

The Impact of Vegetation Dynamics and Landcover Change on Montane Ecosystems in Ekiti State, Nigeria: Evidence from Satellite Imagery

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ABSTRACT

The study provided information on the NDVI and extent of land use/cover in the montane ecosystems in Ekiti State, Southwestern Nigeria which are generally lacking and this is critical for its proper functioning, sustainability and conservation. The LUCC and NDVI were examined for a period of four decades (1986-2025) using Landsat Enhanced Thematic Mapper (ETM). Montane ecosystems were modelled using SPOT6 Digital Elevation Model (DEM) with a Ground Survey Distance (GSD) of 20m. There was steady increase in the NDVI values indicating the resilience of these ecosystems to anthropogenic activities. The dense vegetations were pronounced in altitudes above 700m and this covered 32% while low-lying ecosystems expanded to 62%. Rock-outcrops witnessed fluctuations and markedly a decline in 2001, 2006 and 2025 indicating they are being quarried for landscaping, constructions of roads and buildings. There was also increase in the extent covered by bare lands and built-up areas by 27%. The water body also recorded decline steadily over the periods examined. Concerted and timely interventions are crucial for policy making that will combat the human induced activities towards sustainability, conservations and proper functioning of these ecosystems.

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Keywords: DEM, Ekiti State, LUCC, Montane Ecosystems, NDVI, Rock-outcrops

1. INTRODUCTION

Mountains occupy 24% of the global land surface and are habitat to 12% of the world's populace (Schild, 2008). Tropical montane cloud forest ecosystems which contain some of the world's biodiversity hotspots for endemic species, and supports main biomes such as hyper arid hot deserts

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to polar ice caps; providing essential ecosystem services to including high quality freshwater and microclimate buffering against climate extremes (CBD, 2010; Abera *et al.* 2025). Due to the indispensability of mountains for the maintenance of biodiversity and ecosystem services, there are advancements in studies related to the processes that set their conservation at peril (Wang *et al.*, 2018; Dunets *et al.*, 2019). Satellite images are presently tools for policymaking in conservation through the mapping of the biotic and abiotic components of ecosystems: land-cover, land-use, ecological disruption, and plant phenology (Mihai *et al.*, 2017; Borisade *et al.* 2021). The new methods permit assessing changes over time (MohanRajan *et al.*, 2020) and the generation of ecological indicators at different spatial and temporal scales. The above gives the likelihood of the spatial and temporal tracking of the perceptible phenomena in environmental units and obtaining measurements on the spatial structure: fragmentation, distribution, abundance, and specificity (Espinoza-Guzman' *et al.*, 2023).

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Unplanned land use practices, infrastructure development, unsustainable tourism, and climate change are all foremost to rapid modification in the montane ecosystems, with land cover change, precisely, one of the most significant chauffeurs (Maxwell *et al.* 2016; Chaudhary *et al.*, 2017). The paucity of information on past and present land changes in vulnerable mountain landscapes is a challenge for ecological restorations (Balsiger and Debarbieux, 2015) and poses a noteworthy barrier to understanding and managing ecosystems sustainably and making effective decisions for conservation and sustainable development in inaccessible mountain regions.

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Normalized Difference Vegetation indices (NDVI) is an indicator of vegetation health, because degradation of ecosystem vegetation, or a decrease in green, would be reflected in a decrease in NDVI value. Therefore, if a relationship between the quantity of an indicator – aerial biomass – in various forest ecosystems and the NDVI can be identified, processes of degradation can be

monitored (Meneses-Tovar, 2011). NDVI is becoming a significant indicator in studying the spatial vegetation dynamics of regional ecological changes (Liu *et al.*, 2015; Sun *et al.*, 2021). The montane ecosystems in Ekiti State, Southwestern Nigeria offers ecosystem services such as providing habitat for endemic species, resources for establishment of quarry sites for construction of roads and houses, sacred places for religious purpose, cushioning the impact of climate changes, low lying forests for loggers to harvesting timber and provision of fodders for feeding livestock by herdsmen.

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It has been reported that over the past few decades, there have been rapid modification and alterations in the land use change cover through anthropogenic activities such as residential and institutional activities in Ekiti State, Southwestern, Nigeria (NBS 2012). Some studies e.g. Owoeye and Ogunleye, 2016; Olorunfemi *et al.*, 2018; Ajagbe *et. al.*, 2021 exist on the impact of land use change in urban parts, and the Ekiti State ecosystems. These studies have not looked explicitly at the montane ecosystems in Ekiti State. Furthermore, information on the NDVI of montane ecosystems in Ekiti state, Southwestern Nigeria are generally lacking. Therefore, this study aims at assessing the impact of land use change to affecting the extent of montane ecosystems in Ekiti State, Southwestern Nigeria over the last four decades 1986-2025. The montane ecosystems were also categorized based on elevations and NDVI were evaluated for the health and vitality of the montane ecosystems. This is much needed for ecological restorations and providing adequate information for policy makers towards conservation and sustainability of the montane ecosystems in Ekiti State, Southwestern Nigeria.

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2. MATERIALS AND METHODS

2.1 Study Area

The study area, Ekiti State is located in the southwestern part of Nigeria (Fig 1). Ekiti State is located between Latitudes 7° 25' to 8° 5' N and Longitude 4° 45' to 5° 45' E and occupies a land area of about 5435 km² (NBS 2012). The State is mainly an upland zone with elevation ranging from 250 to 540 m above mean sea level (a.m.s.l.) (Simon-Oke *et al.*,2012). The State lies on an area underlain by metamorphic rock and is potentially rich in mineral deposits, which include channockete, limestone, kaolin, columbite, phosphate, iron ore, aquamine, gemstone, barite, gold among many others, largely deposited in different villages and towns within the study area (Olorunfemi and Fasinmirin 2017). Tropical climate exists in the State with two clear seasons which are rainy season between April–October and dry season between November–March (Olorunfemi and Fasinmirin 2017). High humidity s being experienced in the state. Likewise, the mean air temperature ranges between 21 and 28 °C. Egbeda series and Iwo series are the dominant soils in Ekiti state (Smyth and Montgomery 1962), which under the FAO/UNESCO classification are classified as Orthic and Plinthic Luvisols, respectively (FAO, 1998). Guinea forest vegetation with its attendant climate, fora, and fauna prevail in the State (Olorunfemi and Fasinmirin 2017). Derived savannah predominates exists in the north peripheries, while tropical rainforest predominates in the south (logbaby.com, retrieved—2025, March 6). The study area captured all the montane ecosystems in Ekiti State, Southwestern Nigeria. Ekiti State has been experiencing a change in land use and land cover (LULC). The ever-increasing population which numbered 1.63 million in 1991 grew to 2.38 million in 2006 with a projected population of 3.17 million in 2015 (ekitistate.gov.ng; citypopulation.de, retrieved—2025, March 6).

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Fig. 1: Location of study area in the maps of Nigeria and Southwestern geopolitical zone of Nigeria

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2.2. Land use/land Cover Mapping and Vegetation Index Modeling

Landsat imageries for 1986, 2001, 2006, 2010, 2016, 2020, and 2025 were downloaded from the online archive of United States' Geological Survey. Appropriate bands were combined for the land use/land cover and Normalized Difference Vegetation Index (NDVI). The resultant composite images were subjected to supervised machine learning image classification procedure for land use/land cover classification. Whereas, the composite images were also subjected to the automated procedure of vegetation index computation using the image calculator algorithm on a GIS platform. The output classified images were subjected to mathematical computation to determine the area extents of each land use/land cover class. The equation for NDVI computation is presented as follows:

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

Where, NIR is Near Infrared Band, Red is the Red Band

2.3 Montane Ecosystem Modeling

We acquired SPOT6 Digital Elevation Model (DEM) with a Ground Survey Distance (GSD) of 20m. We classified the DEM based on British Geological Survey's standard for montane ecosystem delineation. In this case, the study area was classified into three distinct types of ecosystems – the Low-lying Ecosystem, Montane Ecosystem > 500m and Montane Ecosystem > 700m. The outputs of these image classifications and analyses are presented in form of maps and the relevant attributes are presented in tabular form.

3. RESULTS

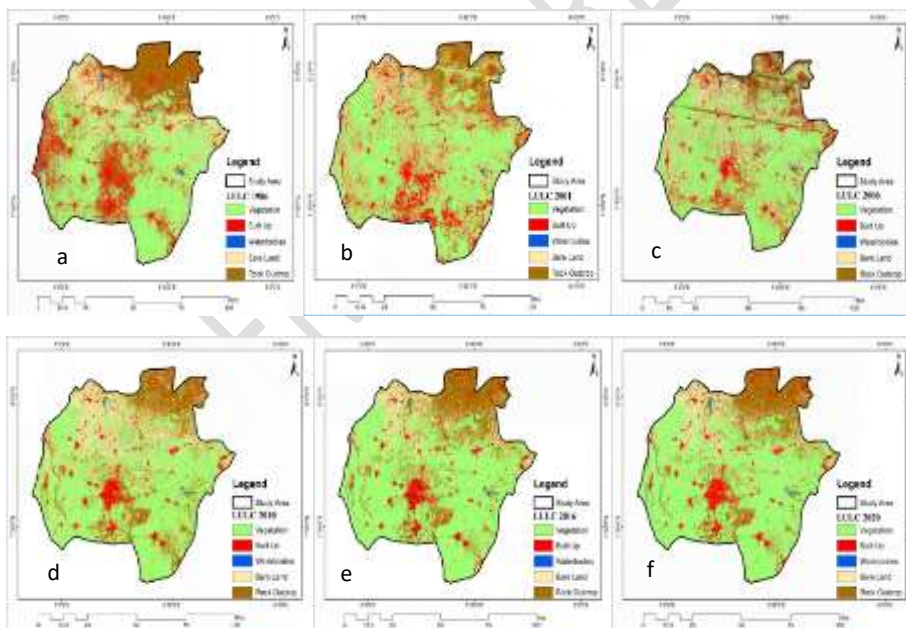
The classified land use and land cover maps for the seven epochs are presented in Figs. 2a – g, and the area extents of the land cover types and the corresponding percentages are presented in Tables 1 and 2. The study area has an area extent of 587,316 Km², been situated in the northwestern extreme of Southwestern Nigeria. In this study, we categorized, Built up area and Bare land as an interwoven entity. This is because, in medium resolution satellite imageries such as Landsat, ancient and recent mud houses are mostly classified as bare land. In addition, bare land is associated and interwoven with settlements in this part of the world, being predominantly rural.

Results showed that 56% of the montane ecosystems was covered by vegetation while human settlements and associated bare land occupy 11% and 16% respectively (Table 2). Analyses showed that 17% of the montane ecosystems comprised of rock outcrop while only 0.6% of the montane ecosystems is covered by water (Table 2). The highest extent of vegetation occurred in 2016 while the least was recorded for 1986 (Table 2). The health and vitality of vegetation of the study area has been rising significantly since year 2001. The [Normalized Differences Vegetation](#)

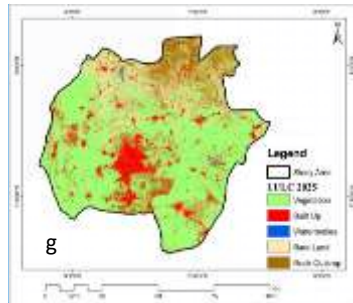
Indices (NDVI) maps of the study area for seven epochs between 1981 and 2025 are presented in Figs. 3a - g. In 1986, NDVI values ranged from -0.001 to 0.39. For 2001, NDVI values varied from -0.001 to 0.42. In 2006 and 2010, the ranges of NDVI values were -0.012 – 0.34 and -0.001 – 0.40 respectively. In 2015, NDVI values varied from -0.08 to 0.51. Whereas, NDVI values ranged from 0.024 to 0.41 and 0.011 to 0.42 in 2020 and 2025 respectively (Fig. 3)

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The ecosystem of the study area is delineated into three – Low-lying Ecosystem, Montane Ecosystem > 500m, and Montane Ecosystem > 700m. The low-lying ecosystem covers 68% of the study area. Whereas, the remaining 32% of the study area is made up of montane ecosystem, with only 208 Km² occurring at the altitude of 700m and above (Fig. 4).



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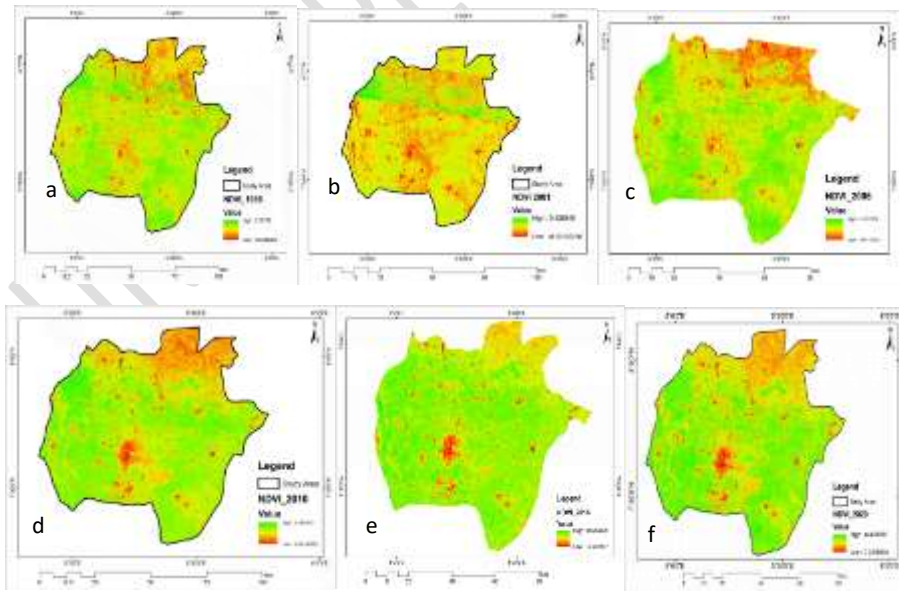
Figure 2. Land use/land cover maps of the study area for: a) 1986, b) 2001, c) 2006, d) 2010, e) 2015, f) 2020, and g) 2025.

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Table 1. The area extents of land use/land cover classes of the study area.

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LULC	1981	2001	2006	2010	2016	2020	2025
Vegetation	299159	325018	319292	300375	348865	348473	343321
Built up	99390	96023	71610	34878	37762	37889	58453
Waterbody	8755	1098	5150	2273	3329	4085	1756
Bare land	79151	94327	121152	128238	75399	79346	91770
Rock	100861	70849	70112	121552	121961	117522	92017
Outcrop							



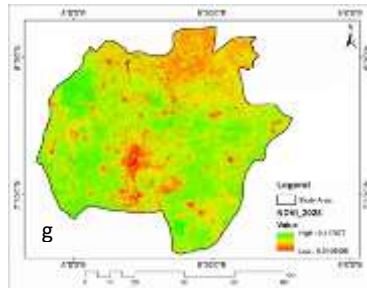


Figure 3. NDVI maps of the study area for: a) 1986, b) 2001, c) 2006, d) 2010, e) 2015, f) 2020, and g) 2025.

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Table 2. The percentages of the area extents of land use/land cover classes of the study area.

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LULC	1981	2001	2006	2010	2015	2020	2025
Vegetation	50.9	55.3	54.36	51.14	59.4	59.3	58.4
Built up	16.9	16.3	12.19	5.94	6.4	6.5	10.0
Waterbody	1.49	0.18	0.87	0.4	0.6	0.7	0.3
Bare land	13.5	13.47	20.63	21.83	12.8	13.5	15.6
Rock	17.2	12.06	11.94	20.69	20.8	20.0	15.7
Outcrop							

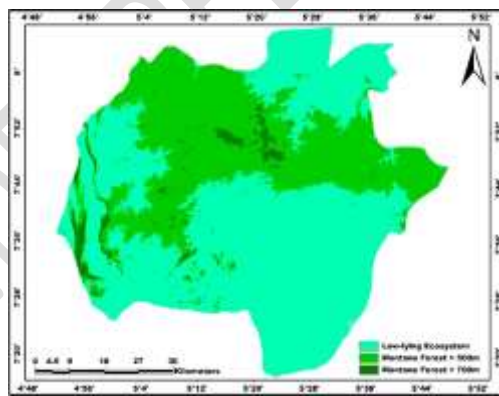


Figure 4. Ecosystem Map of the study area

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4. DISCUSSION

The historical management practices of montane ecosystem in Nigeria are poorly documented and remain one of the most disturbed ecosystems in Southwestern Nigeria. Among the land use cover categorized, the extent in vegetation increased steadily from 1986 - 2020 and a little decline in 2025. This conforms with the findings of other workers e.g. Ajagbe *et al.* (2021) who had categorized and reported an increasing extent in vegetation dynamics of the Ekiti state ecosystems, Southwestern Nigeria. The steady increase in the vegetation dynamics of the montane ecosystems could be attributed to inaccessibility to large portion of these vegetations especially at elevations $\geq 700\text{m}$ which posed as difficult terrain to encroach and security challenges, favorable climatic factors and steady increase in the NDVI values over the period of four decades.

The reduced human activities such as urban construction, mining, road and water infrastructure development could improve the greenness of the montane ecosystems and conspicuously as the elevation increases. The 32% of the areas covered by montane ecosystems with elevation of 500-700m being densely vegetated reiterate the impact of land use changes being intense in lower elevated areas, as low-lying ecosystems which covered 62% were sparsely vegetated. Research on mountain vegetation growth relies heavily on the NDVI, which is an important indicator for assessing the status of mountain vegetation growth, particularly during the growing season (Geng *et al.*, 2019). The NDVI values reported in the study area falls within the range value reported by Olorunfemi *et al.*, 2018 in same region but were lower than those from other regions (e.g. Muradyana *et al.* 2019; Zhu *et al.*, 2021) who worked on mountainous ecosystems in Armenia and China respectively and this indicated that the level of anthropogenic activities ongoing in the study area were higher than what is obtainable in other regions. The spatial pattern of the NDVI

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distribution showing the vegetated areas to have high NDVI values relative to non-vegetated areas aligned with the findings of workers who have worked on montane ecosystems (Muradyana *et al.* 2019; Zhu *et al.*, 2021).

The montane ecosystems have seen a fluctuation in terms of greenness within the study period, with increase since the year 2010. This development could partly be credited to relatively increase in annual rainfall over Nigeria (Ogunrinde *et al.*, 2018), and the continuous efforts of the governments and international organizations to discourage bush burning, lumbering, fuel wood harvesting and unsustainable agricultural practices (Akinwumiju and Olorunfemi, 2023). The bare land extent was pronounced in 2006 and 2010 signaling a decrease in the NDVI values over the four decades considered. The built-up areas and bare lands exerted 27% on extent of the montane ecosystems. It was obvious that human population growth warranted urban expansions, rapid utilization of resources from the montane ecosystems, deforestation and degradation of vegetations for agriculture accounted for variations in bare lands and built-up areas in montane ecosystems in Ekiti State, Southwestern Nigeria. Similar observations have been made by workers who have assessed the impact of land use change cover on various African ecosystems (e.g. Obiahu *et al.* 2021; Gibtan *et al.* 2024).

The water body represented a small fraction in the extent covered in the montane ecosystem and witnessed a steady declined and this aligned with the findings of Abera *et al.* (2025) in their study on impacts of land use and climate change on montane ecosystems in Africa and noted that deforestation weakened the cloud water interception capacity of montane ecosystems in Africa. In the study area, the low-lying ecosystems have witnessed several anthropogenic activities notably deforestation and degradation and ultimately affected the water retention capacity of the montane ecosystems as it has not recorded increase more than in 1986.

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The rock outcrops experienced fluctuations but was peak in 2015. The rock outcrop recorded a decline in 2001, 2006 and more recently 2025. The reason not far-fetched as the rocky outcrops in montane ecosystems in Ekiti State are quarried and used for landscaping, constructing buildings and roads and are also being damaged by livestock such as pigs and goats. The rock outcrops have been reported to play a crucial role in affecting hydrological and erosion process by serving as impermeable surfaces to increasing run off, providing preferential flow paths, and offering flow barriers to hill slopes and crucial habitats to harboring endemic species (Fitzsimons and Micheal, 2017; Zhang et al., 2024).

The study is one of the pioneer studies that provided information on the impact of land use change and NDVI in Montane ecosystems in Ekiti State, Nigeria. Human activities have greatly influenced the quality and extent these ecosystems which is evident by increase in bare surface and built-up areas and decline in water body and rock-outcrops. Concerted and timely management practices should be taken into consideration in order to sustain the ecological functions and services that these montane ecosystems offer. There is the need to assess the impact of climate change on the NDVI; extent and distributions of the montane forests ecosystems and also examine the impact of eco-hydrological drivers to influencing the proper functioning and resilience of the montane ecosystems in Ekiti State, Southwestern Nigeria.

CONCLUSION

The study clearly highlighted the impact of land use and identifies bare lands, built up and rocky outcrops extents in montane ecosystems as core factor responsible to affecting its extent and quality. The NDVI revealed a steady increase over the years examined indicating the resilience of the vegetation to providing and sustaining the health status and services offered by the ecosystems. The land use change also revealed a steady decline in water body which could have resulted from

anthropogenic induced activities notably deforestation and degradation. Furthermore, there was an increase in low-lying montane ecosystems and decline in cover of montane ecosystems having elevations > 700m owing chiefly to urban expansions, quarried rock outcrops for landscaping, construction of roads and buildings.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

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