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Spatiotemporal NDVI Analysis of Kipengere Forest Reserve Dynamics in Tanzania: Evidence from 1995 to 2026

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ABSTRACT

Forest ecosystems are of great importance for biodiversity conservation and water resource regulation but are increasingly subject to environmental and land-use changes. The study analysed the spatiotemporal dynamics of vegetation condition in the Kipengere Forest Reserve, Southwest Tanzania from 1995 to 2026 using the Normalized Difference Vegetation Index (NDVI) generated from Landsat satellite images. Using QGIS, Landsat 5 imagery of March 1995 and Landsat 9 imagery of May 2026 were processed and analysed. The NDVI values were classified into five vegetation-condition categories ranging from very low to very high density and the changes in their spatial coverage were quantified. The results indicate that there is a significant change in the vegetation condition over the 31 years. In 1995, 45% (15,835.50 ha) and 45% (15,801.21 ha) of the reserve was covered by moderate and relatively dense vegetation, respectively, with 3.86% (1,354.24 ha) covered by dense vegetation. Moderate vegetation increased to 73.6% (25,841.30 ha) in 2026 and relatively dense vegetation decreased to 17% (6,058.83 ha). Vegetation cover dropped to 1% (386.73 ha). Very sparse and sparse vegetation increased marginally. Generally, the results suggest a transition from higher density vegetation to predominantly moderate vegetation, indicating reduced vegetation density and greenness. Although specific drivers cannot be identified, it is recommended to have continued monitoring and investigation of land use change, human activities, climate variability, fire, and other environmental factors. The results offer a baseline for conservation planning and sustainable management of the reserve and its related water resources.

INTRODUCTION

Forest ecosystems are one of the most important components of the terrestrial environment, providing a wide range of ecological, hydrological and socioeconomic services. They help regulate and maintain water resources, contribute to climate regulation, and protect soils and support biodiversity (Sehar *et al.*, 2026; Singh & Nair, 2026; Deori, 2025; Ola, 2025; Ngwembe *et al.*, 2022; Turpie *et al.*, 2015). Forests also provide fuelwood (Food and Agriculture Organization of the United Nations (FAO) & Landscape Alliance, 2026), construction materials (Food and Agriculture Organization of the United Nations (FAO), 2011), food, medicinal resources (FAO & Landscape Alliance, 2026) and other ecosystem products (Turpie *et al.*, 2015; Bauhus *et al.*, 2010) that are closely related to the livelihoods of local communities in many regions. Thus, the condition and geographical distribution of forest vegetation are of vital importance for the ecological stability, protection of biodiversity and sustainable management of natural resources.

However, despite that forest ecosystems are ecologically and socioeconomically important, they are increasingly being affected by land-use and land-cover change (Verma *et al.*, 2026; Sanga & Haulle, 2025; Busch & Ferretti-Gallon, 2023), agricultural expansion (Mohiuddin, 2025), settlement (Kut Görgün & Salata, 2025; Yang *et al.*, 2019), resource extraction (Ntukey *et al.*, 2022; Danlami, 2018), fire (Bousfield & Morton, 2026) and climatic variability (Karuppiah *et al.*, 2026; Buba, Gajere, & Ngum, 2020; Mkiramweni *et al.*, 2016; Sârbu *et al.*, 2014). As a result, the structure and density of vegetation have been altered, and the quality of forests and the capacity of forest ecosystems to deliver important ecosystem services have been reduced (Sehar *et al.*, 2026; Ortega-Barrueta *et al.*, 2025; Wani & Sahoo, 2020). Therefore, the situation calls for a reliable assessment of vegetation dynamics in order to understand environmental change and support conservation and forest management, particularly in large and inaccessible forest landscapes, where changes can be subtle and difficult to detect solely from field observations.

Remote sensing (RS) techniques have been a valuable tool to monitor vegetation dynamics over large areas and long periods. Satellite-based observations allow for the repeated assessment of vegetation characteristics and spatially consistent information that can be integrated with geographic information systems (GIS) for mapping and change detection (Karuppiah *et al.*, 2026; Chouiter *et al.*, 2025; Dlamini *et al.*, 2025; Gandri *et al.*, 2025). Among the commonly used satellite-based indicators, Normalized Difference Vegetation Index (NDVI) is widely used to evaluate vegetation greenness, density and condition. NDVI uses the contrast between how vegetation reflects light in the near-infrared and red wavelengths of the electromagnetic spectrum (Rao, 2025; Buba *et al.*, 2020; Huang *et al.*, 2020). NDVI is especially

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helpful for identifying areas with different amounts of vegetation cover and for monitoring changes over time (Dlamini *et al.*, 2025; Bora & Bora, 2024; Vélez *et al.*, 2023). According to El-Gammal *et al.* (2014) the long-term availability of Landsat imagery allows the possibility of examining vegetation dynamics over several decades and, therefore, is suitable for evaluating historical changes in forest ecosystems.

Forest ecosystems are important for biodiversity conservation and regulation of water resources in Tanzania, especially in areas associated with key headwaters and catchments. In recognition of that, the country has had several strategies that aim to manage forest resources sustainably. This strategy includes the National Strategy for Growth and Reduction of Poverty (NSGRP II), which was aligned to the Tanzania Development Vision 2025 and was committed to the Millennium Development Goals (MDGs) (United Republic of Tanzania, 2000). The Tanzania Development Vision 2050 (TDV 2050) is the next step after NSGRP II, which is committed to managing forest resources sustainably by embedding environmental integrity and climate change resilience as a core strategic pillar of national transformation (United Republic of Tanzania, 2025). The TDV 2050 is also related to the Sustainable Development Goal 15, which calls for assuring protection and sustainable management of terrestrial ecosystems (forests), battling desertification, preventing and reversing land degradation and halting biodiversity loss (United Nations, 2015).

The Kipengere Forest Reserve in southwest Tanzania is located within a landscape of considerable ecological importance and contributes to important environmental functions, including watershed protection (The United Republic of Tanzania (URT), Ministry of Natural Resources and Tourism (MNRT), Tanzania Forest Services (TFS), 2026; The URT, MNRT, Tanzania Wildlife Management Authority (TAWA), 2026; Chilagane *et al.*, 2024; Mulungu, 2019). However, like many forested landscapes, the reserve may be subject to interacting environmental and human-induced pressures. Assessing whether vegetation condition has changed or remained stable over time is therefore important for identifying emerging conservation concerns and informing sustainable management.

Despite the ecological importance of the Kipengere Forest Reserve, there is limited information on long-term spatial changes in vegetation condition based on consistent satellite observations. This study therefore analysed spatial and temporal changes in vegetation condition in Kipengere Forest Reserve, southwest Tanzania, between 1995 and 2026 using the NDVI derived from Landsat satellite imagery. Specifically, the study compared vegetation-condition classes between 1995 and 2026 and quantified changes in their spatial extent. The study aimed to provide a long-term assessment of vegetation condition and contribute baseline information to support forest conservation, monitoring, and sustainable management of Kipengere Forest Reserve and associated water resources.

MATERIALS AND METHODS

Description of the Study Area

The Kipengere Forest Reserve, consisting of the montane woodlands (mid-altitude miombo woodlands) in Njombe Region in southwest Tanzania, is located between 8 degrees 50 minutes, 9 degrees 13 minutes, 34 degrees 05 minutes and 34 degrees 25 minutes. Iongitude, lying partly within Makete District and partly within Wanging'ombe District (Figure 1). The Kipengere Forest Reserve is within the Kipengere Ranges, a plateau-ridge of mountains forming part of the eastern escarpment of the East African Rift. It covers an area of about 350.8 km² (TFS: (The United Republic of Tanzania, Ministry of Natural Resources and Tourism, Tanzania Forest Services Agency (TFS), 2026). Its altitude ranges from 1736 to 2832 m above sea level with annual rainfall between 823 and 1500 mm; the rainy season typically extends from November to April (Makwati *et al.*, 2026; Mbululo & Nyihirani, 2012).

The Kipengere Forest Reserve has predominantly two vegetation communities, namely; Tall montane forest trees (such as Podocarpus gracilis, Polyscias fulva, and Pouteria adolfi-friedericii), and Miombo woodland (such as Brachystegia microphylla and Julbernardia globiflora) (Mashalla &Ringo, 2015).

The Kipengere Forest Reserve was established in 1958, and currently is under the Tanzania Forest Services (TFS)

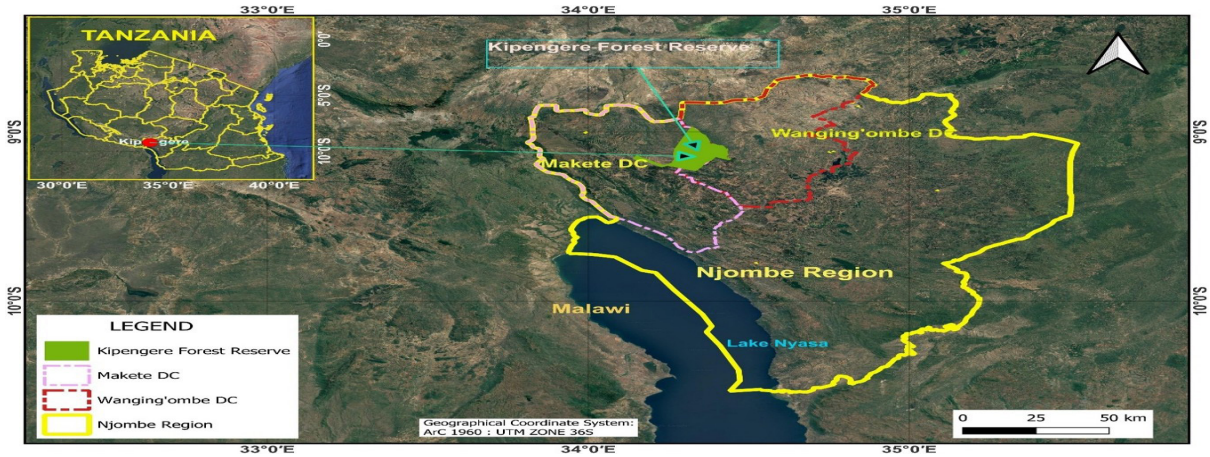


Figure 1: Location of the Kipengere Forest Reserve

Agency. The reserve is part of the Mpanga-Kipengere Game Reserve, which was established in 2002. The Kipengere Forest Reserve supports rare wildlife and endemic species like the Kipengere seedeater and nosed chameleon (TAWA: (The United Republic of Tanzania, Ministry of Natural Resources and Tourism, Tanzania Wildlife Management Authority (TAWA), 2026). The reserve also, is a source of the Mbarali, Mlomboji, Kimani, and Ipera rivers, which are the tributaries of the Great Ruaha River (GRR) sub-basin (Chilagane *et al.*, 2024).

The Great Ruaha River supplies water to the Usangu wetlands, the Ruaha National Park, and the two hydropower stations of Kidatu and Mtera dams (Chilagane *et al.*, 2024; Mulungu, 2019; Sosovele, 2007). It also supplies water for forestry, livestock keeping, fishing, mining and tourism, wildlife activities and irrigation agriculture that are vital for the livelihoods of the people in the region and the economy in Tanzania. However, in the early 1990s, the Great Ruaha River ceased flowing during the dry season, with consequences for the lives and livelihoods of the six million inhabitants of the basin (Pettengell, 2017; Mwakalila, & Masolwa, 2012; Sosovele, 2007). The decline of the Great Ruaha River has multiple contributing factors. Despite the ecological and hydrological importance of the Kipengere Forest Reserve, recent evidence indicates that the Kipengere Ranges in general are experiencing substantial changes in land use and land cover (Sanga & Haulle, 2025). These changes may have some implications on the forest reserve to support biodiversity and regulate water resources within the Great Ruaha River sub-basin. Hence, understanding the spatial and temporal dynamics of vegetation condition in the Kipengere Forest Reserve is crucial for informing conservation and management interventions.

Data Collection

In this study, the time series satellite data were used for the calculation of NDVI. The Landsat 5 (Thematic Mapper sensors (TM)) for the year 1995 and Landsat 9 Operation Landsat Imager (OLI) and Thermal Infrared Sensor (TIRS) for the year 2026, both with 30 m resolution, were obtained from the USGS Earth Explorer platform (https://earthexplorer.usgs.gov). The Red and Near-Infrared (NIR) bands from each sensor were used to calculate the NDVI. In this study Band 4 (NIR)) (LT05_L2SP_169066_19950326_20200912_02_T1_SR_B4) and Band 3 (Red) (LT05_L2SP_169066_19950326_20200912_02_T1_SR_B3) from Landsat 5 (TM) and Band 5 (NIR) (LC09_L2SP_169066_20260526_20260527_02_T1_SR_B5) and Band 4 (Red) (LC09_L2SP_169066_20260526_20260527_02_T1_SR_B4) from Landsat 9 (OLI/TIRS) were extracted for analysis (Table 1).

The Landsat images for the months of March and May in the years 1995 and 2026, respectively, were selected because these months fall during the rainy season in the study area, which is believed to effectively capture the vegetativeness of the forest. Additionally, the selection was influenced by the availability and quality of the Landsat images.

To capture multi-year trajectories of forest dynamics, a 31-year spatiotemporal span (1995-2026) was ideal for monitoring the health of the forest reserve as forests do not change rapidly (Okoduwa *et al.*, 2026; Chouiter *et al.*, 2025).

Table 1: Description of Datasets

S/n	Landsat images	Sensors	Path/ Row	Date of acquisition	Spatial resolution	Bands used
1.	Landsat 5	TM	Path 169 Row 66	26-03-1995	30 m	Band 4 (Near-Infrared (NIR)) and Band 3 (Red)
2.	Landsat 9	OLI/TIRS		26-05-2026		Band 5 (Near-Infrared (NIR)) and Band 4 (Red)

Overview of Approach

Figure 2 shows the summary of methods adopted in the study.

Data Analysis

The analysis of vegetation indices in this study was conducted using QGIS version 4.2.2-Belém do Pará. This helped to process, map and visualise the data. The normalized difference vegetation index (NDVI) was used to examine the health and density of vegetation over the study area (Karuppiah *et al.*, 2026; Huang *et al.*, 2020). According to Huang *et al.* (2020) the NDVI is effective in "differentiating savannah, dense forest, non-forest and agricultural fields and to determine evergreen forest versus seasonal forest types". The NDVI is principally useful for monitoring forest canopies as it is

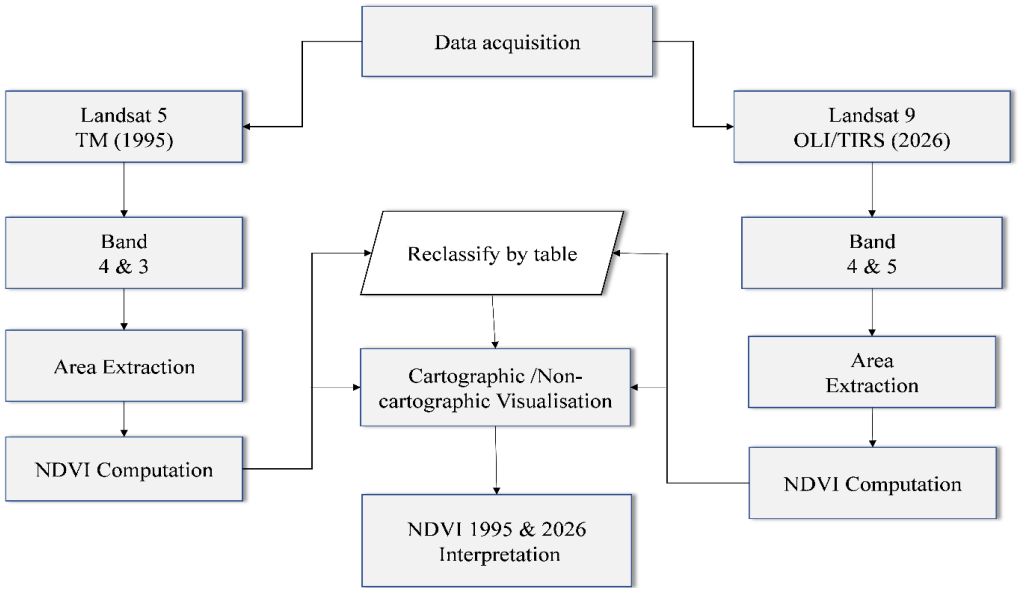


Figure 2: Summary of the Methods

sensitive to chlorophyll (Vélez *et al.*, 2023). The NDVI uses the difference between near-infrared (NIR) and red reflectance from the Earth's surface, divided by their sum (https://www.earthdata.nasa.gov). It is computed mathematically using the formula:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad (1)$$

The NDVI values range between -1 and +1, with higher values indicating healthy and dense vegetation, while lower or negative values indicate sparse vegetation or areas that are not vegetated (Chouiter *et al.*, 2025; Smith-Tripp, 2020).

In this study the NDVI values ranged between 0.066 – 0.498 and 0.066 – 0.469 for the years 1995 (Landsat 5) and 2026 (Landsat 9), respectively. Since, these thresholds are not identical they were reclassified for both years using the same thresholds through reclassify by table-semi-automatic classification Plugin (SCP)-postprocessing-eventually generating the classification report (Tables 3 & 4). Then comparison between the two years was possible and to serve that purpose, five classes were generated (Table 2). The NDVI thresholds generated correspond to the nature of the sensors, study area, vegetation type, and classification method employed (El-Gammal *et al.*, 2014).

Table 2:NDVI Classification

Class	NDVI range*	General interpretation
1 – Very low	0.0 – 0.1	Bare/very sparse vegetation
2 – Low	0.1 – 0.2	Sparse vegetation
3 – Moderate	0.2 – 0.3	Moderate vegetation
4 – High	0.3 – 0.4	Relatively dense vegetation
5 – Very high	0.4 – 0.5	Dense/healthy vegetation

**=Rounded up values*

Percentage Change in Area From 1995 to 2026

To calculate the quantitative shift in vegetation-condition classes between 1995 and 2026, the following formula was used to determine the change:

$$NDVI\ Change\ (\%) = \frac{Area\ (later\ year) - Area\ (earlier\ year)}{Area\ (earlier\ year)} x100 \qquad (2)$$

A positive percentage indicates that the area has increased, while a negative percentage indicates that the area has decreased.

RESULT AND DISCUSSION

Analysis of Kipengere Forest Reserve Vegetation Dynamics Between 1995 and 2026

Vegetation Condition and Greenness

In this study, through visual interpretation of NDVI maps in Figure 3 and the corresponding NDVI classification in Table 2, the vegetation density of the Kipengere Forest Reserve changed at some point during the 31-year period. Generally, the findings show that in 1995 the Kipengere Forest Reserve had stronger concentrations of high NDVI, while in 2026 the reserve was dominated by a greater prevalence of moderate NDVI (Figure 3).

For instance, in the 1995 NDVI map, a large part of the reserve comprised of the dark-green class. It was predominant in the central, southern, and parts of the eastern sections of the forest reserve. These dark-green areas represent high NDVI values (greater than 0.3 and with the darkest class less than 0.4) (Figure 3 & Table 2). This implies that the vegetation condition of the forest reserve was relatively dense and healthy. In the same

NDVI map of 1995, the lighter-green areas are visible around the margins and in some interior patches of the map, representing the presence of lower vegetation density (Figure 3). Generally, the large portions of the Kipengere Forest Reserve had high vegetation greenness and canopy density in the year 1995

On the other hand, the 2026 NDVI map shows that the Kipengere Forest Reserve was dominated more by the light-to-medium-green classes, falling within the 0.1–0.3 range (Figure 3 & Table 2). When compared with the 1995 NDVI map, it appears that there were fewer extensive very-dark-green areas, especially across the central and southern parts of the reserve. This implies that the vegetation is spatially uniform with greater representation of moderate rather than very high NDVI values (Figure 3).

The findings can be concluded that there was a general decline in the vegetation condition and greenness of the Kipengere Forest Reserve between 1995 and 2026. In 1995, large portions of the reserve, particularly the central, southern, and eastern sections, were characterised by high NDVI values, suggesting relatively dense and vigorous vegetation cover. By 2026, these high-NDVI areas had decreased in spatial extent, while moderate NDVI classes (0.1–0.3) became more dominant. This shift suggests a reduction in vegetation density and canopy vigor over the study period. Although the reserve continues to maintain substantial vegetation cover, the reduced prevalence of high NDVI values indicates that parts of the forest may have experienced vegetation degradation, thinning of canopy cover, or reduced vegetation productivity.

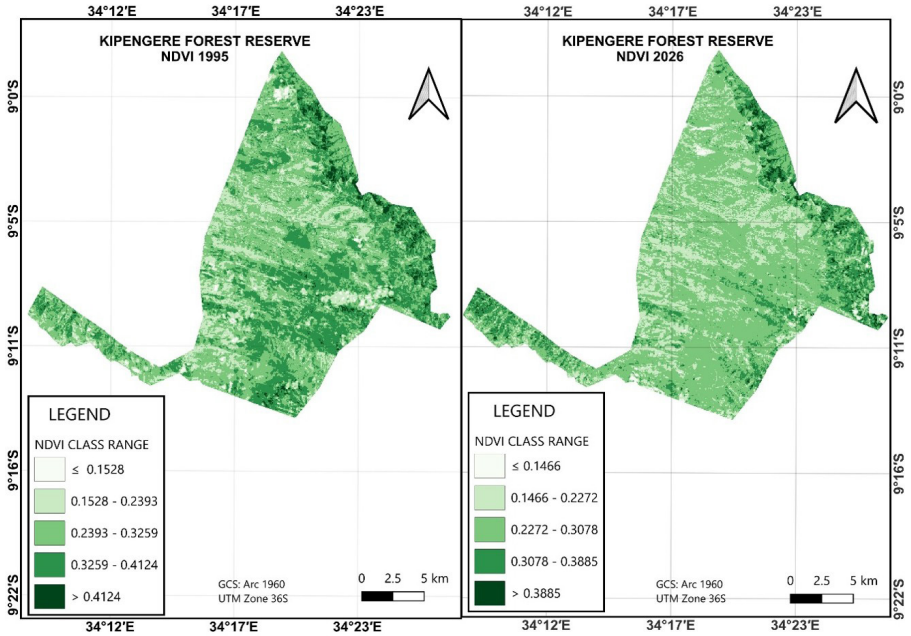


Figure 3: Kipengere Forest Reserve NDVI Maps, 1995-2026

Percentage Change in Area From 1995 to 2026

In order to supplement the visual interpretation of the NDVI maps in Figure 3, the vegetation condition of the Kipengere Forest Reserve was analysed quantitatively between 1995 and 2026. The findings show that in 1995, the areas that were covered by moderate vegetation (class 3) and relatively dense vegetation (class 4) accounted for 45.11% (15,835.50 ha) and 45.01% (15,801.21 ha), respectively (Table 3). This implies that there was an equal distribution of area of the two classes. Then, the area occupied by moderate vegetation (class 3) expanded substantially by the year 2026 to 73.61% (25,841.30 ha), an increase of 10,005.80 ha (28.5%) (Table 4&5).

On the contrary, the area covered by relatively dense vegetation (class 4) decreased to 17.26% (6,058.83 ha), a decrease of 9,742.38 ha (27.75%) by the year 2026 (Table 4&5). Similarly, dense vegetation (class 5) decreased significantly, from 3.86% (1,354.24 ha) in 1995 to 1.10% (386.73 ha) in 2026, losing 967.51 ha (Tables 4 & 5). The area occupied by very sparse vegetation (class 1) and sparse vegetation (class 2) increased from 50.22 ha and 2,059.48 ha in 1995 to 67.05 ha and 2,747.81 ha in 2026, respectively (Tables 4 & 5). In general, the findings reveal a strong redistribution of NDVI classes throughout the 31-year period, with an increase of an area covered by moderate vegetation (class 3) and a contraction of areas covered by relatively dense vegetation (class 4) and dense vegetation (class 5).

The findings can be concluded that there was a notable worsening in the vegetation condition of Kipenegere Forest Reserve between 1995 and 2026. Although moderate vegetation increased substantially from 45.11% to 73.61%, this expansion occurred alongside a pronounced reduction in relatively dense vegetation from 45.01% to 17.26% and dense vegetation from 3.86% to 1.10%. The substantial decline in the higher-density vegetation classes suggests a shift from denser to more moderately vegetated conditions over the study period. Therefore, the forest reserve appears to have experienced progressive reduction in vegetation density, although

Table 3: NDVI Classification Report, 1995

Raster Value	NDVI Range	Pixel Sum	Percentage %	ha	General interpretation
1	0.0 – 0.1	558	0.14	50.22	Bare/very sparse vegetation
2	0.1 – 0.2	22883	5.87	2059.48	Sparse vegetation
3	0.2 – 0.3	175949	45.11	15835.5	Moderate vegetation
4	0.3 – 0.4	175568	45.01	15801.21	Relatively dense vegetation
5	0.4 – 0.5	15047	3.86	1354.23	Dense/healthy vegetation
Total				**35100.74**	

considerable vegetation cover remained in 2026.

This study's general conclusions are in line with the findings of Sanga and Haulle (2025) on the dynamics of the Kipengere Ranges in the southern highland regions of Tanzania in general. They found that land use/land cover of the ranges changed between 1984 and 2014. The changes were attributed to increased agricultural activity, decreased soil fertility, and a lack of land use planning in the area.

Also, studies in other forest reserves in the country show variations in vegetation conditions due to various reasons. For instance, Majule *et al.* (2024) and Mgalula *et al.* (2024) found that the major drivers of land use/cover change in Mgori and Minyughe Forest Reserves in Singida Region in

Table 4: NDVI Classification Report, 2026

Raster Value	NDVI Range	Pixel Sum	Percentage %	ha	General interpretation
1	0.0 – 0.1	745	0.19	67.05	Bare/very sparse vegetation
2	0.1 – 0.2	30531	7.83	2747.80	Sparse vegetation
3	0.2 – 0.3	287124	73.61	25841.30	Moderate vegetation
4	0.3 – 0.4	67320	17.26	6058.83	Relatively dense vegetation
5	0.4 – 0.5	4297	1.1	386.73	Dense/healthy vegetation
Total				**35100.74**	

Table 5: NDVI Change Between 1995 and 2026

NDVI class	1995 area (ha)	2026 area (ha)	Change (ha)	Change (%)
1	50.22	67.05	+16.83	+33.51%
2	2,059.48	2,747.81	+688.32	+33.42%
3	15,835.50	25,841.30	+10,005.80	+63.20%
4	15,801.21	6,058.83	−9,742.38	−61.66%
5	1,354.24	386.73	−967.51	−71.44%

central Tanzania were cultivation, settlement expansion, timber harvesting, charcoal production and livestock grazing. Equally, Kayombo *et al.* (2020) described change in forest reserve in Image Forest Reserve in Kilolo District, Iringa Region, Tanzania from 1990 to 2018. The changes in forest cover were caused by human activity. Moreover, Mdemu and Burra (2016) presented that cultivation and harvesting of forest products damaged vegetation in Pugu and Kazimzumbwi Forest Reserves in Kisarawe District, Coast Region, Tanzania. However, their findings cannot establish that the same causes produced the observed NDVI changes in the Kipengere Forest Reserve, rather they provide a context within which changes in vegetation cover are documented.

CONCLUSION

This study assessed vegetation dynamics in the Kipengere Forest Reserve between 1995 and 2026 using NDVI analysis to determine changes in vegetation density and condition over the 31-year period. The results show a clear change in the spatial pattern of vegetation density in the reserve. In 1995 large parts of the reserve were covered with relatively dense and dense vegetation, especially in the central, southern and eastern parts. Moderate vegetation was the dominant NDVI class in 2026, but the spatial extent of relatively dense and dense vegetation had decreased considerably.

Quantitative analysis shows that moderate vegetation increased from 15,835.50 ha (45.11%) in 1995 to 25,841.30 ha (73.61%) in 2026, an increase of 10,005.80 ha (63.20%). In contrast, the relatively dense vegetation decreased from 15,801.21 ha (45.01%) to 6,058.83 ha (17.26%) and the dense vegetation from 1,354.24 ha (3.86%) to 386.73 ha (1.10%). Vegetation was at the same time sparse and very sparse slightly increased. These changes imply a pronounced transition from higher density vegetation classes to moderate, and to a lesser degree, lower density vegetation classes. The overall

findings indicate a decline in vegetation density and greenness of the Kipengere Forest Reserve during the period of study, while a substantial portion of the reserve still had a moderate vegetation cover in 2026.

The observed changes are consistent with general evidence of vegetation and land-use/land-cover changes reported for other forest reserves and landscapes in Tanzania. Previous studies have documented the effect of activities such as cultivation, expansion of settlement, timber harvesting, charcoal production, livestock grazing and harvesting of forest products on forest vegetation. However, the present analysis is not enough to directly attribute these factors to the NDVI changes observed in Kipengere Forest Reserve. Instead, the results suggest that to identify specific causes of vegetation change additional research into land-use change, human activity, climate variability, fire occurrence and other environmental factors would be needed.

Therefore, the study concludes that, from 1995 to 2026, the Kipengere Forest Reserve experienced a remarkable decrease in the area covered by high-density vegetation, as well as a significant growth in moderate vegetation. The findings emphasise the need for ongoing monitoring, effective forest management and further research on the determinants of vegetation dynamics in the reserve to support long-term conservation and sustainable management of its forest resources.

REFERENCES

Bauhus, J., van der Meer, P., & Kanninen, M. (Eds.). (2010). *Ecosystem goods and services from plantation forests.* Earthscan.

Bora, R., & Bora, A. K. (2024). Monitoring forest health using geographical information system based weighted overlay method in Sonaikushi Reserved Forest, Morigaon District, Assam, India. *International Journal of Ecology and Environmental Sciences, 50*(1), 113–121. https://doi.org/10.55863/ijees.2024.3134

Bousfield, C. G., & Morton, O. (2026). Escalating fire-driven forest loss in protected tropical forests. *Global Change Biology, 32*(8), e71051. https://doi.org/10.1111/gcb.71051

Buba, F. N., Gajere, E. N., & Ngum, F. F. (2020). Assessing the Correlation between Forest Degradation and Climate Variability in the Oluwa Forest Reserve, Ondo State, Nigeria. *American Journal of Climate Change, 9*, 371-390. https://doi.org/10.4236/ajcc.2020.94023

Busch, J., & Ferretti-Gallon, K. (2023). What drives and stops deforestation, reforestation, and forest degradation? An updated meta-analysis. *Review of Environmental Economics and Policy, 17,* 217–250. https://doi.org/10.1086/725051

Chilagane, N., Mkome, P., Chundu, E., Wandelage, G., Mbungu, W., Silungwe, F., & Kashaigili, J. (2024). Mapping and assessing the ecological status of water sources in Mbarali River sub-catchment. *Journal of Water Resources, Engineering, Management and Policy, 1*(2). https://doi.org/10.56542/wi.jwempo.v1.i2.a3

Chouiter, N., Benoumeldjadj, M., & Rached-Kanouni, M. (2025). Spatio-temporal assessment of vegetation dynamics in the Zouagha Forest, northeastern Algeria (2000–2020). *Journal of Landscape Ecology, 18*(4). https://doi.org/10.2478/jlecol-2025-0031

Danlami, U. D. (2018). *Assessing the impacts of fuelwood harvesting activities on forest degradation in Kwata Area, Mutum-Biyu, Gassol Local Government Area, Taraba State, Nigeria* (Master's thesis, Kampala International University)

Deori, S. (2025). Ecosystem services provided by forests: Methods for economic valuation. In *Emerging paradigms in biological sciences* (Vol. I, pp. 152–158, Chap. 18). National Press Associates.

Dlamini, C. M., Odindi, J., Matongera, T. N., & Mutanga, O. (2025). Exploring the utility of remote sensing technology in vegetation below-ground biomass (BGB) estimation: A critical review of methods and challenges. *Frontiers in Remote Sensing, 6,* 1668676. https://doi.org/10.3389/frsen.2025.1668676

El-Gammal, M. I., Ali, R. R., & Abou Samra, R. M. (2014). NDVI threshold classification for detecting vegetation cover in Damietta Governorate, Egypt. *Journal of American Science, 10*(8), 108–113. http://www.jofamericanscience.org

FAO & Landscape Alliance. (2026). *Forests for food: Nourishing people, sustaining the planet.* Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd3592en

Food and Agriculture Organization of the United Nations. (2011). *Rural structures in the tropics: Design and development.* FAO.

Gandri, L., Fatahuddin, M., Bana, S., Hasani, U. O., Sakti, A., Fitriani, D., … Fitriani, V. (2025). Spatiotemporal dynamics of vegetation density in moramo district protected forest: A remote sensing approach. *Applied Environmental Science, 3*(1), 20- 38. https://doi.org/10.61511/aes.v3i1.2025.1812

Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2020). A commentary review on the use of the normalised difference vegetation index (NDVI) in the era of popular remote sensing. *Journal of Forestry Research.* https://doi.org/10.1007/s11676-020-01155-1

Karuppiah, C., Periyasami, E., Mayan Ayyanar, S., Meer, M. S., Faqeih, K. Y., Alamri, S. M., & Alamery, E. R. (2026). Spatio-temporal assessment of vegetation response to climatic variability using NDVI and VCI in the forested landscape. *Rangeland Ecology & Management, 105,* 25–36. https://doi.org/10.1016/j.rama.2025.12.007

Kayombo, C.J., Ndangalasi, H.J., Mligo,C. & Giliba, R.A. (2020). Analysis of Land Cover Changes in Afromontane Vegetation of Image Forest Reserve, Southern Highlands of Tanzania. *The Scientific World Journal;* 7402846. https://doi.org/10.1155/2020/7402846

Kut Görgün, E., & Salata, S. (2025). Settlement expansion

versus environmental protection: Ecosystem services for environmental regulation planning in Izmir, Türkiye. *Sustainability, 17,* 3237. https://doi.org/10.3390/su17073237

Majule, A.E., Saria, A.E., & Mwakisunga, B. (2024). Land use and land cover changes and their driving forces in selected forest reserves in Central Tanzania. *Trees, Forests and People 16;* 100584. https://doi.org/10.1016/j.tfp.2024.100584

Mashalla, A., & Ringo, J. (2015). Status of human-wildlife conflicts in Mpanga/Kipengere Game Reserve, Tanzania. *International Journal of Environment and Bioenergy, 10*(1), 26–40.

Mbululo, Y., Nyihirani, F., 2012. Climate characteristics over southern highlands Tanzania. Atmos. Clim. *Sci. 2*, 454–463. https://doi.org/10.4236/acs.2012.24039.

Mdemu, M. V., & Burra, M. M. (2016). Drivers of Land Cover Dynamics for Pugu and Kazimuzumbwi Forest Reserves in Kisarawe, Tanzania. *Open Journal of Forestry, 6,* 348-360. http://dx.doi.org/10.4236/ojf.2016.65028

Mkiramweni, N., DeLacy, T., Jiang, M., & Chiwanga, F. (2016). Climate change risks on protected areas ecotourism: Shocks and stressors perspectives in Ngorongoro Conservation Area, Tanzania. *Journal of Ecotourism, 15,* 139–157. https://doi.org/10.1080/14724049.2016.1153645

Mohiuddin, A. K. (2025). Global deforestation in focus: Uncovering the scale and forces behind deforestation. *Innovare Journal of Sciences, 13,* 20–34. https://doi.org/10.22159/ijs.2025v13.58316

Mulungu, D. (2019). Assessment of surface water resources in Great Ruaha River sub-basin Tanzania: Application of WEAP model for water allocation and utilisation impacts analysis. *Tanzania Journal of Engineering and Technology (TJET), 38*(1), 27-46. https://doi.org/https://doi.org/10.52339/tjet.v38i1.494

Mwakalila, S., & Masolwa, P. (2012). Environmental flow assessment of Great Ruaha River in southwestern part of Tanzania. *Journal of Environmental Science and Engineering A, 1,* 303–310.

Ngwembe, J. F., Minja, G. S., Tegeje, A. J., & Mkonda, M. Y. (2022). Socio-economic and ecological benefits of forest reserves in Tanzania: A case of Nambinga Forest in Ulanga District. *Russian Agricultural Sciences, 48* (3), 219-226. https://doi.org/10.3103/S1068367422030089

Ntukey, L. T., Munishi, L. K., & Treydte, A. C. (2022). Land use/land cover change reduces woody plant diversity and carbon stocks in a lowland coastal forest ecosystem, Tanzania. *Sustainability, 14*(14), 8551. https://doi.org/10.3390/su14148551

Okoduwa, A. K., Amaechi, C. F., Ogbebor, J. U., & Obayagbona, N. O. (2026). Spatio-Temporal Patterns of Forest Loss and Gain in Okomu Forest Reserve, Nigeria. *Trends in Ecological and Indoor Environmental Engineering, 4*(1), 70–78. https://doi.org/10.62622/TEIEE.026.4.1.70-78

Ola, A. (2025). Multifunctional roles of forest ecosystem services in environmental sustainability and climate regulation. *Journal of Forest Reserve, 14* (555).

Ortega-Barrueta, U., Sertutxa, U., Ametzaga-Arregi, I., Curiel Yuste, J., Esteban, R., Ruiz de Larrinaga, L., San Miguel-Oti, F., & Peña, L. (2025). Effect of forest management on the ecosystem services supply and multifunctionality in the Urdaibai Biosphere Reserve. *Ecosystem Services, 76,* 101793. https://doi.org/10.1016/j.ecoser.2025.101793

Pettengell, C. (2017). *Final report: Great Ruaha River Basin climate vulnerability and capacity analysis (CVCA).* CARE-WWF Alliance in Tanzania.

Rao, M. K. (2025). Assessment of vegetation health & drought using NDVI & SAVI in Anantapur District, Andhra Pradesh by geospatial technology. *Journal of Emerging Technologies and Innovative Research (JETIR), 12*(3). https://www.jetir.org/

Sanga, F & Haulle, E (2025). The paradox of the land use/land cover change in Kipengere ranges in southern highlands of Tanzania. Geology, *Ecology, and Landscapes, 9*:4, 1507-1514, https://doi.org/10.1080/24749508.2024.2429206

Sehar, A., Mustfa, W., Tahir, M., Batool, M., Tabassum, A., Parveen, A., Tehreem, S., Razia, S. E. T., Amber, H., & Javed, F. (2026). Role of forest in sustaining ecosystem services. In A. Zahra, M. Jamil, N. Ghafoor, & I. Zahra (Eds.), *Forests, wildlife, and biodiversity: Pathways to conservation and ecological resilience* (pp. 97–104). Unique Scientific Publishers. https://doi.org/10.47278/book.TL/2026.042

Singh, V., & Nair, P. (2026). Forest ecology and ecosystem services: A review of their contributions to environmental stability and human well-being. *Tropical Agroforestry Research Insight, 1*(1). https://doi.org/10.53623/tari.v1i1.1236

Smith-Tripp, S. (2020). *Remote sensing as a tool for efficient forest health and landscape monitoring in Metro Vancouver's water supply areas, 2020–2022*. Metro Vancouver.

Sosovele, H. (2007). The Root Causes of the Declining levels of Water in the Great Ruaha River, Tanzania. *Tanzania Journal of Development Studies, Vol. 7,* No. I,

The United Republic of Tanzania, Ministry of Natural Resources and Tourism, Tanzania Forest Services Agency. (2026). *Tanzania Forest Services Agency.* https://www.tfs.go.tz/

The United Republic of Tanzania, Ministry of Natural Resources and Tourism, Tanzania Wildlife Management Authority. (2026). Contact us. https://www.tawa.go.tz/index.php/contact-us

Turpie, J., Warr, B., & Carter Ingram, J. (2015). *Benefits of forest ecosystems in Zambia and the role of REDD+ in a green economy transformation.* United Nations Environment Programme.

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development.* https://sdgs.un.org/2030agenda

United Republic of Tanzania. (2000). *Tanzania development*

vision 2025. National Planning Commission.

United Republic of Tanzania. (2025). *Tanzania development vision 2050*. National Planning Commission.

Vélez, S., Martínez-Peña, R., & Castrillo, D. (2023). Beyond vegetation: A review unveiling additional insights into agriculture and forestry through the application of vegetation indices. *J, 6,* 421–436. https://doi.org/10.3390/j6030028

Verma, P., Singh, R., Chauhan, V., & Singh, A. K. (2026). Forest degradation and deforestation: Drivers and solution. *In Forestry for a carbon-neutral and sustainable future* (pp. 345–369). Springer. https://doi.org/10.1007/978-3-032-06427-1_15

Wani, A., & Sahoo, G. (2020). Forest ecosystem services and biodiversity. *In Forest ecosystem services and biodiversity*. Springer. https://doi.org/10.1007/978-3-030-56542-8_22

Yang, J., Yang, J., Luo, X., & Huang, C. (2019). *Impacts by expansion of human settlements on nature reserves in China. Journal of Environmental Management, 248,* 109233. https://doi.org/10.1016/j.jenvman.2019.07.004

Yu, M., & Liu, Y. (2025). Landscape ecological integrity assessment to improve protected area management of forest ecosystem. *Ecologies, 6*(2), 38. https://doi.org/10.3390/ecologies6020038