ЛЕСНОЕ ХОЗЯЙСТВО

Original article
УДК 528:630
DOI: 10.37482/0536-1036-2026-1-9-29

Remote Monitoring of Land Use in Fragmented Urban Green Space Landscapes in Central Tanzania

Heri Labani Sagali[1,2], Postgraduate Student; ResearcherID: P-9598-2018, ORCID: https://orcid.org/0000-0003-2103-1482
Yingli Huang[1]✉, PhD, Prof.; ORCID: https://orcid.org/0000-0002-0168-1536
[1]College of Economics & Management, Northeast Forestry University, Harbin, 150040, China; sagherry@gmail.com, hlhuangnefu@163.com✉
[2]Institute of Rural Development Planning, P.O.Box 138, Dodoma, Tanzania; heri.sagali@mipango.ac.tz

Received on February 11, 2025 / Approved after reviewing on May 13, 2025 / Accepted on May 17, 2025

Abstract. This research explores how long-term land use and cover changes affect urban ecosystems and local livelihoods. It is focused on the impact of rapid urban expansion on sustainable urban planning. The study has been conducted in Nkonko and Sasilo Wards, Manyoni District, Tanzania, from 1993 to 2023. Remote sensing, GIS, satellite imagery, participatory methods, and field surveys have been used to examine deforestation, urbanization, and ecosystem services, detailing land use and land cover and their impact on local environments and livelihoods. The study has revealed significant urban expansion and increased forest cover, accompanied by a decline in agricultural lands, indicating a shift towards urbanization. The landscape has experienced a 2.88 % rise in forest cover, adding 246.82 km², and a 9 % increase in urban areas, expanding by 222.76 km². In contrast, agricultural lands have decreased by 17.17 %, a reduction of 119.72 km². These changes highlight a transformation in land use patterns, demonstrating a change from traditional agriculture towards urban development and reforestation, reshaping the region's topography and land use dynamics. The research has demonstrated that urbanization and land fragmentation in the Manyoni District has disturbed the ecosystem and the community's socioeconomic structure. It highlights the need for coherent urban planning and sustainable land management. It has emphasized advanced remote sensing and GIS skills in planning and conservation strategies.

Keywords: community livelihood, forest changes, GIS, land use change, remote sensing, Tanzania
Acknowledgment: The authors would like to acknowledge and thank the China National Key Research and Development Program for funding this research with a grant no. 2022YFF1300503-06.

For citation: Sagali H.L., Huang Y. Remote Monitoring of Land Use in Fragmented Urban Green Space Landscapes in Central Tanzania. *Lesnoy Zhurnal* = Russian Forestry Journal, 2026, no. 1, pp. 9–29. https://doi.org/10.37482/0536-1036-2026-1-9-29

Научная статья

Дистанционный мониторинг землепользования фрагментированных ландшафтов городских зеленых насаждений Центральной Танзании

Х.Л. Сагали[1,2]***,*** *аспирант;* ResearcherID: P-9598-2018,
ORCID: https://orcid.org/0000-0003-2103-1482
И. Хуанг[1✉]***,*** *д-р наук, проф.;* ORCID: https://orcid.org/0000-0002-0168-1536
[1]Колледж экономики и управления, Северо-Восточный лесной университет, г. Харбин, Китай, 150040; sagherry@gmail.com, hlhuangnefu@163.com✉
[2]Институт планирования сельского хозяйства, а/я 138, г. Додома, Танзания; heri.sagali@mipango.ac.tz

Поступила в редакцию 11.02.25 / Одобрена после рецензирования 13.05.25 / Принята к печати 17.05.25

Аннотация. Изучено влияние долгосрочных изменений землепользования и растительного покрова на городские экосистемы и образ жизни населения. Основное внимание уделяется быстрому расширению городов и воздействию этого процесса на устойчивое городское планирование. Исследование проводилось в районах Нконко и Сасило округа Маньони, Танзания, с 1993 по 2023 гг. Для анализа обезлесения, урбанизации и экосистемных услуг использовались методы дистанционного зондирования, ГИС-технологии, спутниковые снимки, партисипативные методы и проводились полевые исследования, детализирующие изменения землепользования и растительного покрова и их влияние на местную окружающую среду и население. Выявлено значительное расширение городов и увеличение лесного покрова, сопровождающееся сокращением сельскохозяйственных земель, что указывает на сдвиг в сторону урбанизации. Площадь лесного покрова повысилась на 2,88 %, или на 246,82 км^2, а городов – на 9 %, или 222,76 км^2. Территория сельскохозяйственных угодий, напротив, уменьшилась на 17,17 %, или на 119,72 км^2. Эти изменения свидетельствуют о трансформации моделей землепользования, переходе от традиционного сельского хозяйства к городскому развитию и лесовосстановлению. При этом рельеф региона и динамика землепользования становятся другими. Показано, что урбанизация и фрагментация земель в округе Маньони нарушили экосистему и социально-экономическую структуру сообщества. Подчеркивается необходимость последовательного городского планирования и устойчивого управления земельными ресурсами. Особое внимание уделено методам, базирующимся на использовании материалов дистанционного зондирования и ГИС-технологий при разработке стратегий природопользования.

Ключевые слова: образ жизни сообщества, изменения в лесах, ГИС, изменение в землепользовании, дистанционное зондирование, Танзания

Благодарности: Авторы выражают благодарность Китайской национальной программе ключевых исследований и разработок за финансирование данного исследования по гранту № 2022YFF1300503-06.

Для цитирования: Sagali H.L., Huang Y. Remote Monitoring of Land Use in Fragmented Urban Green Space Landscapes in Central Tanzania // Изв. вузов. Лесн. журн. 2026. № 1. С. 9–29. https://doi.org/10.37482/0536-1036-2026-1-9-29

Introduction

Urban development issues and environmental sustainability are closely related to changes in land use and land cover (LULC), a crucial aspect of the worldwide environmental transformation. The surface of the Earth is significantly altered by this intricate dynamics, which is emphasized by both natural occurrences like floods and wildfires and human activities like agriculture, urbanization, deforestation, and industrialization. LULC changes have far-reaching effects on biodiversity, climatic patterns, soil health, water and air quality, and ecological balance, ultimately affecting the resilience and ecological balance of natural systems [15, 17]. People's quality of life and access to resources are directly impacted by the changes in spatial organization of the cities and regions [4, 58]. The necessity for sustainable urban planning becomes evident when considering how to manage the changes in LULC to accommodate urban expansion, especially given that the world's population is expected to approach 10 bn people by the middle of the 21st century [34]. Understanding land-atmosphere interactions in depth is crucial, as evidenced by the complex relationship between land use and climate change. Because of their complexity, LULC changes must be efficiently monitored, predicted, and managed using advanced tools such as remote sensing, Geographic Information Systems (GIS), and modelling methodologies [28, 33]. This body of research is essential in linking environmental science and policy-making to create pathways for achieving sustainable development goals. It contributes to promoting a mutually beneficial interaction between human communities and natural ecosystems even as we negotiate increasingly severe changes in the global environment. [9, 13, 24], providing us with new perspectives on creative approaches to socioeconomic development and ecological preservation, both of which are crucial for fostering peaceful cohabitation in a world undergoing fast change.

Urban planning, biodiversity, climate control, and human well-being are all impacted by changes in LULC, and these effects are complex and require careful analysis to be fully comprehended. Using a GIS-based analysis, Shah et al. [56] illustrate how LULC changes impact the values of urban ecosystem services in Chandigarh, India. This highlights the importance of incorporating the changes into urban planning to guarantee sustainable development. In a similar way, Shah et al. [56] argue for strategic land management to maintain biodiversity by highlighting the grave effects of LULC changes on ecosystem services and biodiversity. In order to improve climate resilience and mitigate the negative consequences of LULC changes, the importance of green infrastructure in urban development is highlighted [55]. Additionally, overviews by Pereira et al. [48] and Pugara et al. [49] provide insight into the ways in which LULC dynamics impact ecosystem services and climate management, highlighting the critical role LULC research plays in developing policies promoting both socioeconomic success and ecological preservation. The importance of LULC research in promoting a sustainable coexistence between human activity and natural ecosystems is highlighted by these observations taken as a whole.

A gap in the understanding of the complex connections between urban growth, environmental sustainability, and ecosystem services across fragmented landscapes has been brought to light by the study of LULC changes in Central Tanzania during the past 30 years. There is still an urgent need for a localized, in-depth analysis despite a large body of research demonstrating substantial global impact of LULC changes caused by a confluence of natural phenomena and human activities on biodiversity, climatic patterns, soil health, water and air quality, and ecological balance as a whole. This is necessary because of the complex ways in which these changes impact the services provided by urban ecosystems and, consequently, the means of subsistence for people living in certain geographical and socioeconomic circumstances. The literature indicates that, in order to promote both socioeconomic growth and ecological preservation, there is widespread agreement on the significance of incorporating LULC dynamics into sustainable urban planning and policy-making. Nevertheless, there aren't many in-depth case studies that connect these alterations to the delivery of urban ecosystem services and their effect on local lives, particularly in developing countries like Tanzania. Previous research is important for frequently highlighting the necessity for strategic land management and the incorporation of green infrastructure into urban development plans, however it does not offer specific data or techniques for evaluating these effects locally. In addition, while acknowledged, the role the cutting-edge technologies like remote sensing and GIS play in tracking, forecasting, and managing LULC changes has not received enough attention in terms of how well they can be applied to the particular problems that Central Tanzania's fragmented landscapes face. This research attempts to close these gaps by providing a thorough analysis of LULC variations, their direct consequences on ecosystem services and local livelihoods, and identifying the main factors underlying these changes. The Manyoni District from 1993 to 2023 has been chosen as its object. A study with this level of focus is essential for developing evidence-based, targeted policies for sustainable development and for the larger conversation about striking a balance between human progress and the preservation of natural ecosystems in a world that is changing quickly.

The aim of the research has been to study LULC changes in the Manyoni District from 1993 to 2023 and their effects on urban ecosystem services and local livelihoods. This has required the fulfilling of the following objectives:

1. To evaluate the variations in LULC that emerged from 1993 to 2023;
2. To assess the impact of LULC on ecosystem and community livelihood in the study area;
3. To identify the primary driving factors for the changes within the study area.

Different studies [42, 63, 64] have focused on the changes in LULC in tropical and fragmented landscapes. Their findings and methods shed light on the intricate dynamics in these ecosystems. In order to record and analyze the changes in LULC, deforestation, urban growth, and agricultural methods, remote sensing and GIS have proven essential. In addition to using the cutting-edge instruments like NDVI to evaluate the dynamics of land cover and vegetation health, these studies also make use of field surveys and participatory techniques to gather firsthand information and comprehend socioeconomic factors. The studies highlight how these landscapes are significantly impacted by both natural and human-caused processes. For instance, as the study by Miringay et al. [42] points out, deforestation is mostly caused by logging and agricultural expansion, which results in habitat fragmentation and biodiversity loss. Increased urbanization, especially in peri-urban areas as another research by this team of scientists [41] shows, brings impermeable surfaces that interfere with soil permeability and water movement. Zella et al. [63] and Zhang et al. [64], on the other hand, highlight the adaptability and resilience of some ecosystems focusing on the regions of natural regeneration and regrowth. To lessen the negative effects of LULC changes, sustainable land management and conservation measures are desperately needed. In addition, combining LULC data with socioeconomic factors provides deeper understanding of the relationship between humans and the environment, which helps shape planning and policy for sustainable development. Together, the methods and results which are reported in the previous studies [42, 59, 64] highlight the significance of continuous observation and all-encompassing management strategies for preserving the ecological integrity and welfare of human populations relying on tropical and fragmented landscapes.

Ecosystem service theories have been developed to provide a thorough understanding of the various advantages that ecosystems offer human society, with an emphasis on urban environments. The idea, which can be generally divided into providing, regulating, sustaining, and cultural services, emphasizes the intrinsic importance of ecosystems in urban settings where human activity has dramatically changed the natural landscape [36]. The influence of changes in LULC on urban ecosystem services has been the subject of more research using these frameworks. For example, the studies have demonstrated that the loss of biodiversity, the reduction of carbon sequestration, and the elimination of green spaces due to urban growth all have an adverse effect on the quality of life and environmental sustainability in metropolitan areas [35, 61]. On the other hand, it has been shown that the incorporation of green infrastructure and strategic planning into urban landscapes improves ecosystem services, including air and water quality, urban biodiversity, and aesthetic and recreational advantages. In order to maintain and improve the well-being of urban populations, the studies emphasize how crucial it is to include ecosystem service considerations in decisions about land use and urban planning [8, 62].

Today, to monitor LULC, environmental studies and urban planning mostly rely on remote sensing technology. Because remote sensing provides timely, accurate, and wide spatial coverage of the Earth's surface, it makes tracking the dynamics of LULC changes conceivable [7]. Advanced methods such as LiDAR (Light Detection and Ranging), SAR (Synthetic Aperture Radar), and multispectral and hyperspectral imaging can provide comprehensive insights on vegetation cover, urban sprawl, and landscape fragmentation. Since remote sensing data has a temporal component that helps us understand the pattern and velocity of change, we are able to study LULC trends [27]. This capacity allows for the detection of deforestation, urbanization, and agricultural expansion, making it simpler to assess the impact of these changes on ecosystem services and biodiversity. Research using data from remote sensing has identified areas vulnerable to ecological deterioration, quantified the amount of agricultural land lost, and shown how urban areas are encroaching on natural ecosystems [38, 57]. With remote sensing technology providing a thorough awareness of changing landscapes, it is easier to create targeted therapies aimed at ecosystem conservation and restoration in the face of rapid LULC changes [5].

Research Objects and Methods

The research has been done in the Nkonko and Sasilo Wards located in the Manyoni District as one of the districts in the Singida Region [54].

The Nkonko and Sasilo Wards are situated in the Manyoni District's southern part (as shown in fig. 1), which is located at (–5°27′–6°92′ S and 34°42′–35°36′ E). The Manyoni District has 3 distinct seasons: the cold dry (May–August), hot dry

(August–November), and rainy (November–April) [53, 54]. The Manyoni District experiences a uniform distribution of precipitation, with 49 rainy days on average and an average annual rainfall of 624 mm on the higher elevations, where the majority of thickets are found. Temperatures range from 19 °C in July to 24.4 °C in November [39]. The borders of the Manyoni District Council are shared by the following districts: the Ikungi District in the north-west; the Chemba District in the east; the Bahi District in the east; the Chamwino District in the south-east; the Iringa District in the south-west; and the Itigi Council in the west.

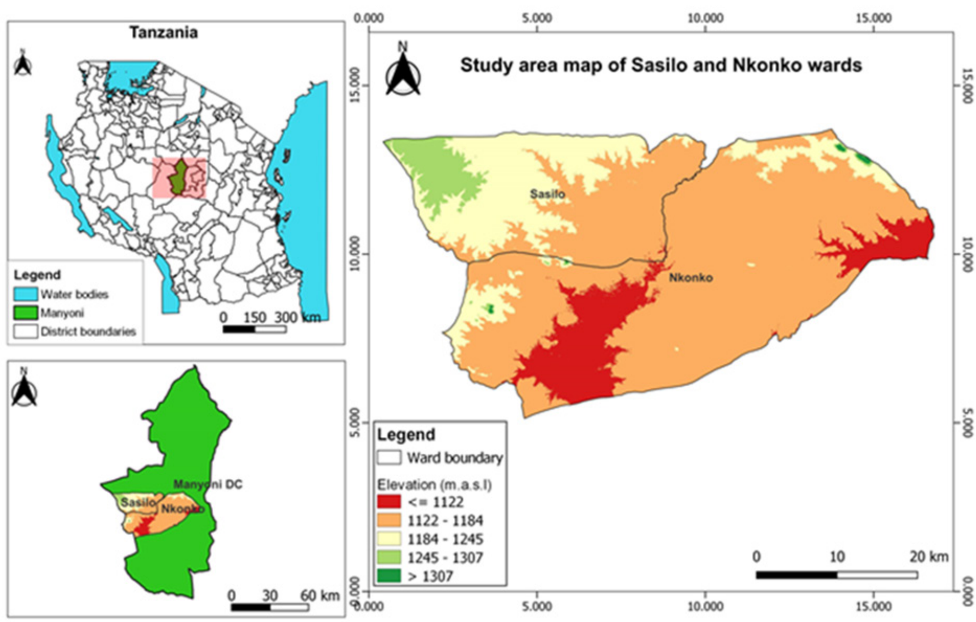


Fig. 1. The maps of the Sasilo and Nkonko Wards and their position in Tanzania

Over a 30-year period (1993, 2003, 2013, and 2023), the study has used a multimodal research methodology to examine how the changes in the land use have affected the livelihoods of those living in the Nkonko and Sasilo Wards. In addition to supervised classification algorithms and satellite imagery analysis, a combination of qualitative and quantitative methods have been used in this work. Using supervised classification approaches, patterns of land transformation have been identified by carefully tracking the temporal changes in land use within the designated periods through satellite pictures. Stakeholder meetings have been another way the research has entailed interacting with the community. Professional groups from the study region have attended these meetings, which have offered a forum for exchanging ideas about the potential impacts of changing land use on local livelihoods. A carefully planned and carried out household survey has been conducted in addition to these discussions with the aim of collecting information on the land ownership statuses and socio-economic characteristics. 353 households including men and women 25 years of age and older have been polled in total, providing a large dataset for further study. Focus group discussions (FGDs) have been conducted in order to get further insight into the subtleties of livelihood transitions and to corroborate the results of household surveys. A wide range of viewpoints has been ensured by the fact that the participants in these talks have not been the same as those who have taken part in the household surveys. The goal of the FGDs has been to investigate the different aspects and changes in livelihood strategies, supporting the information from the survey. Meticulous data processing protocols have served as the foundation for this methodological approach. IBM SPSS 27 has been used to process the quantitative data obtained from the surveys. A comprehensive picture of the dynamic interaction between the changes in land use and livelihood adjustments throughout time has been provided by this combination of approaches, which has included direct community engagement through surveys and conversations and the study of satellite images.

Results and Discussion

In this study, we have used Landsat images that have spanned a 30-year period from 1993 to 2023. The selected images have been represented by the geometrically corrected Level 1T (L1T) scenes, acquired from the Operational Land Imager (OLI) sensor, offering cloud-free operational land image data. Specifically, the images have been captured along Worldwide Reference System (WRS) path 169 and row 064, with a spatial resolution of 30 m accessed from the USGS Earth Explorer platform.

Multiple satellite images have been used in the study to capture LULC changes over time. Specifically, Landsat images from the years 1993 (Landsat 5), 2003 and 2013 (Landsat 7), and 2023 (Landsat 9) have been acquired (Fig. 2). Each image represents a different time point in the 30-year analysis period. These images have not been merged across years, but analyzed separately to compare LULC transitions between time intervals. The selection of images has prioritized those acquired during the dry season months (June to August) to ensure minimal cloud cover and consistency in vegetation phenology for accurate comparison. All the images have been Level 1T scenes, geometrically corrected, and accessed from the USGS Earth Explorer platform.

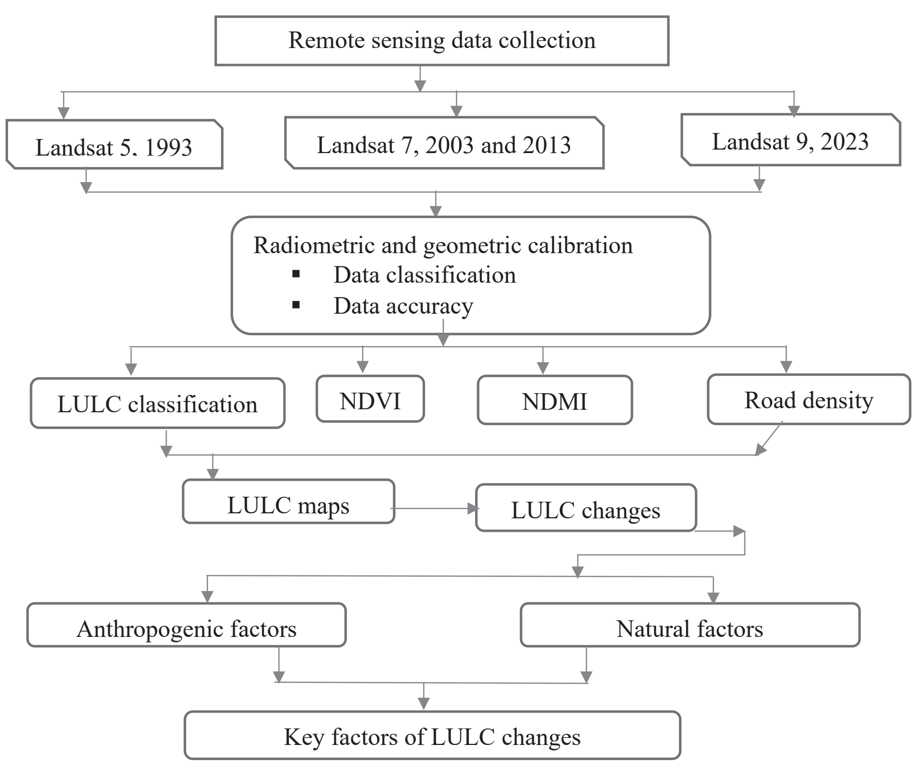


Fig. 2. The methodology and diagram structure framework of the study

We have analyzed the vegetation change cover where for accurate land cover analysis reflective of accurate land cover change, Landsat 5, 7, 8 and 9 image bands have been utilized, as recommended by Thonfeld et al. [60]. Prior to the Landsat image classification process, various preprocessing steps have been implemented to enhance imagery quality, as outlined by John and Ngondo et al. [21, 46]. Radiometric corrections have been applied using semi-automatic classification plugin of QGIS 3.28.2 to calibrate the data, eliminate atmospheric effects, and normalize the impact of light factors [10]. The classification of Landsat images has employed a supervised classification method known as Maximum Likelihood, conducted with ArcGIS 10.5 software. To validate the land cover classification, a 2-fold approach has been employed. The 1st step has been to do ground truthing during the 2023 field survey. This has involved utilizing GPS to find reference sites in different types of land cover, such as farmland, settlement, forest and barren land. These observations in the field have given us precise information for judging the 2023 categorization [43, 44]. Second, Google Earth's high-resolution satellite photos have been utilized to visually interpret land cover features and check the categorized outputs for years before 1993, 2003 and 2013. This made up for the lack of historical field data. [23, 60]. We have utilized these reference sources to build confusion matrices and figure out the usual accuracy measures.

The classification for 2023 has had an overall accuracy of 89.7 % and a Kappa coefficient of 0.85, which shows that the classified data and reference inputs have agreed with each other quite well. The fundamental attributes of the primary LULC categories employed in the current investigation are following: farmland – agricultural area, crop fields, fallow lands, vegetable lands; settlement – residential, commercial, industrial + other built-up areas; forest – deciduous forest, mixed forest, palms, conifers, shrubs, etc; barren land – land which has very limited or no trees/plants (modified from Rahman, Huq and Mukul, 2023 [51]).

The land cover classification accuracy has been validated using ground truth data and high-resolution Google Earth imagery. The overall classification accuracy for 2023 has been 89.7 %, with a Kappa coefficient of 0.85, indicating strong agreement between classified outputs and reference data. Similar accuracy levels have been achieved for other years.

To assess vegetation dynamics and monitor changes over time, the NDVI has been calculated using the spectral bands of red (*Rred*) and near-infrared (*Rnir*) of the Landsat 5, 7 and 8 in QGIS 3.34.4 using the following equation [20, 31]:

$$NDVI = \frac{Rnir - Rred}{Rnir + Rred}.$$

This approach provides a robust tool for vegetation dynamics analysis, assessment of environmental changes, and assistance with the management and preservation of natural resources by effectively distinguishing between vegetated and non-vegetated areas. Differentiating between vegetated and non-vegetated regions is within its analytical capabilities. Enhancing our awareness of environmental change, improving our knowledge of vegetation dynamics, and contributing to conservation strategies and natural resource management are all outcomes of this work.

The Key Forest Products as Drivers of Income and Forest Management. The regression study has looked at how different factors that lead to changes in forest cover affect the major source of income (Table 1). The parameter "Most important forest products” has proved the only one to have major effect (B = 0.994, p = 0.000), which suggests that it is strongly linked to revenue. This implies that some forest products are particularly vital for people’s livelihoods. If forest cover goes down and makes them difficult to access, it might have a strong influence on income, but the fact that people depend on important forest products shows how important it is to manage forest resources in a way that is good for the environment.

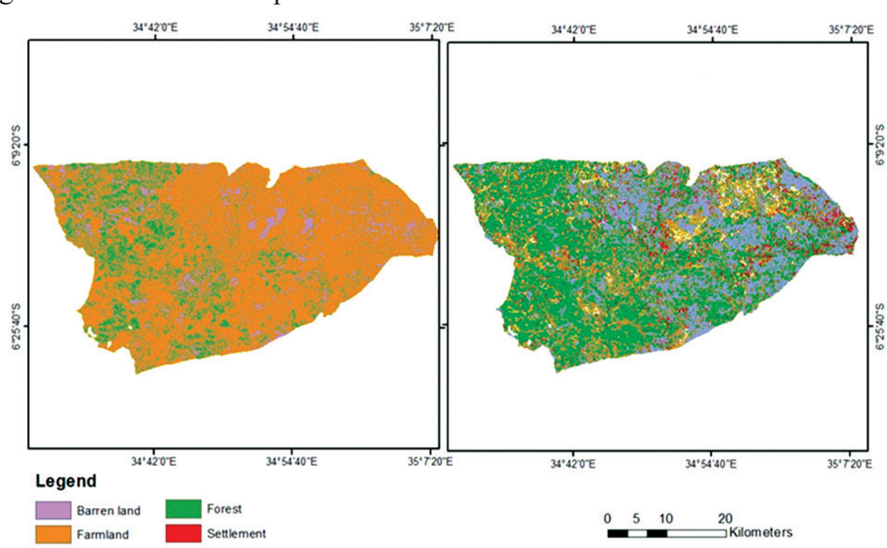
Table 1

The regression coefficients affecting forest cover change

Model	Coefficient*			t	Sig.
	unstandardized		standardized		
	B	Std. Error	Beta		
Constant	0.032	0.034	–	0.938	0.349
Education level	–0.006	0.007	–0.004	–0.924	0.356
Sex of respondents	0.002	0.008	0.001	0.244	0.807
Reasons for decline	–0.003	0.003	–0.006	–1.210	0.227
Current availability status	–0.010	0.032	–0.002	–0.327	0.744
Firewood and charcoal	0.003	0.003	0.005	0.963	0.336
Most important forest products	0.994	0.005	0.996	215.478	0.000

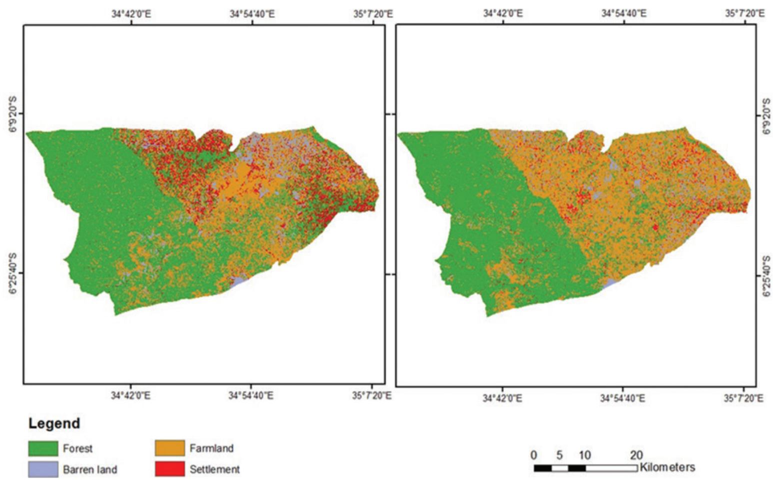
*Dependent variable: The main source of income.

The Evaluation of Variations in LULC from 1993 to 2023. Over the past 30 years, the study region has experienced considerable changes in land use and land cover, altering as much as 31.46 % of the region’s landscape, equivalent to 440.48 km² (Figs. 3, 4 and 5). These transformations are characterized by a 2.88 % increase in forest cover, adding up to 246.82 km², alongside a 9.09 % growth in settlements, which expands the urban area by 222.76 km². Additionally, barren lands have seen a 5.20 % rise, growing by 98.07 km². Conversely, farmland has witnessed a significant reduction, decreasing by 17.17 % or 119.72 km² (Table 2). Collectively, these changes signal a dynamic evolution in the region’s landscape, marked by the decline in agricultural areas and expansion of both urban and forested zones.



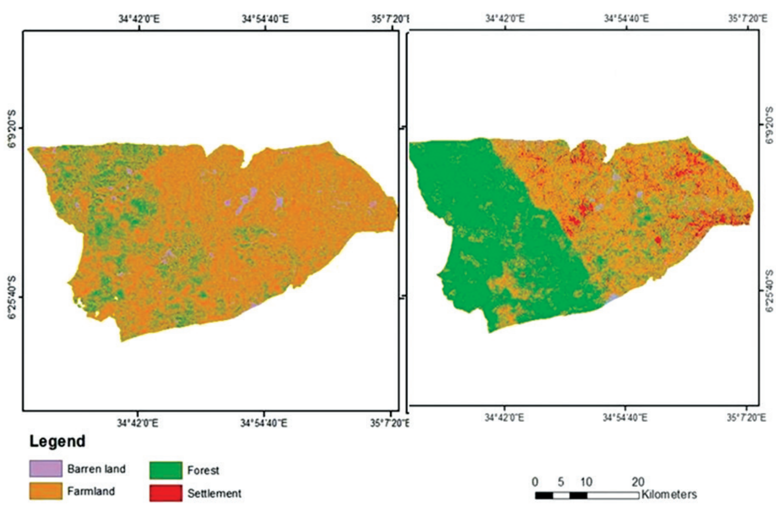
a *b*

Fig. 3. The LULC change for the period from 1993 (*a*) to 2003 (*b*)



a *b*

Fig. 4. The LULC change for the period from 2013 (*a*) to 2023 (*b*)



a *b*

Fig. 5. The LULC change for the period from 1993 (*a*) to 2023 (*b*)

Table 2

The changes in LULC from 1993 to 2023

Land cover	1993, km²	2023, km²	Δ, km²	1993, %	2023, %	Δ, %
Forest	596.00	842.82	246.82	43.40	46.28	2.88
Barren land	10.14	108.21	98.07	0.74	5.94	5.20
Settlement	175.59	398.35	222.76	12.79	21.87	9.09
Farmland	591.41	471.69	–119.72	43.07	25.90	–17.17

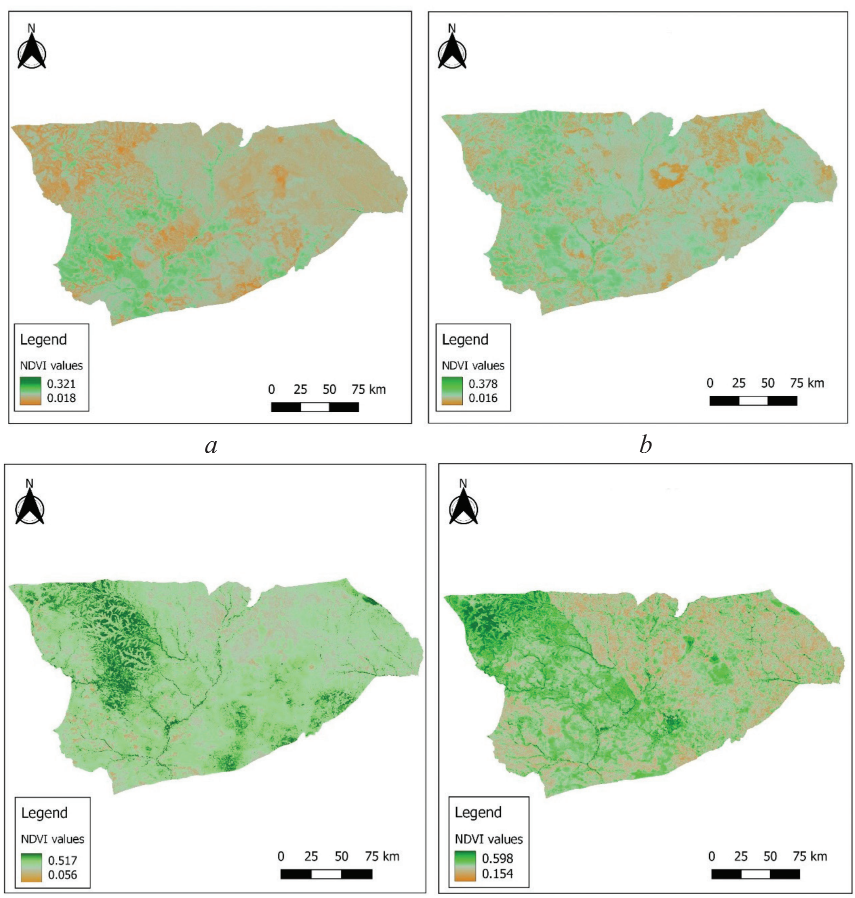
The Impact on Ecosystem and Community Livelihood. Over the past 30 years, from 1993 to 2023, the NDVI has consistently and significantly increased, showing that the study area's vegetation health and density have significantly improved (Table 3). In addition to correlating well with the observed increase in forest cover in the area, the steady rise in NDVI values over the period indicates a strengthening of vegetation growth and biomass build-up. Areas with higher NDVI indicators appear to have had considerable gains in vegetation health and density, as indicated by the positive trend in NDVI values, which indicates a strong link. Consistent with conservation initiatives and shifts in land use, this enhancement is more noticeable in vegetated regions. This research shows that changes in land cover have a direct impact on ecosystem health, as measured by NDVI.

Table 3

The NDVI with Standard Deviation from 1993 to 2023

Year	NDVI	Standard deviation
1993	0.28	0.14
2003	0.33	0.13
2013	0.38	0.12
2023	0.43	0.11

The mean and standard deviation of NDVI values in Table 4 and Fig. 6 have been calculated for each time period (1993, 2003, 2013, and 2023, respectively). The results have shown a consistent upward trend in vegetation health over the 30-year period. Specifically, in Table 4 the mean NDVI has increased from 0.28 in 1993 to 0.43 in 2023, indicating a significant improvement in vegetation density and greenness. The standard deviation has decreased slightly from 0.14 to 0.11, suggesting a more uniform vegetation distribution across the study area in recent years. These values support the observed forest cover expansion and reinforce the findings of improved ecosystem conditions due to conservation efforts and land management policies.



c *d*

Fig. 6. The NDVI for the period from 1993 to 2023: *a* – 1993; *b* – 2003; *c* – 2013; *d* – 2023

Table 4

The percentage of land area by the NDVI class (1993–2023)

NDVI range	Vegetation Status	1993, %	2003, %	2013, %	2023, %
<0.1	Non-vegetated/Bare	18.2	13.5	10.9	8.1
0.1–0.3	Sparse	34.6	31.2	26.7	18.7
0.3–0.5	Moderate	30.1	34.8	38.4	43.0
>0.5	Dense	17.1	20.5	24.0	30.2

The analysis of the NDVI from 1993 to 2023 exposes a substantial improvement in vegetation cover across the study area of the Sasilo and Nkonko Wards in the Manyoni District (Fig. 7). The proportion of land with dense vegetation (NDVI > > 0.5) has increased from 17.1 % in 1993 to 30.2 % in 2023, while the areas with sparse or no vegetation (NDVI < 0.3) has decreased from 52.8 to 26.8 %. These results confirm that vegetation recovery is not limited to isolated pixels but represents a widespread ecological improvement, reflecting the impact of conservation efforts and changing land use practices over 30 years.

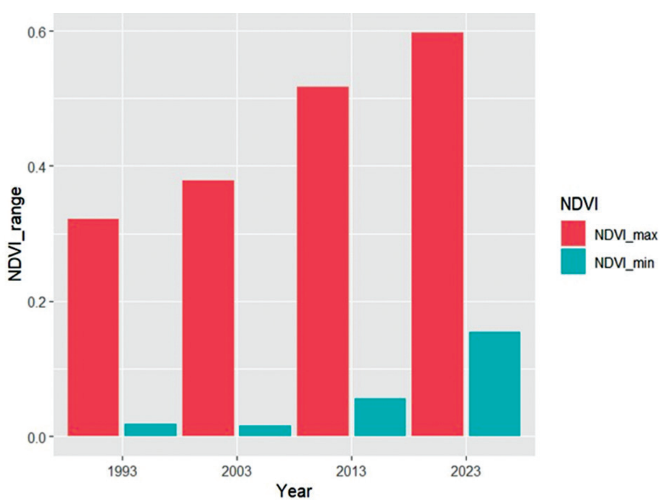


Fig. 7. The NDVI minimum and maximum values graph

The benefit of the NDVI chart is that it provides a clear temporal trend of vegetation change across the entire study area, complementing the spatial insights from the maps. To address the concern about isolated high values, we have included the percentage distribution of NDVI ranges, which more accurately reflects broad-scale vegetation improvement rather than relying on extreme pixel values.

The Primary Driving Factors for LULC Changes. The changes in LULC observed in the area over the past 30 years can be attributed to a complex mixture of contributing factors. Notably, conservation policies enacted after 2003 aimed at protecting community forests near the Rungwa-Kizigo-Muhesi Game Reserves have significantly influenced the rejuvenation of forest cover, highlighting the critical role of legislative frameworks in land use management and conservation efforts. Concurrently, the growth of settlements driven by population expansion and the desire for new sources of income has put greater demands for land resources, resulting mostly in the conversion of farmland into settlement areas, while protected forested areas have been recovering and expanding.

Settlement expansion has primarily transformed farmland, while protected forest areas have been experiencing recovery due to conservation policies. This resolves the earlier contradiction and distinguishes between the areas of pressure and regeneration.

Additionally, agricultural practices have adapted to the shifting availability of arable land, with the changes in land use patterns emerging from both settlement expansion and conservation measures. The temporary halt in the decrease of farmland areas observed in 2013 and 2023 illustrates the community's adaptive strategies to overcome the challenges posed by restricted land availability.

Forest Products Status in the Study Area. The residents of the Nkonko and Sasilo Wards are obviously significantly dependent on forest products for a variety of needs connected to their livelihood, as seen by the staggering 98 % of community members using these resources (Table 5). The tiny minority of 2 % who do not use forest resources contrasts sharply with the large majority, signifying unusual circumstances or non-normative preferences. The primary usage of firewood and charcoal by over half of the respondents (51.3 %) highlights the vital role that these resources play in providing families with the energy they need on a daily basis. There is a need for improvement in community education and awareness of sustainable forest utilization, as evidenced by the acknowledgement of non-timber forest products (NTFPs) and the slight uncertainty (2.3 %). A few more forest products that demonstrate the diverse range of uses for forest resources are grass for livestock (12.3 %), timber and bamboo (13.9 %), and honey (11.3 %).

Table 5

The forest products status in the study area

Variables	Items	Frequency, N	Relative frequency, %	Cumulative frequency, %
Constant use of forest products	Yes	346	98.0	98.0
	No	7	2.0	100
Forest products, which are the most important	Firewood and charcoal	181	51.3	51.3
	Grass for livestock	44	12.3	63.6
	Timber and bamboo	49	13.9	77.5
	Honey	40	11.3	88.8
	Other NTFPs	31	8.2	97.0
	Do not know	8	2.3	100
NTFPs availability status	Declined	345	97.7	97.7
	Increased	0	0	97.7
	Do not know	8	2.3	100
Reasons for increase or decline	Agriculture	196	55.5	55.5
	Charcoal burning	78	22.1	77.6
	Bush burning	43	12.2	89.8
	Timber harvesting	32	9.1	98.9
	Do not know	4	1.1	100

Significant changes in LULC over the last 30 years, primarily due to conservation initiatives, population shifts, and changes in agricultural methods, are intersected with this deep community engagement with forest resources. Land use patterns have been permanently altered by the 1990s extension of the Rungwa-Kizigo-Muhesi

Game Reserves, which has forced the migration of communities that had previously been involved in agriculture inside these boundaries. This expansion has acted as a contributing factor to the observed decline in farmland areas and demonstrated the importance of conservation and legislative initiatives in influencing land use patterns. The community's adaptive methods in response to shifting land availability and conservation policies are further reflected in the modifications made to agricultural practices and the rise of settlements, which are driven by population increase and the pursuit for new chances for livelihood. A complex interaction between conservation efforts, land use management, and community livelihoods is highlighted by these developments as well as the community's reliance on forest products. This emphasizes the need for well-balanced approaches that support both ecological sustainability and human well-being.

A regression investigation has shown that the variable "Most important forest products" is the only one that significantly predicts income ($B = 0.994$, $p < .001$). This shows that people depend on crucial forest products for their livelihoods. This is similar to what happened in Liberia, where activities related to forest products have raised household income by up to 167 % for non-timber items [1, 2]. A research from Malawi has also shown that reliance goes beyond money and includes time and access issues [45]. When the forest cover declines, it becomes much harder for people to get crucial materials, as it one way or another can directly affect various sources of income. This shows the importance of long-term sustainable forest management plan for environment and people who depend much on these forests.

There have been noticeable changes to the study area's geography over the past 30 years, with more urban areas and forests appearing, less farmland disappearing, and more desolate terrain spreading out. Because of urbanization, changes in agriculture, and conservation efforts, land use is changing all throughout the world, and these movements reflect that. The significance of satellite imagery in monitoring environmental changes is underscored by the fact that the increase in forest cover, as confirmed by López-Amoedo et al. [32], may indicate the success of afforestation and reforestation initiatives or even natural regrowth [52]. At the same time, the larger tendencies of urbanization, as those seen in Jodhpur city, where the social, economic, and ecological effects of growing cities are being observed, are consistent with the 9 % growth in urban settlements [19]. This demonstrates the increasing urbanization of the research area and highlights the need for environmentally responsible approaches to city planning.

There is an urgent need for more sophisticated methods such as object-based image analysis (OBIA), multi-temporal change detection techniques, LiDAR, high-resolution satellite data, and machine learning-based classification for detecting changes in LULC if we are to solve the mystery of the increasing number of desolate landscapes, which may be the result of overexploitation or the negative impact of climate on soil quality. Simultaneously, the decrease in farmlands is in line with predictions made for Dongying City, China, which shows that agricultural land is being replaced by urban one according to the results of predictive modelling. This tendency is also mirrored in the research area [65]. Furthermore, studies that utilize Normalized Difference Built-up Index (NDBI) to forecast changes in LULC raise concerns about the growing demands for natural ecosystems, as evidenced by the shrinkage of naturally vegetated lands [26]. NDBI is an index used to detect built-up or urbanized areas [25]. Incorporating findings from the current research to situate the conversation within Tanzania framework of land use dynamics, these findings emphasize the need for careful oversight and control of land cover changes to prevent detrimental environmental effects.

The strong rise in NDVI values from 1993 to 2023 in the study area is consistent with the current scientific findings and highlights the impact of conservation efforts and careful land management on plant dynamics. This increase indicates better plant health and density. According to dos Santos et al. [14], who has examined the NDVI and its use in human health research, this upward tendency reflects the multidisciplinary nature of NDVI, which expands its utility beyond ecological studies to human health consequences. Simultaneously, changes in NDVI estimation methods, like the ones described by A.L.P. De Ocampo [12], using NDVI estimation based on filter augmented imaging, corroborate our findings, confirming that technological advancement is crucial for improving the accuracy of vegetation monitoring. The research by de la Iglesia Martinez et al. [11] and other studies on policy interventions allude to the use of NDVI in urban greening policies, which supports our findings on its positive effects on ecosystems. Consistent with the encouraging trends in vegetation that have been found, these references show that NDVI is valuable in many ecological, technological, and socioeconomic contexts, and that it plays an essential role in fostering environmental sustainability and urban well-being.

LULC changes in the study area over the past 30 years reflect broader worldwide trends found in present research. These changes have been determined by the dynamic interplay of conservation policies, settlement growth, and agricultural adaptations. These findings are in line with the ones by Gaur et al. [18] insisting on the significance of policy in sustainable land management, as the legislative frameworks passed after 2003 to save community forests close to Game Reserves, have been crucial in enabling the restoration of forest cover. The ecological consequences brought up by Anthony et al. [3] are echoed by the pressures caused by population development and settlement expansion, which result in the conversion of agriculture and forested areas for human consumption. This case study, together with the technological developments in monitoring LULC changes that Karandikar et al. [22] analyze, highlights the precarious equilibrium between protecting natural ecosystems and allowing for human population growth. Through the temporary stabilization of farmland areas, the community has been able to adapt to the changing availability of arable land, which mirrors the hydrological and environmental impacts on LULC dynamics studied by Lazurca (Andrei) et al. and Mekonnen et al. [30, 40]. These studies shed light on the many facets of LULC changes and show how important it is to have policies that drive comprehensive solutions combining human socioeconomic requirements with ecological sustainability.

Based on their almost universal use (98 %) and dependence on forest products, people living in the Nkonko and Sasilo Wards share views found in the current research on sustainable forest utilization. The studies by E.R. Eslit [16] and M. Qanitha et al. [50] shed light on the complex interplay between livelihoods and forest conservation. These researches support integrated strategies that, by using sustainable practices, not only improve community welfare but also protect ecosystems. These references emphasize conservation partnerships, the application of sustainable livelihood frameworks, and the influence of community narratives in designing conservation strategies all of which are pertinent to the needs and reality of the Nkonko and Sasilo Wards. The recognition of NTFPs and the wide range of uses of forest products, particularly the heavy reliance on firewood and charcoal, highlight the need for integrated forest management approaches. In order to guarantee that communities' means of subsistence are sustainable and compatible with conservation efforts, these tactics ought to involve and instruct local populations to follow the best sustainable forest management practices.

The comparison demonstrates a general agreement regarding the crucial equilibrium between utilizing forest resources for community sustenance and applying sustainable methods to guarantee long-term ecological and economic well-being.

A complicated situation that is consistent with findings in current academic literature is presented by the large changes in LULC. This has been seen over the previous 30 years due to conservation programs, demographic shifts, and agricultural revolutions. The 1990s development of the Rungwa-Kizigo-Muhesi Game Reserves, which has forced agricultural villages to migrate and resulted in a reduction of arable areas, highlights the significant influence of conservation and legal measures on patterns of land use. The complex link between conservation efforts, land use management, and community livelihoods that is highlighted in the studies [6, 29], is reflected in this scenario. The study clarifies how forest conservation efforts might change the use of agricultural land, requiring impacted communities to find alternate means of subsistence. Longitudinal studies like the one by Nigussie et al. [47] show how conservation policies change land use over time. These changes affect not just the physical landscapes but also the ways communities adapt. Also studies like the one by Masayi et al. [37] show how these kinds of changes directly influence the livelihoods of households. This shows how important it is to make sure that conservation efforts are in line with regionally feasible and sustainable ways to make a living.

The state of the Rungwa-Kizigo-Muhesi Game Reserves and the aggregate results from these studies highlight the urgent need for balanced approaches to land use planning and conservation that take into account both ecological sustainability and the welfare of local residents. In the face of shifting land use and conservation landscapes, they support laws and procedures that guarantee ecological preservation while also enabling communities to develop adaptable livelihood alternatives. Achieving long-term ecological integrity and socioeconomic stability requires this dual approach.

Conclusion

The landscape of the area under study has undergone major changes over the past 30 years, as evidenced by a thorough examination of changes in LULC. Notably, there has been a considerable expansion of urban settlements and forest cover, combined with a notable drop in cropland. These alterations highlight how dynamically population expansion, agricultural adaptations, and conservation initiatives interact within the research region. The expansion of settlements brought about by demographic changes and the rise in forest cover, which is attributable to conservation measures implemented close to the Rungwa-Kizigo-Muhesi Game Reserves, serve as an example of the many variables influencing LULC changes. The group's heavy reliance on forest resources for subsistence, together with the noted LULC changes, emphasizes how closely land management strategies, conservation initiatives, and community livelihoods are intertwined. This study clarifies not just how the environment is changing but also how important it is to implement sustainable management practices that balance environmental preservation with human welfare.

Policymakers and urban planners must devise and put into action plans that improve urban ecosystem services while meeting the increasing needs of urbanization in the light of the findings. In order to fully comprehend the effects of LULC changes, future studies should concentrate on the in-depth evaluation of particular ecosystem services, such as carbon sequestration and biodiversity protection. Innovative remote imaging technologies and GIS may also make it easier to track the health of ecosystems over time and give us a better understanding of how LULC changes over space. Policymakers should consider including community-based conservation programs that leverage regional knowledge and traditions in order to guarantee the sustainable use of forest resources. Urban planning frameworks should prioritize the protection of green spaces and stimulate the rehabilitation of damaged lands in order to maintain ecological balance and enhance the quality of life for urban inhabitants.

REFERENCES

1. Amadu F.O., Miller D.C. Food Security Effects of Forest Sector Participation in Rural Liberia. *Food Security*, 2024, vol. 16, pp. 1099–1124. https://doi.org/10.1007/s12571-024-01468-7

2. Amadu F.O., Miller D.C. The Impact of Forest Product Collection and Processing on Household Income in Rural Liberia. *Forest Policy and Economics*, 2024, vol. 158(C), art. no. 103098. https://doi.org/10.1016/j.forpol.2023.103098

3. Anthony T., Shaban N., Nahonyo C. Land Cover Change as a Proxy of Changes in Wildlife Distribution and Abundance in Tarangire-Simanjiro-Lolkisale-Mto wa Mbu Ecosystem. *Tanzania Journal of Science*, 2023, vol. 49, no. 1, pp. 196–206. https://doi.org/10.4314/tjs.v49i1.17

4. Azizi P., Soltani A., Bagheri F., Sharifi S., Mikaeli M. An Integrated Modelling Approach to Urban Growth and Land Use/Cover Change. *Land*, 2022, vol. 11, no. 10, art. no. 1715. https://doi.org/10.3390/land11101715

5. Babaremu K., Taiwo O., Ajayi D. Impacts of Land Use and Land Cover Changes on Hydrological Response. *TWIST*, 2024, vol. 19, no. 1, pp. 256–267.

6. Banadzem T. J.-L., Ambukwa G.A. Forest-Culture Relationship in NSO and Mbiame Fondoms: Case of the Montane Forests of Ngongbaa, Kovifem and Kovkinkar, North West Cameroon. *International Journal of Innovative Science and Research Technology*, 2022, vol. 7, iss. 1, pp. 919–935. https://doi.org/10.5281/zenodo.6291303

7. Beroho M., Briak H., Cherif E.K., Boulahfa I., Ouallali A., Mrabet R., Kebede F., Bernardino A., Aboumaria K. Future Scenarios of Land Use/Land Cover (LULC) Based on a CA-Markov Simulation Model: Case of a Mediterranean Watershed in Morocco. *Remote Sensing*, 2023, vol. 15, no. 4, art. no. 1162.

8. Bindajam A.A., Mallick J., Talukdar S., Islam A.R.Md.T., Alqadhi S. Integration of Artificial Intelligence–Based LULC Mapping and Prediction for Estimating Ecosystem Services for Urban Sustainability: Past to Future Perspective. *Arabian Journal of Geosciences*, 2021, vol. 14, art. no. 1887. https://doi.org/10.1007/s12517-021-08251-4

9. Cobbinah P.B. Urban Resilience in Climate Change Hotspot. *Land Use Policy*, 2021, vol. 100, art. no. 104948. https://doi.org/10.1016/j.landusepol.2020.104948

10. Dasgupta S., Lall S., Wheeler D. Spatiotemporal Analysis of Traffic Congestion, Air Pollution, and Exposure Vulnerability in Tanzania. *Science of the Total Environment*, 2021, vol. 778, art. no. 147114.

11. De la Iglesia Martinez A., Labib S.M. Demystifying Normalized Difference Vegetation Index (NDVI) for Greenness Exposure Assessments and Policy Interventions in Urban Greening. *Environmental Research*, 2023, vol. 220, art. no. 115155. https://doi.org/10.1016/j.envres.2022.115155

12. De Ocampo A.L.P. Normalized Difference Vegetation Index (NDVI) Estimation based on Filter Augmented Imaging. *2023 International Electrical Engineering Congress (iEECON)*. Thailand, Krabi, 2023, pp. 84–88. https://doi.org/10.1109/iEECON56657.2023.10126616

13. Debangshi U., Ghosh P., Tiwari H., Maurya D.K., Kumar M. Urban Resiliency towards Climate Change. *International Journal of Environment and Climate Change*, 2022, vol. 12, no. 11, pp. 2037–2055. https://doi.org/10.9734/IJECC/2022/v12i1131194

14. Dos Santos J.d.B.G., de Souza Hacon S., Alves da Silva Neves S.M. Índice de Vegetação por Diferença Normalizada (NDVI) e Seu Uso no Estudo da Saúde Humana: Uma Revisão de Escopo. *Revista Brasileira de Geografia Física*, 2023, vol. 16, no. 3, pp. 1115–1144. (In Port.). https://doi.org/10.26848/rbgf.v16.3.p1115-1144

15. Enoh M.A., Njoku R.E., Okeke U.C. Modeling and Mapping the Spatial–Temporal Changes in Land Use and Land Cover in Lagos: A Dynamics for Building a Sustainable Urban City. *Advances in Space Research*, 2023, vol. 72, iss. 3, pp. 694–710. https://doi.org/10.1016/j.asr.2022.07.042

16. Eslit E.R. Whispers of the Woodlands: Unveiling the Interplay of Forest Conservation and Livelihood through Community Narratives. *Preprints*, 2023. 15 p. https://doi.org/10.20944/preprints202306.1207.v1

17. Fahad S., Li W., Valjarević A., Kavroudakis D., Sharifi A. The Impact of Rapid Urban Growth on Land Use and Land Cover Change and Urban Heat Island: The Case of Babuzai, Pakistan. *Research Square*, 2023. https://doi.org/10.21203/rs.3.rs-2828285/v1

18. Gaur S., Singh R. A Comprehensive Review on Land Use/Land Cover (LULC) Change Modeling for Urban Development: Current Status and Future Prospects. *Sustainability*, 2023, vol. 15, no. 2, art. no. 903. https://doi.org/10.3390/su15020903

19. Gupta N., Mathew A., Khandelwal S. Spatio-Temporal Impact Assessment of Land Use/Land Cover (LU-LC) Change on Land Surface Temperatures over Jaipur City in India. *International Journal of Urban Sustainable Development*, 2020, vol. 12, no. 1, pp. 283–299. https://doi.org/10.1080/19463138.2020.1727908

20. Huang W., Huang J., Wang X., Wang F., Shi J. Comparability of Red/Near-Infrared Reflectance and NDVI Based on the Spectral Response Function between MODIS and 30 Other Satellite Sensors Using Rice Canopy Spectra. *Sensors*, 2013, vol. 13, no. 12, pp. 16023–16050. https://doi.org/10.3390/s131216023

21. John E.M. *A Forest Monitoring System for Tanzania: Mapping Change and Extent*: Thesis. Aberystwyth University, 2023. 373 p.

22. Karandikar A.M., Agrawal A.J., Welekar R.R. Decadal Forest Cover Change Analysis of the Tropical Forest of Tadoba-Andhari, India. *Signal, Image and Video Processing*, 2023, vol. 18, pp. 1705–1714. https://doi.org/10.1007/s11760-023-02872-w

23. Kija H.K., Ogutu J.O., Mangewa L.J., Bukombe J., Verones F., Graae B.J., Kideghesho J.R., Said M.Y., Nzunda E.F. Land Use and Land Cover Change within and around the Greater Serengeti Ecosystem, Tanzania. *American Journal of Remote Sensing*, 2020, vol. 8, iss. 1, pp. 1–19. https://doi.org/10.11648/j.ajrs.20200801.11

24. Klimas E. Sustainable Development and Urban Planning Regulations in the Context of Climate Change Management Measures. *Entrepreneurship and Sustainability Issues*, 2020, vol. 8, no. 1, pp. 24–37. https://doi.org/10.9770/jesi.2020.8.1(2)

25. Kshetri T.B. NDVI, NDBI and NDWI Calculation Using Landsat 7 and 8. *GeoWorld*, 2018, vol. 2, pp. 32–34.

26. Kulkarni K., Vijaya P.A. NDBI Based Prediction of Land Use Land Cover Change. *Journal of the Indian Society of Remote Sensing*, 2021, vol. 49, pp. 2523–2537. https://doi.org/10.1007/s12524-021-01411-9

27. Kuma H.G., Feyessa F.F., Demissie T.A. Assessing the Impacts of Land Use/Land Cover Changes on Hydrological Processes in Southern Ethiopia: The SWAT Model Approach. *Cogent Engineering*, 2023, vol. 10, no. 1, art. no. 2199508. https://doi.org/10.1080/23311916.2023.2199508

28. Lachir A. Climate Integration in Sustainable Urban Planning. *Addressing Environmental Challenges through Spatial Planning*. IGI Global Publ., 2022, pp. 152–173. https://doi.org/10.4018/978-1-7998-8331-9.ch008

29. Lambi C.M. *International Journal of Resource and Environmental Management*, 2021, vol. 6, no. 2.

30. Lazurca (Andrei) L.G., Mihăilă D., Ionel Bistricean P., Dănuț Horodnic V. Air Quality Assement for Suceava County, Romania. *EGU23, the 25th EGU General Assembly*, 2023, art. no. EGU23-397. https://doi.org/10.5194/egusphere-egu23-397

31. Lim J., Watanabe N., Yoshitoshi R., Kawamura K. Simple In-Field Evaluation of Moisture Content in Curing Forage Using Normalized Differece Vegetation Index (NDVI). *Grassland Science*, 2020, vol. 66, iss. 4, pp. 238–248.

32. López-Amoedo A., Álvarez X., Lorenzo H., Rodriguez J.L. Multi-Temporal Sentinel-2 Data Analysis for Smallholding Forest Cut Control. *Remote Sensing*, 2021, vol. 13, no. 15, art. no. 2983. https://doi.org/10.3390/rs13152983

33. Luthra A. Climate Change and Sustainable Urban Transport Environment. *Climate Change and Urban Environment Sustainability*. Spinger Singapore, 2023, pp. 31–45. https://doi.org/10.1007/978-981-19-7618-6_3

34. MacDonald G. Climate, Capital, Conflict: Geographies of Success or Failure in the Twenty-First Century. *Annals of the American Association of Geographers*, 2020, vol. 110, no. 6, pp. 2011–2031. https://doi.org/10.1080/24694452.2020.1800300

35. Maruf J.K., Ara S. Examining the Ecosystem Service Values due to LULC Changes: A Case Study on Cox's Bazar, Bangladesh. *Khulna University Studies*, 2022, p. 443–457. https://doi.org/10.53808/KUS.2022.ICSTEM4IR.0079-se

36. Maruf J.K., Ara S. Examining the Spatio-Temporal Changes of Ecosystem Service Value Due to LULC Changes: A Case Study on Cox's Bazar, Bangladesh. *Research Square*, 2023. https://doi.org/10.21203/rs.3.rs-2500133/v1

37. Masayi N., Tsingalia M., Omondi P. Land Use Changes and Impacts on Livelihoods of the Communities Adjacent to Mt Elgon Forest Ecosystem. *Journal of Geography, Environment and Earth Science International*, 2020, vol. 24, no. 7, pp. 1–12. https://doi.org/10.9734/JGEESI/2020/v24i730239

38. Masolele R.N. Mapping the Diversity of Land Uses Following Deforestation across Africa. *Scientific Reports*, 2024, vol. 14, no. 1, art. no. 1681.

39. Mbwambo E.P., Kabote S.J., Kazuzuru B. Impact of Climate Variability and Change Adaptation Strategies on Technical Efficiency of Sorghum Production in Manyoni District, Tanzania. *Tanzania Journal of Agricultural Sciences*, 2023, vol. 22, no. 1, pp. 153–168.

40. Mekonnen Y.A., Manderso T.M. Land Use/Land Cover Change Impact on Streamflow Using Arc-SWAT Model, in Case of Fetam Watershed, Abbay Basin, Ethiopia. *Applied Water Science*, 2023, vol. 13, art. no. 111. https://doi.org/10.1007/s13201-023-01914-5

41. Miringay G.J., Burra M.M., Babere N.J. The Administrative Transformation of the Urban Authority and the Emerging Quarantined Rural Satellite Towns (ERSTs) in Urban Authorities. The Case of Dodoma National Capital City, Tanzania. *International Journal of Social Science Research and Review*, 2022, vol. 5, no. 11, pp. 180–192. https://doi.org/10.47814/ijssrr.v5i11.721

42. Miringay G.J., Burra M.M., Babere N.J. The Administrative Transformation of the Agrarian Urban Authority and the Emergence of Urban Village in Urban Settings. *African Journal of Land Policy and Geospatial Sciences*, 2023, vol. 6, no. 1, pp. 107–128. https://doi.org/10.48346/IMIST.PRSM/ajlp-gs.v6i1.32450

43. Mosha D., Kakolwa M.A., Mahende M.K., Masanja H., Abdulla S., Drakeley C., Gosling R., Wamoyi J. Safety Monitoring Experience of Single-Low Dose Primaquine Co-Administered with Artemether–Lumefantrine among Providers and Patients in Routine Healthcare Practice: a Qualitative Study in Eastern Tanzania. *Malaria Journal*, 2021, vol. 20, art. no. 392. https://doi.org/10.1186/s12936-021-03921-w

44. Mugo R., Waswa R., Nyaga J.W., Ndubi A., Adams A.C., Flores-Anderson A.I. Quantifying Land Use Land Cover Changes in the Lake Victoria Basin Using Satellite Remote Sensing: The Trends and Drivers between 1985 and 2014. *Remote Sensing*, 2020, vol. 12, no. 17, art. no. 2829. https://doi.org/10.3390/rs12172829

45. Nerfa L., Rhemtulla J.M., Zerriffi H. Forest Dependence is More than Forest Income: Development of a New Index of Forest Product Collection and Livelihood Resources. *World Development*, 2020, vol. 125, art. no. 104689. https://doi.org/10.1016/j.worlddev.2019.104689

46. Ngondo J., Mango J., Liu R., Nobert J., Dubi A., Cheng H. Land-Use and Land-Cover (LULC) Change Detection and the Implications for Coastal Water Resource Management in the Wami–Ruvu Basin, Tanzania. *Sustainability*, 2021, vol. 13, no. 8, art. no. 4092.

47. Nigussie G., Fekadu M., Demissew S., Warkineh B. Impact of Conservation Management on Land Change: a Case Study in Guassa Community Conservation Area for the Last 31 Years (1986–2015). *Modeling Earth Systems and Environment*, 2019, vol. 5, pp. 1495–1504. https://doi.org/10.1007/s40808-019-00650-7

48. Pereira P., Inacio M., Kalinuskas M., Bogdzevič K., Bogunovic I., Zhao W. Land-Use Change Impacts on Ecosystem Services: An Overview. *EGU General Assembly 2022*, 2022, art. no. EGU22-6301. https://doi.org/10.5194/egusphere-egu22-63-1

49. Pugara A., Pradana B., Priambudi B.N. The Impact of the Land Use Changes through Batang Spatial Planning on the Ecosystem Services on Climate Management. *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 1082, art. no. 012022. https://doi.org/10.1088/1755-1315/1082/1/012022

50. Qanitha M., Hardjanto H., Sundawati L. Strategy on Sustainable Livelihood Community after Implementation Conservation Partnership in National Parks Bantimurung-Bulusaraung. *Media Konservasi*, 2023, vol. 28, no. 1, pp. 77–83. https://doi.org/10.29244/medkon.28.1.77-83

51. Rahman Md.M., Huq H., Mukul S.A. Implications of Changing Urban Land Use on the Livelihoods of Local People in Northwestern Bangladesh. *Sustainability*, 2023, vol. 15, no. 15, art. no. 11769. https://doi.org/10.3390/su151511769

52. Rynkiewicz A., Hoscilo A., Chmielewska M., Lewandowska A., Aune-Lundberg L., Nilsen A. Detection of Land Cover Changes Based on the Sentinel-2 Multitemporal Data on the GEE Platform. *EGU23, the 25th EGU General Assembly*, 2023, art. no. EGU23-17586. https://doi.org/10.5194/egusphere-egu23-17586

53. Sagali H.L., Yingli H. Barriers to Equity: Investigating Community Challenges in Accessing and Benefiting from Forest Resources in Manyoni, Tanzania. *International Forestry Review*, 2024, vol. 26, no. 2, pp. 234–247. https://doi.org/10.1505/146554824838819914

54. Sagali H.L., Yingli H., Mendako R.K. Assessing the Economic Significance of Forest Income in Community Livelihoods in Manyoni District, Tanzania. *International Forestry Review*, 2024, vol. 26, no. 2, pp. 248–259. https://doi.org/10.1505/146554824838819888

55. Semeraro T. Impact Assessment of Green Infrastructure in Urban Planning. *Current Advances in Geography, Environment and Earth Sciences*, 2022, vol. 9, pp. 82–94. https://doi.org/10.9734/bpi/cagees/v9/4118E

56. Shah M.I., Abbas S., Olohunlana A.O., Sinha A. The Impacts of Land Use Change on Biodiversity and Ecosystem Services: An Empirical Investigation from Highly Fragile Countries. *Sustainable Development*, 2023, vol. 31, iss. 3, pp. 1384–1400. https://doi.org/10.1002/sd.2454

57. Simon O., Lyimo J., Gwambene B., Yamungu N. Unveiling the Transforming Landscape: Exploring Patterns and Drivers of Land Use/Land Cover Change in Dar es Salaam Metropolitan City, Tanzania. *African Geographical Review*, 2024, vol. 43, no. 2, pp. 875–891. https://doi.org/10.1080/19376812.2024.2309405

58. Singh B., Venkatramanan V., Deshmukh B. Monitoring of Land Use Land Cover Dynamics and Prediction of Urban Growth Using Land Change Modeler in Delhi and its

Environs, India. *Environmental Science and Pollution Research*, 2022, vol. 29, pp. 71534–71554. https://doi.org/10.1007/s11356-022-20900-z

59. Sumari N.S., Xu G., Ujoh F., Korah P.I., Ebohon O.J., Lyimo N.N. A Geospatial Approach to Sustainable Urban Planning: Lessons for Morogoro Municipal Council, Tanzania. *Sustainability*, 2019, vol. 11, no. 22, art. no. 6508. https://doi.org/10.3390/su11226508

60. Thonfeld F., Steinbach S., Muro J., Kirimi F. Long-Term Land Use/Land Cover Change Assessment of the Kilombero Catchment in Tanzania Using Random Forest Classification and Robust Change Vector Analysis. *Remote Sensing*, 2020, vol. 12, no. 7, art. no. 1057. https://doi.org/10.3390/rs12071057

61. Vatitsi K., Ioannidu N., Mirli A., Siachalou S., Kagalou I., Latinopoulo D., Mallinis G. LULC Change Effects on Environmental Quality and Ecosystem Services Using EO Data in Two Rural River Basins in Thrace, Greece. *Land*, 2023, vol. 12, no. 6, art. no. 1140. https://doi.org/10.3390/land12061140

62. Wang R., Xu X., Bai Y., Alatalo J.M., Yang Z., Yang W., Yang Z. Impacts of Urban Land Use Changes on Ecosystem Services in Dianchi Lake Basin, China. *Sustainability*, 2021, vol. 13, no. 9, art. no. 4813. https://doi.org/10.3390/su13094813

63. Zella A.Y., Kitali L.J., Lusiru S.N., Malekela A.A., Msambichaka S., Nassor Z., Ntaturo E. Adapting Innovation of Information and Communication Technologies to Climate Change Risks for Agriculture Sustainability in Central Tanzania. *World Journal of Advanced Science and Technology*, 2023, vol. 3, no. 1, pp. 52–66. https://doi.org/10.53346/wjast.2023.3.1.0057

64. Zhang J., Chen S.S., Gao Q., Shen Q., Kimirei I.A., Mapunda D.W. Morphological Characteristics of Informal Settlements and Strategic Suggestions for Urban Sustainable Development in Tanzania: Dar es Salaam, Mwanza, and Kigoma. *Sustainability*, 2020, vol. 12, no. 9, art. no. 3807. https://doi.org/10.3390/su12093807

65. Zhao X., Wang P., Gao S., Yasir M., Islam Q.U. Combining LSTM and PLUS Models to Predict Future Urban Land Use and Land Cover Change: A Case in Dongying City, China. *Remote Sensing*, 2023, vol. 15, no. 9, art. no. 2370. https://doi.org/10.3390/rs15092370

Конфликт интересов: Авторы заявляют об отсутствии конфликта интересов
Conflict of interest: The authors declare that there is no conflict of interest

Вклад авторов: Все авторы в равной доле участвовали в написании статьи
Authors' Contribution: All authors contributed equally to the writing of the article