens	190	
	Administrative authorities and technical services	Health, 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	384
	Local population	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**	

Source: Author's fieldwork (2022)

The interviews, which lasted an average of around 35 minutes with each individual, were conducted in French and Bambara, the local language, using the Kobo toolbox (Agyekum, 2022; Owusu, 2021). The bulk of participants in Bamako (51%) were citizens and students, followed by farmers and private landowners (41%), administrative agencies and technical services, and private landowners (8%). 52% of participants in Sikasso were private landowners and farmers, 35% were citizens and students, and 13% were representatives of the administrative and technical services sectors.

b) Climate data

Over a thirty-year period from 1990 to 2020, precipitation data for four sites were provided by the Malian Meteorological Agency (Mali-meteo) and the soil-water-plant laboratory of the Institute of Rural Economy (IER), Sotuba. Monthly maximum temperature and rainfall data were collected to determine the trend in the total annual rainfall and the regional distribution of temporal patterns in Bamako and Sikasso. Three different approaches were really taken, as the following sections explain (Yaro and Hesselberg, 2016).

The maximum and minimum temperature as well as the precipitation time series data were analysed using the Mann-Kendall trend test to see if a pattern was present. A non-parametric, non-dimensional trend analysis test is the Mann-Kendall test (Akpoti *et al.*, 2016; Koudahe *et al.*, 2017a); therefore, there is no underlying assumption regarding the normality of the data. It is important to highlight that, in our investigation, the Mann-Kendall test statistic is not only non-dimensional but also provides no means of quantifying the strength of the trend in the time series units examined (Koudahe *et al.*, 2017b). The SPI and SPEI were used to determine wet and dry periods based on threshold values of +2 and -2.

Using Mann-Kendall methods, the trend's spatial distribution and statistical significance were first examined. The following formula defines the Mann-Kendall (S) statistic for a sample (xi,....xn):

$$S = \sum_{i=1}^{n-1} \sum_{j=i1}^{n} sign\left(x_{i-x_j}\right) \qquad (3.1)$$

Where n is the quantity of information. Presuming $(x_i - x_j) = 0$, the value of sign $(x_i\text{-}x_j)$ is computed as follows:

$$1, si\ \left(x_{i-x_j}\right) > 0, \qquad (3.2)$$

$$Sign\ \left(x_{i-x_j}\right) = 0, si\ \left(x_{i-x_j}\right) = 0, \qquad (3.3)$$

$$-1, si\ \left(x_{i-x_j}\right) < 0 \qquad (3.4)$$

This statistic displays the overall number of positive differences less the total number of negative differences for all differences taken into account. For large samples (n > 10), the test is conducted using a normal distribution, with the mean and variance as follows:

$$E[S] = 0 \qquad (3.5)$$

$$var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{n} t_{k(t_{k-1})(2t_{k+5})}}{18} \qquad (3.6)$$

Where t_k is the number of data points in the kth tied group and n is the number of tied (zero difference between compared values) groups. Next, Z-statistics, or the standard normal deviation, is calculated as

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{var(S)}} \; if \; S < 0 \end{cases} \quad (3.7)$$

Second, to evaluate the progression of rainfall in both cities, the Standardized precipitation index (SPI), a Normalized index that shows the probability of an observed rainfall amount occurring when compared to the rainfall climatology of a particular station, was employed (Mckee *et al.,* 1993), such as Sikasso, Bamako Senou (airport), Bamako Town, and Bamako Sotuba. The combination of precipitation and potential evapotranspiration data allowed the calculation of the simple multiscale drought index SPEI. In fact, they used the same method as originally proposed to calculate the SPI in order to calculate the SPEI. The input data consisted of temperature and precipitation on a monthly (or weekly) basis. However, in any climatic region of the world, the SPI, which requires the maximum amount of additional data compared to the SPEI, is of great use for drought analysis and monitoring (Dhangar *et al.*, 2019).

3.2.3. Compare urban green spaces and their ecosystem services in the study areas

Urban green space can be promoted through a variety of means, such as government policies, municipalities, and schools; reducing the number of "kilometers of foods" produced in the vicinity of urban markets and the benefits of food security, which are especially valued in African cities; organising public events and activities, such as family days, sporting events, festivals, and markets; organising small-scale group activities, like guided walks or green gyms; or establishing partnerships with local organisations to manage and maintain urban green spaces or use them for their own purposes (like urban gardening allotments) (World Health Organization, 2017).

The assessment was based on baseline knowledge (indigenous and local knowledge, expert knowledge) available at the regional level, used quantitative data, or combined, methods including benefit transfer, to provide the planner with a tool to evaluate different planning alternatives. The notion of hemeroby which expresses the degree of naturalness of land use types and, therefore, provides a differentiated assessment of urban ES, was transferred into the urban context in this study, by using the degree of imperviousness and the amount of tree and vegetation cover (Arnold *et al.*, 2018). Sampling points were identified to use the classification of urban green space types (tree and agriculture areas) and determined the standard for classification (Hang and Ang, 2019).

In addition, higher spatial resolution Google Earth Pro imagery was combined to identify plot type (Huang and Yang, 2017). To make an updated cartography of urban green spaces and to propose new planning strategies for urban green spaces by integrating with urban agriculture, samples were carried out at geo-referenced points distributed in all the green spaces. The number of sites were identified to determine the number of samples that were taken into account agro-ecological zones.

Before sampling, a three-day training and harmonization workshop were organized for technical teams on sampling methods and the use of GPS. Maps were developed from the geographic coordinates of the sample collection points in some of the selected urban green areas (latitude, longitude, and altitude) and the analysis results. A random selection of sites were made to assess the categorization of map using field survey data and Google Earth images (Shen *et al.*, 2019). Some urban green space interventions, nevertheless, ought to take a dual approach, combining social promotion initiatives with urban agriculture to carry out tangible changes (like enhancing or adding new green space).

3.2.4. Determine the availability and quality of green spaces in the study areas.

The characteristics of the study area were combined with the regulations for land use investigation in the cities of Sikasso and Bamako, and the types of green spaces were classified into six categories: water areas, urban green spaces (trees, market gardening, flours, and grasslands), urban road land, urban settlement land, and open land (unused land) (Shen *et al.,* 2019). The classification of public green spaces in the cities were based on the AIVF typology.

However, our study recognized the green spaces accompanying rivers and water points. In order to demonstrate why developing nations must use remote sensing methods to track changes in the geographical distribution of agricultural land and urban and peri-urban areas, several methods of comparison are used to illustrate the benefits or strengths of remote sensing (Addo, 2010). However, for use in the classification of urban green space types, sampling points were identified and determined using the standard for urban green space classification (Hang and Ang, 2019).

The classification of urban green space types was manually done according to their location and services. The boundary and kind of each parcel, as well as its location, size, shape, and spatial interactions with neighboring parcels, were taken into consideration while extracting information about green areas through visual interpretation. Urban green space types were carefully categorized. Table 3.2 lists the definitions of each kind of green space.

Table 3. 3: Definition of Types of Urban Green Spaces

Green space	Definition
Streets trees	For aesthetic and shade purposes, these trees are typically placed in a linear and uniform pattern alongside streets.
Grassland	Is an area of plants that grow on the ground and have slender leaves.
Private Garden	A private garden is a green area that is either urban or rural and is owned by an individual.
Public Garden	This is an area with trees and flowers that is open to the public. In cities, they are most frequently located next to boulevards and monuments.
Urban defence forests	Urban defence forests are places set aside for cultural and traditional purposes in cities, guarded by local communities.
Urban Park	This is a public area featuring playgrounds for kids, open fields, walking trails, and sports facilities like football fields.
Market Garden	This is a tiny farm that mostly raises fruits and vegetables for sale.
Roadside tree groups	A single tree or a collection of trees designated for a certain tree care procedure
Riverbank greenery	Trees planted along the river's banks.

Source: Author's fieldwork (2022)

In order to classify the primary terrestrial vegetation (such as trees and cropland), they determined sampling places based on this information (Hang and Ang, 2019). Photographs were taken in Bamako along the Niger River, in Sikasso along the watershed, in public and private settings, and in market gardening areas.

The results of the study made it possible to create a database that lists the locations of green spaces in the communes of Sikasso and Bamako as well as the kind of green space based on the vegetation cover and the typology provided by (Henri Kabanyegeye *et al.*, 2020; Kong *et al.*, 2014; Kong and Nakagoshi, 2006; Mensah, 2014; Sambieni *et al.*, 2018).

The green spaces in both cities were categorized based on interviews, fieldwork, the master plan for urbanisation, these groups are street trees, grass, private gardens, public gardens, urban defensive forests, urban parks, market gardens, roadside tree rangers, and riverbank vegetation. The types of green spaces near the respondents' homes and their opinions of green spaces in relation to sustainability in their communities were among the questions utilized in this study. Field photographs were taken at different locations in Bamako and Sikasso cities, with the following options being considered in order to identify the elements allowing the development of the typology of urban green spaces according to the urban green spaces’ strategy (Plates 3.1 to 3.5). Streets, public and private areas, market gardens, Bamako's Niger River waterfront, and Sikasso's watershed.

Plate I: i. ii, and iii. Market Garden Areas in the Cities of Bamako and Sikasso along Water Points, River Banks, and Unbuilt Areas (Photos: FOMBA *et al.*, 2024)

Plate II: i, ii and iii. Street Trees and the Front of Houses in Bamako and Sikasso (Photos: FOMBA et al., 2024)

Plate III: i, ii. Public Park of the Faculty of Science and Technology (FST) of the University of Bamako, opposite the Campus Numérique Francophone (CNF); iii, iv. Groundnut Fields, Roadside Tree Rangers and Grassland Occupy the Space between the Faculty and the tarred Road, Mali (Photos: FOMBA et al., 2024)

Plate IV: i, ii. Market Gardens along the River and iii. Grass on the Bank used as Fodder for Animals, Bamako, Mali (Photos: FOMBA et al., 2024)

3.2.5. Examine the implications of the existing green spaces on the resilience cities.

With reference to the strategic planning document published by Cheshire East Council, the innovative ways in which they have looked at providing excellent green spaces for local communities and visitors to enjoy for their health and well-being. Today, these benefits are scientifically proven and recognized in all published strategic planning documents. This vital important document aims to coordinate the provision of green spaces and the different partners involved for effective use at a time when public financial resources are scarce (Cheshire East, 2020).

The urban green spaces sites were automatically divided into grid squares. Urban green spaces were be mapped out again using the online modelling platform GISCAME (GIS = geographic information system, CA = cellular automaton, ME = multi-criteria evaluation). New planning strategies for urban green spaces will be suggested by integrating them into the urban master plans of the cities of Sikasso and Bamako. Urban green spaces will be mapped out again using the online modelling platform GISCAME. New planning strategies for urban green spaces will be suggested by integrating them into the urban master plans of the cities of Sikasso and Bamako. Indeed, GISCAME was created with the intention of assisting planning processes through the simulation and assessment of alternative land-use scenarios.

Additionally, cellular automata with GIS functionalities and multi-criteria evaluation are used to combine the distinct contributions of specific land uses with the regional capacities to offer green spaces. This is carried out using mathematical normalization and indicators, whose values vary from zero to 100 in relation to other green areas in the spaces (Arnold *et al.,* 2018; Müller *et al.,* 2020). In general, remote sensing measurements were adopted for the identification and typology of green spaces. Also, for the analysis and implementation of mapping strategies for urban green spaces, GISCAME was developed to simulate land use, land cover, land management changes, and assess their effects on the capacity to provide ecosystem services or other objectives, including structural impacts at the landscape scale.

3.3. Statistical Processing

The data analysis of LULC and mapping was processed through Envi 4.7, GIS 10.8, GISCAME tools, and remote sensing measurements for the spatial analysis of green areas, and the technique made it easy to differentiate vegetative areas from non-vegetative areas. The Mann-Kendall trend, SPEI, and SPI s were performed using RStudio, Excel, and XLSTAT 2014 at a significant level of 5%, while different correlations used Phyton for this assessment.

3.3.1. Evaluation of the spatial changes and the characteristics of the different types of green spaces in Bamako and Sikasso cities

3.3.1.1. Image pre-processing

ENVI 4.7 was used to process the L5TM, L7 ETM+, and L8 OLI pictures prior to analysis. Pre-processing satellite images before change detection serves only to establish a direct link between the collected data and the biophysical event occurring on the ground. The primary goal of image classification is to assign a group of pixels in a picture to LU/LC classes such that, using the reflectance properties of the various LULC types, meaningful thematic information can be extracted (Cheruto *et al.,* 2016).

As a result, green regions in satellite photos are typically identified and analysed using remote sensing techniques. Thus, by computing and dispersing various indices, such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Building Index (NDBI), and Normalized Difference Water Index (NDWI), the qualitative characteristics of green areas and their relationship are revealed (Yang *et al.,* 2017).

In order to emphasize elements of relevance for the spatial analysis of green areas, GIS tools and methodologies (Envi and ArcGIS) are utilised. Nonetheless, the data was adjusted via a field survey using questionnaires that were distributed using the Kobo Toolbox data collection tool. After that, the data was examined using R-Studio and Excel, among other application systems. In order to enhance the visual representation of many things in the images, several colour mixtures were employed. The infrared colour composites NIR (4), SWIR (5), and red (3) were utilised to identify the various stages of vegetation growth and to separate the various colours of vegetation. The shortwave infrared (7), near infrared (4), and red (2) colour composites, which are sensitive to variations in moisture content, were utilised to identify built-up areas and barren terrain (Cheruto *et al*., 2016).

Regular field trips to the two cities (Sikasso and Bamako) made it possible to identify the primary land use categories. Training samples were chosen by drawing polygons around typical sites for each of the predefined land-use classes. Classifying land use and land cover was done by supervised image classification using the greatest likelihood classification technique. (LULC) using Envi 4.7 on Landsat images taken between 1990 and 2020. Additionally, the degree of variability and simplicity of identification using training sites differed throughout LULC classes. In general, supervised classification is used to map the spatial pattern and change of urban sprawl. The defined land use types are represented in Table 3.4 and include built-up areas, bare land, cultivated land, high (trees), medium (market gardens), and low (grass and flowers) vegetation, as well as water bodies.

Table 3. 4: Land Classes and Attributes for Supervised Classification

N	Land Cover	Description
1	Bare land	It is uncultivated, barren ground that has been left fallow and frequently degraded due to changes in road surfaces and soil deterioration.
2	Built-Up	This is terrain that is covered in buildings used for transportation infrastructure, residential, commercial, and industrial uses in both urban and rural regions.
3	Farmland	This is land that is dedicated to agricultural, growing food crops such as cassava, mangoes, green beans, and maize. Despite being forbidden for security reasons; cereal crops are nevertheless grown in cities.
4	High Vegetation	There are only a few trees and bushes in these places.
5	Medium Vegetation	The spaces in cities that are home to small-scale market gardens are covered in this class.
6	Low Vegetation	The primary vegetation cover in this class includes grass, lawns.
7	Water Body	These are regions that are submerged under water, either on the riverbank or in the surrounding bed, or created by man-made earth dams, random constructions, filled sand dams, or ponds**.**

Source: Author’s fieldwork (2022)

3.3.1.2. Land cover classification system

Generally speaking, the techniques for classifying land cover necessitate the availability of predetermined land cover classifications within the study region. In fact, a lot of studies have established and extensively used classification systems. Common vegetation types could be distinguished clearly according to the FAO's dichotomous phase land cover classification system (Terrestrial main vegetated: Cultivated and managed, natural and semi-natural; Terrestrial primary non-vegetated: artificially managed and semi-natural), while modifying the classes according to the nature of the land cover, the quality of the data, and the methods applied (School of Environment, 2015). However, for use in the classification of urban green space types, sampling points were identified and determined using the standard for green space classification in urban areas (Hang and Ang, 2019).

3.3.1.3. LULC mapping and its accuracy assessment

Through the development of numerous strategies and instruments, remote sensing techniques are designed to autonomously identify classes of land cover and guarantee accuracy (School of Environment, 2015). The need for developing nations to use remote sensing techniques to monitor spatial changes in urban and peri-urban agricultural land is thus emphasised by highlighting the benefits or strengths of remote sensing (Addo, 2010).

In general, many land-use planning projects, especially the UGS studies, apply GIS and remote sensing. Up-to-date information on the current status of UGS is crucial for land users and planners in certain spatial areas. Remote sensing is widely used in UGS mapping and is consistent with several techniques such as maximum likelihood, object-oriented approach, and support vector machines. The spatial database in this work, which included both vector and raster data, was managed and analysed using ArcGIS 10.8.1 software (Linh *et al.*, 2022).

Using data from March 1990, 2000, 2010, and 2020, the land surface coverage study was conducted using Landsat 5 ETM, Landsat 7 ETM+, and Landsat 8; the research site had zero cloud cover (Linh *et al.,* 2022). Thirty meters of resolution data were employed in the investigation (Linh *et al.,* 2022). For the purpose of classifying Landsat images and assessing the overall accuracy of the classification results, reference points gathered via the use of the geographic positioning system (GPS) served as ground truth data for urban green spaces (Cheruto et al., 2016). Urban sprawl trends and patterns were evaluated and quantified with the aid of landscape measures and post-classification change detection tools. Through the development of numerous strategies and instruments, remote sensing techniques are designed to autonomously identify classes of land cover and guarantee accuracy (School of Environment, 2015).

Remote sensing measures are generally adopted to identify and analyse green areas on satellite images. Therefore, the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), and Normalized Difference Water Index (NDWI) were calculated and distributed in this study to reveal the qualitative characteristics of green areas and their relationship in the two cities, Bamako and Sikasso (Li *et al.,* 2015) and (Yang *et al.,* 2017). Equation 3.8 uses the visible and near-infrared light that the plant reflects to create the most commonly used vegetation index. Most of the visible light is absorbed by healthy vegetation, which is affected and reflected by much of the near infrared light. This index allowed us to easily differentiate between vegetative and non-vegetative areas. The index is calculated using the formula below (equation 3.8):

$$\text{NDVI}=\frac{(\text{NIR-RED})}{(\text{NIR+RED})} \quad (3.8)$$

- ✓ NIR is the Near Infrared Band, represented by band 4 in Landsat 5TM and 7ETM+ images and band 5 in Landsat 8 OLI/TIRS images;
- ✓ Red is the Red Band, represented by band 3 in Landsat 5TM and 7ETM+ images and band 4 in Landsat 8OLI/TIRS images.

The NDVI values are theoretically between -1 and +1. Non-vegetated surfaces are indicated by negative values. Values close to zero indicate bare soil, positive values between 0.1 and 0.7 indicate vegetation formations; and those above 0.7 indicate the densest cover.

The NDBI is used to assess the condition of buildings and to map human settlements and some surrounding building elements. These values, depending on the spectral signature, can range from the mid-infrared to the near-infrared band (Climate and 2017, 2017). The index is calculated using the formula below (equation 3.9):

$$NDBI=\frac{(MIR\text{-}NIR)}{(MIR+NIR)} \qquad (3.9)$$

- ✓ MIR is the mid-infrared band represented by bands 5 in ETM+ and 6 in OLI/TIRS;
- ✓ NIR is referenced in equation 1.

Like NDVI, NDBI values also vary from -1 to +1.

The NDWI is used to calculate the water index to extract water bodies, which effectively improves water information in most cases. It is calculated using the following formula (equation 3.10):

$$NDWI=\frac{GREEN\text{-}NIR)}{(GREEN+NIR)} \qquad (3.10)$$

- ✓ NIR is the Near Infrared band, represented by band 4 in Landsat 5TM and 7ETM+ images and band 5 in Landsat 8OLI/TIRS images;

- ✓ The green band is represented by band 2 in Landsat 5TM and 7ETM+ images and band 3 in Landsat 8OLI/TIRS images.

The analysis of land cover change was possible using the NDVI index during our study period from 1990 to 2020. The correlation of NDVI with population data allowed us to analyse the effect of population growth and urbanisation on land cover.

3.3.2. Analysis of the effects of green spaces identified on sustainability and climate change resilience and their ecosystem services

This study examines how the people in Bamako and Sikasso perceive green spaces and the sustainability of cities in the face of rising urbanisation and climate change. Individual community interviews with Kobo Toolbox, focus group discussions among communities, participatory mapping, planning cells, etc. are needed to ensure that urban green spaces are developed where people need them, accept them, and see them as an asset to the city. It is essential for us to be able to assess the positive impacts on quality of life, health, and potential economic values of living spaces before implementing urban greening. Furthermore, a meteorological analysis was conducted utilising temperature and rainfall data from 1990 to 2020 to compare the population's impression of urban green spaces with their availability and exposure.

The strategic urban green spaces were chosen and offered by remote sensing data to the advantages of multidate and macroscopic observations. In addition, a meteorological analysis was carried out using rainfall and temperature data from 1990 to 2020 to compare the perception of urban green spaces among the populace with their accessibility and exposure. Population data is statistical data used in this study to calculate the population density using the formula below (equation 3.11). This data is taken from the website and refers to the distinct characteristics of a population. Age, gender, education, ethnicity, or religion, to name a few, are examples of demographic data.

$$\text{Density}=\frac{\boldsymbol{Total_{hts}}}{\boldsymbol{Area_{Km^2}}} \tag{3.11}$$

Where $Total_{hts}$ is the total population per administrative zone (district in this study) and $Area_{km}{}^2$ is the area of each administrative boundary in square kilometer (Traore *et al.*, 2015). Heavy rainfall and very heavy rainfall were used as indices to measure flood concurrence in green spaces in cities (Parvez, 2018). But they focused on rainfall, maximum temperatures, and minimum temperatures.

In this study, the Mann-Kendall test with a significance level of $p< 0.05$ was used to determine the trends of the rainfall and temperature series of the different stations in Sikasso and Bamako for the period 1990–2020 (John and Brema Professor, 2018) (Anie Joh and Brema, 2018).

The traditional Mann-Kendall test, which determines whether a time series has a trend, and the seasonal Mann-Kendall test, which accounts for the time series' seasonality, were the two tests provided by XLSTAT. They used the Seasonal Mann-Kendall option and entered 12 (=months) in the period field (period = number of lags between two seasons) in order to apply the second one. XLSTAT estimates the distribution of the average Kendall tau using a normal approximation, which is then used to compute the test's p-value. If the user chooses, a continuity correction can also be implemented. To characterize rainy and dry periods, the Standardized precipitation index (SPI) and the Standardized precipitation evapotranspiration index (SPEI) were created. The analysis was performed with R-Studio.

3.3.3. Compare urban green spaces and their ecosystem services in the study areas

Contrary to the above-mentioned classification of green space based on satellite image processing in Table 3.4, they also divided green space into two categories: natural green space and artificial or planted green space. This allowed the maps to have a comparable range of values.

Types of urban green spaces were manually categorized based on their services and locations. Using visual interpretation, data on green spaces was collected, accounting for each parcel's kind and boundary as well as its location, size, shape, and spatial interactions with neighboring parcels. In order to classify urban green spaces (trees, agricultural lands, and flours) and establish the classification criteria, they identified sampling places (Hang and Ang, 2019). Furthermore, green places were identified by combining better spatial resolution Google Earth photos with GPS coordinates and waypoints (Huang and Yang, 2017).

The results of the classification of the cities of Bamako and Sikasso between 1990 and 2020 made it possible to analyse the evolution of vegetation formations by evaluating the surface areas of the different land use classes using ArcGIS 10.8 software, and to analyse their evolution between 1990 and 2020.

The formula was used to determine each land cover class's rates of cover, average yearly change, and annual increase in area (Karambe, 2014; Mbaiyetom *et al.*, 2020).

$$\boldsymbol{Coverage\ rate} = \left(\frac{\boldsymbol{Area\ per\ unit}}{\boldsymbol{Total\ area}}\right) * \mathbf{100} \qquad (3.12)$$

$$\boldsymbol{Average\ annual\ change} = \left(\frac{\boldsymbol{Final\ area\ - Initial\ area}}{\boldsymbol{Number\ of\ Years}}\right) * \mathbf{100} \qquad (3.13)$$

$$\boldsymbol{Annual\ growth\ rate} = \left(\frac{\boldsymbol{Final\ area\ - Initial\ area}}{\boldsymbol{Initial\ area\ * Number\ of\ years}}\right) * \mathbf{100} \qquad (3.14)$$

The four types of ecosystem service organisations that respondents were aware of where those that supplied services, those that controlled and maintained services, and those that offered cultural services were the main emphasis of the study's findings. Criteria include, but are not limited to, distances from the city core, the urban area, height, the road network, and water bodies (Nadizadeh Shorabeh *et al.,* 2020). The criteria of the maps were normalised to the scale of lowest potential to highest potential using the minimum and maximum functions. Planning recommendation strategies and urban green space mapping will be updated and adapted to improve and increase the resilience of urban green space systems to climate change effects in the cities of Sikasso and Bamako. This theory of resilience is the key to opposing conventional single equilibrium views that better understand environmental problems in terms of cause and effect. They worked to strengthen the resilience of cities and human settlements through the adoption of quality spatial planning in the implementation of the policy and integrated plan.

The promotion of urban green spaces was of paramount importance in awareness-raising activities to ensure their use by diverse population groups while providing a setting for local residents. Urban planners can design greening initiatives to enhance the area's appearance, enhance air quality, give inhabitants access to public space, and even heighten the feeling of peace and tranquilly among residents in order to mitigate some of the negative consequences of urbanisation.

3.3.4. Determine the availability and quality of green spaces in the study areas

In this study, natural green space refers to any kind of naturally growing plant without artificial planting, while man-made or planted green space, as the name suggests, refers to plants artificially planted in selected areas. Actually, "land, water, and geological features that are naturally inhabited by plants and animals and that are accessible on foot to a large number of residents" is the definition of natural and semi-natural green spaces (Space, 2015).

Therefore, they have to consider street trees, market gardening, garden centres, parks, landscaping around buildings, and flowers on monuments and public buildings as artificial green spaces. 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 (Figure 3.2). Thus, the total area of green areas in the municipality of Bamako is 1,439 hectares (AEDD, 2023), the largest of which is Municipality 1, since it has the classified forest of Koulouba, which occupies a very large area.

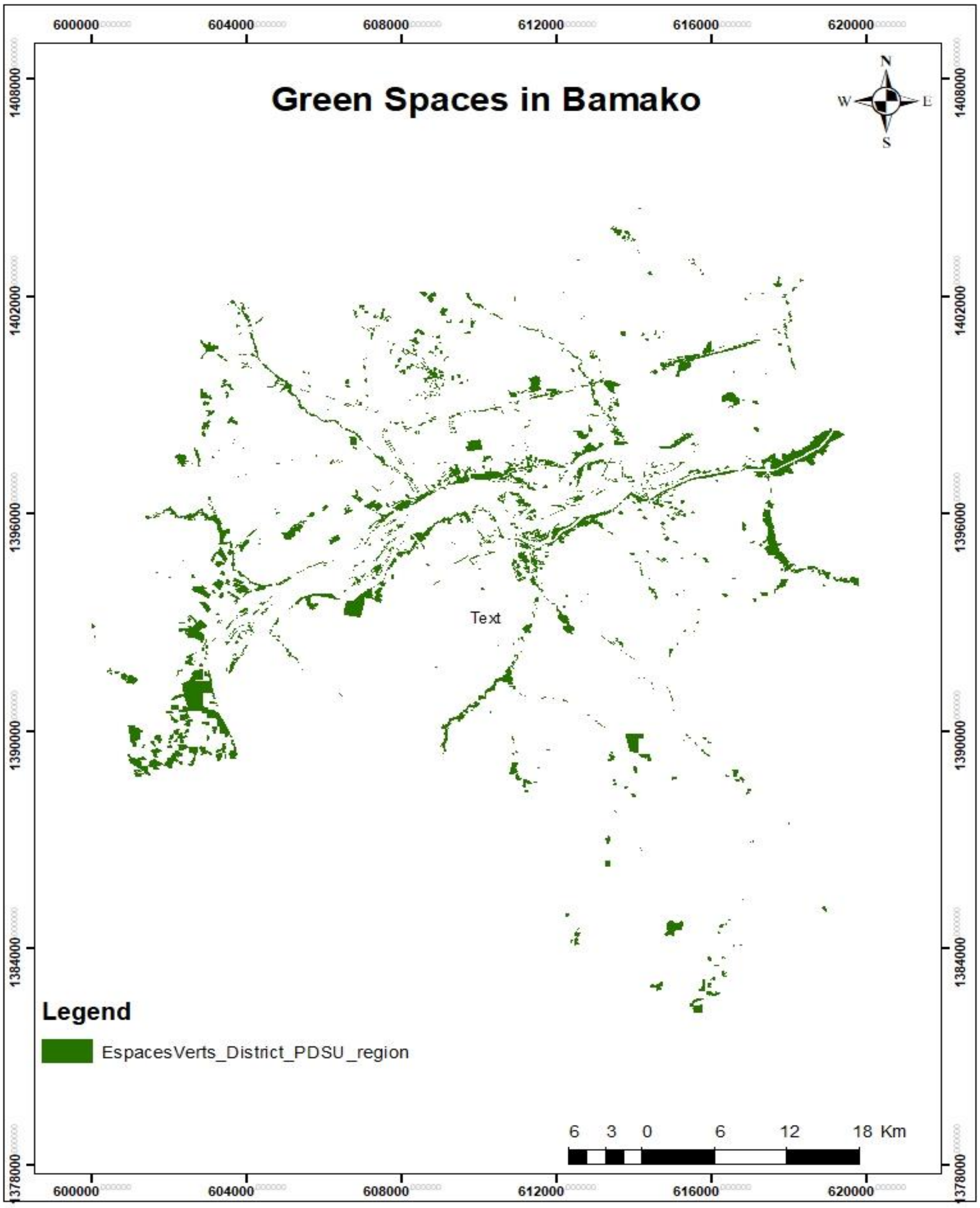


Figure 3. 2: Urban Green in Bamako District (AEDD, 2023)

According to the Regional Direction of Urbanism and Habitat of Sikasso, the total green area of the municipality of Sikasso is 164,329.79 square metres (16.43 hectares). Additionally, the city of Sikasso and the surrounding areas have severe environmental concerns, despite being situated in a region where nature protection agencies oversee the development of natural resources. These consist of erosion, bushfires, and deforestation (URBATEC, 2006). Overuse of natural resources causes soil and plant degradation, which reduces subsistence output structurally and exacerbates poverty.

Restoring the ecosystem of the living tissue is the foundation of every mitigation plan. There isn't a policy for prudent natural resource management in Sikasso. It should be mentioned, nonetheless, that there are plantations, either individual or group, and groves in every settlement within the municipality (L'Urbanisme, 2005; URBATEC, 2006) lists the following: one (01) hectare of Boubacar DIALLO forest in a residential area; fifty.06 hectares of conservation space on Bouake Road (RN7); ninety hectares of reforested land on Koutiala Road (RN11); and one (01) hectare cashew plantation in a residential neighborhood. This indicates that there are roughly 142.02 hectares in total with two different types of classified woods within the settlement area: Kaboïla (410 ha) and Zamblara (60 ha) (URBATEC, 2006).

However, these woodlands are not developed or maintained, and the community places less importance on the task of preventing mixed erosion on farmed land. The various urban green space types were categorized based on asset condition, users, and spatial characteristics (Hernandez *et al.*, 2020).

3.3.5. Examine the implications of the existing green spaces on the resilience cities

They comprehend the significance of urban greening for our cities, thanks to Council Magazine Editor Eliza Booth. Planners are using urban greening programmes to counteract some of the negative effects that urban expansion can have on the environment and the larger community as our cities keep growing and becoming denser (Eliza Booth, 2023). But what precisely is urban greening, why is it important for our expanding cities, and how are the fast-expanding urban green spaces in Bamako and Sikasso doing right now? With the highest population growth of any city in the country, they are confident that people like living in the cities of Bamako and Sikasso because of the exciting opportunities that come with it.

However, to create lovely green places, urban greening integrates landscape design, knowledge, and creative design; the most notable examples of greening in our communities are parks and street trees. City planners have to think about how new infrastructure and buildings will affect the environment and communities while they are being created. The best choice for greening depends on many factors, such as built-up, the size of the available area, whether the area already has trees or needs to be planted, whether it is possible to green the roof, or whether it is possible to install vertical gardens on the side of the building.

Based on existing land use and land cover analysis data, they loaded different input layers into GISCAME to simulate strategies for improving green space supply in two cities. Therefore, land use and land use scenarios are driven by thematic input levels, such as vegetated areas such as green spaces (consisting of high, medium, and low vegetation), built-up areas, water bodies, etc. Additionally, these scenarios are based on existing land use and land cover analysis data. In fact, these scenarios are based on the conversion of vegetation into built-up areas on the one hand and on the possible development of vegetation (green spaces) in cities on the other. The obtained values were Standardized using a Likert scale ranging from 0 to 100 value points (Asante-yeboah and Furst, 2023; Koschke *et al.*, 2012). In fact, this scale is used to determine an individual's likelihood of transitioning from a land use category. Values are entered by land use category and ecosystem service group according to the study preparation process.

In this way, they get different weight results and, at the same time, show the overall results of the evaluation (Koschke *et al.*, 2014). Participatory development scenarios were supported by GISCAME to develop sets of scenarios and examine their synergistic impacts and trade-offs for multiple ecosystem services related to climate change, as shown in the assessment matrix below (Figure 3.3.).

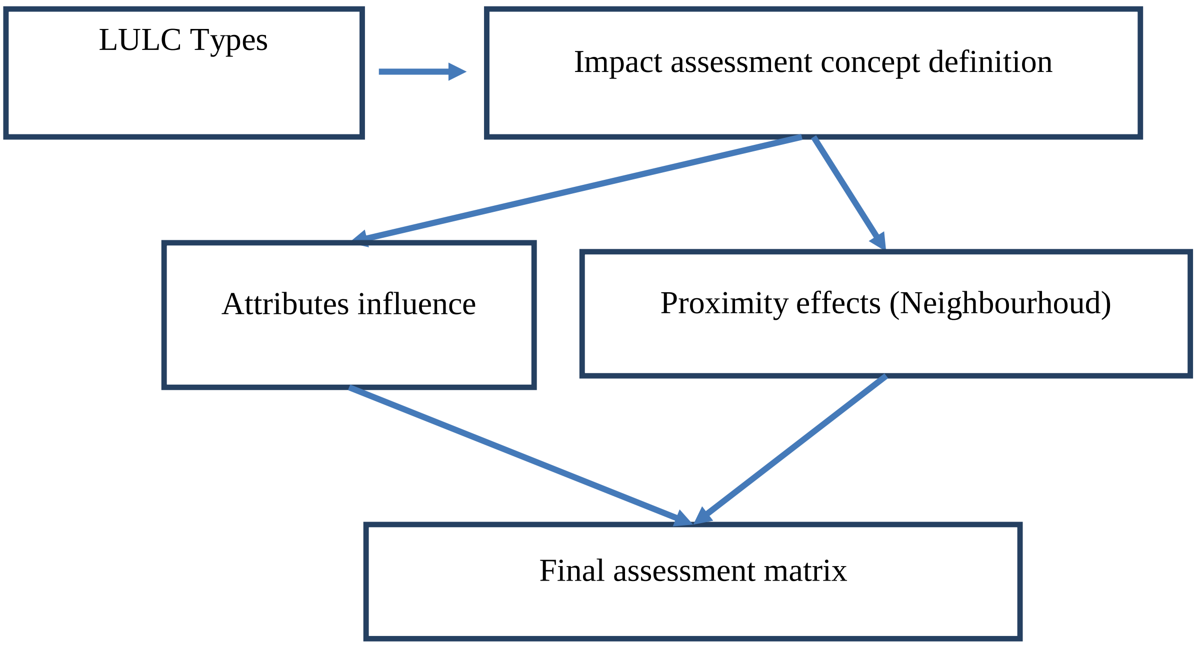


Figure 3. 3: Methodological Workflow for Development Scenarios using GISCAME

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1. Results Presentation

4.1.1. Evaluation of the spatial changes and the characteristics of the different types of Urban Green Spaces (UGS) in Bamako and Sikasso cities

The growth of vegetation formations, the accuracy of maps showing land use and cover, and the various indicators that come after this goal's main points are the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), and Normalized Difference Water Index (NDWI), together with the two cities' green space types, characteristics, and connections.

4.1.1.1. LULC mapping and its accuracy assessment

(a) Land Use/Land Cover Maps

The analysis by using supervised classification between 1990 and 2020 showed that the study areas were covered with various land features (bare land, built-up areas, farmland, high vegetation: trees and shrubs, medium vegetation: market gardens, low vegetation: grass, flowers, and water bodies). The LULC classification's outcomes demonstrate that the overall classification accuracy of 1990, 2000, 2010, and 2020 is respectively 84,81%, 90,60%, 98,68%, and 99,17% for Bamako (Table 4.1) and 97,92%, 98,42%, 98,02% and 96,96% for Sikasso (Table 4.2). The LULC classification of the two cities (Bamako and Sikasso) is shown in Figures 4.1 and 4.2.

Table 4. 1: Land Use and Land Cover (LUC) Change Classes in Different Periods from 1990 to 2020 in Bamako

Class name	Areas (ha) 1990	(%)	Areas (ha) 2000	(%)	Areas (ha) 2010	(%)	Areas (ha) 2020	(%)
BAMAKO								
Bare land	4 562	19.34	3 617	15.33	2 924	12.40	3 291	13.95
Built-Up	5 176	21.94	10 381	44.01	10 633	45.08	12 995	55.09
Farmland	3 456	14.65	1 407	5.97	1 373	5.82	1 136	4.82
High Vegetation	492	2.09	412	1.75	399	1.69	352	1.49
Medium Vegetation	2 222	9.42	2 107	8.93	1 825	7.74	1 150	4.88
Low Vegetation	6 288	26.66	4 293	18.20	4 679	19.84	3 365	14.27
Water Body	1 391	5.90	1 370	5.81	1 754	7.44	1 298	5.50

Table 4. 2: Land Use/ Land Cover (LUC) Change Classes in Different Periods from 1990 to 2020 in Sikasso

SIKASSO								
Bare land	1385	30.55	178	3.93	730	16.10	1243	27.42
Built-Up	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

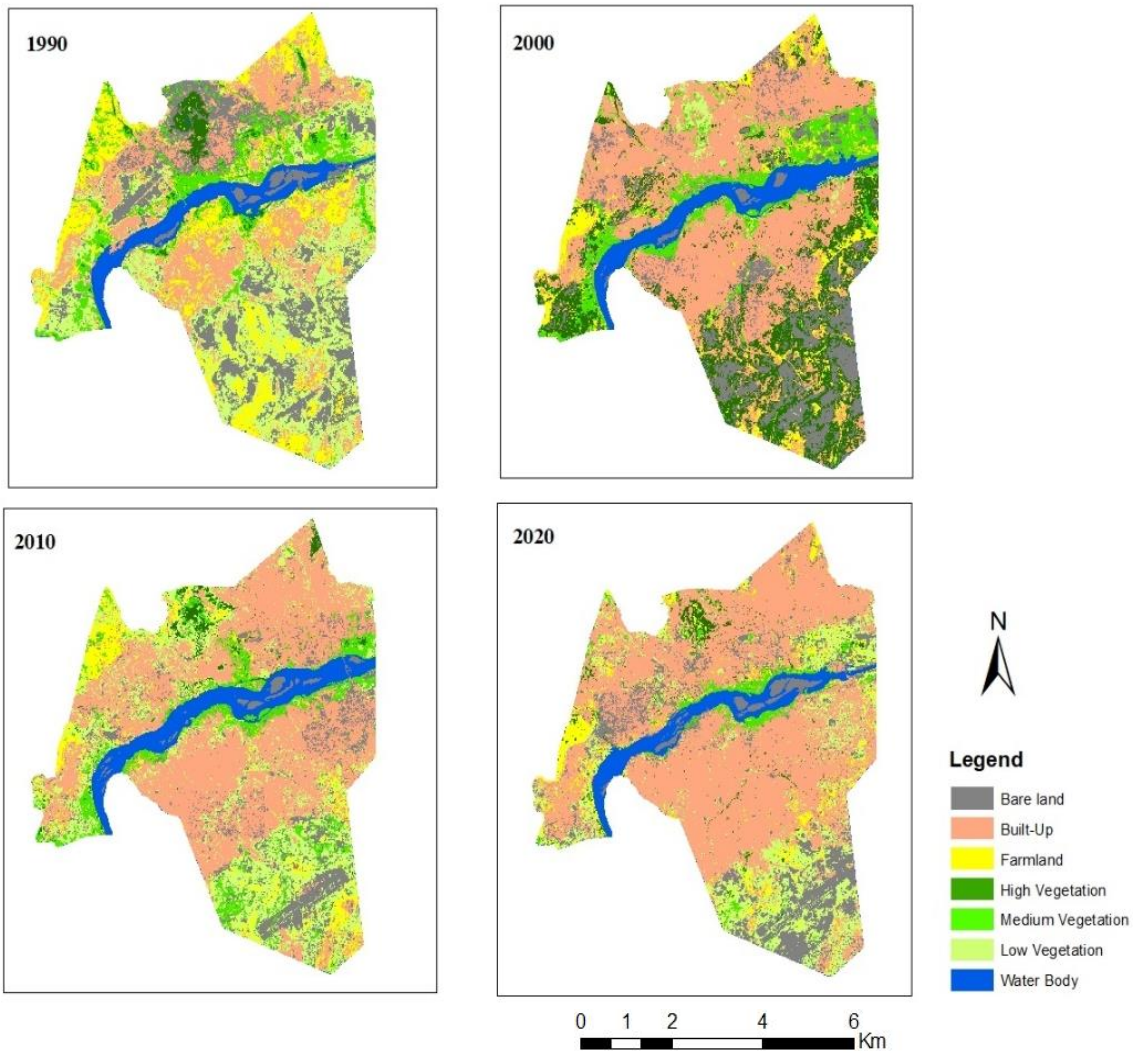


Figure 4. 1: **Land Use and Land Cover Change in Bamako from 1990 to 2020 (ArcGIS v. 10.8)**

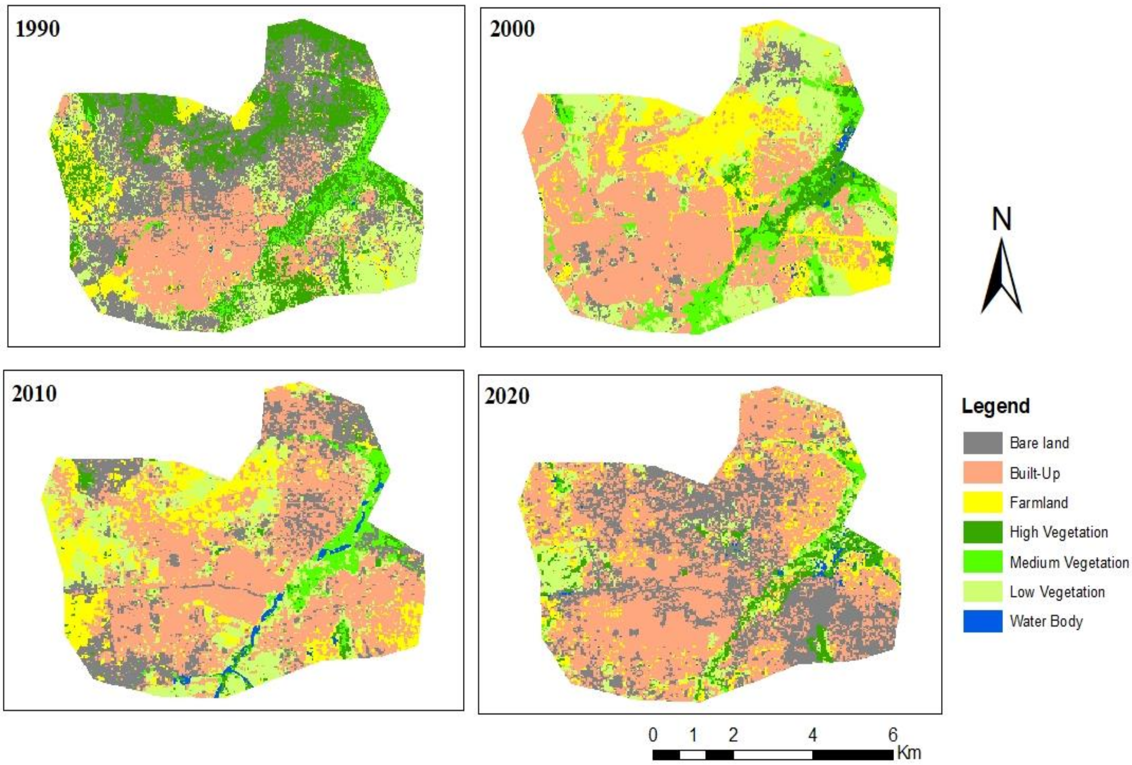


Figure 4. 2: Land Use and Land Cover Change in Sikasso from 1990 to 2020 (ArcGIS v. 10.8)

(b) Accuracy assessment

When classifying images, accuracy is considered an important step in evaluating different image processing methods (Hussain *et al.*, 2020). The error matrix is the maximum of the general and mutual means of the current accuracy results. Various statistical methods for evaluating accuracy can be derived from error matrices with manufacturer accuracy percentage, user accuracy, and overall accuracy, which account for randomly generated errors (Hussain *et al.*, 2020). As shown in Tables 4.3 and 4.4, supervised maximum likelihood classification was applied to generate high accuracy LULC maps. The overall accuracy in Bamako is 84,81%, 90.00%, 98.68%, and 99.17% respectively for the 1990, 2000, 2010, and 2020 classification; that in Sikasso is 97.92%, 98.42%, 98.02%, and 96.96%, respectively for the 1990, 2000, 2010, and 2020 classifications.

Table 4. 3: Accuracy Assessment of Land Use and Cover in Bamako between 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 4. 4: Accuracy Assessment of Land Use and Cover in Sikasso between 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

4.1.1.2. Description of different index (Normalized Difference Vegetation Indexes (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI)).

The relative distribution of spatial indices measured for each study year is expressed. The following indexes as NDVI, NDBI, and NDWI, were used to create maps for different time periods in 1990, 2000, 2010, and 2022. In 1990, 2000, 2010, and 2020, NDVI was used to create vegetation cover maps (Figures 4.3 and 4.4). Within these two cities (Bamako and Sikasso), there was a significant reduction in vegetation cover (scattered vegetation and forest). Water also showed lower NDVI values, while the highest NDVI values of 0.4 and 0.6 in 1990, for Bamako and Sikasso respectively; and 0,2 and 0,1 in

2020 mean less vegetation growth and more urban growth (Table 4.5). Development maps were created by visualizing local development using the NDBI (Normalized Difference Building Index) (Figures 4.5 and 4.6). Developed and vacant land in densely populated areas has higher NDBI scores.

The maximum NDBI increases significantly due to the conversion of land into construction land, including industrial and commercial buildings, residential buildings, roads, and traffic communications. Therefore, high NDBI values occur in built-up areas and other impervious surfaces, while low NDBI values occur in water bodies and vegetation cover (Table 4.6). The highest concentration of NDWI is in the water area, and the lowest concentration is in the built-up area. In a way, the presence of water helps to reduce the temperature of the area and its surroundings (Table 4.7). The spatial distribution of NDWI in 1990, 2000, 2010, and 2020 was extracted using the NDWI index (Figures 4.7 and 4.8) (Sarkar, 2022).

Table 4. 5: Normalized Difference Vegetation Index (NDVI) in Bamako and Sikasso from 1990 to 2020

	Bamako		**Sikasso**	
NDVI				
Dates	**Minimum**	**Maximum**	**Minimum**	**Maximum**
1990	- 0,192661	0,4	- 0,0833333	0,6
2000	- 0,513308	0,189744	- 0,336957	0,022222
2010	- 0,395349	0,590909	- 0,0705882	0,592105
2020	- 0,60154	0,200914	- 0,0582877	0,169659

Table 4. 6. Normalized Difference Building Index (NDBI) in Bamako and Sikasso from 1990 to 2020

NDBI				
1990	- 0,177829	0,615819	- 0,0707692	0,577889
2000	- 0,284635	0,684211	- 0,257732	0,369369
2010	- 0,211055	0,905405	- 0,142857	0,352941
2020	- 0,326404	0,523684	- 0,280594	0,210894

Table 4. 7. Normalized Difference Water Index (NDWI) in Bamako and Sikasso from 1990 to 2020

NDWI				
1990	- 0,483077	0,112583	- 0,522124	- 0,0108696
2000	- 0,294118	0,598394	- 0,315364	0,26087
2010	- 0,554286	0,631579	- 0,530726	0,126761
2020	- 0,43431	0,156316	- 0,388335	0,0753701

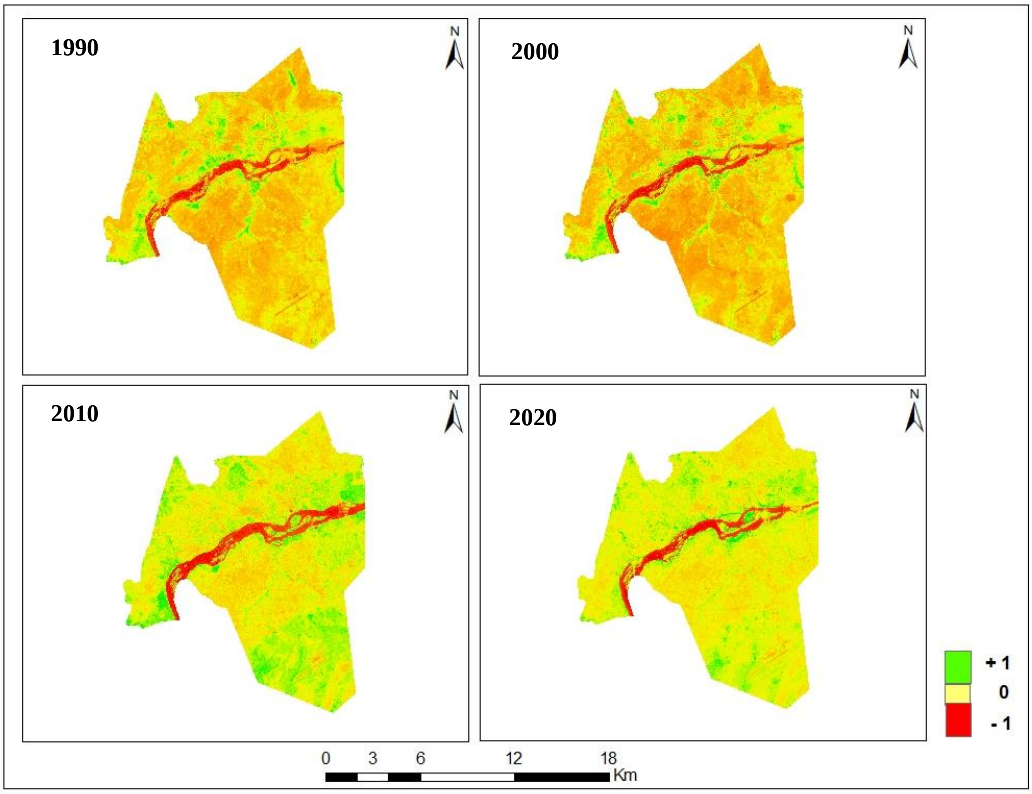


Figure 4. 3: Normalized Difference Vegetation Index (NDVI) of Bamako from 1990 to 2022

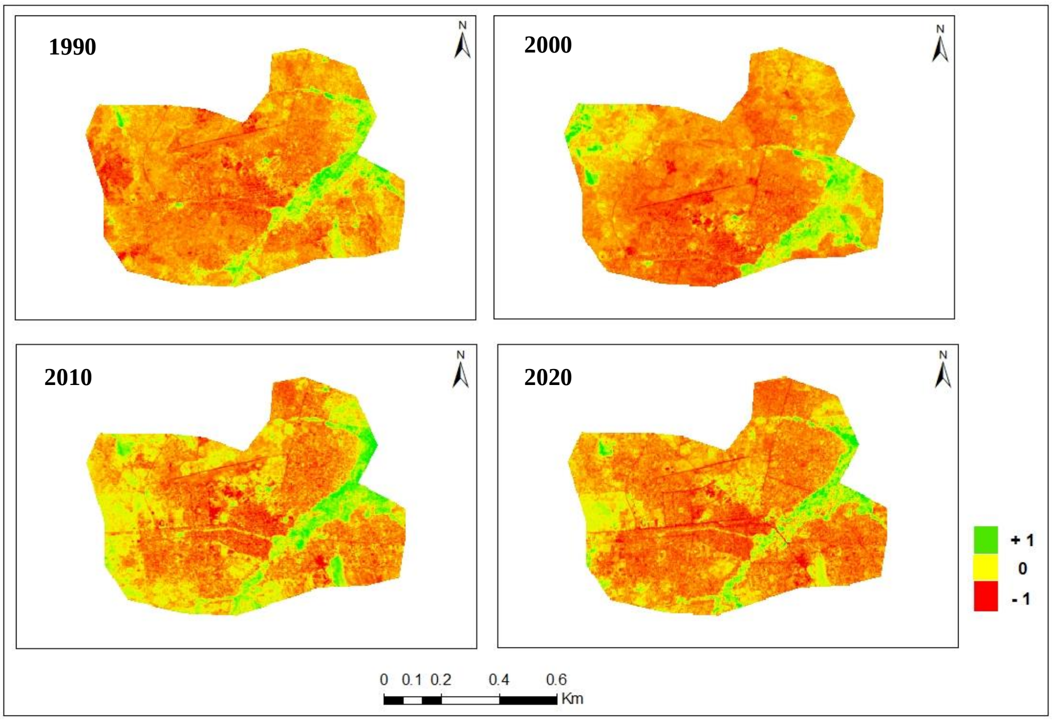


Figure 4. 4: Normalized Difference Vegetation Index (NDVI) of Sikasso from 1990 to 2022

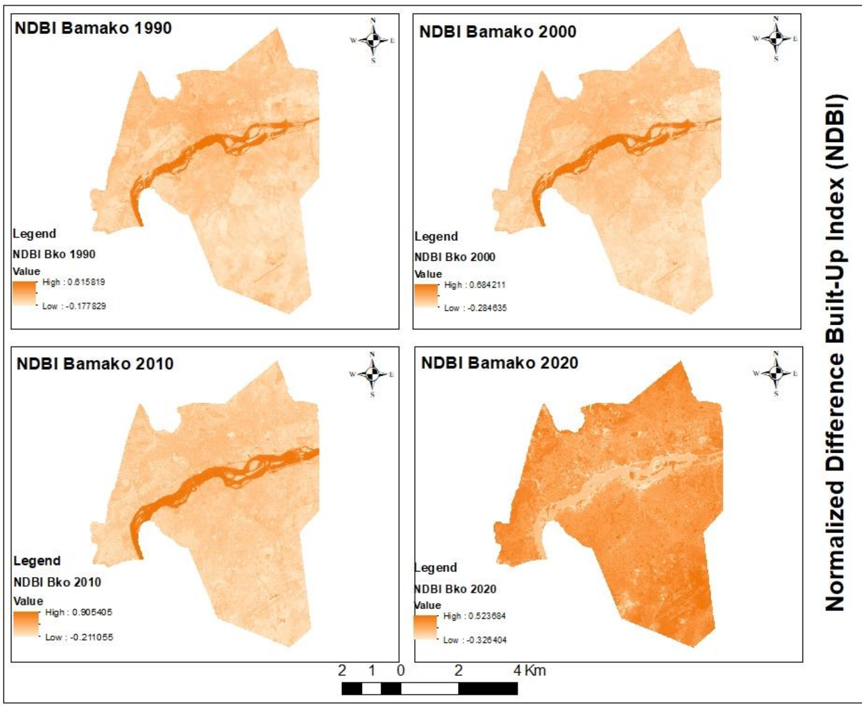


Figure 4. 5: Normalized Difference Built-Up Index (NDBI) Bamako from 1990 to 2022

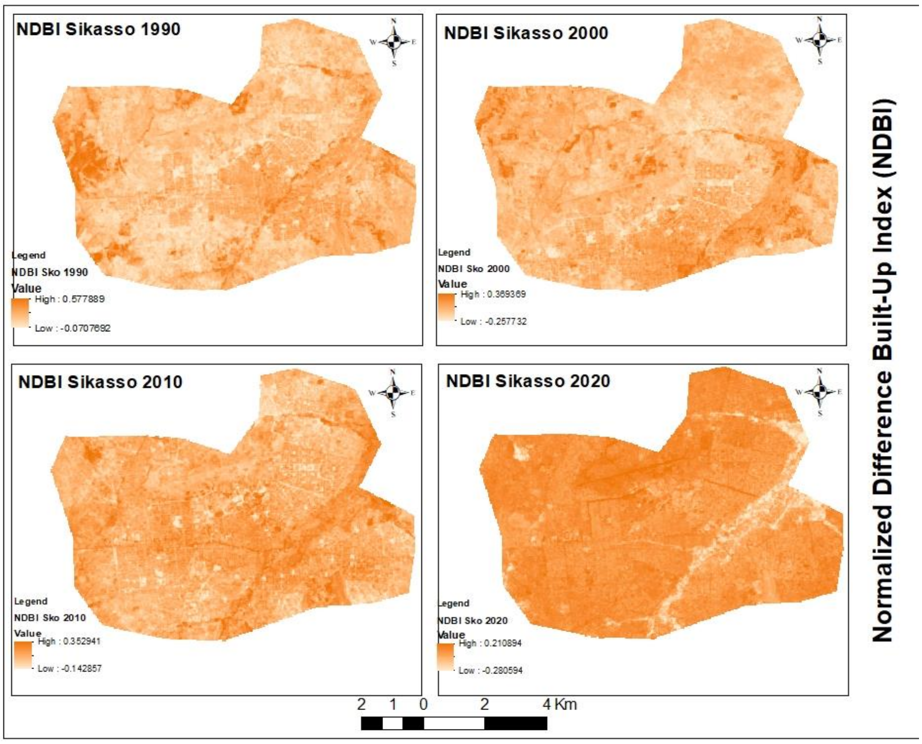


Figure 4. 6: Normalized Difference Built-Up Index (NDBI) Sikasso from 1990 to 2022

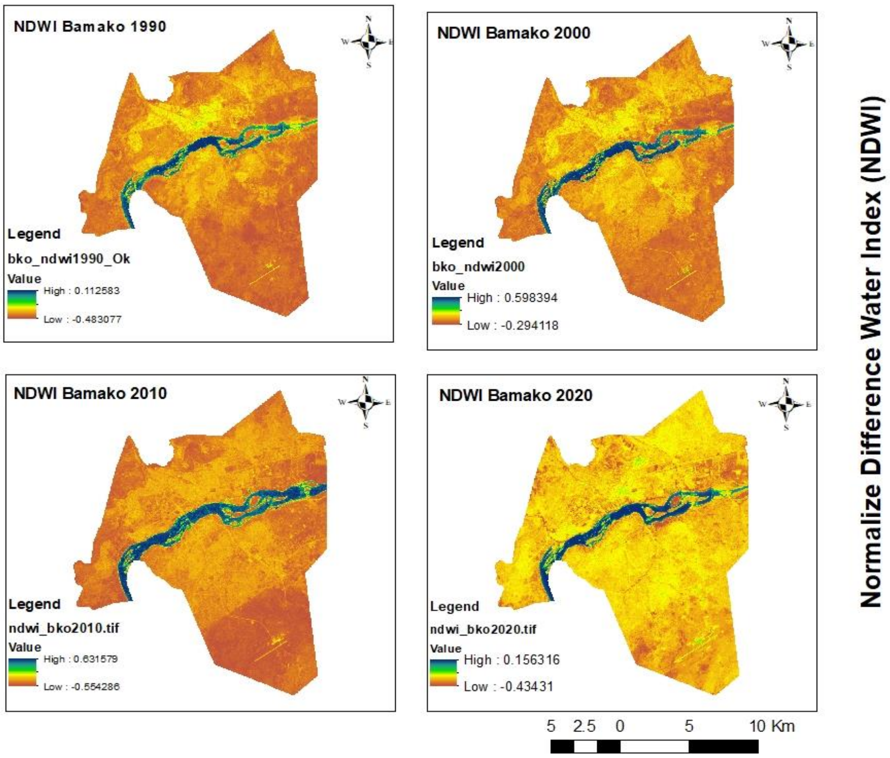


Figure 4. 7: Normalized Difference Water Index (NDWI) Bamako from 1990 to 2020

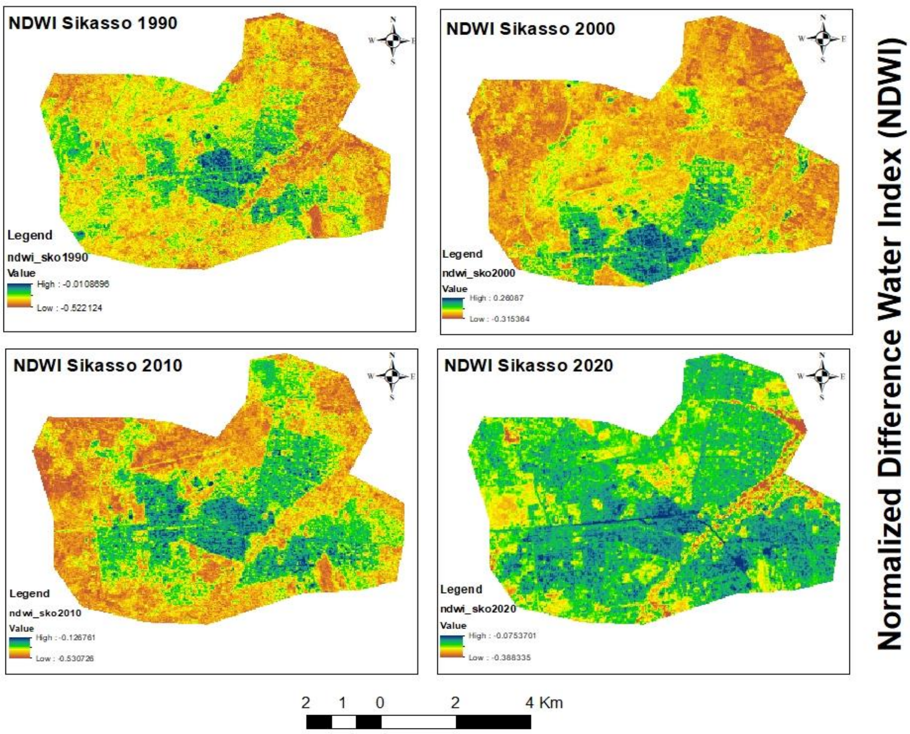


Figure 4. 8: Normalized Difference Water Index (NDWI) Sikasso from 1990 to 2020

4.1.2. The impact of urban green space and ecosystem service distribution dynamics on climate change resilience

4.1.2.1. Socio-demographic characteristics of the respondent

The characteristics of the respondents range from 20 to 70 years and are shown in Figures 4.9, 4.10, 4.11, and 4.12. The gender (Figure 4.9), fields of education (Figure 4.10), residence status (Figure 4.11) and professional status as main activities of respondents (Figure 4.12) are shown in those figures. Most of the respondents in Bamako are male (78%), with high educational level (47%). Analysis of those figures shows that the majority of respondents are house owners (36%), use free accommodation (33%) and use rented house (29%). The main activities of respondents are students, with 30% female and 25% male, followed by farmers. They have high levels of residence status and main activities.

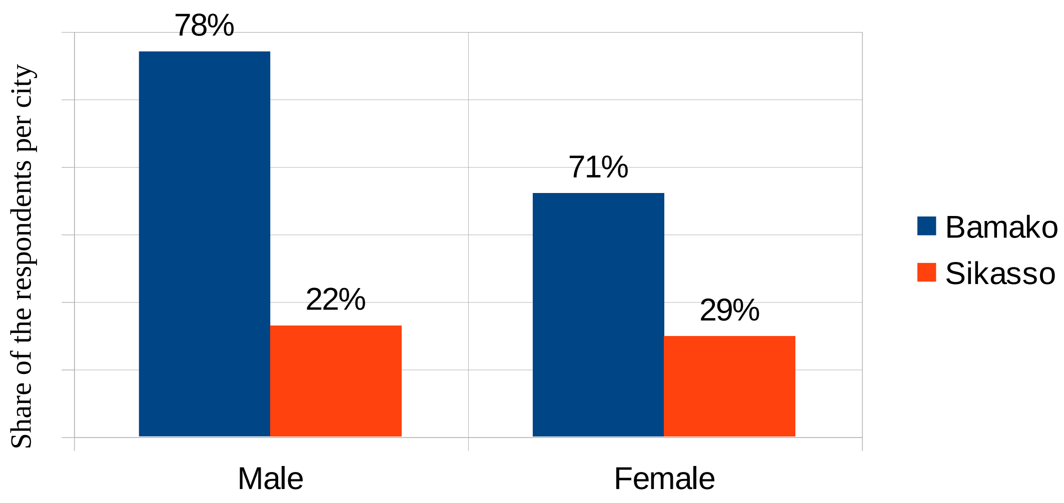


Figure 4. 9: Gender of Respondents Bamako and Sikasso

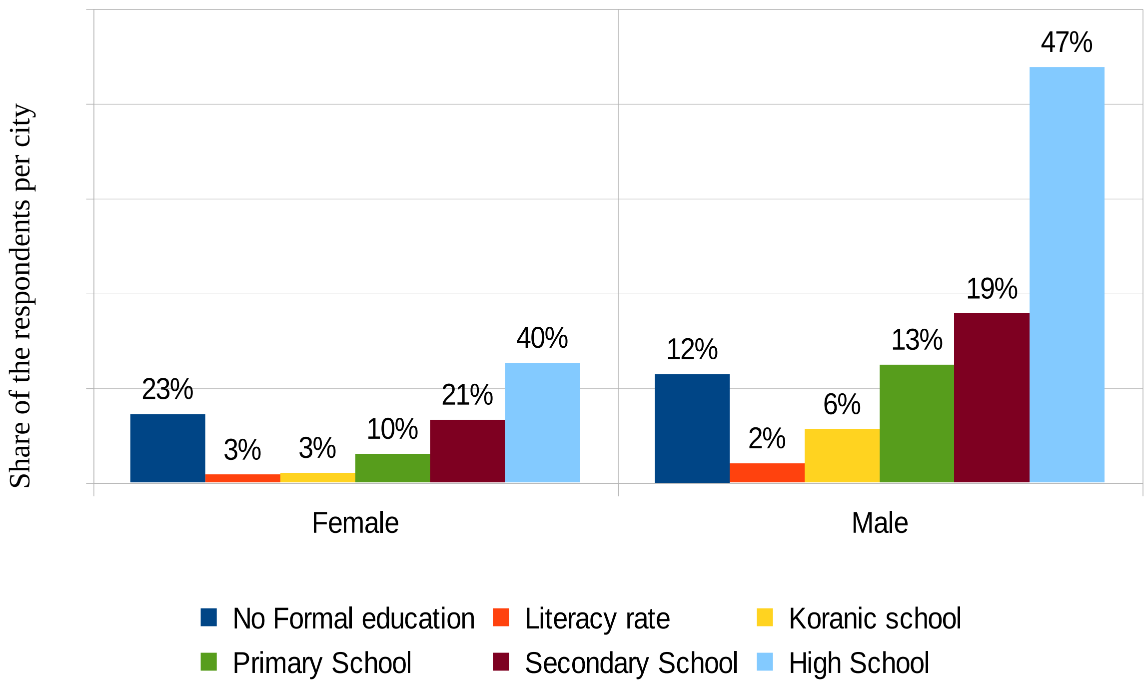


Figure 4. 10: Educational Level of Respondents in Bamako and Sikasso

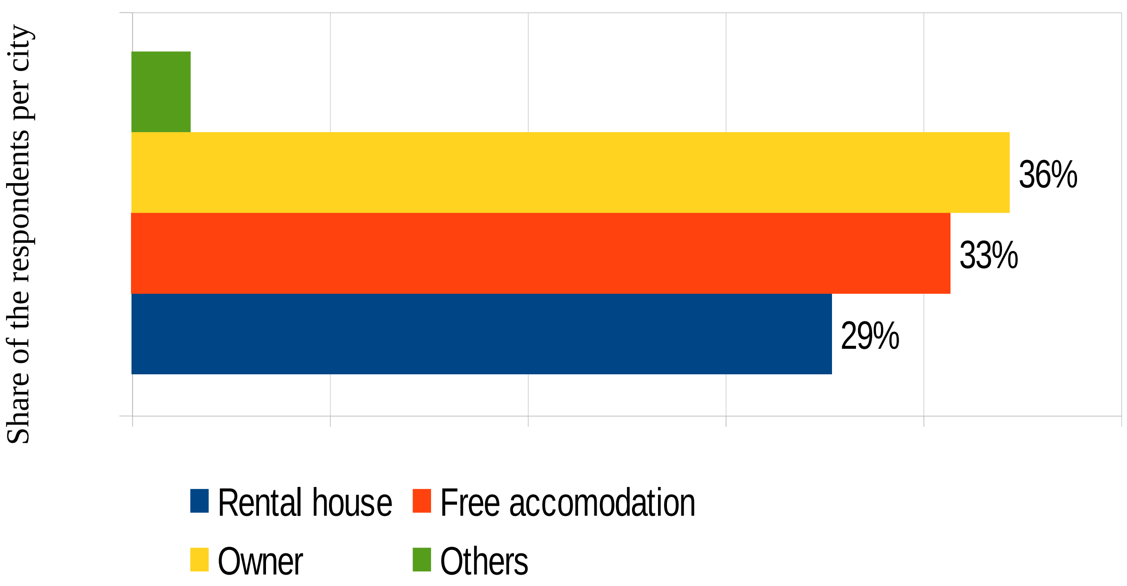


Figure 4. 11: Residence Status of Respondents in Bamako and Sikasso

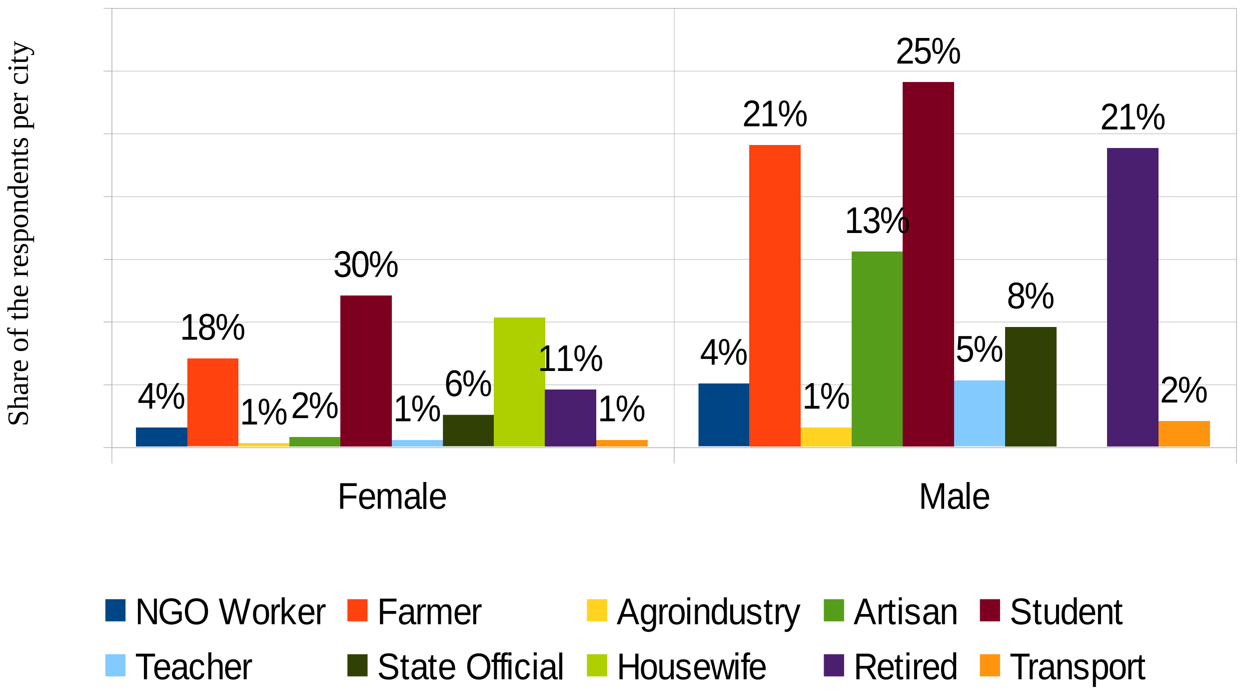


Figure 4. 12: Main Activities of Respondents in Bamako and Sikasso

4.1.2.2. UGS perception and ecosystem services (ES)

The results of the study made it possible to create a database that lists the locations of green spaces in the municipality of Bamako and Sikasso, as well as the kind of green space based on the vegetation cover and the typology mentioned by (Henri Kabanyegeye *et al.*, 2020; Kong *et al.*, 2014; Kong and Nakagoshi, 2006; Mensah, 2014; Sambieni *et al.*, 2018). So, according to the criteria shown in Table 4.8, the majority of the respondents have a good perception of UGS in Bamako and Sikasso, with 42%, and 72%, respectively (Figure 4.13); the majority of respondents indicated regulating services as the highest level of ES provided, followed by provisioning services in both cities (Figure 4.14). Most of the respondents in Bamako and Sikasso indicated that they have lived in the city for 15 years and over, with 61% in Sikasso and 47% in Bamako (Figure 4.15).

Figure 4.16 showed a high-level different change observed under green spaces in both cities: 26% for improvement of air quality and increased air temperature (19%) in

Bamako, while in Sikasso, 29% for good microclimate, followed by rapid water infiltration (22%). These major changes were seen from 5 to 10 years in both cities, with 40% in Bamako and 30% in Sikasso (Figure 4.17). The main advantages of various green space types and ecosystem services, with 21% in both cities, are resting places, as shown in Figure 4.18. Figure 4.19 shows that most respondents (55%) and 49% in Bamako and Sikasso, respectively, indicated high levels of migration in Bamako. Most of the respondents in both cities attributed social advantages as the major benefits of types of ecosystem services, with 37% in Sikasso and 33% in Bamako (Figure 4.20).

The Figure 4.21 showed that the advantages of the relationship with citizen and green spaces are agriculture in Sikasso with 37% and sport in Bamako with 22%. Figure 4.22 shows that the majority of respondents indicated that the relationship description with ecosystem services is social, with 66% in Sikasso and 44% in Bamako. Figure 4.23 showed the degradation of urban green spaces as the main of problems and difficulties, with 40% in Sikasso and 29% in Bamako.

Table 4. 8: Perception of Population in Green Spaces

Criterias	**Perceptions**
Provisioning; Regulation and Maintenance; Cultural	Excellent
Provisioning; Regulation and Maintenance	Good
Provisioning and regulating or Provisioning and Cultural or Cultural and Regulating	Moderate
Any of them	Poor

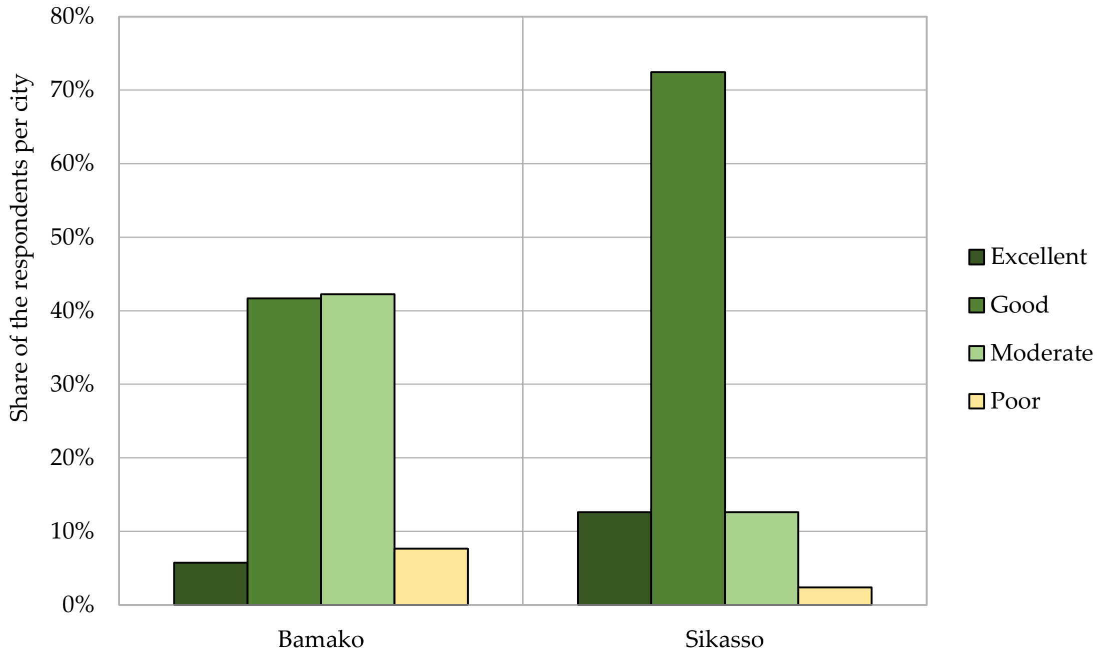


Figure 4. 13: Perception of the Status of Urban Green Space in Bamako (n = 370) and Sikasso (n = 384) related to the Sustainability of the Respective Respondents´ Communities

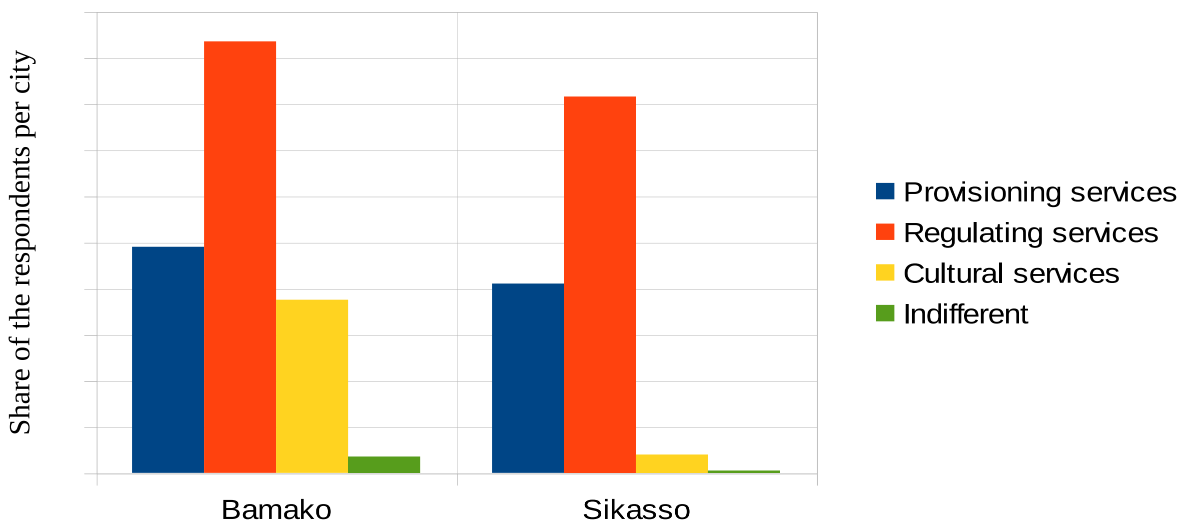


Figure 4. 14: Ecosystem Services Provided

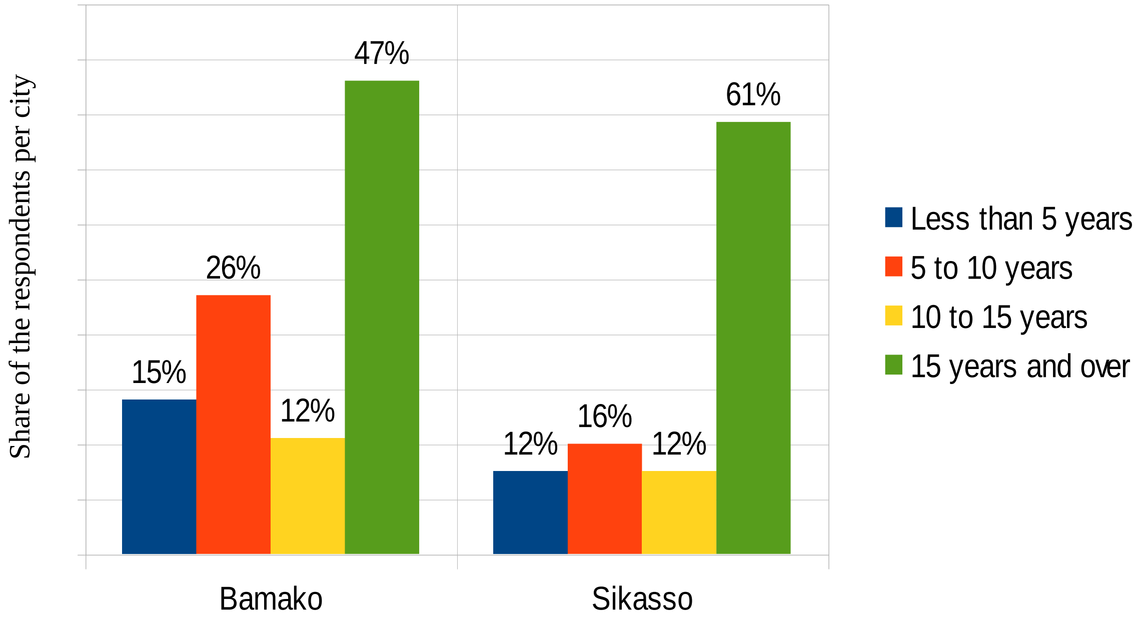


Figure 4. 15: Living in the City in Recent years (more than 5 years)

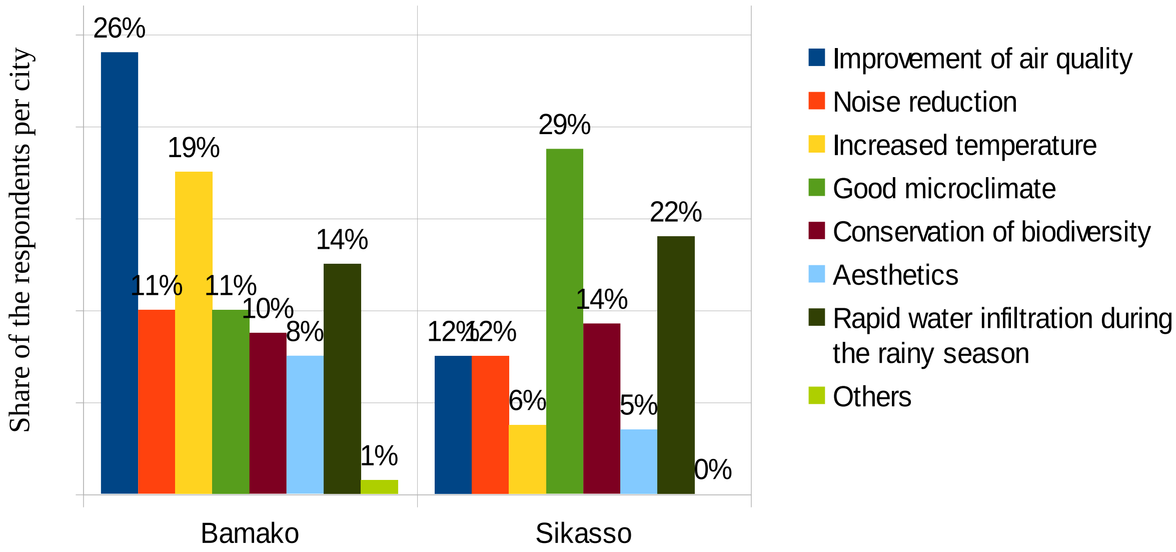


Figure 4. 16: Different Changes Observed Under Green Spaces

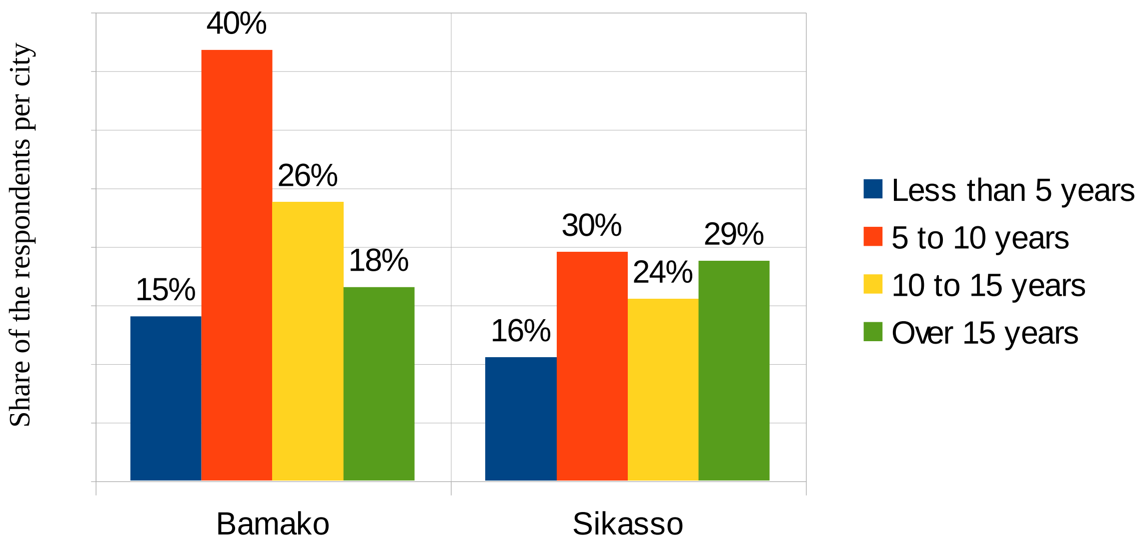


Figure 4. 17: How many years have you seen these Changes?

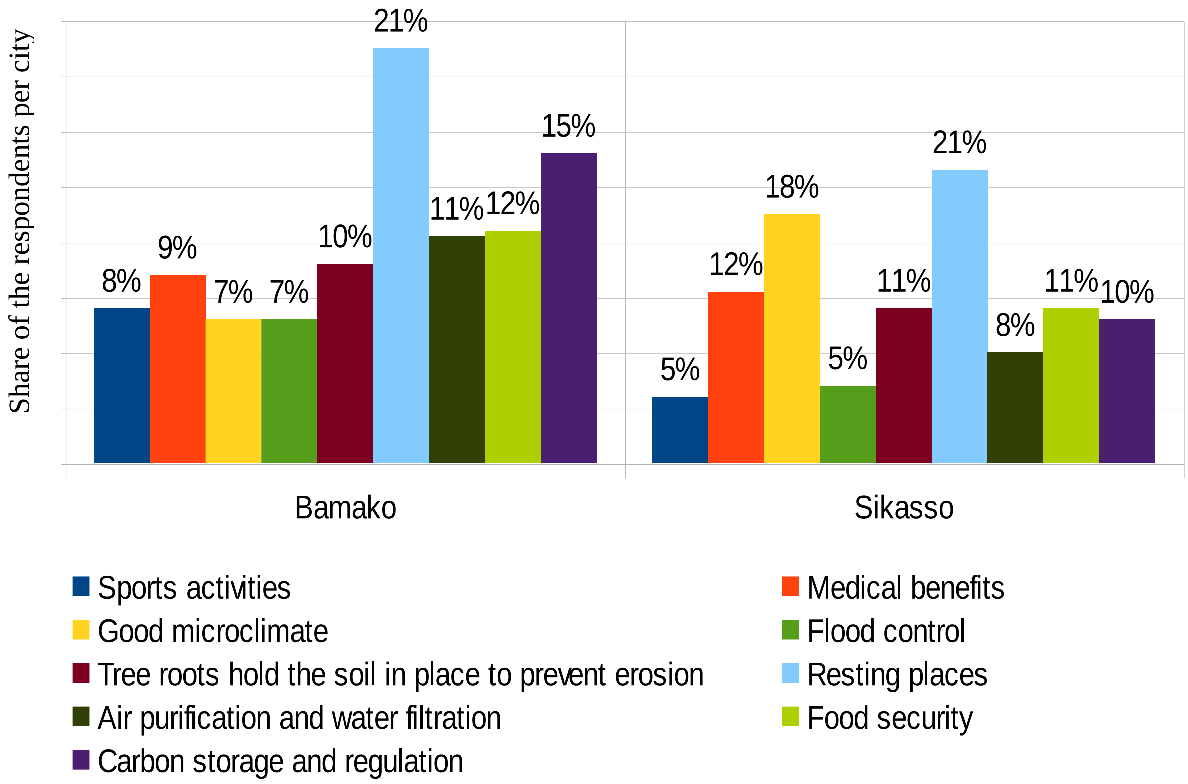


Figure 4. 18: Benefits of Different types of Green Spaces

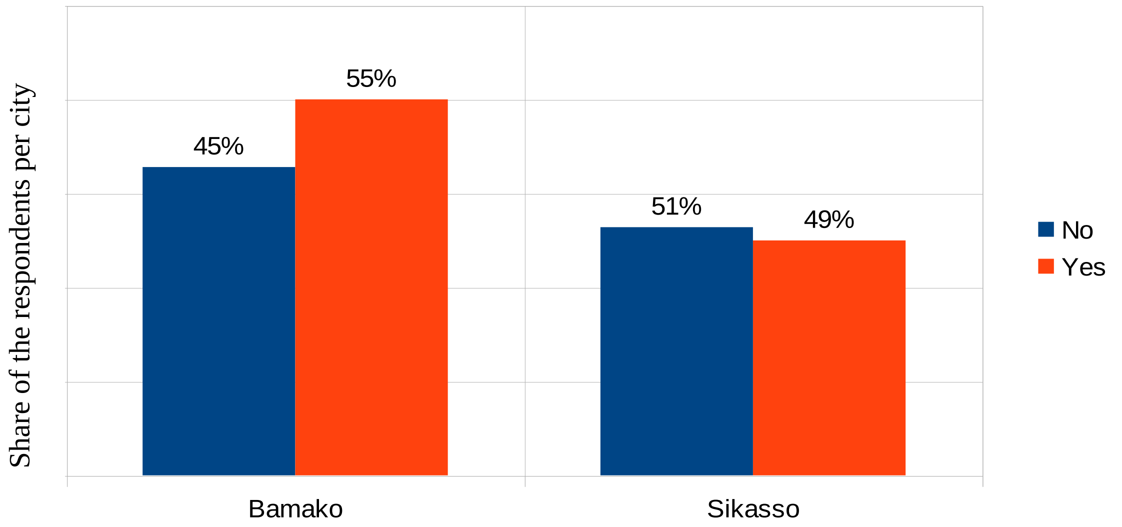


Figure 4. 19: Have you seen any Migration in your City in recent years?

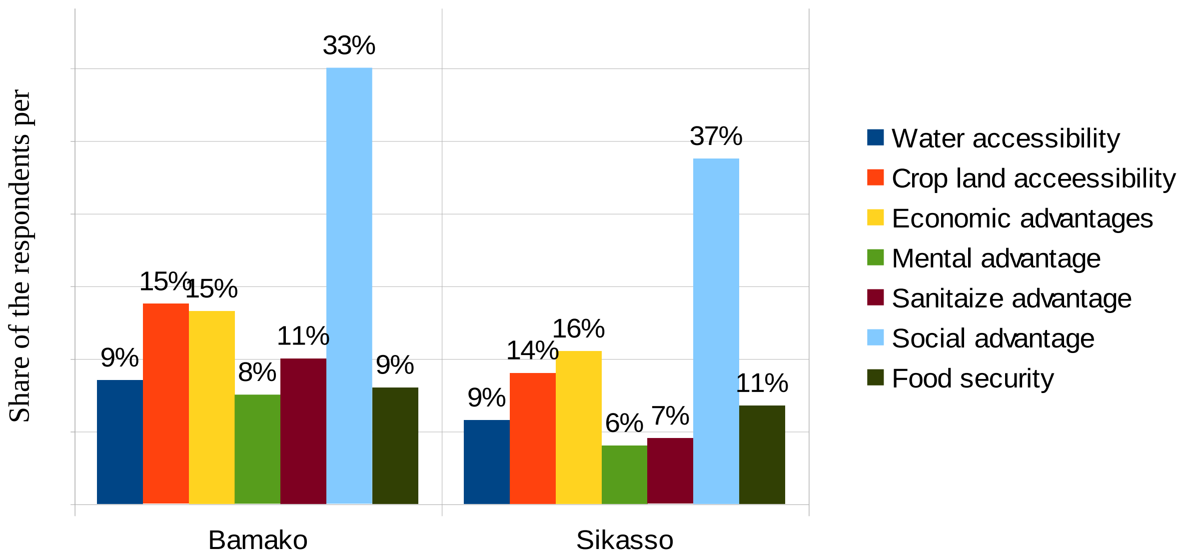


Figure 4. 20: Benefits of Different Types of Ecosystem Services

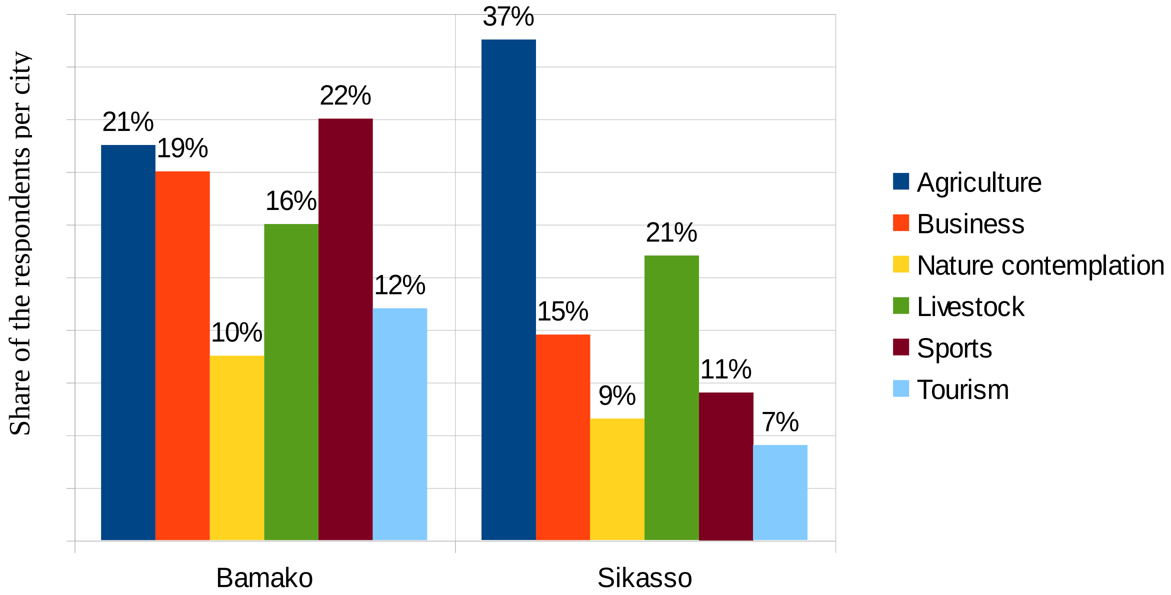


Figure 4. 21: Advantages of Relationships

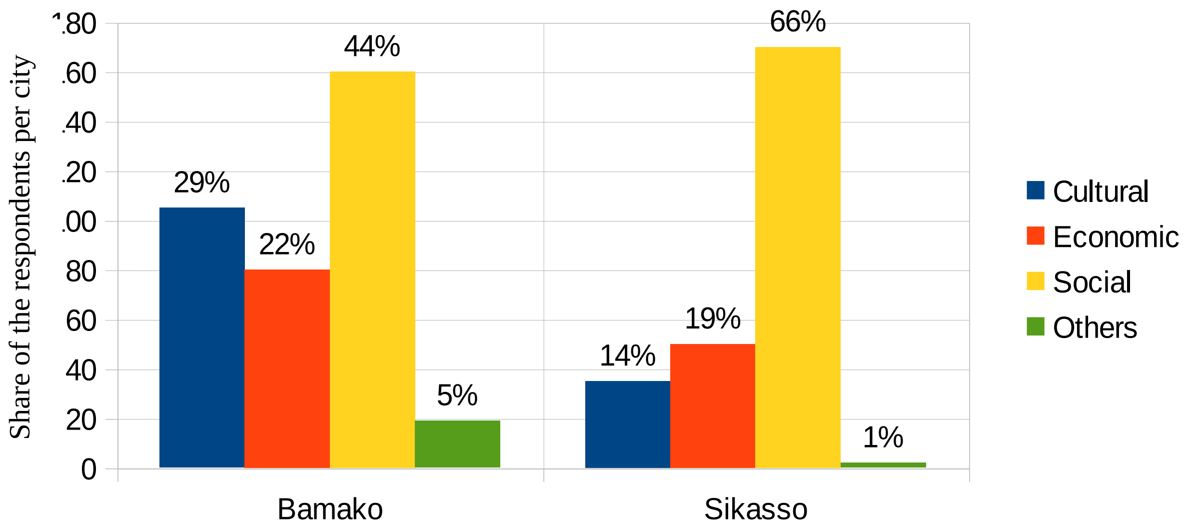


Figure 4. 22: Relationship Description with Ecosystem Services

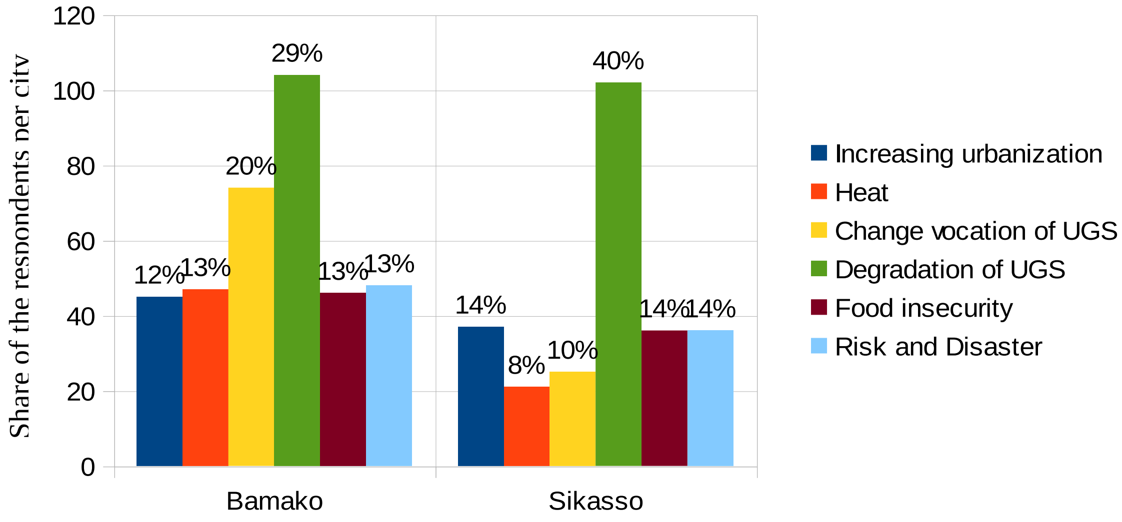


Figure 4. 23: Hierarchization of Problems or Difficulties

4.1.2.3. Mann-Kendall trend test for Bamako's three stations and Sikasso

The Mann-Kendall test is most useful when used as an exploratory investigation to locate stations with significant or large-scale changes and to quantify these findings. So, monotonic upward or downward trends in precipitation (as rain) and annual maximum and minimum temperatures (T max and T min) were tested from 1990 to 2020 in the cities of Bamako (Bamako Senou, Bamako Sotuba and Bamako ville), and Sikasso using the Mann-Kendall test.

The annual trends of the climate parameters obtained by Mann-Kendall are shown in Figures 4.24 to 4.35. Although rainfall shows a non-significant trend in all cities with P-value = 0,587 in Bamako Senou, P-value = 0,587 in Bamako Sotuba, P-value = 0,771 in Bamako ville, and P-value =0,742 in Sikasso city; seasonal minimum temperatures show increasing trends in all cities (P-value < 0.0001 in Bamako Sotuba, Bamako ville and Sikasso) except Bamako Senou, where the trend is downward with P-value < 0,0001.

Thus, the seasonal maximum temperature of the city of Sikasso shows an upward trend (P-value < 0,0001), unlike the other stations where no trend is observed.

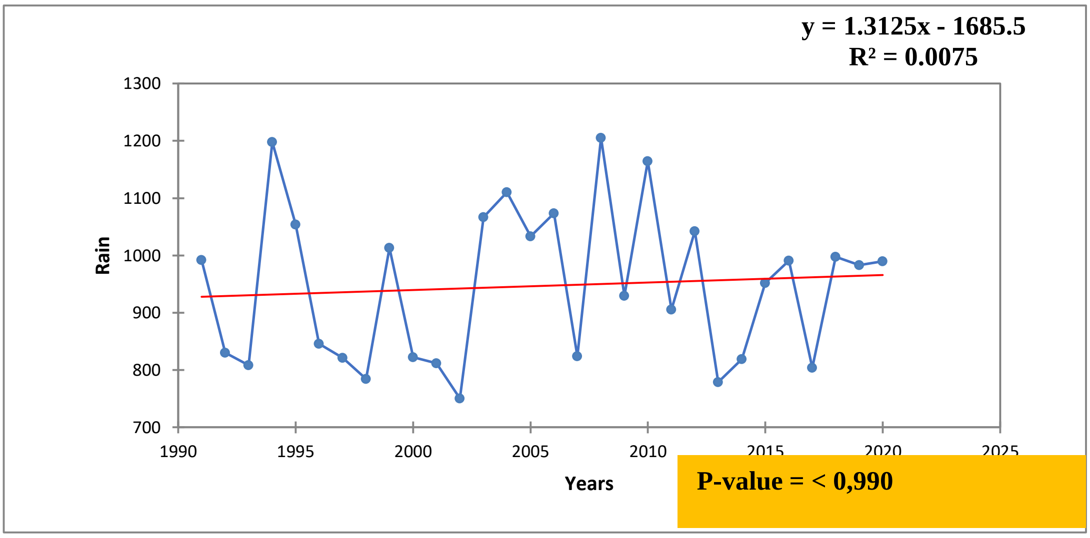


Figure 4. 24: Mann-Kendall Trend Test for Bamako Senou (Rain)

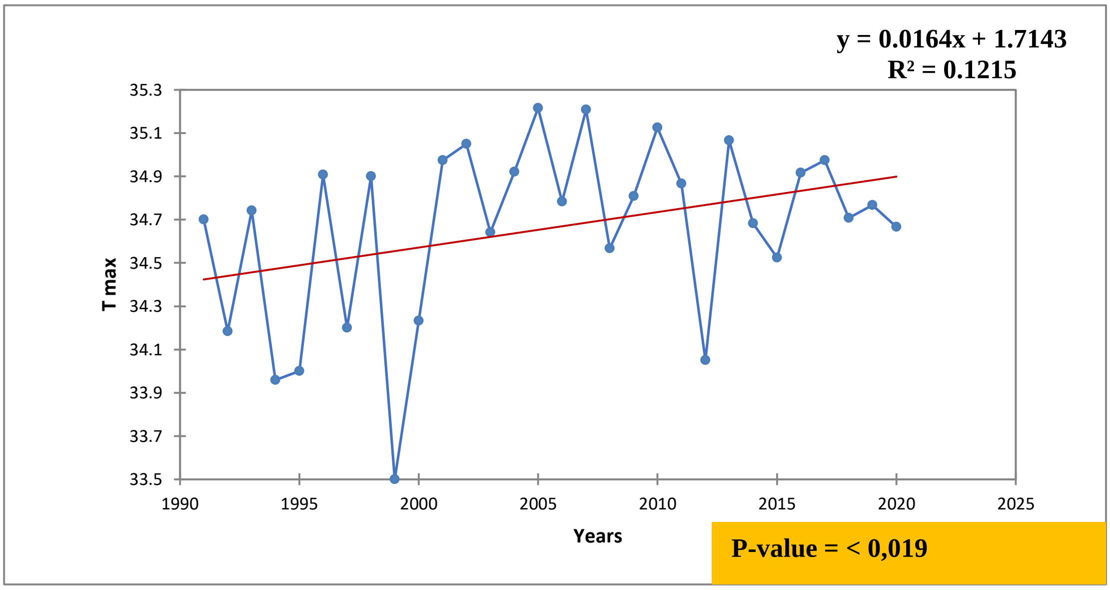


Figure 4. 25: Mann-Kendall Trend Test for Bamako Senou (T max)

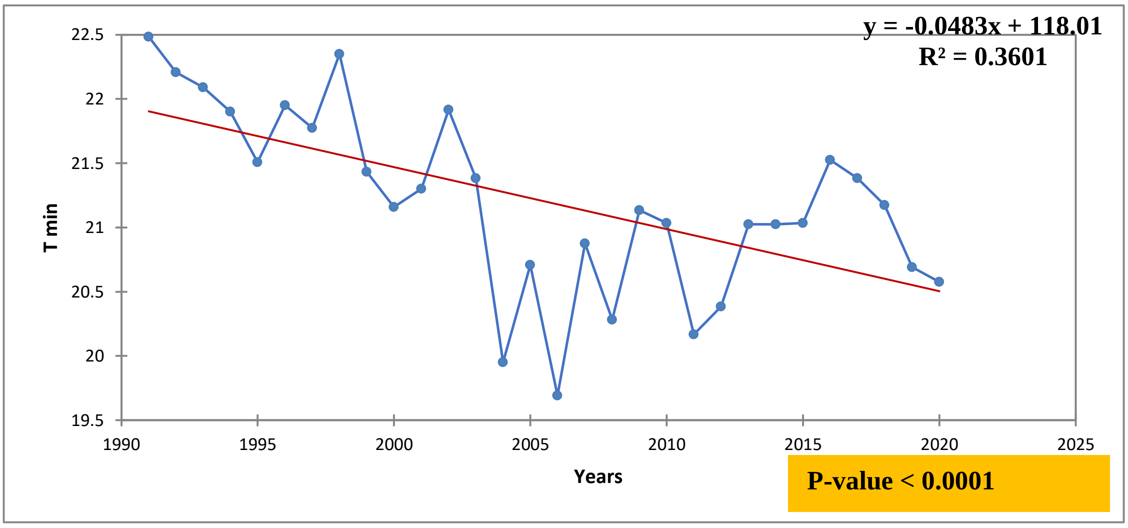


Figure 4. 26: Mann-Kendall Trend Test for Bamako Senou (T min)

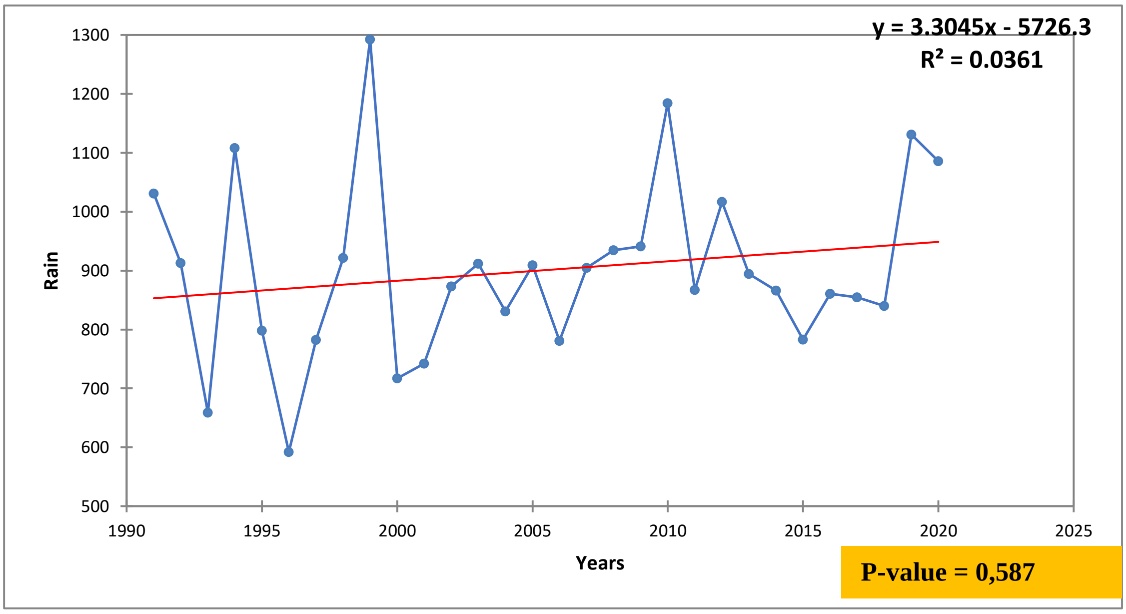


Figure 4. 27: Mann-Kendall Trend Test for Bamako Sotuba (Rain)

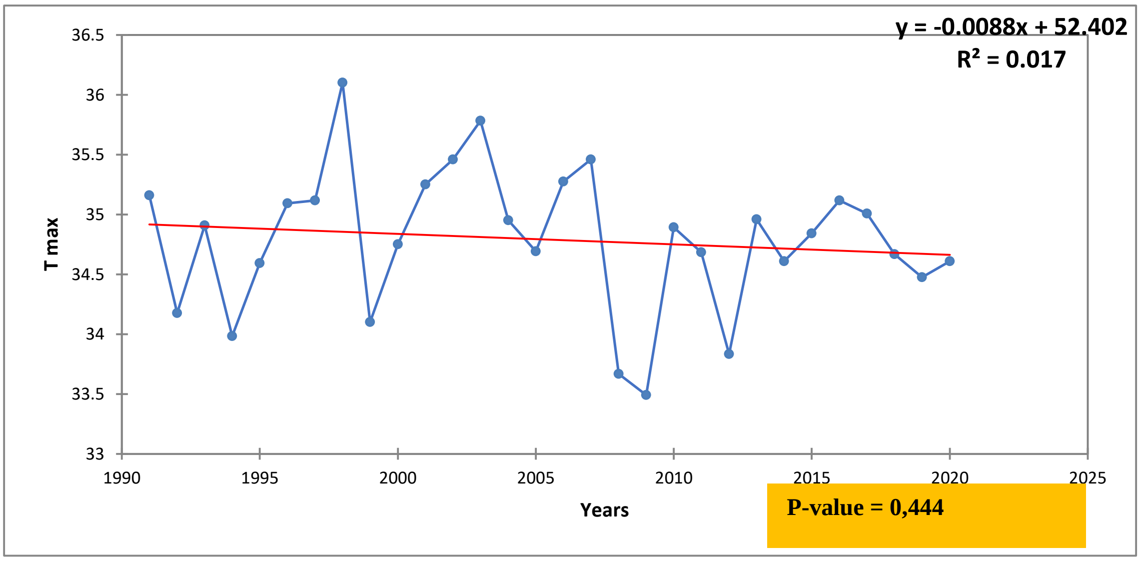


Figure 4. 28: Mann-Kendall Trend Test for Bamako Sotuba (T max)

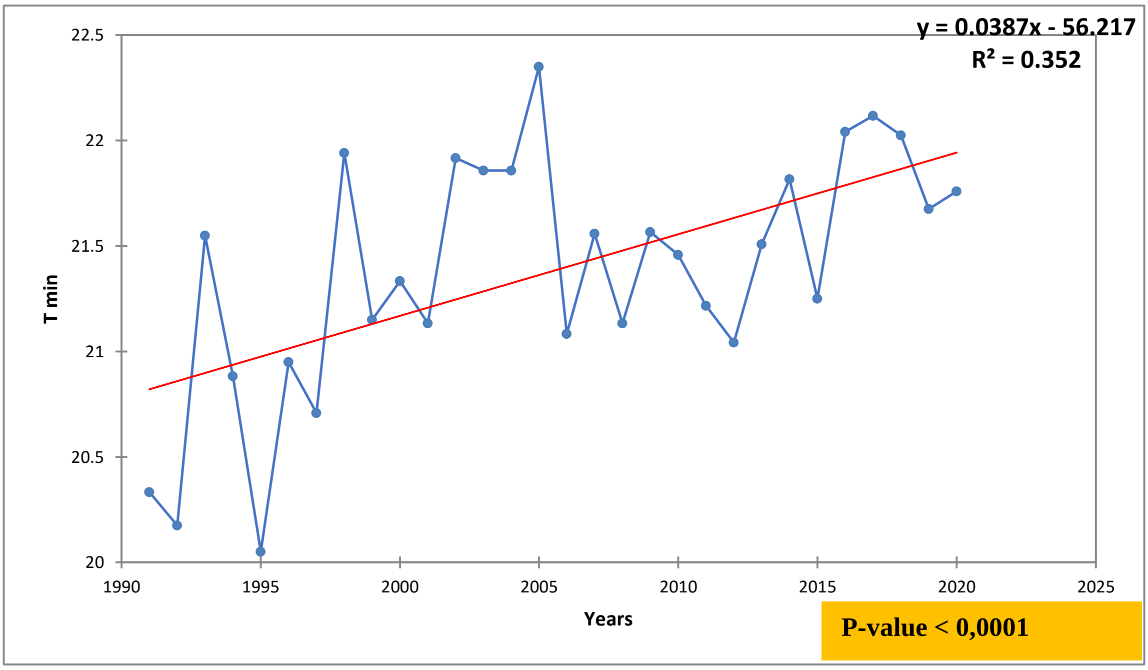


Figure 4. 29: Mann-Kendall Trend Test for Bamako Sotuba (T min)

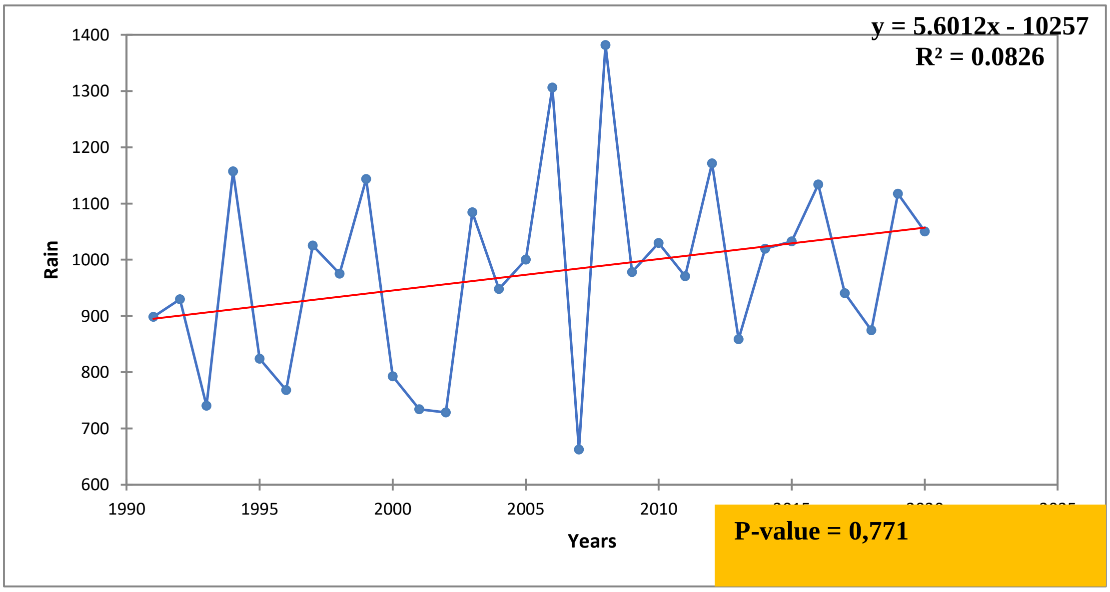


Figure 4. 30: Mann-Kendall Trend Test for Bamako Ville (Rain)

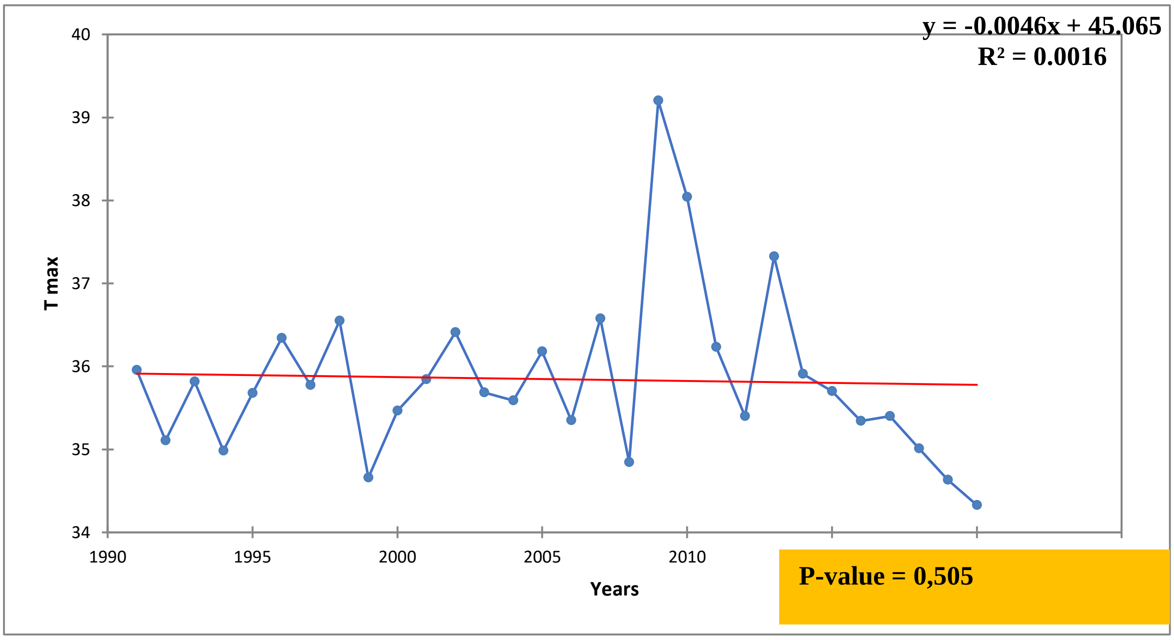


Figure 4. 31: Mann-Kendall Trend Test for Bamako Ville (T max)

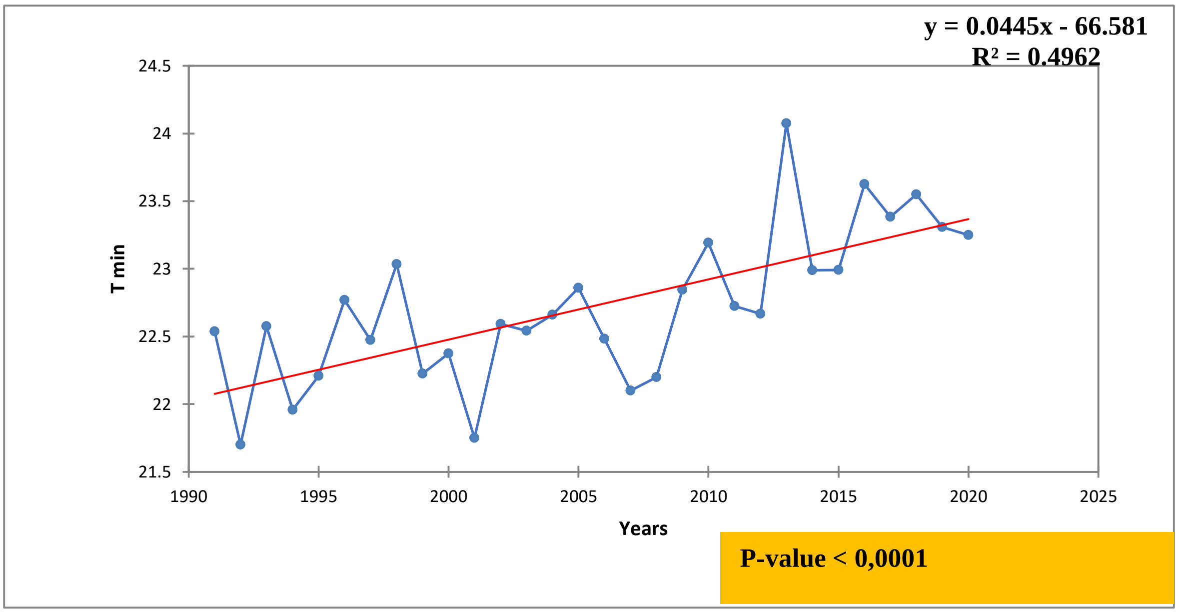


Figure 4. 32: Mann-Kendall Trend Test for Bamako Ville (T min)

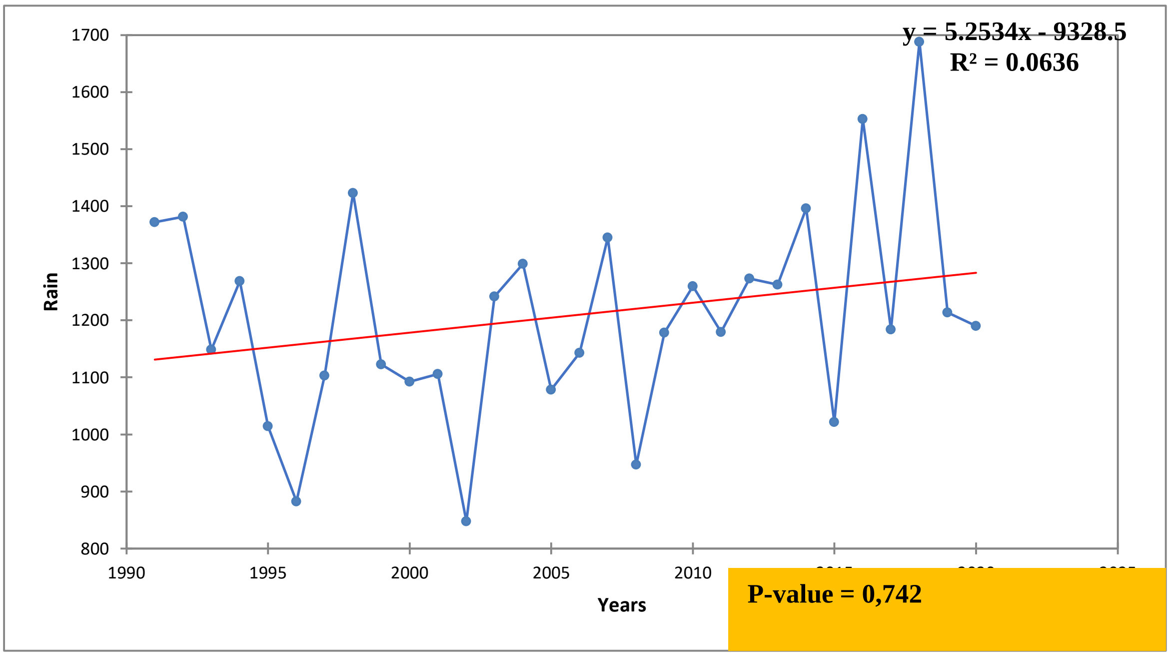


Figure 4. 33: Mann-Kendall Trend Test for Sikasso (Rain)

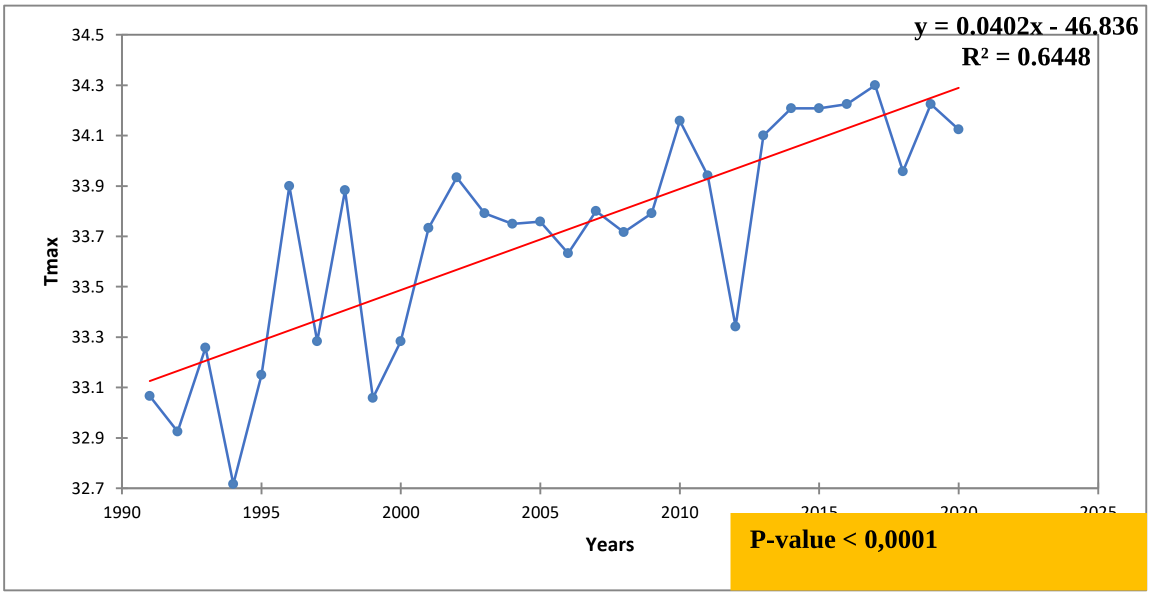


Figure 4. 34: Mann-Kendall Trend Test for Sikasso (T max)

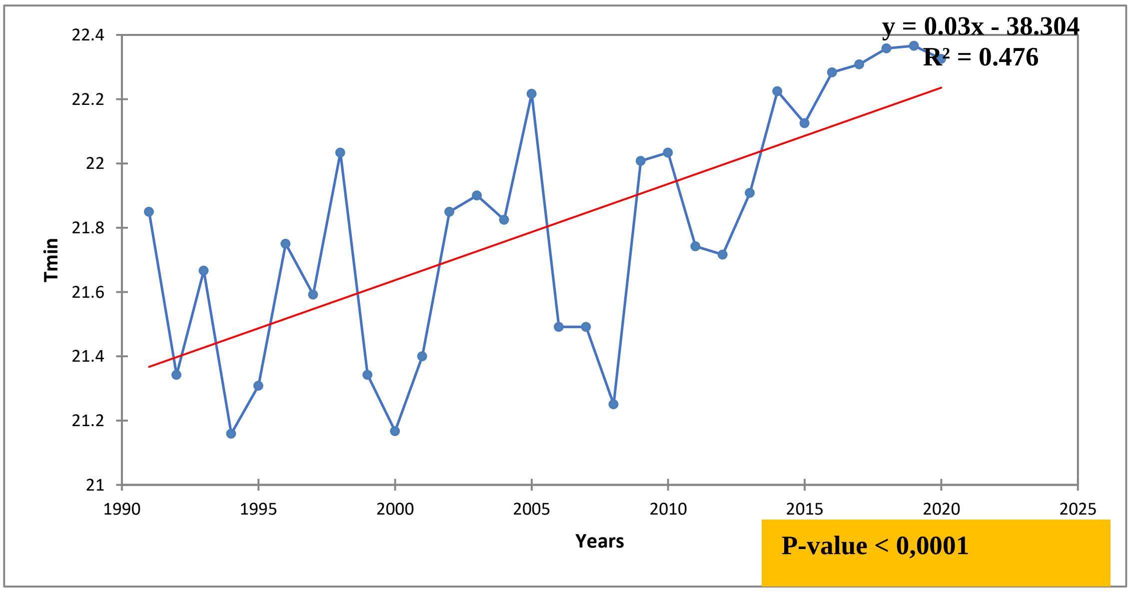


Figure 4. 35: Mann-Kendall Trend Test for Sikasso (T min)

4.1.2.4. Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI)

The SPI calculated on the basis of monthly precipitation records allows us to understand the precipitation deficit shown in the Figures 4.36 to 4.39 for SPI and 4.40 to 4.43 for SPEI in both cities. These figures, respectively, depict the SPI and SPEI index at 12-month time intervals for the cities of Bamako and Sikasso from 1990 to 2020. Thus, they have taken into account the study of Lorenzo-Lacruz *et al.* (2010) by incorporating the temperature to calculate the SPEI, which here gives us a drought (between -2 and 2). The figure allows us to determine the onset, duration, and magnitude of drought conditions compared to normal conditions in a variety of natural systems, such as green spaces.

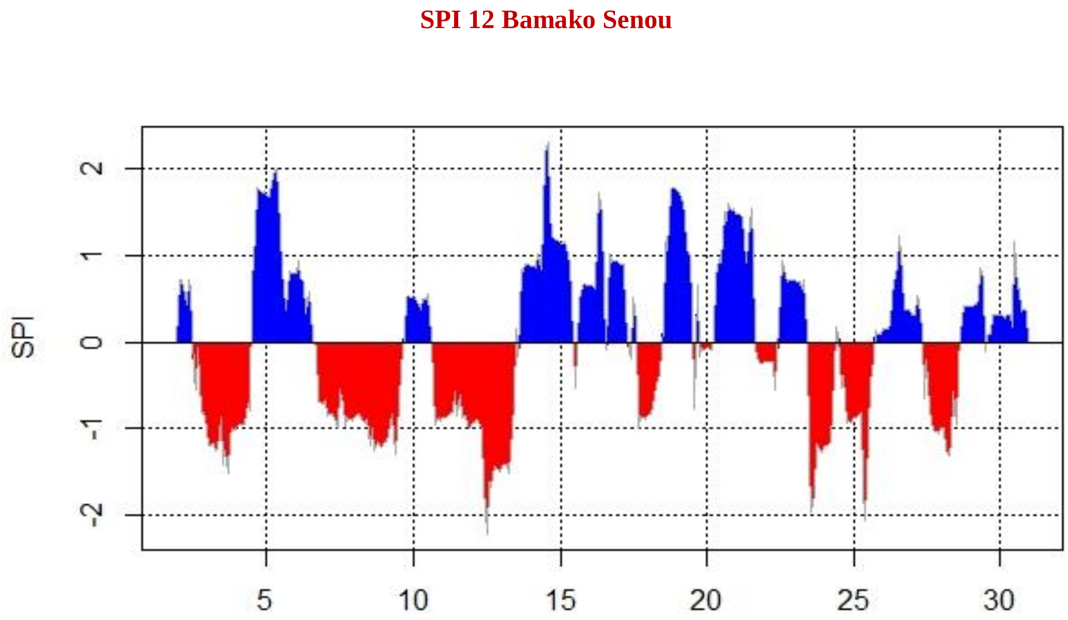


Figure 4. 36: SPI 12 Bamako Senou

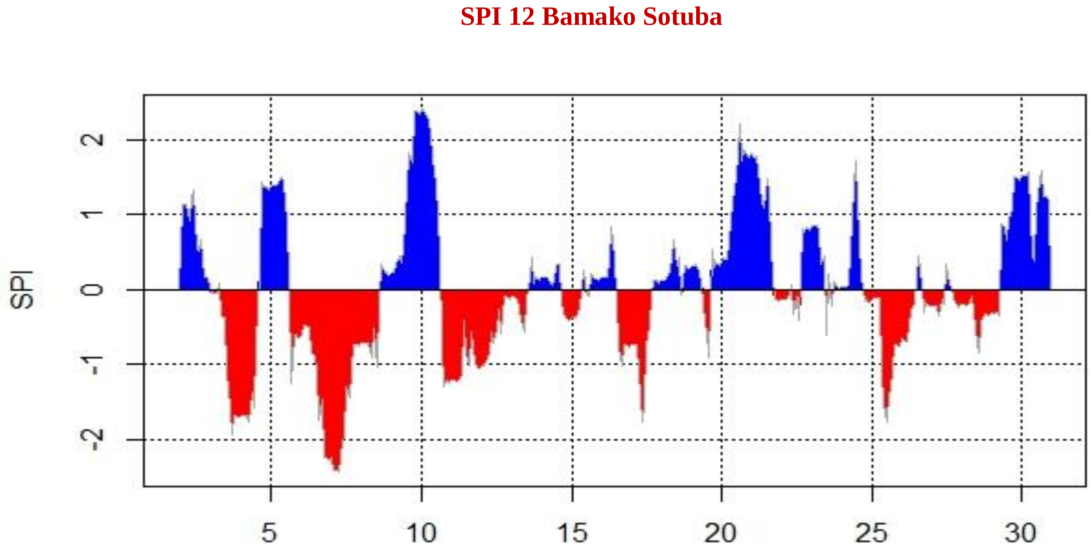


Figure 4. 37: SPI 12 Bamako Sotuba

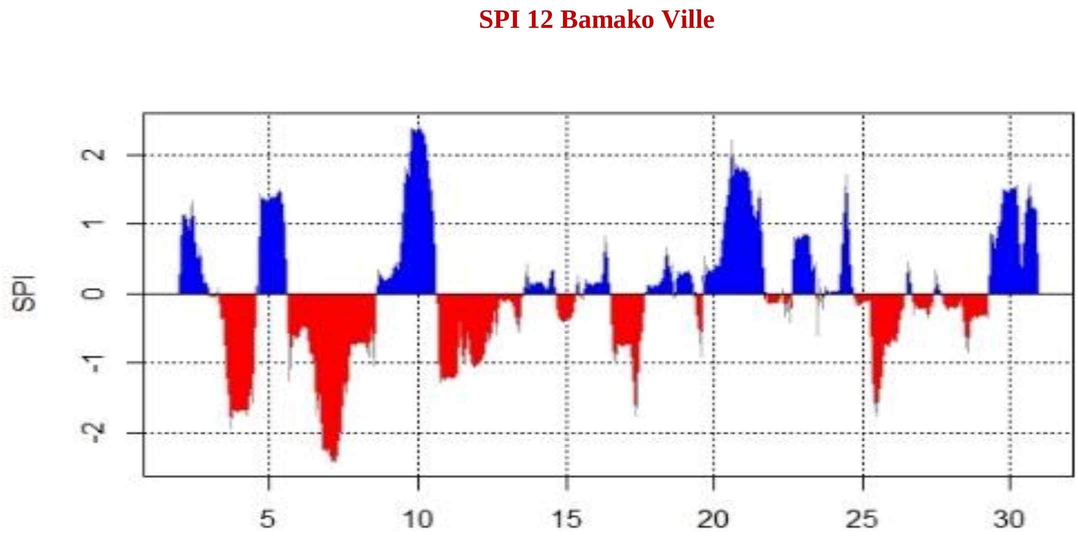


Figure 4. 38: SPI 12 Bamako Ville

SPI 12 Sikasso Ville

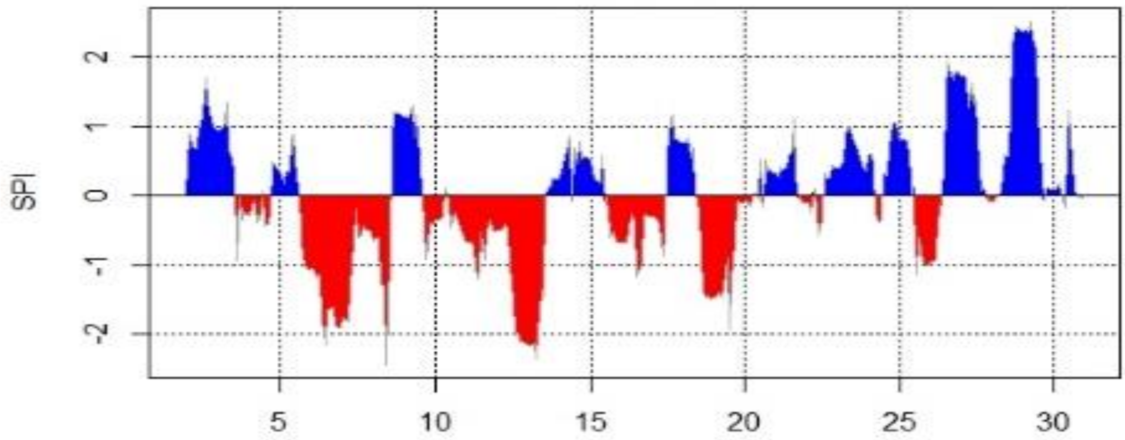


Figure 4. 39: SPI 12 Sikasso Ville

SPEI 12 Bamako Senou

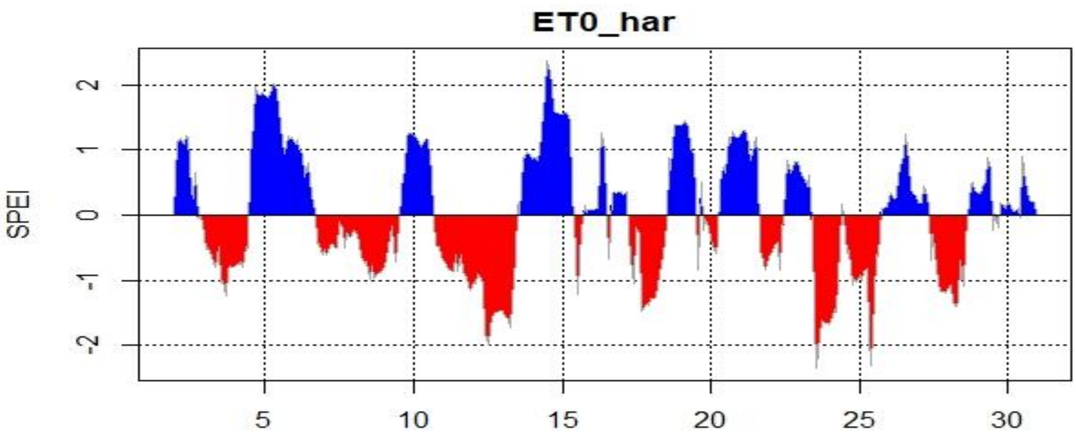


Figure 4. 40: SPEI 12 Bamako Senou

SPEI 12 Bamako Sotuba

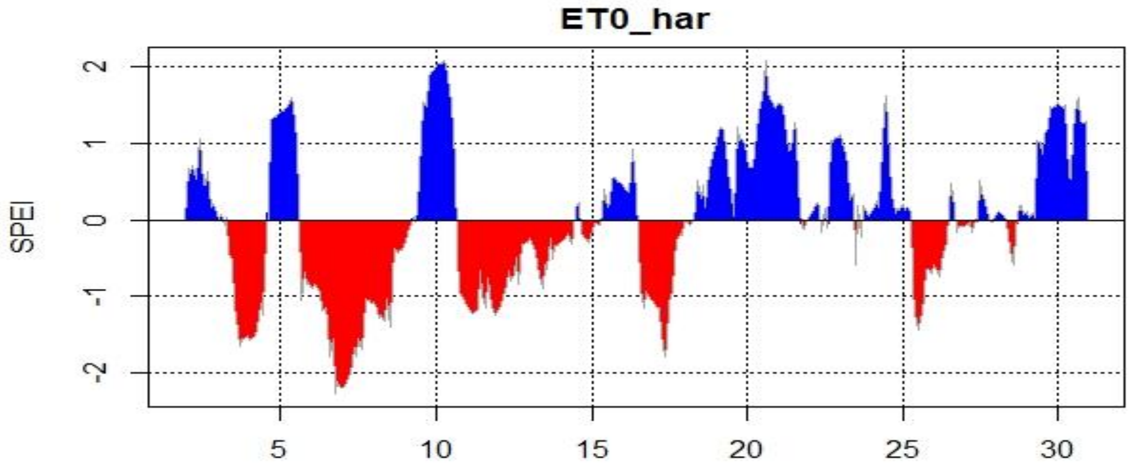


Figure 4. 41: SPEI 12 Bamako Sotuba

SPEI 12 Bamako Ville

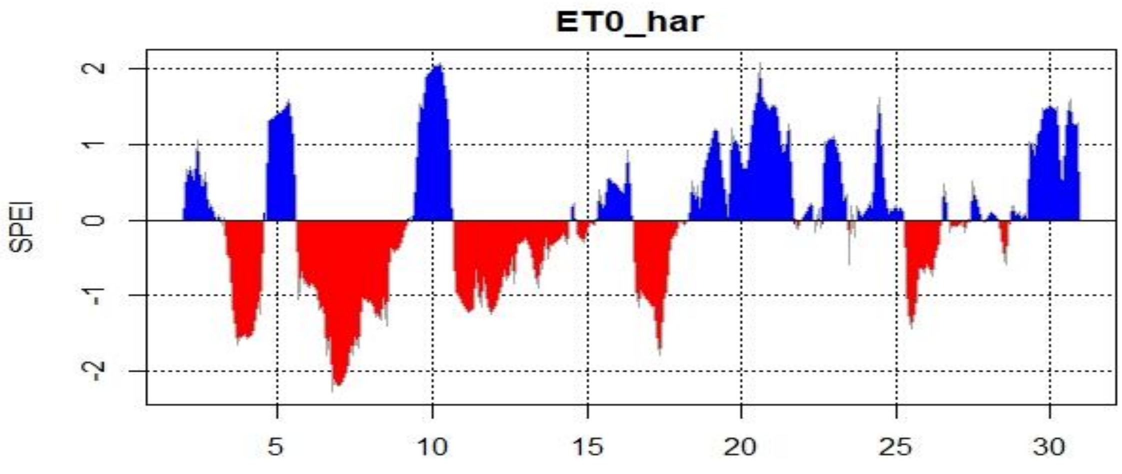


Figure 4. 42: SPEI 12 Bamako Ville

SPEI 12 Sikasso Ville

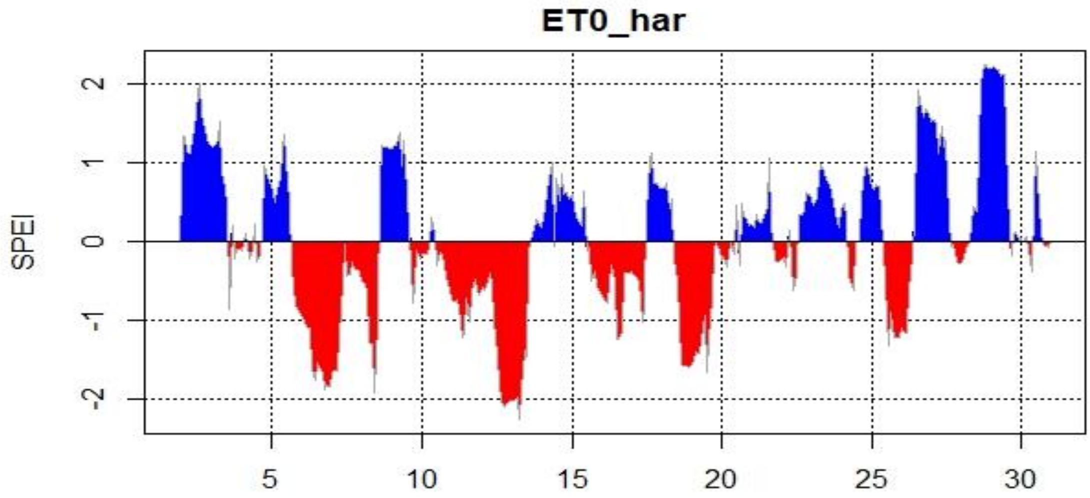


Figure 4. 43: SPEI 12 Sikasso Ville

4.1.3. Compare urban green spaces and their ecosystem services in the study areas

4.1.3.1. Evolution of vegetation formations from 1990 to 2020

(a) Evolution of vegetation formations in Bamako from 1990 to 2020

The vegetation formations in the city of Bamako have changed between 1990 and 2020. Tables 4.9, 4.10, and 4.11 show the proportions of the 1990, 2000, 2010, and 2020 classes, as well as the rates and nature of change. The average annual expansion of vegetation formations and other land use units in Bamako between 1990 and 2020 is shown in Figure 4.3. The statistics on the evolution of land use units in Bamako in 30 years show that built-up areas have progressed from 1990 to 2020; high vegetation and water bodies have progressed, respectively, from 1990 to 2000 and from 1990 to 2010. On the other hand, bare land, farmland, and medium vegetation, low vegetation has regressed in the spaces occupied in Bamako city from 1990 to 2020, Figure 4.3.

Table 4. 9: Statistics on the Evolution of Land Use Units in Bamako city in 10 years, from 1990 to 2000

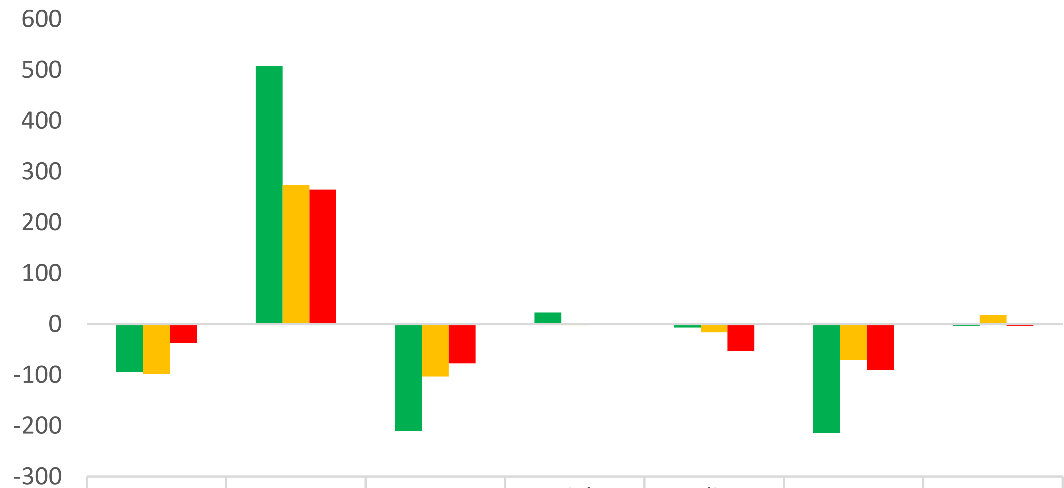
Units	Vegetations formations in 1990		Vegetations formations in 2000		Average annual change	Average growth rate	Nature
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)			
Bare Land	4742	19.31	3797	15.46	-94.5	-0.020	Regression
Built-Up	5421	22.08	10496	42.74	507.5	0.094	Progression
Farmland	3691	15.03	1587	6.46	-210.4	-0.057	Regression
High Vegetation	531	2.16	756	3.08	22.5	0.042	Progression
Medium Vegetation	2325	9.47	2257	9.19	-6.8	-0.003	Regression
Low Vegetation	6432	26.19	4293	17.48	-213.9	-0.033	Regression
Water Body	1414	5.76	1370	5.58	-4.4	-0.003	Regression

Table 4. 10: Statistics on the Evolution of Land Use Units in Bamako city in 20 years, from 1990 to 2010

Units	Vegetations formations in 1990		Vegetations formations in 2010		Average annual change	Average growth rate	Nature
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)			
Bare Land	4742	19.31	2775	11.3	-98.35	-0.021	Regression
Built-Up	5421	22.08	10902	44.4	274.05	0.051	Progression
Farmland	3691	15.03	1623	6.61	-103.4	-0.028	Regression
High Vegetation	531	2.16	486	1.98	-2.25	-0.004	Regression
Medium Vegetation	2325	9.47	1994	8.12	-16.55	-0.007	Regression
Low Vegetation	6432	26.19	5006	20.39	-71.3	-0.011	Regression
Water Body	1414	5.76	1770	7.21	17.8	0.013	Progression

Table 4. 11: Statistics on the Evolution of Land Use Units in Bamako city in 30 years, from 1990 to 2020

Units	Vegetations formations in 1990		Vegetations formations in 2020		Average annual change	Average growth rate	Nature
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)			
Bare Land	4742	19.31	3617	14.73	-37.50	-0.008	Regression
Built-Up	5421	22.08	13350	54.37	264.30	0.049	Progression
Farmland	3691	15.03	1370	5.58	-77.37	-0.021	Regression
High Vegetation	531	2.16	492	02	-1.30	-0.002	Regression
Medium Vegetation	2325	9.47	710	2.89	-53.83	-0.023	Regression
Low Vegetation	6432	26.19	3708	15.1	-90.80	-0.014	Regression
Water Body	1414	5.76	1309	5.33	-3.50	-0.002	Regression



	Bare Land	Built-Up	Farmland	High Vegetation	Mdium Vegetation	Low Vegetation	Water Body
Average annual change Bamako 1990 - 2000	-94.5	507.5	-210.4	22.5	-6.8	-213.9	-4.4
Average annual change Bamako 1990 - 2010	-98.35	274.05	-103.4	-2.25	-16.55	-71.3	17.8
Average annual change Bamako 1990 - 2020	-37.50	264.30	-77.37	-1.30	-53.83	-90.80	-3.50

Figure 4. 44: Average Annual Expansion of Vegetation Formations and Other Land Use Units in Bamako between 1990 and 2020

(b) Evolution of vegetation formations in Sikasso from 1990 to 2020

The vegetation formations in the city of Sikasso have drastically changed between 1990 and 2020. Tables 4.12, 4.13, and 4.14 show the proportions of the 1990, 2000, 2010, and 2020 classes, as well as the rates and nature of change. The average annual expansion of vegetation formations and other land use units in Sikasso between 1990 and 2020 is shown in Figures 4.4.

The statistics on the evolution of land use units in Sikasso in 30 years, show that built-up areas and farmland have progressed from 1990 to 2020; medium vegetation, low vegetation, and water bodies have progressed from 1990 to 2010. On the other hand, bare land, and high vegetation have regressed in the spaces occupied in Sikasso city from 1990 to 2020, while water bodies have progressed from 1990 to 2020.

Table 4. 12: Statistics on the Evolution of Land Use Units in Sikasso city in 10 years, from 1990 to 2000

Units	Vegetations formations in 1990		Vegetations formations in 2000		Average annual change	Average growth rate	Nature
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)			
Bare Land	1385	30.55	178	3.93	-120.7	-0.087	Regression
Built-Up	929	20.49	1940	42.79	101.1	0.109	Progression
Farmland	280	6.18	790	17.42	51	0.182	Progression
High Vegetation	975	21.50	223	4.92	-75.2	-0.077	Regression
Medium Vegetation	199	4.39	408	9.00	20.9	0.105	Progression
Low Vegetation	749	16.52	970	21.39	22.1	0.030	Progression
Water Body	17	0.37	25	0.55	0.8	0.047	Progression

Table 4. 13: Statistics on the Evolution of Land Use Units in Sikasso city in 20 years, from 1990 to 2010

Units	Vegetations formations in 1990		Vegetations formations in 2010		Average annual change	Average growth rate	Nature
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)			
Bare Land	1385	30.55	730	16.10	-32.75	-0.024	Regression
Built-Up	929	20.49	1974	43.54	52.25	0.056	Progression
Farmland	280	6.18	656	14.47	18.8	0.067	Progression
High Vegetation	975	21.50	83	1.83	-44.6	-0.046	Regression
Medium Vegetation	199	4.39	219	4.83	1	0.005	Progression
Low Vegetation	749	16.52	823	18.15	3.7	0.005	Progression
Water Body	17	0.37	49	1.08	1.6	0.094	Progression

Table 4. 14: **Statistics on the Evolution of Land Use Units in Sikasso city in 30 years, from 1990 to 2020.**

Units	**Vegetations formations in 1990**		**Vegetations formations in 2020**		**Average annual change**	**Average growth rate**	**Nature**
	Area (ha)	**Proportion (%)**	**Area (ha)**	**Proportion (%)**			
Bare Land	1385	30.55	1243	27.42	-4.73	-0.003	Regression
Built-Up	929	20.49	2213	48.81	42.80	0.046	Progression
Farmland	280	6.18	339	7.48	1.97	0.007	Progression
High Vegetation	975	21.50	228	5.03	-24.90	-0.026	Regression
Medium Vegetation	199	4.39	54	1.19	-4.83	-0.024	Regression
Low Vegetation	749	16.52	422	9.31	-10.90	-0.015	Regression
Water Body	17	0.37	35	0.77	0.60	0.035	Progression

	Bare Land	Built-Up	Farmland	High Vegetation	Mdium Vegetation	Low Vegetation	Water Body
Average annual change Sikasso 1990 - 2000	-120.7	101.1	51	-75.2	20.9	22.1	0.8
Average annual change Sikasso 1990 - 2010	-32.75	52.25	18.8	-44.6	1	3.7	1.6
Average annual change Sikasso 1990 - 2020	-4.73	42.80	1.97	-24.90	-4.83	-10.90	0.60

Figure 4. 45: **Average Annual Expansion of Vegetation Formations and Other Land Use Units in Sikasso between 1990 and 2020**

4.1.3.2. Digitalization of UGS

Eliza Booth, Editor of Council Magazine, explains why urban greening is crucial for our cities. Urban greening programmes are being used by planners to mitigate some of the negative effects that urban expansion may have on the environment and the larger community as our cities continue to expand and get denser (Eliza Booth, 2023).

What, though, is urban greening exactly, and why is it so important for our expanding cities? Also, how are these quickly expanding urban green spaces now? (https://councilmagazine.com.au/green-streets-why-urban-greening-is-vital-to-our-cities/). With the highest population growth of any city in the country (Plates 4.1 and 4.2), they are confident that people like living in the cities of Bamako and Sikasso because of the exciting opportunities that come with it (Figures 4.46 and 4.47). The streets of Bamako and Sikasso are displayed in the most exact detail possible in Plates 4.1 and 4.2, which provide an example of data visualization in Google Earth Pro set against an aerial photo backdrop.

Plate V: Bamako city digitalized

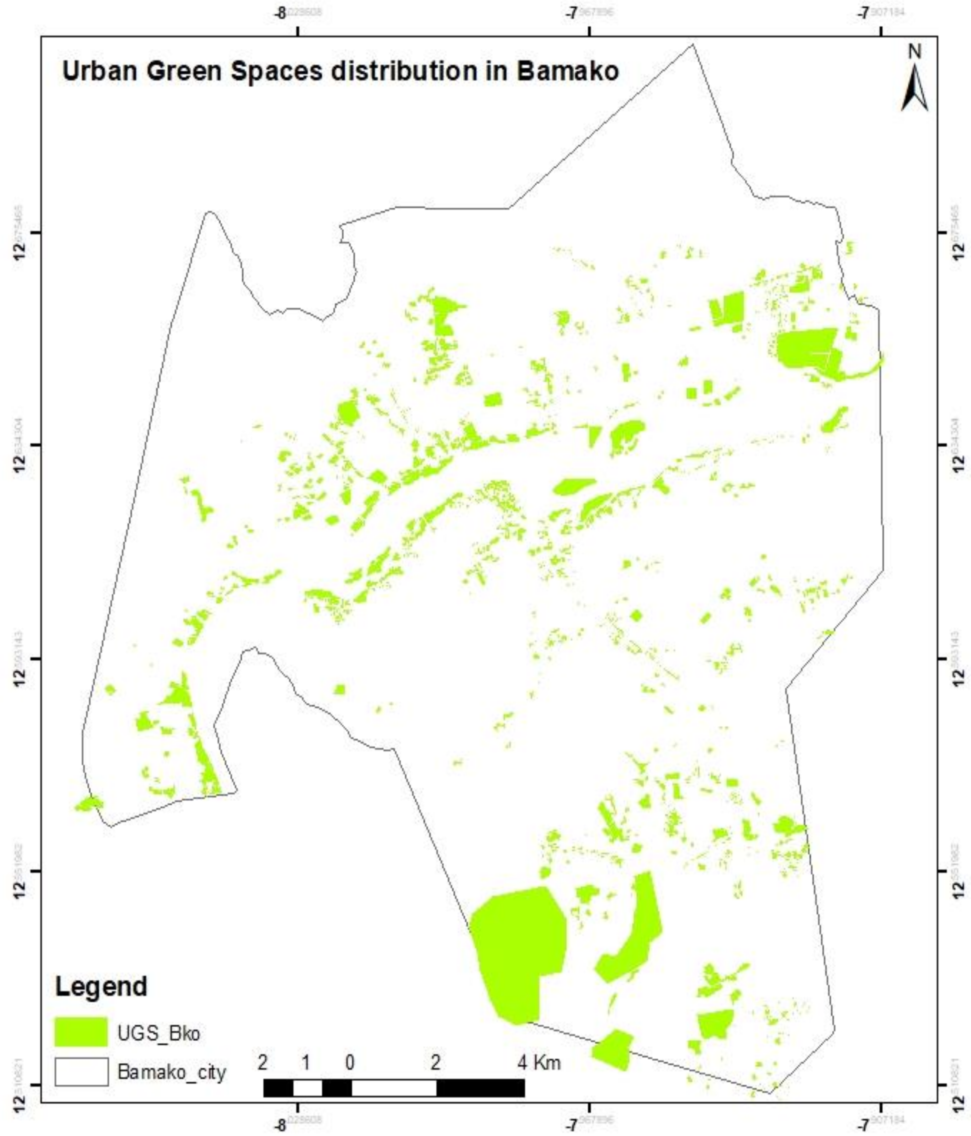


Figure 4. 46: Green Spaces Distribution in Bamako.

Plate VI: Sikasso City digitalized

Figure 4. 47: Green Spaces Distribution in Sikasso

4.1.4. Determine the availability and quality of green spaces in the study areas

4.1.4.1. Types of green spaces and characteristics

The main types of green spaces encountered in the cities are classified according to their typology, location, size, function, etc. (Vargas-Hernández, Pallagst, and Hammer, 2018). Thus, Sikasso's urban green spaces were categorized into nine groups, as follows, according to survey data and the Ministry of Urbanism and Habitat's Standard for Classification of Urban Green Spaces through the Regional Direction of Urbanism and Habitat: the planting of street trees, grass, market gardens, private and public gardens, urban parks, roadside tree rangers, and greening of riverbanks. Figure 4.48 revealed that street trees (20% in Bamako and 24% in Sikasso) and roadside tree ranges (16% in Bamako and 18% in Sikasso) were the UGS categories most frequently highlighted by respondents. Additionally, the majority of respondents in Sikasso and Bamako reported having good status (65% and 44%, respectively), which has been rising over the past few years (Figures 4.49).

Figure 4.50 showed that the high relationship between UGS and population is respectively for Bamako, the place of business (24%), and visitors (20%); for Sikasso, the social cohesion (18%); and for the urban heat island (14%). The majority of respondents in Bamako think that the ecosystem services provided by UGS are breathing fresh air in Bamako with 23% and food security in Sikasso with 26% (Figure 4.51). Figure 4.52 showed that the majority of responses about the benefits of UGS and their ES provided in Bamako and Sikasso, respectively, were social cohesion (33% and 23%) and food security (13% and 20%). In addition, the term "green space" covers a wide range of areas. Integrating multiple green spaces to create an urban green space network that connects locations with urban habitats is a trend in nature conservation.

Other classifications recognise a wide range of green spaces in urban areas and comprise diverse forms of green spaces for design, planning, and sustainable management, hence facilitating particular strategic approaches. However, this data has to be enhanced because any research based on consistently recorded estimates needs to employ the typology of urban green space users by person and activity as a framework. Users of urban green spaces are categorized according to their age, gender, ethnicity, and level of physical and mental ability. The following figures are the typical justifications for utilising urban green spaces (Vargas-Hernández, Pallagst, and Hammer, 2018).

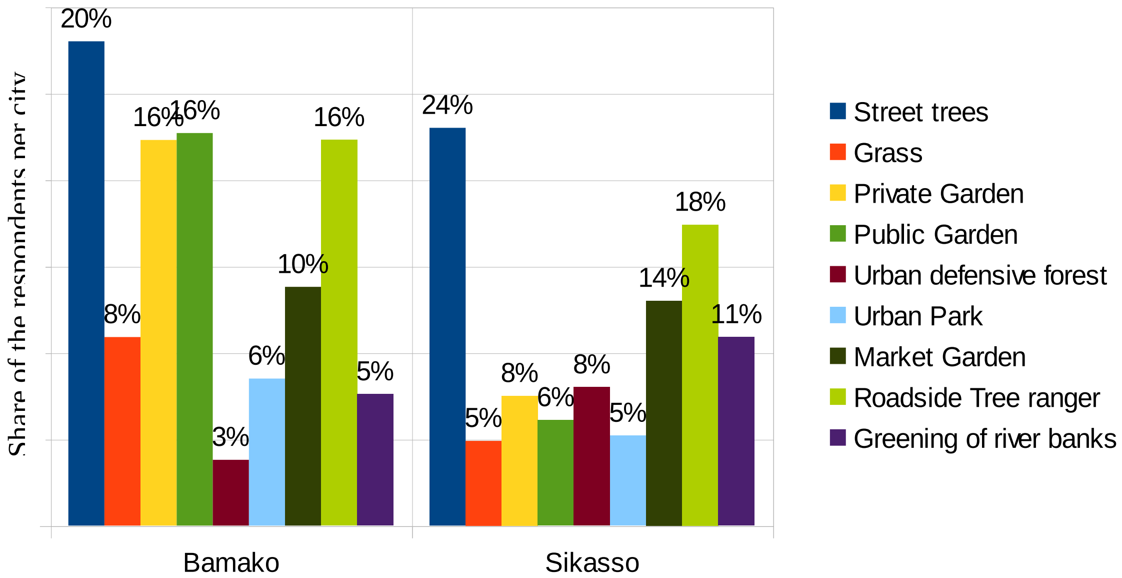


Figure 4. 48: Types of Urban Green Spaces Close to Respondents´ Localities in Bamako (n = 370) and Sikasso (n = 384). Multiple answers were possible

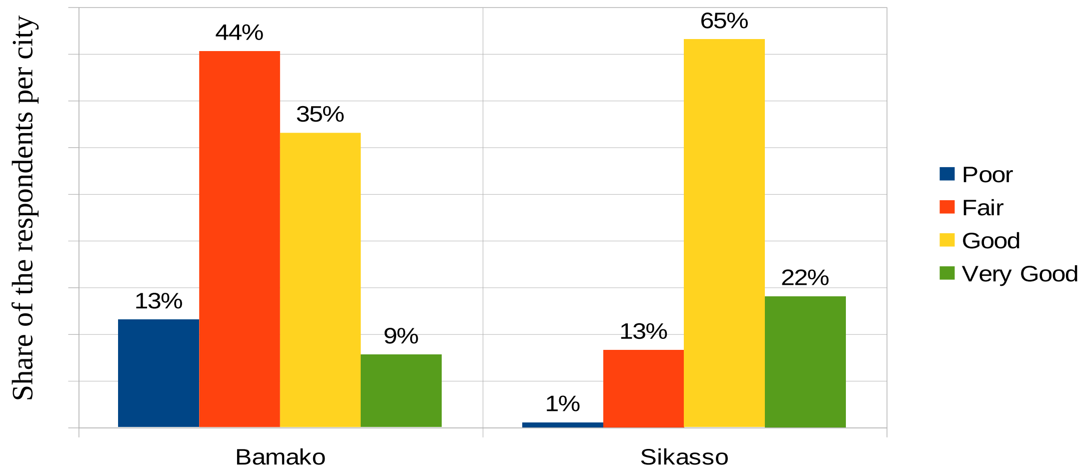


Figure 4. 49: Current Status of these Green Spaces in recent years

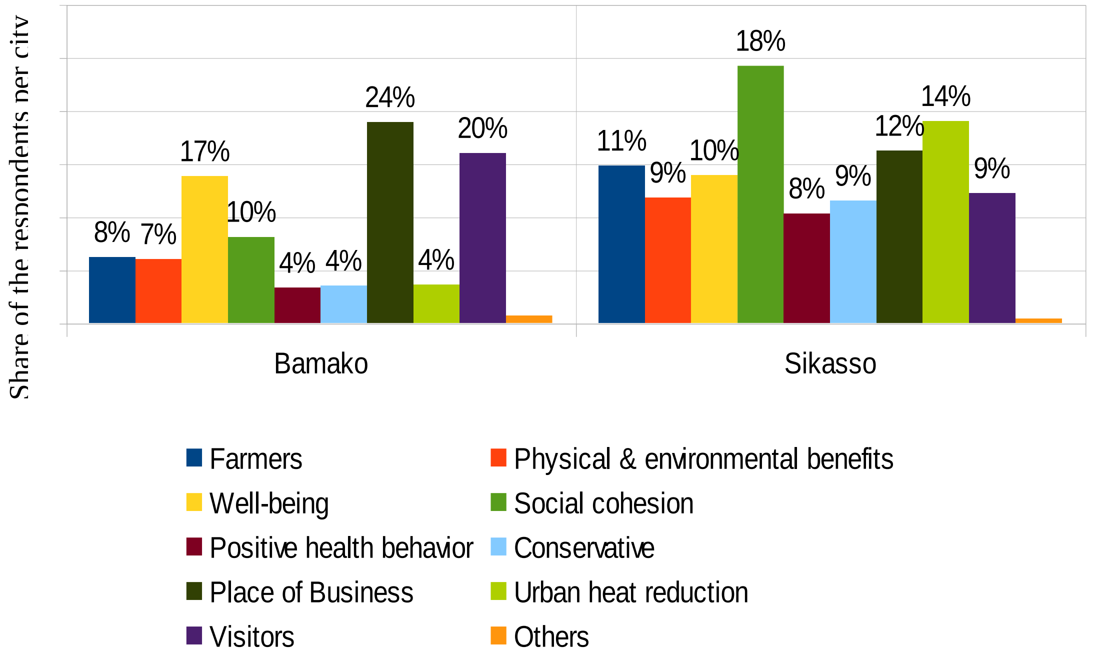


Figure 4. 50: Relationship between Population and Urban Green Spaces in Bamako and Sikasso

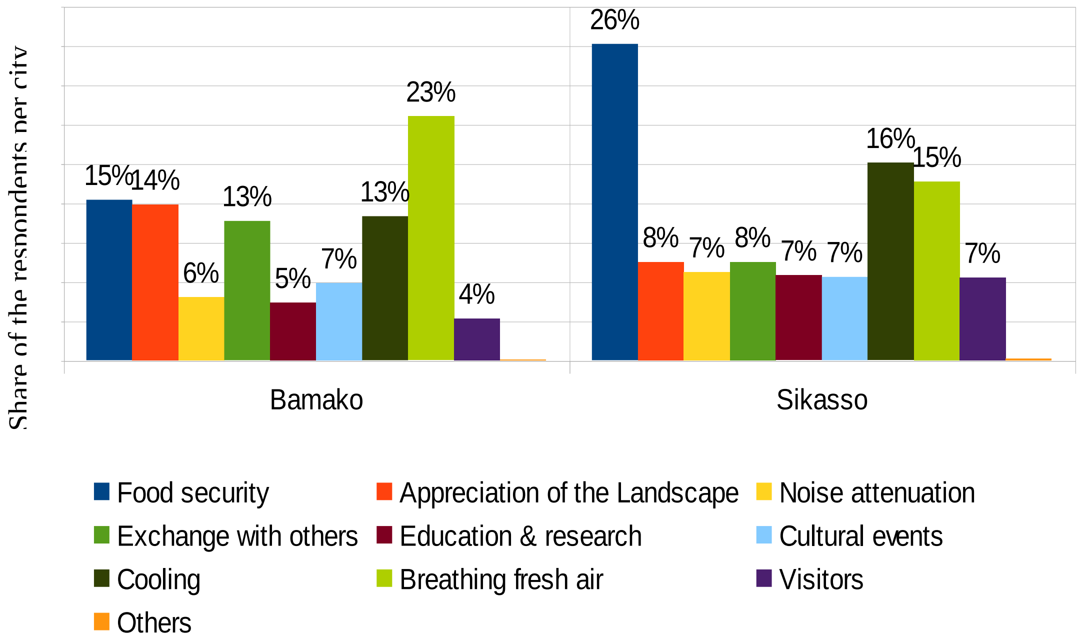


Figure 4. 51: Ecosystem Services provided by Green Spaces

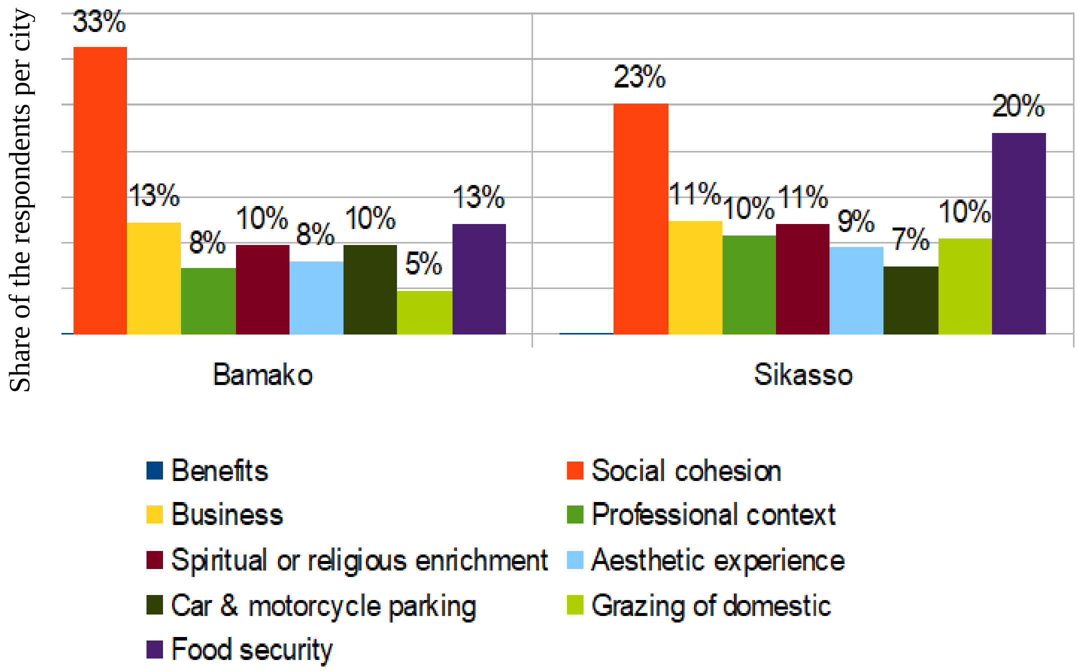


Figure 4. 52: Benefits from UGS and the Ecosystem Services provided

4.1.4.2. Correlations between Land Use Land Cover (LULC) and climate variability demographics and different indexes (NDVI, NDBI, and NDWI)

(a) Correlation between Climate Variability and LULC

The correlation analysis between climate variability and LULC showed a positive correlation between rainfall and temperature in both cities (Bamako and Sikasso) with correlation coefficients of 1 and 0.9 from 1990 to 2020 (Figures 4.53 and 4.54). In Sikasso, positive correlations are observed between rainfall, temperature, built-up and farmland; temperature and bare land; built-up and medium vegetation (Figure 4.54).

(b) Correlation between Population Demographics Growth, Temperature, and LULC

The analysis of correlation between population, temperature, and LULC showed positive correlations between built-up and population in both cities (Figures 4.55 and 4.56); negative correlations were observed between built-up and vegetations areas (high, medium and low) in both cities, while a correlation was observed between built-up and medium vegetation in Sikasso (Figure 4.56).

(c) *Correlation between Population Demographics Growth and Different Indexes NDVI,* NDBI, and NDWI

The correlation analysis between population and different indexes (NDVI, NDBI, and NDWI) showed in (Figures 4.57 and 4.58), a positive correlation between NDVI and NDBI in both cities (Bamako and Sikasso). The positive correlation between NDBI and NDWI in Bamako is shown in Figure 4.58.

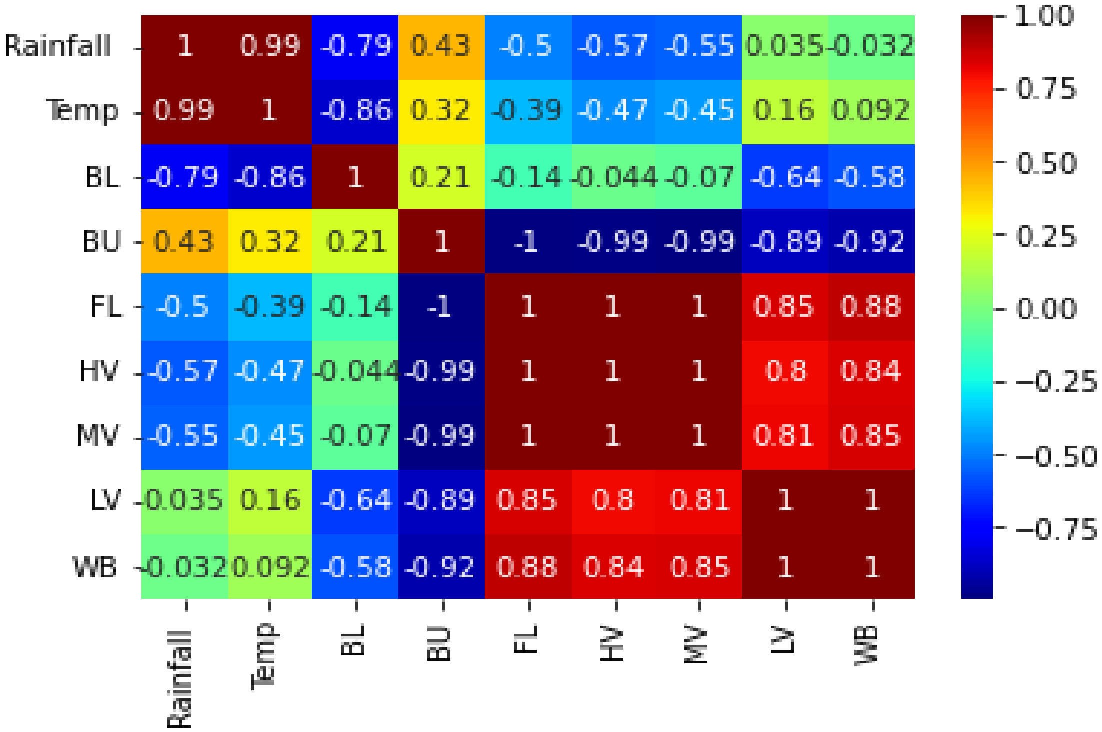


Figure 4. 53: Correlations between Land Use Land Cover (LULC) and Climate Variability in Bamako from 1990 to 2020

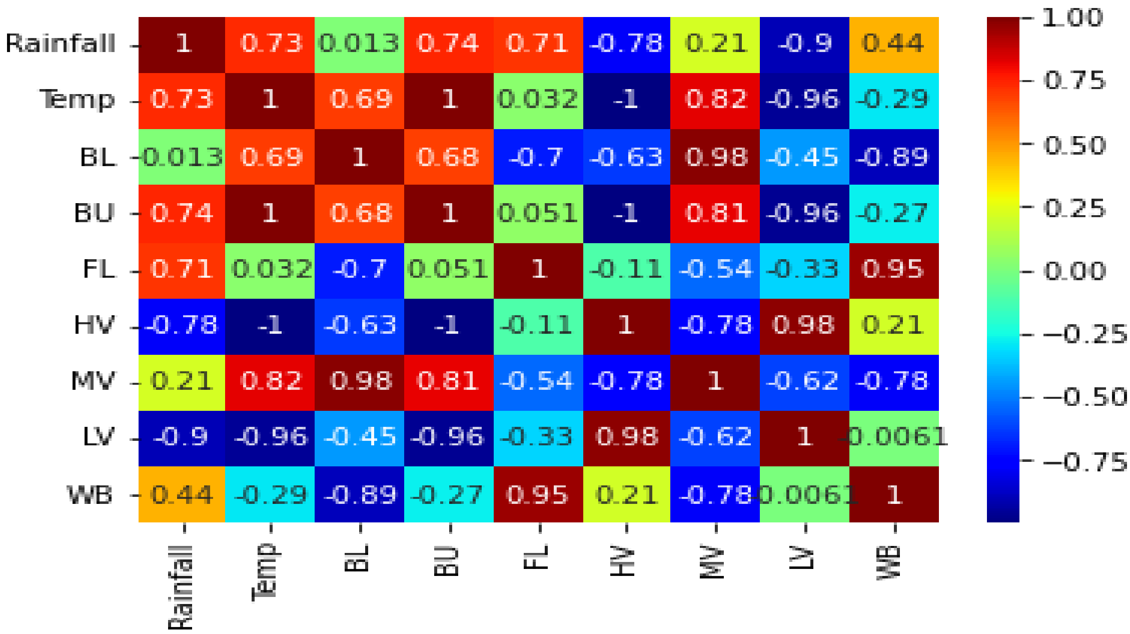


Figure 4. 54: Correlations between Land Use Land Cover (LULC) and Climate Variability in Sikasso from 1990 to 2020

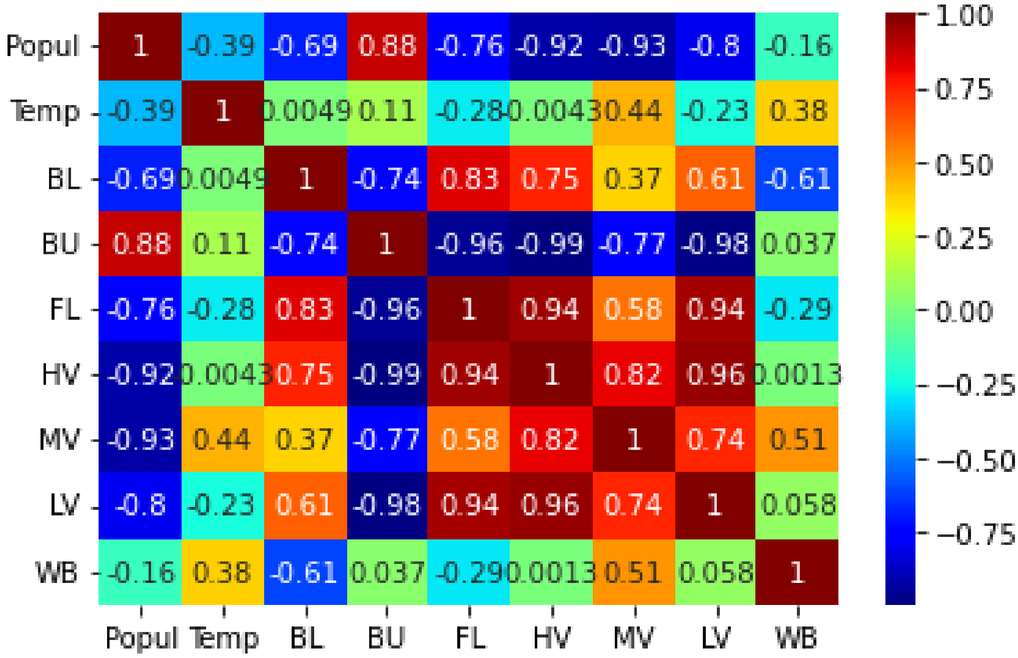


Figure 4. 55: Correlation between LULC and Demographic in Bamako from 1990 to 2020

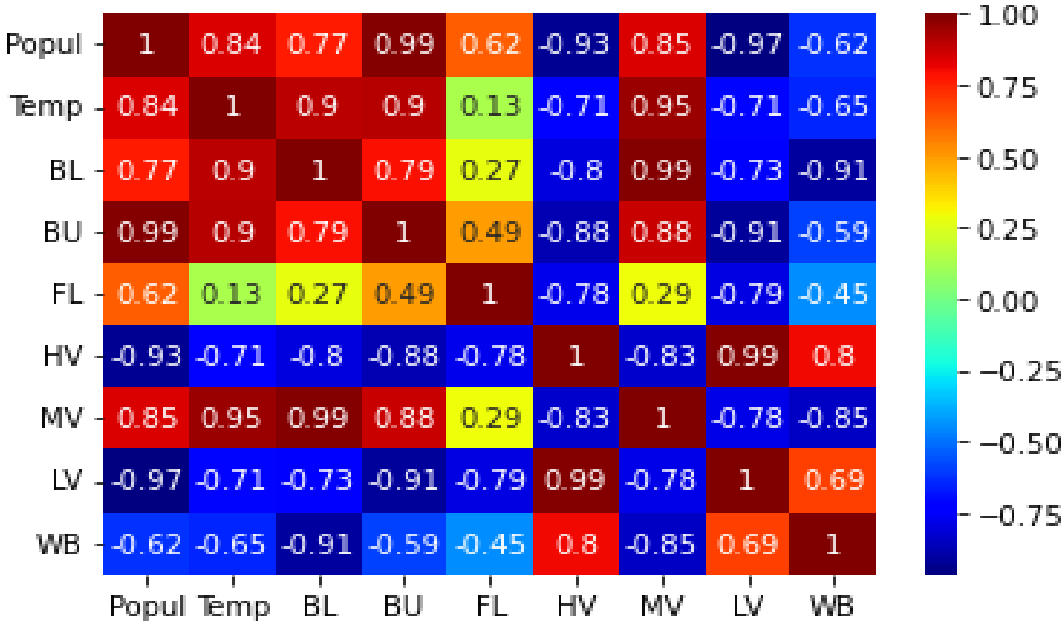


Figure 4. 56: Correlation between LULC and Demographic in Sikasso from 1990 to 2020

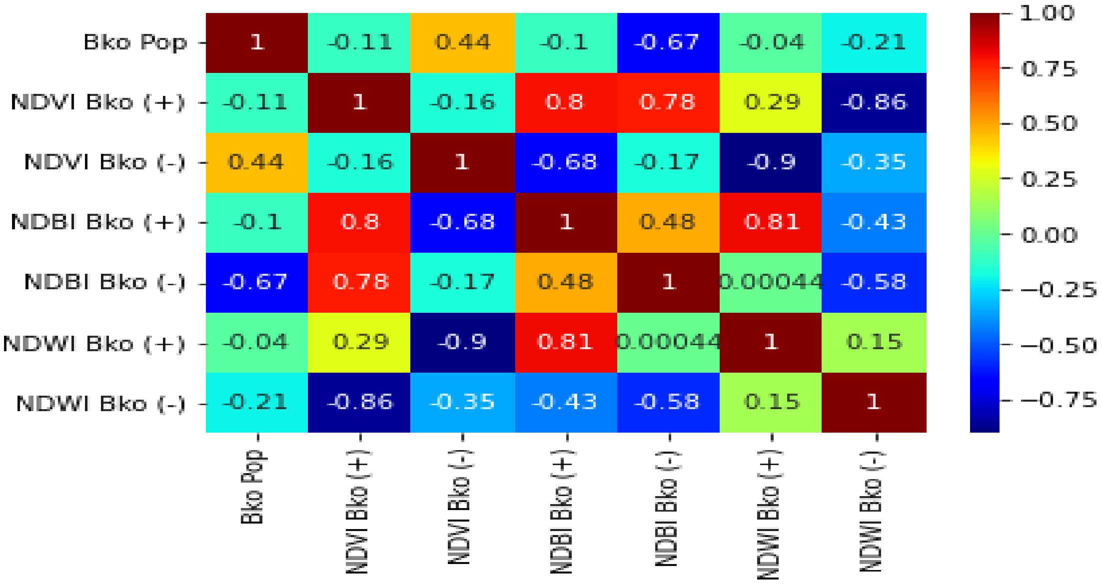


Figure 4. 57: Correlation between Population Growth and Different Indexes: NDVI, NDBI, and NDWI, in Bamako from 1990 to 2020

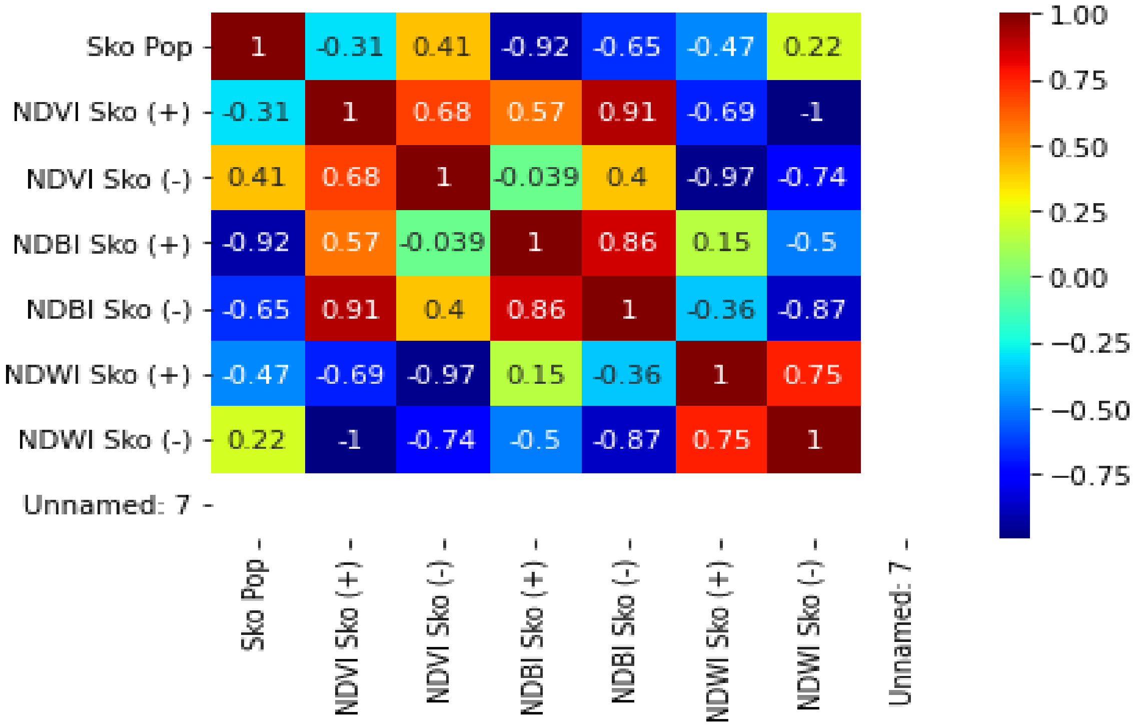


Figure 4. 58: Correlation between Population Growth and Different Indexes: NDVI, NDBI, and NDWI; in Sikasso from 1990 to 2020

4.1.5. Examine the implications of the existing green spaces on the cities' resilience

4.1.5.1. Changing urban planning strategies, social, physical, and environmental benefits

The district's short, medium, and long-term (to 2021) housing (and plot) requirements have been estimated based on development scenarios, where the standards for occupying the District's urban space are those defined by the 2nd revision of the Master Plan for Development and Urban Planning (SDAU) = 58% of the surface area is reserved for plots and 42% for green spaces and infrastructure. This is because the current housing situation in the District is unknown with certainty due to the lack of recent and reliable statistics (Bureau national d'etudes techniques et de developpement, 2001).

"Public landscaping and urban forestry projects that create mutually beneficial relations hips between city dwellers and their environment" is the definition of "urban greening." It's basically about bringing greenery into urban areas. For urban green spaces, the strategy is a tool to promote green spaces in the creation of sustainable communities; coordinate the different partners to ensure that resources are used efficiently and benefits are maximized; and make an effective case for investment. The most recent data available dates from the 1987 census and the 1992 housing situation in Mali. As a result, it is difficult to determine the precise housing situation in the city of Bamako. Therefore, the short-, medium-, and long-term housing requirements (as well as the number of plots) for the District of Bamako were estimated using development scenarios. These scenarios included standards for occupying urban space in the District that were defined by the SDAU's second revision, which states that 58% of the district's surface area is reserved for plots and 42% for green spaces and infrastructure (Bureau national d'etudes techniques et de developpement, 2001).

Africa's fastest-growing metropolis at the moment is Bamako. The Administration will need to put forth a lot of work to provide the community facilities and infrastructure necessary to support this increase. It was vital to have long-term urban planning in this difficult situation. As a result, the government established the previously mentioned boundaries of the future Mali National Park. However, as part of a public-private partnership, the Mali government has asked the Aga Khan Trust for Culture (AKTC) to work on the 103-hectare site, which is located between the presidential palace complex and the national museum and contains a large semi-circular canyon of protected forest beneath the terraced outcrops of the Koulouba plateau (Complex, 2010).

The importance of green spaces in rapidly growing megacities like as Mali cannot be overstated. Parks and gardens have been established in a number of the world's quickly expanding cities, including Bamako, Cairo, Kabul, and Delhi, thanks to the efforts of the Aga Khan Development Network (AKDN). In actuality, Bamako's urban environment is greatly improved by the National Park of Mali. It's one of the biggest city parks in Africa and a very amazing accomplishment in many ways. AKTC signed a 25-year deal with Mali's Minister of Culture and Ministry of the Environment and Sanitation for the building, maintenance, upkeep, and expansion of the park by AKTC, taking into consideration that the park's growth and upkeep could someday become a burden for the city.

Some of the negative effects of urbanisation are offset by the contribution of urban greening. Urban planners therefore design greening projects in a way that enhances the aesthetics of the neighbourhoods, and air quality, creates communal areas for the community, and even heightens the sense of peace and quiet among inhabitants. Thus, there are numerous ways that urban planners can create and implement green areas in our cities; yet, when planning green initiatives, planners need to keep a few key factors in mind. An essential factor to take into account is the kind of tree or shrub to be planted. It is not logical to plant trees that demand a lot of water in areas that receive little precipitation; instead, planners should take into account the changing climate of their cities and what kinds of greenery would flourish in those settings. Likewise, consideration must be given to how the vegetation blends in with the indigenous animals and plants. To create a harmonious environment overall, planners can benefit from hiring horticultural specialists to assist in selecting the appropriate green spaces for their specific cities. Urban planners must also take into account the long-term maintenance requirements of various interventions.

The basis for this investigation was the Standard for Classification of Urban Green Spaces by the Ministry of Urbanism and Habitat via the Regional Direction of Urbanism and Habitat. Urban green space planning strategies and development were defined and understood, and primary social, physical, and environmental benefits within the governance context were identified by utilising data from the multi-level governance framework and digitization using Google Earth Pro.

Multi-level governance framework

The multi-level governance framework (Figure 4.59) of transition management, which was created by (Loorbach, 2010) and used by Coronil, (2021); Kabisch, (2015b), was modified for this purpose and applied to the case of green space planning strategies. The framework serves as an analytical tool for defining how various actors-planners, institutions, practitioners, etc. - deal with complex issues related to green space planning strategies, as well as the activities and processes that are associated with them (Kabisch, 2015b).

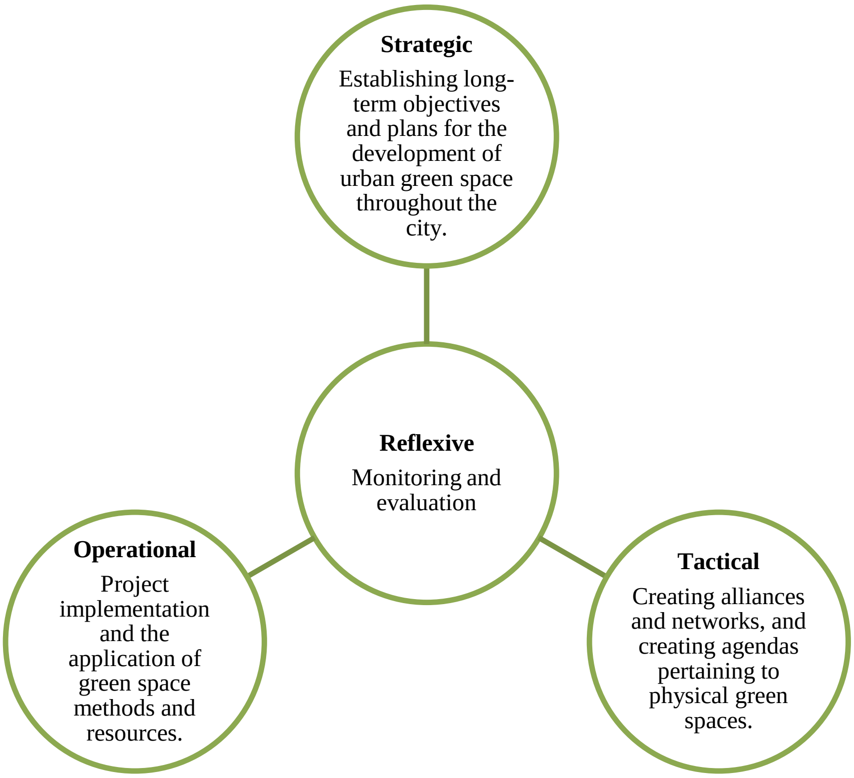


Figure 4. 59: Multilevel Governance Framework.

Strategic: The process of addressing the overall urban green space planning, vision, and identity of the entire city is the focus of the strategic component of governance. There were two primary issues found. They have to do with how people value and identify with green spaces, as well as how urban green spaces will develop in the future. The following are some of the difficulties: (a) when conceptualizing urban open spaces, policymakers, urban planners, citizens, and some users of green spaces may have conflicting interests; (b) Bamako and Sikasso have low cognitive urban green space quality (Kabisch, 2015a).

Operational: Putting an existing vision into practice is what the operational dimension of governance entails: procedures and actions pertaining to the management and execution of the green space plan and facilities.

Two main challenges were identified: (a) the successful example of greening in Berlin cannot be effectively transferred to other parts of the city where district responsibility is required; (b) urban green spaces throughout the city are not developed or maintained to a suitable degree due to county and local budgetary constraints. These two difficulties can be suggested for this research (Kabisch, 2015a).

Tactical: The goals, networks, and collaborations associated with particular green development projects, as well as funding sources, are reflected in the tactical governance levels. The Berlin urban green planning process is confronted with two main challenges: (a) communication and the continued requirement for a best-practice definition to guarantee citizen participation in green space planning from the beginning. Formal strategy has its share of difficulties (Kabisch, 2015a).

Reflexive: Monitoring and assessing the use of current planning techniques, as well as their networks and execution, are all part of reflexive governance. One significant issue that emerged from the interviews was: (A) the implementation of the approach was not adequately evaluated or monitored. Due to a lack of funding and personnel, few agencies have integrated evaluations of the execution of planning goals and objectives (Kabisch, 2015a).

However, planners are in favour of an assessment, as it can serve as a positive argument for developing green infrastructure. Since urban green spaces benefit city people and serve as vital animal habitat, the planning and management of these places is crucial to the idea of compact cities (Plate 4.1). So, all world leaders have committed to creating a better, greener world by 2030, and we all have a role to play in making this happen.

Urban green areas are vital for both providing important habitat for animals and important advantages to urban people, making their management and design key to the compact city concept (Plate 4.2). These illustrations show the concept of ecosystem services, which is inspired by the SDG and draws benefits and values for human well-being from plants and/or biophysical structures and functions implemented in green spaces.

Plate VII: Example of Urban Green Space Benefits

Plate VIII: Example of Urban Green Spaces Distribution

4.1.5.2. Scenario development for multiple ecosystem services related to climate change

In order to simulate scenarios, this study concentrated on forecasts based on modifications in land use and perceptions of green spaces in urban areas based on the findings of land use analysis. With consideration for the estimates and rule-based values for every land cover type, as well as the Likert scale indicator, which runs from 0 to 100, as well as the Normalized values for each land cover category and its ecosystem services, they are defined as presented in tables 4.15 and 4.16 respectively, which show the locally important ES values provided by the land use classes such as bare land, built-up, farmland, high vegetation, medium vegetation, low vegetation, and water bodies; while figures 4.60 and 4.61 present the loads scenarios as Normalized values determined according to the criteria established in this study to assess people's perception of green spaces and their ecosystem services.

In the balancing table that corresponds with the spider map, the highest values of ecosystem services offered by urban green spaces in Bamako and Sikasso are provisioning services, with 26 and 24, respectively, followed by regulating and maintaining services and cultural services. In this way, they obtain different weighting results and, at the same time, show the overall results (Figures 4.62 and 4.63) of the assessment (Koschke *et al.*, 2014).

Table 4. 16: Definition of Functions and Services of UGS

F&S-->	Provisioning services	Regulating and maintaining s	Cultural services
template.csv Indicator Editor	0	0	0
Bare land	0	0	5
Built-Up	0	0	0
Farmland	50	40	20
High Vegetation	100	100	100
Medium Vegetation	100	80	60
Low Vegetation	80	60	20
Water Body	100	70	30

Table 4. 15: Definition of Functions and Ecosystem Services assessment matrix showing the relationship between land-use types and their capacity to provide ES within a range between 0 (no capacity to provide ES) and 100 (highest Page 10/35 capacity to provide ES)

template.csv Indicator Editor	0	0	0	0	0	0	0	0	0
Bare land	0	10	40	40	30	0	20	0	0
Built-Up	0	50	30	60	70	65	50	10	10
Farmland	70	40	40	5	20	10	20	30	10
High Vegetation	50	100	80	75	80	100	60	100	90
Medium Vegetation	100	50	40	20	60	20	50	60	50
Low Vegetation	0	30	40	20	30	40	40	20	20
Water Body	80	70	80	70	60	60	50	60	70

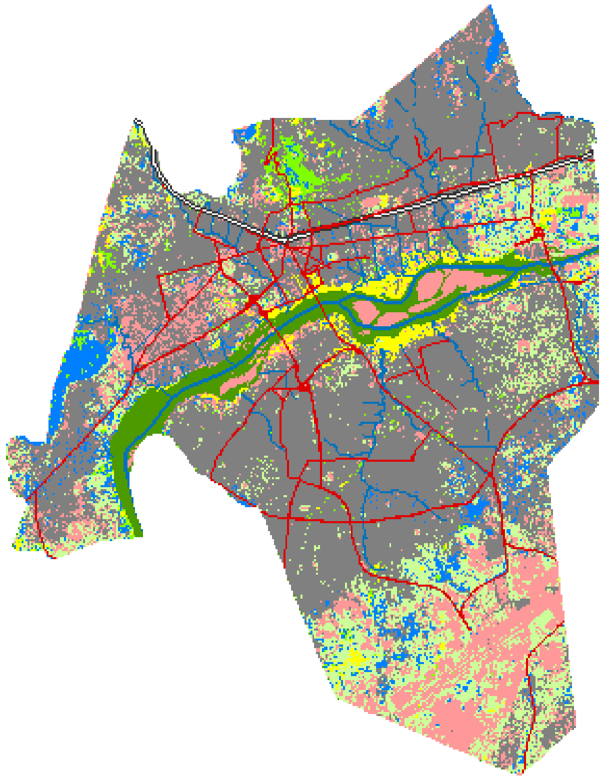


Figure 4. 60: Load Scenario of Bamako

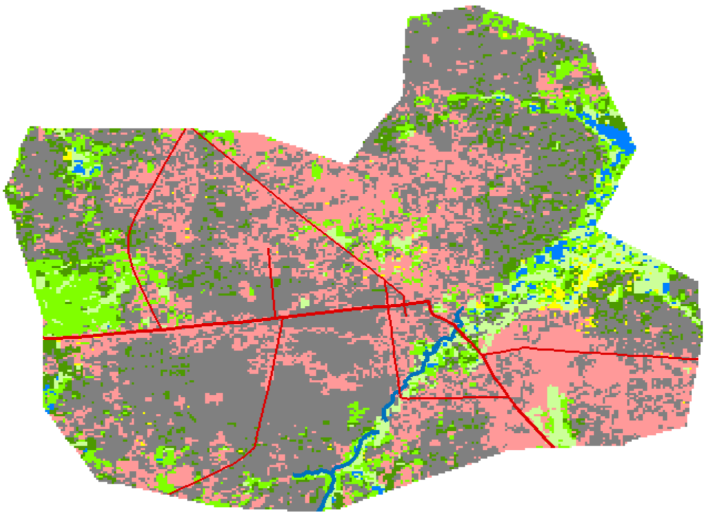
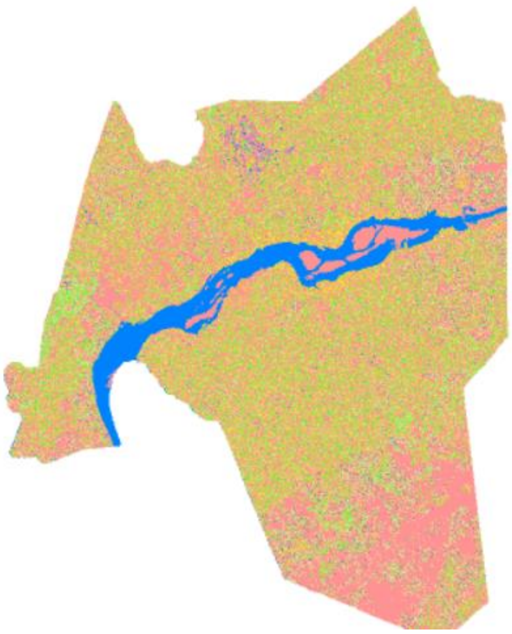
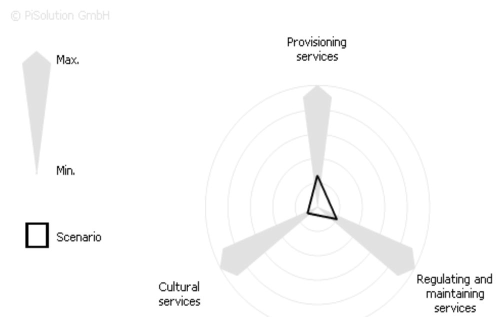


Figure 4. 61: Load Scenario of Sikasso

a. Land use and land cover status in Bamako **b. Status of the ES balance**

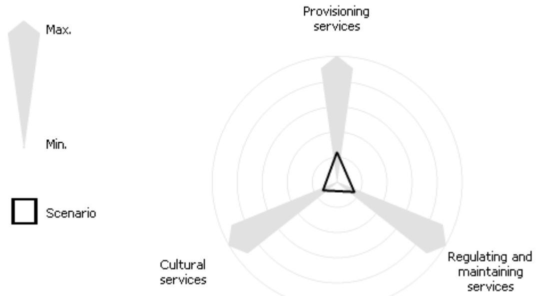




Provisioning services	26
Regulating and maintaining services	20
Cultural services	10

Figure 4. 62: Values of Ecosystem Services Provided by Urban Green Spaces in Bamako: a. The Current Land-Use Pattern, b. The Status of Ecosystem Services is shown in the Balance Table corresponding to the Spider Chart

a. Land use land cover status in Sikasso **b. Status of ES balance**



Provisioning services	24
Regulating and maintaining services	16
Cultural services	13

Figure 4. 63: Values of Ecosystem Services Provided by Urban Green Spaces in Sikasso: a. The Current Land-Use Pattern, b. The Status of Ecosystem Services in the Balance Table Corresponding to the Spider Chart

4.2. Discussion of Results

Various methods are used to assess green space development and its contribution to urban sustainability and climate change resilience, including remote sensing and surveys of local populations.

4.2.1. Spatial changes and the characteristics of the different types of UGS

The study areas Bamako and Sikasso have a total area of 23,587 ha and 45,459 ha respectively. Bamako and Sikasso are the two major densely populated cities. Supervised maximum likelihood classification was applied to generate the LULC map in 1990, 2000, 2010, and 2020 with high accuracy, as shown in Table 4.1 and 4.2. The agreement between the classification and ground truth data is relatively high for all years of 1990, 2000, 2010, and 2020 for both cities, with Kappa coefficients of 82.26%, 88.17%, 93.98%, and 99.02%, respectively, for Bamako (Table 4.3), and 93.43%, 98.14%, 97.65%, and 96.43%, respectively, for Sikasso (Table 4.4). The results of the land use classification in table 4.1 show the decreasing of vegetation in Bamako for 1990, 2000, 2010, and 2020, respectively, 9 002 ha (38,17%), 6 812 ha (28,88%), 6 903 ha (29,27%), and 4 867 ha (20,63%) of urban vegetation, of which market gardens cover about 2 222 ha (24,68%), 2 107 ha (30,93%), 1 825 ha (26,44%), and 1 150 ha (23,63%), respectively, for 1990, 2000, 2010, and 2020).

In Sikasso, they observed in 1990, 2000, 2010, and 2020, respectively, 31,194 ha (68,62%), 26,450 ha (58,18%), 24,738 ha (54,42%), and 17,045 ha (37,50%) urban vegetation, which market gardens cover about 823 ha (2,64%), 907 ha (3,43%), 2 173 ha (8,78%), and 2 565 ha (15,05%). Built-Up and Bare land are increasing from 1990 to 2020 in both cities. Thus, the growth of built-up areas was the primary cause of the decline in UGS (Diallo and Bao, 2010). This increase can be attributed to population growth linked to urbanisation which affects UGS and ES (Monika *et al.*, 2017).

Within the framework of building land reserves, building land reserves are also provided for residential construction: Mamassoni West, 16 hectares; 135 hectares south of Kamale Sirakoro; and 35 hectares south of Hamdallaye (URBATEC, 2006). Currently, 90,441.07 square metres (9.04 hectares) of dwellings (45,892.89 square metres or 4,589 hectares), mosques (12,487.50 or 1.248 hectares), children's cottages or kindergartens (2,801.08 or 0.28 hectares), truck parks and caretaker's houses (1,664.60 or 0.166 ha), a school and a kindergarten (25,095 or 2.50 ha), and a community centre (CSCOM) (2,500.00 or 0.25 ha) are available, so only 73,888.72 m^2 or 7.388 ha are available for providing Ecosytems services (DRUH, n.d.; URBATEC, 2006). So, with regard to environmental measures to protect and enhance green areas, in the city of Sikasso, natural conservation measures must be taken in view of the increasing degradation of the ecosystem.

However, the Sikasso urban master plan promotes the preservation of already-existing green areas as well as the establishment of new ones, as well as the development of existing ones and the encouragement of people to restore natural species, particularly large trees that are in danger of extinction or have already vanished, as well as the establishment of both communal and private groves.

Change detection in Bamako between 1990 and 2020: 55, 09%, 14, 27%, 13,95%, 4,88%, 4,82%, 1,49%, and 5,56% of land under built-up, low vegetation, bare land, medium vegetation, farmland, high vegetation, and water bodies, respectively, remained under the same LULC categories in 2020. In Sikasso, the change detection between 1990 and 2020 is as follows: 24,92%, 21,29%, 20,59%, 16,04%, 10,57%, 5,64%, and 0,96% of land under built-up, low vegetation, farmland, bare land, high vegetation, medium vegetation, and water bodies, respectively remained under the same LULC categories in 2020. In fact, throughout the same time period in both cities, there were notable conversions from every type of vegetative cover to built-up, bare ground, and agricultural land (Cheruto *et al.,* 2016).

4.2.2. Analysis of the effects of green spaces identified on sustainability and climate change resilience and their ecosystem services

Overall, the samples in both cities are dominated by respondents aged 20 to 70, with a higher proportion of men than women. The majority of the respondents are male with 78%, and the highest level of education is high school with 47%. The majority of respondents in both cities have at least a college degree and live in homes they own or have inherited. Despite the fact that there are fewer urban green spaces in both cities, respondents said that the ones that were there were generally decent. The impression of urban green spaces in Bamako as just "moderate" was greater than in other cities, which may indicate that the city is under more pressure to maintain its urban green spaces.

In fact, Decree No. 111PGRN ("Projet de Gouvernance des Ressources Naturelles") approved the Plan for Management and Urban Planning of Bamako and Surrounding Areas in 1979, and it became effective on April 1, 1981, for a thirty-year term (1981-2010). In 1990 and 1995, it underwent revisions (Agence d'urbanisme de Bamako, 2014). Nevertheless, no five-year periodicity has been observed as intended; therefore, in order to improve the development and urban planning of Mali's cities, the five-year modification of the plan must continue. Many studies show that climate change has negative impacts on urban green spaces and their ecosystem services (Dursun and Science, 2010; Gill *et al.*, 1998; Govindarajulu, 2014; Kim and Kim, 2017; Nations and Settlements, 2011; Nero *et al.,* 2019).

Generally speaking, these changes have positive or negative impacts on green spaces. Like all countries in the Sahel, Mali is vulnerable to the impacts of current and future climate change. Climate change may be natural in nature in terms of long-term climate fluctuations in temperature and weather conditions, but it may also be caused by increasing urbanisation, which has led to more and more people living in cities, up to about four three-quarters of the population by 2020. As the results of the analysis show, this also reduces access to urban green spaces and their ecosystem services. Therefore, addressing the challenges of urban sustainability and climate resilience is crucial (The World Bank, 2011).

The climate variables most affected by global warming are precipitation and temperature (Mamadou, 2021). Temporal trends in temperature and annual precipitation were analysed for the two cities between 1990 and 2020. The location Standardized anomaly index of each station showed an increasing trend by location at the different stations, as per the Mann-Kendall test results. The analysis of trends in climate variables has revealed a shift in the climate that calls for particular actions to be taken in order to manage resources sustainably and conserve them. The change in climate requiring specific action has been indicated by the results of the analysis of trends in climate variables for the development and sustainable management of green spaces.

This growing trend has adverse effects on green spaces in the cities of Bamako and Sikasso and is thus conducive to climate change. It requires concrete measures to achieve climate sustainability and resilience, sustainable management, and resource protection.

4.2.3. Urban green spaces comparison and their ecosystem services in the study areas

Between 1990 and 2020, there were notable conversions in both cities from all vegetative cover categories to built-up areas, bare land, and farms; these conversions were verified by (Dembele, 2017) (Diallo *et al.,* 2020), (Fomba *et al.,* 2024), (Cheruto *et al.,* 2016). According to Diallo and Bao, (2010), the rise of built-up regions was the primary cause of the decline in urban green space, which was also likely brought on by population growth (Monika *et al.,* 2017). Mali's towns and cities are expanding quickly, which is indicative of the Global South's tendency towards more urbanisation. With a population ten times larger than that of Sikasso, Mali's second-largest city, Bamako stands out among the other cities in the nation (Agence d'urbanisme de Bamako, 2014). Bamako is one of the world's fastest-growing cities, with over 2 million residents and a population growth rate of about 5.4% per year (Agence d'urbanisme de Bamako, 2014), (Dembele *et al.,* 2016).

The Mali government has given decentralized organisations, aided by technical services, authority over urban administration in response to this expansion. A conflict between collective interests and individual approaches to land management resulted from the entry of new political players into the urban management space (BNETD, 2001). The land use analysis's findings support the research conducted by Dembele *et al*. (2016), which located, mapped, and described close to 1,600 places in Bamako. Accordingly, Dembele *et al*.'s research demonstrates that because between 10% and 50% of the classified areas have had their functions changed, the legal instruments that were classified by the President of the Republic no longer safeguard public space (Dembele *et al.,* 2016).

The area of green space in Bamako was estimated to be 918.7 ha by Diana *et al.* (2003) in their study on urban structure and spatial dynamics. It was discovered, meanwhile, that vegetated areas are not the same as green areas, which are defined as public green spaces. The master plan for the year 2000 called for 15 m^2 of vegetated area per resident, a far cry from the 8.75 m^2 of surface area that was available in 1996 relative to the population of Bamako (Diallo *et al.,* 2020; Diana *et al.,* 2003). The Sikasso urban master plan calls for the development and upkeep of current green areas as well as the creation of new ones; it also calls on people to encourage the regeneration of natural species, particularly large trees that are in danger of going extinct or disappearing, and the establishment of both communal and private groves. Grand Bamako 2030 is, in fact, a planning strategy that outlines management priorities or action items to be completed by 2030. The statistics show that built-up formation has increased in areas of Bamako city from 1990 to 2020, while the high vegetation and water bodies have increased from 1990 to 2000 and 1990 to 2010. On the other hand, bare land, farmland, medium vegetation and low vegetation have regressed by the spaces occupied in Bamako city from 1990 to 2020.

In Sikasso, the statistics showed that from 1990 to 2000, a part of bare land and high vegetation which have decreased, all others classes (built-up, farmland, medium vegetation, low vegetation and water body) have increased. On the other hand, Bare land and Vegetation have regressed in 20 years from 1990 to 2010, while in 30 years (from 1990 to 2020), built-up, farmland and water body have increased. In view of the changes observed in these two cities, they note the conversion of certain vegetation formations as green spaces into other units such as buildings and bare soil (Karambe, 2014). The expansion of built-up regions and rising urbanisation, coupled with rapid population growth, have put growing strain on the ecosystem services that green spaces supply (Diallo and Bao, 2010; L'Urbanisme, 2005; URBATEC, 2006). This has resulted in the conversion via regression. According to the findings of the LULC analysis conducted on the cities between 1990 and 2020, the majority of the vegetation classes in both cities have been replaced by built-up areas and bare land (Diana *et al.*, 2003).

Both cities' built-up and bare land percentages increased between 1990 and 2020. Thus, the growth of built-up areas was the primary cause of the decline in UGS. This increase can be attributed to population growth linked to urbanisation which affects UGS and ES.

4.2.4. Availability and quality of green spaces determination in the study areas

Street trees and roadside tree groups were the most common types of green spaces that the respondents saw in both cities, while Bamako had a high concentration of both public and private gardens. Owing to the significance of trees in Mali culture, new housing projects are being constructed, starting with buildings and roads and finishing with trees, which are typically planted late in order for them to mature late as well (Agence d'urbanisme de Bamako, 2014). Every year, residents of Mali's cities volunteer and support the planting of street trees, particularly during the country's annual August winter reforestation drive. One option that can raise people's standard of living is reforestation, particularly in light of the loss of the forest regions surrounding large towns. Reforestation-based initiatives are among the 17 priority adaptation areas that have been defined as part of Mali's national policy for adapting the forestry industry to the effects of climate change. According to (L'Environnement, 2018), Strategy 4 suggests planting plantations for levelling, enrichment, shade, green spaces, reception parks, shrub areas, orchards, hedges, windbreaks, etc.

The Bamako Regional Government should make up for plant losses along the main asphalt route and develop green spaces in public locations, according to the ESIA (Environmental and Social Impact Assessment) report, which also suggests that the First and Fourth Municipal Authorities collaborate to construct green spaces (AGETIPE MALI/Groupement GTAH-LOBOU CONSEILS-ECIA, 2018). The afforestation of cities lacks a strategic plan, although trees are widely planted within the boundaries of the real estate agency's zone (Agence de Cessions Immobilières, ACI), which was established in 2000 by a real estate agency that considered green spaces when creating its development plan and in some boulevards and developments dating back to the colonial era (Agence d'urbanisme de Bamako, 2014). There is relatively little natural vegetation left as a result of this anthropomorphisation, with sporadic trees and grass species (MAFUH, 2021).

Nonetheless, this assignment was a component of an urban reflection process that was started at the 2010 Urban Development Forum and continued at the 2011 International Urban Project Management Workshop, which focused on the operational plan for the new centre of the Bamako Metropolis and was themed "The New Centre of the Bamako Metropolis." More recently, a number of urban planning and development initiatives were carried out as part of "Grand Bamako 2030," with an emphasis on initiatives that can significantly influence how the metropolis functions, the involvement of private actors and citizens, and the city's allure.

Furthermore, the majority of studies on urban green spaces have been carried out in industrialized countries, and the results confirm the positive impacts of these areas on ecosystem service provision, population health, mitigation of climate change, and sustainable and strategic urban development (Farkas *et al.,* 2023; Gairola *et al.,* 2014; Jabbar *et al.,* 2022; Lee and Maheswaran, 2011). Enhancing green spaces and the ecosystem services they offer is therefore essential to making the towns of Bamako and Sikasso resilient to climate change and sustainability.

4.2.5. Implication of the existing green spaces on the cities' resilience

Within the green spaces envisioned in the master plan for urban planning and development, Bamako's distinct communities are collaborating with the urban planning administration to create new green spaces and enhance those that already exist (Agence d'urbanisme de Bamako, 2014). One such project is a green space initiative in Commune III, which was started by the Youth Association with technical assistance from the Higher School of Engineering, Architecture, and Urbanism (ESIAU). Part of the Action Plan for

Preconfigured Units of the Bamako Urban Planning Directorate provided funding for the mission (Agence d’urbanisme de Bamako, 2014). There's also the airport zone, which is fully humanized because of its use for agriculture (orcharding and market gardening), the dumping of sewage sludge and solid waste, and human settlement (homes, housing estates, farms).

In Sikasso, the strategy based on the terms of reference and the consultants' recommendations indicated that the preservation and expansion of the current green areas is a part of the green area measures; specifically, the planned development of 200 hectares surrounding the cattle market and abattoir along the "Tata" (a swamp) Marigot; planting trees and protecting the green belt along diversion roads; the establishment and/or reinforcement of forests; green safety belts in industrial and oil (URBATEC, 2006). The two primary sections of the document that the consultants, the URBATEC/Atelier 21 consortium, created, outline the urban master planning approach: (i) So using, large commercial areas, roads, various networks, and large facilities are just a few of the issues that the assessment and consensus seek to diagnose in relation to the development of the city of Sikasso. (ii) The programme report contains 20 years' worth of development recommendations, summary cost estimates, and implementation strategies and recommendations (URBATEC, 2006). The key factors to be taken into account when planning large cities are green spaces, which have considerable advantages, such as reducing high temperatures, increasing rainfall, and reducing pollution.

However, it is the responsibility of urban planners to do everything possible to mitigate the effects in built-up areas. A number of urban environment specialists have conducted studies on the freshness of green spaces, the urbanisation impact on rainfall, the heat island phenomenon in urban areas and the concentration of atmospheric pollution (Aflaki *et al.*, 2017a, 2017b; Arshad *et al.*, n.d.; Dursun and Science, 2010; Exploring the impacts of urban expansion on green spaces availability and delivery of ecosystem services in the Accra metropolis | Elsevier Enhanced Reader, n.d.; Kruize *et al.,* 2019; Maheng *et al.*, 2021; Makhelouf, 2009; Xiao *et al.*, 2018). Some of the results obtained by researchers are confirmed by this study. Through the GISCAME multi-criteria evaluation approach, the application of the Likert scale to explore and explain the landscape capacities and structural relevance, dominated by green space were used to provide regulating ES in the cities of Bamako and Sikasso. Long-term impacts on green spaces such as urbanisation, climate change-induced drought, vegetation health and its ecosystem services, and strategic planning are specifically addressed.

Temporary changes in vegetation cover attributes (e.g., high, medium, low vegetation) and permanent shifts in vegetation cover were observed. Important aspects of the change process can be seen in the cities of Bamako and Sikasso as given here: (1) Decreasing green space, implying increasing habitat during the study period from 1990 to 2020, during which time both cities transformed into human-dominated landscapes. (2) The prevalence of man-made surfaces such as buildings, asphalt, pavements, and areas in both cities, making it easy to test scenarios for converting land use classes into green spaces, is very interesting. As shown by the multicriteria analysis, conservation efforts should focus on the waters of both cities to ensure that they develop harmoniously with green spaces.

4.3. Summary of the findings

The results of the LULC analysis showed that most of the natural vegetation has decreased in both cities and has been converted into built-up areas, farmland, and bare land. 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. The results of the survey indicate that the majority of respondents have a strong relationship (social cohesion) with green spaces (96.13%) and attribute a good status to green spaces in Sikasso (64.59%).

Rainfall in the two cities is statistically insignificant; however, seasonal minimum temperatures in Bamako City differ statistically significantly (p=0.0001, R2=0.4027).
The seasonal minimum temperature (p=0.0001, R2=0.476) and seasonal maximum temperature (p=0.0001, R2=0.6448) in Sikasso differ statistically significantly due to climate change and entropic activities. Bamako city has higher temperature than Sikasso because Sikasso is located in the humid and sub-humid zones, with high vegetation density while Bamako is located in the Sudanese climate zone. The onset, duration and magnitude of drought conditions (between -2 and 2) compared to normal conditions in a variety of natural systems such as green spaces have been determined.
The results showed the same areas covered by vegetation in LULC maps in Bamako and Sikasso cities, with high level density of settlements.
The highest values for ecosystem services in both cities are provisioning services.

CHAPTER FIVE

5.0. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The main objective of this study was to analyse the distribution design and evaluate the contribution of urban green spaces to sustainable climate change resilience in the cities of Bamako and Sikasso in Mali between 1990 and 2020. The study combined use of GIS, observational data processing, and social science methods to integrate the perceptions of people in both areas as well as key informants from the literature on green spaces and their ecosystem services. This chapter concludes with recommendations for more research and provides a summary of the key findings based on the four distinct objectives of our study. Our study's primary goal was to assess how urban green spaces in Mali's towns of Bamako and Sikasso contributed to sustainability and climate change resilience between 1990 and 2020. They did this by analysing the distribution patterns of these spaces.

The majority of the natural vegetation in both cities has diminished and has been replaced by built-up areas, farms, and barren ground, according to the results of the LULC research conducted between 1990 and 2020. In both cities, street trees made up the majority of the urban green spaces noted, followed by clumps of roadside trees. Between 1990 and 2020, Sikasso's built-up area expanded from 20.49% to 48.81% and Bamako's from 22.08% to 54.37%, while both cities' vegetative areas saw a decline. This study provided a first level of knowledge about urban green spaces and their evolution in the two cities. In the course of the study, remote sensing and GIS geoinformation (remote sensing, GIS, and mapping) were applied to better diagnose the dynamics of land use states in the two cities and are essential to understanding the spatial dynamics of green spaces in Bamako and Sikasso cities. Indeed, two processes were recorded: changes and conversions.

These changes are mainly due to disturbances related to the construction of new houses and other infrastructure and to population growth as urbanisation increases. The dynamics of land use in the two cities were studied using geostatistical approaches. Thanks to these tools, they were able to identify that green spaces or vegetation formations are in accentuated regression over the study period from 1990 to 2020. In fact, the majority of the vegetation classes in both cities have been transformed into built-up areas and barren ground, according to the findings of the LULC research conducted on the cities between 1990 and 2020. Furthermore, the NDVI values have continuously decreased in both cities between 1990 and 2000, increased in 2010, and decreased between 2010 and 2020 in both cities.

The main cause of the loss of vegetation cover can be attributed to urbanisation due to population growth, with leads to increasing pressure on the ecosystem services provided by green spaces. The NDBI values have increased in both cities between 1990 and 2020, while the NDWI values have increased in Bamako between 2000 and 2020 and between 1990 and 2020. The analysis of trends in climate variables indicated a significant trend only in temperatures, which have a positive correlation with rainfall, bare land, built-up, medium vegetation, and population. The results of the study show that there are few UGS available at short distances in both Bamako and Sikasso. However, the situation in both cities (Bamako and Sikasso) is critical, with only 20.61%, and 15.52%, respectively, of the total land area covered by UGS.

In general, groundwater resources are considered non-existent, as shown by the SPEI and SPI indexes and per capita deficits, especially in Bamako, although residents have the possibility to benefit from groundwater resources in their environment, which they should share with inhabitants of neighboring areas. Regardless of the few facilities available in the area, residents feel that they benefit to some extent. The inhabitants of Sikasso perceive more regulating services available, associated with street trees and wetlands in the area. In Bamako, cultural services are strongly recognized due to the presence of a sports field. Overall, residents in both areas accept that there is a low level of UGS provision for ES in the area.

Furthermore, despite the low level of UGS provision in both areas, residents are satisfied that there is little land space to accommodate more. Nevertheless, the majority expressed the need for additional facilities in both cities. A larger proportion of respondents show an interest in cultural services in Sikasso, hence their demand for sports fields. This represents a gap, as there are no sports fields available in the area. On the Bamako side, regulation and supply services are requested by a larger proportion of respondents. Thus, street trees and gardens are requested to provide these services. Here, demand exceeds supply, leaving a large number of residents dissatisfied. It is also observed that the availability of green cover in the green spaces of both areas is perceived as poor; however, a larger proportion of the interviewees attach a positive value to this condition not meeting their needs. It was found that the demand is influenced by the demographic characteristics of the respondents, of which women, young people, and people with low levels of education are the most important. In addition, it was decided that the gaps identified could be filled by spatial planning and management strategies. These require a collaborative effort by all relevant actors, supported by effective legislation.

5.2 Recommendations

The following are highly recommended in light of the study's findings.

5.2.1. Recommendations related to policy improvement

In order to ensure that the Master Plan for Urban Planning and Development for the cities of Bamako and Sikasso is up to date and takes into consideration the National Urban Policy, the Ministry of Land Affairs, Urban Planning and Housing should consult with the Ministries of the Environment and Sanitation and Agriculture. Target 11 of the SDG, which calls for ensuring that everyone has universal access to safe, inclusive, and accessible green and public spaces by 2030 especially women, children, the elderly, and individuals with disabilities must be immediately considered in these new plans.

The Bamako and Sikasso Master Plans for Development and Urban Planning ought to outline the green space development policies. Governments committed to the following during the Habitat III conference of the New Urban Agenda: fostering the development of excellent, secure, and welcoming public green spaces; enhancing the natural cultural heritage, both tangible and intangible; and supporting territorial systems that integrate urban and rural activities; encourage the sustainable management of urban natural resources. The development of green areas in the cities of Bamako and Sikasso requires investigation for those involved in urban planning, policy-making, and other aspects of society. It is also necessary that land division and construction be carried out in accordance with the urban master plan, which also needs to be reviewed in light of the spatial dynamics of the cities.

Moreover, with respect to the UN's definition of the Sustainable Development Goals (SDGs), which mandate that all nations attain inclusive and sustainable urban development by 2030, Mali's policymakers are required to create and/or modify policies that align with one of the 17 SDGs that the UN outlined in 2015. This is targeting number 11, which addresses concerns about inclusive, secure, resilient, and sustainable cities and human settlements. More than half of the world's population already resides in urban areas, and by 2050, this percentage is predicted to climb dramatically, making this aim imperative. Policymakers and researchers can use the study's findings to evaluate the sustainability and climate resilience of green spaces in Mali's towns of Bamako and

Sikasso, as well as their current level of development, and address climate challenges through targeted mitigation and resilience initiatives in sustainable city development.

5.2.2. Recommendations related to performance improvement

The urban planners must take into account the public's perception of the benefits of urban green spaces for a sustainable city. The respondents' assessment of the state of urban green spaces was largely positive, in contrast to the decline in these areas. The relationship between local residents' perspectives and the current shifts in land use needs more investigation. For a balanced and sustainable supply of ES from green spaces in the two cities (Bamako and Sikasso), urgent actions emanating from our study results recommend the development and protection of green spaces, providers of sustainable ecosystem services in the cities. Therefore, to preserve and enhance urban green spaces in Bamako and Sikasso, new measures must be developed or current ones must be enforced.

5.2.3. Suggestions for further research

Both the high-resolution and low-resolution photos do not accurately depict the two cities' respective land covers, notwithstanding the classification of the land cover (Bamako and Sikasso). It can be used in the future as a starting point to create more accurate land cover maps using higher-resolution imagery than Landsat. Therefore, a more detailed classification of vegetation can be expected in future studies. It is also important to validate results on the ground and engage urban planners and policymakers. However, the increasing population will likely put further strain on urban green spaces. As a matter of fact, given the paucity of previous studies on the topic, this study indicates that more investigation is warranted into the climate variability suggested by rising temperatures and decreasing rainfall in these two cities.

5.3. Contributions to Knowledge

Based on the results of this study, there was progressed (264.30 ha) of built-up areas in 30 years in Bamako, from 1990 to 2020. On the other hand, bare land, farmland, and medium vegetation, low vegetation has regressed in the spaces occupied in Bamako city from 1990 to 2020.

The statistics on the evolution of land use units in Sikasso in 30 years, show that built-up areas and farmland have progressed respectively 42.80 ha and 1.97 ha, from 1990 to 2020, while bare land, and high vegetation have regressed in the spaces occupied in Sikasso city from 1990 to 2020. There was a significant reduction in vegetation cover (scattered vegetation and forest) from 1990 to 2020 with the highest NDVI values of 0.4 and 0.6 in 1990, for Bamako and Sikasso respectively; and 0,2 and 0,1 in 2020 mean less vegetation growth and more urban growth. The breathing fresh air are considered like the majority of respondents in Bamako according to the majority of respondents, which think that the ecosystem services provided by UGS, with 23% and food security in Sikasso with 26%.

The correlation analysis between climate variability and LULC showed a positive correlation between rainfall and temperature in both cities (Bamako and Sikasso) with correlation coefficients of 1 and 0.9 from 1990 to 2020. In Sikasso, positive correlations are observed between rainfall, temperature, built-up and farmland; temperature and bare land; built-up and medium vegetation. The analysis of correlation between population, temperature, and LULC showed positive correlations between built-up and population in both cities; negative correlations were observed between built-up and vegetations areas (high, medium and low) in both cities, while a correlation was observed between built-up and medium vegetation in Sikasso. The correlation analysis between population and different indexes (NDVI, NDBI, and NDWI) showed a positive correlation between NDVI and NDBI in both cities (Bamako and Sikasso).

Most of the respondents in Bamako and Sikasso indicated that they have lived in the city for 15 years and over, with 61% in Sikasso and 47% in Bamako. These major changes were seen from 5 to 10 years in both cities, with 40% in Bamako and 30% in Sikasso. The advantages of the relationship with citizen and green spaces are agriculture in Sikasso with 37% and sport in Bamako with 22%. The majority of respondents indicated that the relationship description with ecosystem services is social, with 66% in Sikasso and 44% in Bamako. The degradation of urban green spaces as the main of problems and difficulties, with 40% in Sikasso and 29% in Bamako. Although rainfall shows a non-significant trend in all cities, seasonal minimum temperatures show increasing trends in all cities except Bamako Senou, where the trend is downward.

The district’s short, medium, and long-term (to 2021) housing (and plot) requirements have been estimated based on development scenarios, where the standards for occupying the District's urban space are those defined by the 2nd revision of the Master Plan for Development and Urban Planning (SDAU) = 58% of the surface area is reserved for plots and 42% for green spaces and infrastructure. In the balancing table that corresponds with the spider map, the highest values of ecosystem services offered by urban green spaces in Bamako and Sikasso are provisioning services, with 26 and 24, respectively, followed by regulating and maintaining services and cultural services. The people living in the cities of Bamako and Sikasso will find this study to be significant and helpful in getting ideas and information about the growth of urban green areas and how they contribute to the climate resilience of cities.

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APPENDICES

APPENDIX A:

Urban Planning to Support Various Functions of Urban Agriculture

Function	Description and Justification	Supportive Planning Strategies
Production	Urban agriculture produces fruits, vegetables, mushrooms, herbs, medicinal plants, meats, milk, cheese, eggs, and other products	Provide suitable, accessible, and safe land with good solar access and an irrigation source
Energy Conservation	Producing food locally reduces the embodied energy resulting from inputs, transport, and packaging.	Develop transportation systems and networks to efficiently yet food to consumers.
Waste Management	Organic waste products can be composted and used as a fertility resource for growing food and other products	Identify systems to collect, divert, and transport organic wastes away from landfills to urban agriculture.
Biodiversity	Agricultural systems can support a wide range of species, including some native plants, as crops or associated plants.	Convert some open space areas of low diversity (i.e, turf) to community gardens and farms.
Microclimate Control	Urban agriculture can positively alter microclimate through humidity control, wind protection, and shade.	Allow edible plantings in built areas to combat the heat island effect and other unfavorable climatic conditions.
Urban Greening	Community and backyard gardens contribute to the greening of urban areas, improving aesthetics and well-being.	Support efforts to convert vacant and derelict lands into productive green spaces for use by residents.

Economic Revitalization	Urban agriculture ventures offer new jobs for neighborhood residents and vitality from improved economics of the community.	Create networks to connect laborers, farmers, and markets to help retain and grow new ventures.
Community	Community members often find gardening and farming to be a social activity through sharing food, knowledge, and labor.	Along with community garden spaces, integrate other activities and features to encourage socializing.
Human health	In addition to the known benefits of access to green space, urban agriculture offers healthy food and encourages physical activity.	Explore opportunities to develop community programming around gardening/ farming as a healthy lifestyle.
Cultural heritage	Urban agriculture can provide access to rare ethnic foods that are typically not available in existing markets.	Integrate community garden spaces in areas known to have high immigrant populations, and link with culture.
Education	Children and adults learn about foods, nutrition, cooking, environment, economics, and cultures through urban agriculture.	Offer gardening and urban agriculture activities within existing programmes, particularly during summer.

APPENDIX B:

Questionnaires

Questionnaire pour les parties prenantes dans la contribution des espaces verts à la durabilité et la résilience au changement climatique dans les villes de Sikasso et Bamako

Afin de promouvoir la durabilité et la résilience dans nos villes en ces périodes du changement climatique, nous avons initié cet entretien pour r les effets des espaces dans les villes de Sikasso et Bamako à travers les services écosystémiques fournis.

L'entretien a été réalisé en langue Bambara pour les analphabètes et en Français pour les alphabètes.

Date de l'entretien	**Jour**	**Mois**	**Année**	**Ville**	
				Quartier	

I SECTION A. CARACTERISTIQUES SOCIO-DEMOGRAPHIQUES DU REPONDANT

Q.01	**Prénom et NOM de l'interviewe**	
Q.02	**Age** (estimation en annees revolues)	**/______/**
Q.03	**Sexe:** *1= Homme; 2= Femme*	
Q.04	**Statut matrimonial :** *1 = marie (e) ; 2 = Veuf (ve) ; 3= Divorce ; 4= Célibataire*	/______/
Q.05	**Niveau d'éducation et de formation :** *0 = Pas été à l'école ; 1 = Primaire ; 2 = Secondaire ; 3 = Supérieur ; 4 = Ecole coranique ; 5 = Alphabétisation en langue locale*	
Q.06	**Groupe ethnique** : *1= Sénoufo ; 2 = Minianka ; 3 = Bambara ; 4 = Bobo ; 5 = Samogo ; 6 = Dogon ; 7 = Peulh ; 8 = Autre (Précisez)*	/______/

Q.07	**Religion** : *1 = Musulmane ; 2 = Chrétienne ; 3 = Traditionnelle ; 4 = Autre à préciser*	/______/
Q.08	**Statut de Résidence :** *1 = Location ; 2 = Propriétaire ; 3= Loge gratuitement ; 4= Don ou legs ; 5= Bail ; 6= Autre à préciser*	/______/
Q.09	**Principale activité :** *1= Agriculture ; 2= Elevage ; 3= Transporteur ; 4= Agro-industrie (Transformation) ; 5= Artisan ; 6= Enseignant ; Fonctionnaire de l'Etat ; 7= Etudiant ; 8= Elève ;9= Ouvrier, 10= Retraite ; 11= Autre à préciser*	/______/

II SECTION B. CARACTERISTIQUES ET PERCEPTION DES ESPACES VERTS

N°	**QUESTIONS**	**REPONSES**
Q.10	**Quels sont les types d'espaces verts qui existent dans votre localité?** *1= Périmètres maraichers urbain; 2= Rangers d'arbres des routes; 3= Mise en défends urbain; 4= Parc urbain; 5= Jardin public; 6= Jardin prive; 7= Arbres devant les concessions; 8= Gazon; 9= Verdure au bord de rivière; 10= Autre à préciser*	/_____/
Q.11	**Quel est l'état actuel des espaces verts ces dernières années?** *1= Très bénéfique; 2= Moins bénéfique ; 3= Pas bénéfique ; 4= Autre à préciser*	
Q.12	**Quel type de lien ou de relation entretenez-vous avec les espaces verts ?** *1= Visiteur; 2= Agriculteur; 3= Cultures maraîchères, 4= Cultures fruitières; 5= Cohésion sociale; 5= Bien-être ; 6= Comportements de sante positifs; 7= Reduction de la chaleur urbaine; 8= Avantages physiques et environnementaux; 9= Conservateur; 10= Lieux d'achat; 11= Lieux de vente; 12= Autre à préciser*	
Q.13	**Quels sont les services écosystémiques (ES) fournis par ces espaces verts ?** *1= Refroidissement, 2= Alimentation, 3= Tourisme, 4= Appréciation du paysage, 5=*	

	Éducation et recherche, 6= Échange avec d'autres, 7= Légumes, 8= Élevage; 9= Respirer de l'air frais, 10= Pêche, 11= Évènements culturaux, 12= Atténuation de bruits; 13= Autre à préciser	
Q.14	**Quels bénéfices tirez-vous des espaces verts?** *1= Achat de légumes, 2= Raisons familiales, 3= Enrichissement spirituel ou religieux, 4= Expérience esthétique, 5= Contexte professionnel, 6= Autre à préciser*	/_____/
Q.15	**Quel est votre perception à la durabilité des espaces verts dans votre localité?** *1 = Excellente; 2= Bonne; 3= Moyenne; 4= Mauvaise; 5= Aucune*	**/_____/**
Q.16	**Selon votre perception, lequel des services écosystémiques fournis est plus bénéfique dans les villes?**	/_____/
Q.17	**Pensez-vous avoir un rôle à jouer dans la conservation et la protection des espaces verts urbains?** **Si oui, dans quelle mesure êtes-vous concernes?** *1= Très concerne, 2= Un peu concerne, 3= fortement concerne, 4= Pas du tout concerne*	
Q.18	**Si l'on vous demande de contribuer à la durabilité et à la résilience climatique des espaces verts sur une échelle de 1 à 5, quel chiffre mettriez-vous? /............/**	/_____/

III SECTION C. URBANISATION, CHANGEMENT DE STRATEGIE DE PLANIFICATION URBAINES, AVANTAGES SOCIAUX, PHYSIQUES ET ENVIRONNEMENTAUX

Q.19	**Avez-déjà entendu parler de changement climatique ?** *1= Oui, 2= Non*	/_____/
Q.20	**Croyez-vous aux Changements Climatiques ?** *1= Oui, 2= Non*	
Q.21	**Si oui, quelles sont selon vous, les causes de ces changements ?** *1= Naturelles ; 2= Urbanisation ; 3= Activités Humaines ; 4 = Autre à préciser*	/_____/
Q.22	**Etes-vous conscient des risques liés aux changements climatiques ?** *1= Oui ; 2= Non*	
Q.23	**Si oui, quels sont les risques liés à ces changements ?** *1= Dégradation des sols ; 2= Dégradation des espaces verts ; 3= Augmentation de la température ; 4= Inondation ; 5= Sécheresse ; 6= Migration ; 7= Conflits ; 8= Emission des Gaz à effet de serre ; 9= Autre à préciser.*	
Q.24	**Depuis combien d'année habitez-vous en ville ?** ***1****= Moins de 5 ans ;* ***2****= 5 à 10 ans ;* ***3****= 10 à 15 ;* ***4****= plus de 15 ans.*	/_____/
Q.25	**Avez-vous constaté de changement de vocation des espaces verts dans votre localité ?** *1= Oui ; 2= Non ; 3= Ne sais pas*	
Q.26	**Quels sont les différents changements que vous avez constatés à travers les espaces verts de votre localité ces dernières années ?** *1= Bon microclimat ; 2= Augmentation de la température ; 3= Infiltration rapide de l'eau pendant la saison des pluies ; 4= Conservation de la biodiversité ; 5= Amélioration de la qualité de l'air ; 6= Esthétique ; 7= Atténuation de bruits ; 8= Autre à préciser*	

Q.27	**Depuis combien d'année avez-vous constaté ces changements dans votre localité ?** *1= Moins de 5 ans ; 2= 5 à 10 ans ; 3= 10 à 15 ans ; 4= Plus de 15 ans*	
Q.28	**Quels peuvent êtres les services de régulations pour adapter et atténuer les impacts du changement climatique dans les villes ?** *1= Réguler le climat, 2= Contrôler les inondations, 3= Réduire les rejets nets de CO_2, 4= Réduire la pollution, atténuer les effets du réchauffement climatique, 5= Améliorer l'isolation thermique des bâtiments, 6= Purifier l'eau, 7= Erosion, 8= Autres*	
Q.29	**De quels types de services écosystémiques bénéficiez-vous grâce aux espaces verts de votre localité ?** *1= Bon microclimat ; 2= Légumes ; 3= Eau potable ; 4= Bénéfices médicaux ; 5= Purification de l'air et filtration de l'eau ; 6= Les racines des arbres maintiennent le sol en place pour éviter l'érosion ; 7= Purification de l'eau ; 8= Contrôle des inondations ; 9= Stockage de carbone et régulation du climat ; 10= Autre à préciser*	
Q.30	**Avez-vous observé des migrations ces dernières années dans votre ville ?** *1 = Oui ; 2 = Non*	
Q.31	**Quelles sont vos relations avec les migrants qui accèdent aux services écosystémiques ?** *1 = Business ; 2 = Agriculture ; 3 = Elevage ; 4= Sports ; 5= Tourisme ; 6= Contempler la nature ; 7= Autres (Précisez)*	
Q.32	**Quels avantages/ bénéfices tirez-vous des relations cites ci-dessus ?** *1= Avantages économiques, 2= Avantages sociaux, 3= Avantages sanitaires, 3 = Avantages mentaux, 4 = Sécurité alimentaire, 5= Accès aux terres agricoles, 6 = Accès à l'eau, 7= Autres (Précisez)*	

Q.33	**Seriez-vous prêt à contribuer à la bonne planification des Espaces verts urbain et à leurs promotions ?** *1= Oui ; 2= Non ; 3= Ne sais pas*	
Q.34	**Selon vous, quelles peuvent êtres les principales contraintes à la planification stratégique des espaces verts dans les villes ?**	

IV SECTION D. RELATION ET MOTIVATION A FREQUENTER LES ESPACES VERTS FOURNISSANTS DES SERVICES ECOSYSTEMIQUES

Q.35	**Avez-vous une relation personnelle et ou une motivation sur les services écosystémiques fournis par les espaces verts ?** *1= Oui ; 2= Non*	/_______/
Q.36	**Si oui, quelle est la meilleure description de votre relation avec les services écosystémiques ?** *1= Economique ; 2= Culturelle ; 3= Sociale ; 4= Autre à préciser*	/_______/
Q.37	**Si oui, qu'est ce qui décrit le mieux votre motivation à fréquenter les espaces verts fournissant les services écosystémiques ?** *1= Acheter des fruits/légumes ; 2= Amélioration de la qualité de l'air ; 3= Faire de l'exercice ; 4= Apprendre sur la nature ; 5= Profiter de la solitude/ du calme ; 6= Faire promener les animaux ; 7= Profiter de la vue ; 8= Profiter de la compagnie des autres ; 9= Autre à préciser*	/_______/
Q.38	**Quels autres facteurs ont déterminé votre choix de conserver et de protéger les espaces verts en ville ?** *1 = Sécurité alimentaire, 2= Villes pensantes, 3= Absorption et infiltration de l'eau, ce qui réduit le taux de ruissellement, 4= Reduction de l'ilot de chaleur urbaine, 5= Partie substantielle du développement durable des villes, 6= Moyens de subsistances durables, 7= Autre à préciser*	/_______/
Q.39	**Avez-vous des connaissances des services techniques ou institutions en charge des espaces verts dans votre localité ?** *1= Oui ; 2= Non*	

Q.40	**Si oui, quels sont ces services techniques ou institutions ?** *1= Urbanisme ; 2= Domaine ; 3= Mairie ; 4= Service de l'environnement ; 5= Service de l'Agriculture ; 6= Service des eaux et forêts ; 7=ONGs à spécifier ; 8= Autre à préciser*	
Q.41	**Existe-il de relation de collaboration entre ces services techniques ou institutions et les usagers des espaces verts ?** *1= Oui ; 2= Non*	
Q.42	**Si oui, quel est le niveau de collaboration entre les usagers et services techniques ou institutions autour des espaces verts ?** *1= Faible ; 2= Moyen ; 3= Elevé ; 4= Ne sais pas*	

V SECTION E. HIERARCHISATION DES PROBLEMES/ DIFFICULTES

Q.43. Si vous deviez-vous occuper à ses difficultés pour les résoudre, lesquelles choisiriez-vous ?

N°	**CONTRAINTES**	**COCHER**	**N° ORDRE**
01	Augmentation de l'urbanisation		
02	Dégradation des espaces verts		
03	Canicules/ rechauffement climatique		
04	Insecurite alimentaire		
05	Risques et catastrophes		
06	Autre a preciser		

Q.44. Quels sont vos propositions de solutions aux cinq premières difficultés majeures ?

N°	PROPOSITION DE SOLUTIONS	COCHER	N° ORDRE
01	Multiplication des espaces verts dans les villes		
02	Gestion et securisation des espaces verts		
03	Verdir les villes en cultivant les legumes, en plantant des arbres autour des maisons, des routes, des lieux publics, des ecoles, des services techniques de l'etat,…..		
04	Securite alimentaire		
05	Adaptation et resilience		
06	Autre a preciser		