Land use and Land cover Change Analysis and Its Implications for Conservation Planning in the Agumatsa Range, Ghana

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Abstract

Tropical montane landscapes in West Africa are undergoing rapid land-use and land-cover (LULC) transformation, with cascading effects on biodiversity and ecosystem services. This study quantified multi-decadal LULC dynamics in the Agumatsa Range, Ghana, an Important Bird Area and a critical forest-savanna ecotone, using supervised classification of Landsat imagery (1990, 2000, 2010, and 2020). Five classes (closed-canopy forest, open canopy, dense shrub/herbaceous, grassland/herbaceous, and bare surface/built-up) were outlined, yielding a Kappa coefficient of 0.86. Over 30 years, closed-canopy forest declined sharply from 51.0% to 31.0% (a net loss of 20 percentage points, 30 km²), while bare surface/built-up areas increased from 2.0% to 18.0%. Dense shrub/herbaceous cover expanded from 5.5% to 16.0%, signaling widespread secondary succession following selective logging and shifting cultivation. Change-detection maps revealed upslope retreat and fragmentation of closed-canopy forest, with the most pronounced conversion occurring between 2010 and 2020 in the highly disturbed area. These patterns align with intensified anthropogenic pressures (agriculture, road expansion, peri-urban development) amplified by climate variability. The observed degradation gradient has direct implications for biodiversity conservation. The findings underscore the urgency of landscape-scale conservation planning, including riparian buffers, enrichment planting, assisted natural regeneration, and community-based resource management (CREMAs), to reverse forest loss and sustain biodiversity in this unique hotspot.

Keywords: Land-use/land-cover change, Landsat classification, forest degradation, Agumatsa Range, conservation planning

Introduction

Tropical forests are undergoing unprecedented transformation driven by land-use and land-cover (LULC) change, with profound consequences for global biodiversity and ecosystem services (Bergstrom et al., 2023; Rocha et al., 2021). Between 1990 and 2020, the Upper Guinea Forest Block of West Africa lost approximately 15–20 % of its closed-canopy cover, primarily through agricultural expansion, selective logging, infrastructure development, and fire (FAO, 2012; Ofori et al., 2016). These changes fragment habitats, intensify edge effects, and alter microclimatic conditions, often leading to shifts in species composition, reduced functional diversity, and heightened extinction risk for habitat specialists (Pardini et al., 2010; Taubert et al., 2018). The Agumatsa Range in Ghana's Volta Region exemplifies this regional trend. As part of the Akwapim-Togo mountain system and a designated Important Bird Area, it supports high endemicity and functions as a critical wildlife corridor within a rapidly urbanizing forest-savanna mosaic (Boahene et al., 2021). Yet, subsistence agriculture, road expansion, selective logging, and peri-urban development have created a pronounced disturbance gradient across its four principal habitats (undisturbed to highly disturbed). A quantitative, spatially explicit assessment of LULC trajectories and their implications for conservation planning has been lacking. This study therefore integrates multi-temporal Landsat classification and post-classification change detection to (i) quantify the rate, extent, and spatial pattern of vegetation cover change from 1990 to 2020, (ii) identify dominant transition pathways, and (iii) evaluate the implications of these dynamics for biodiversity conservation and adaptive land-management strategies in the Agumatsa Range.

Materials and Methods

Study Area

The research was conducted within Ghana's Hohoe Municipality (1,172 km²), which straddles the southwestern portion of the Akwapim-Togo-Attakora mountain complex (Owusu et al., 2005). The area forms an ecological crossroads between the humid Guinea-Congo phytogeographic province and the drier Sudanian zone (latitudes 7°00′–7°30′ N, longitudes 0°15′–0°45′ E) (Owusu et al., 2005). Altitudinal variation exceeds 600 m, generating steep microclimatic and edaphic gradients. Lowland terraces support intensive rain-fed agriculture, while upland quartzite ridges retain fragments of semi-deciduous forest.

Satellite Imagery Analysis and Change Detection

Multi-decadal Landsat scenes (Landsat 5 TM for 1990; Landsat 7 ETM+ for 2000 and 2010; Landsat 8 OLI for 2020) were acquired from the United States Geological Survey Earth Explorer portal. Images underwent radiometric normalisation to minimise haze and striping artefacts (Chander et al., 2009), geometric co-registration to <0.5 pixel misalignment, and reprojection to UTM Zone 31 N (WGS 84 datum; Jensen, 2015). A bounding rectangle of 150 km² encompassing all field sites was extracted. Processing in ERDAS Imagine 2014 included contrast enhancement, calculation of the Normalised Difference Vegetation Index (NDVI; Rouse et al., 1974), and supervised classification into five LULC classes: closed-canopy forest, open canopy, dense shrub/herbaceous, grassland/herbaceous, and bare surface/built-up (Richards & Jia, 2006). Classification accuracy was assessed with 100 stratified random validation points verified in Google Earth and field surveys, yielding a Kappa coefficient of 0.86 (Congalton, 1991; Landis & Koch, 1977). Area statistics were exported to Microsoft Excel for post-classification change detection. Thematic maps were produced in ArcMap 10.8 (ESRI, 2014). Dominant transition pathways were visualised, and dominant conversion trajectories summarised for the period 1990–2020.

Results

Land-Cover Distribution and Change Trajectories (1990–2020)

Supervised classification revealed a clear and consistent trajectory of forest loss and conversion to open, anthropogenic land-cover types (Table 1). Closed-canopy forest declined from 51.0 % (1990) to 31.0 % (2020), representing a net loss of 20 percentage points

TABLE 1

Percentage land-cover distribution in the Agumatsa Range, 1990–2020

Land Cover Class	1990 (%)	2000 (%)	2010 (%)	2020 (%)	Net Change 1990–2020 (%)
Closed-canopy forest	51.0	46.2	38.5	31.0	-20.0
Open canopy	37.0	33.8	29.4	26.0	-11.0
Dense shrub/herbaceous	5.5	8.1	14.2	16.0	+10.5
Grassland/herbaceous	4.5	6.9	8.7	9.0	+4.5
Bare surface/built-up	2.0	5.0	9.2	18.0	+16.0
Total	100	100	100	100	—

(30 km² within the study area). Open-canopy woodland decreased from 37.0% to 26.0%. These reductions were offset by increases in dense shrub/herbaceous cover (5.5 % to 16.0 %) and bare surface/built-up land (2.0 % to 18.0 %). Grassland/herbaceous cover rose modestly from 4.5 % to 9.0 %. The most accelerated change occurred between 2010 and 2020, when closed-canopy forests lost an additional 7.5 percentage points, and built-up areas nearly doubled (Table 1).

Change detection maps

The change detection maps (1990-2020) illustrated dominant pathways: (i) closed canopy to dense shrub/herbaceous (most widespread, concentrated in mid-slope zones), (ii) closed-canopy to bare surface/built-up (prominent along roads and settlements, and (iii) open canopy to grassland/herbaceous (valley bottoms). The undisturbed area retained the largest closed-canopy blocks, while the highly disturbed area showed the greatest loss and fragmentation (Figure 3.1).

Discussion

The change detection maps generated from supervised classification of multi-temporal Landsat imagery (1990, 2000, 2010, and 2020) offer a spatially explicit chronicle of landscape transformation in the Agumatsa Range. These maps reveal a consistent and accelerating contraction of closed-canopy forest, which retreated upslope and fragmented into smaller, isolated patches, while open woodland, dense shrub/herbaceous, and bare

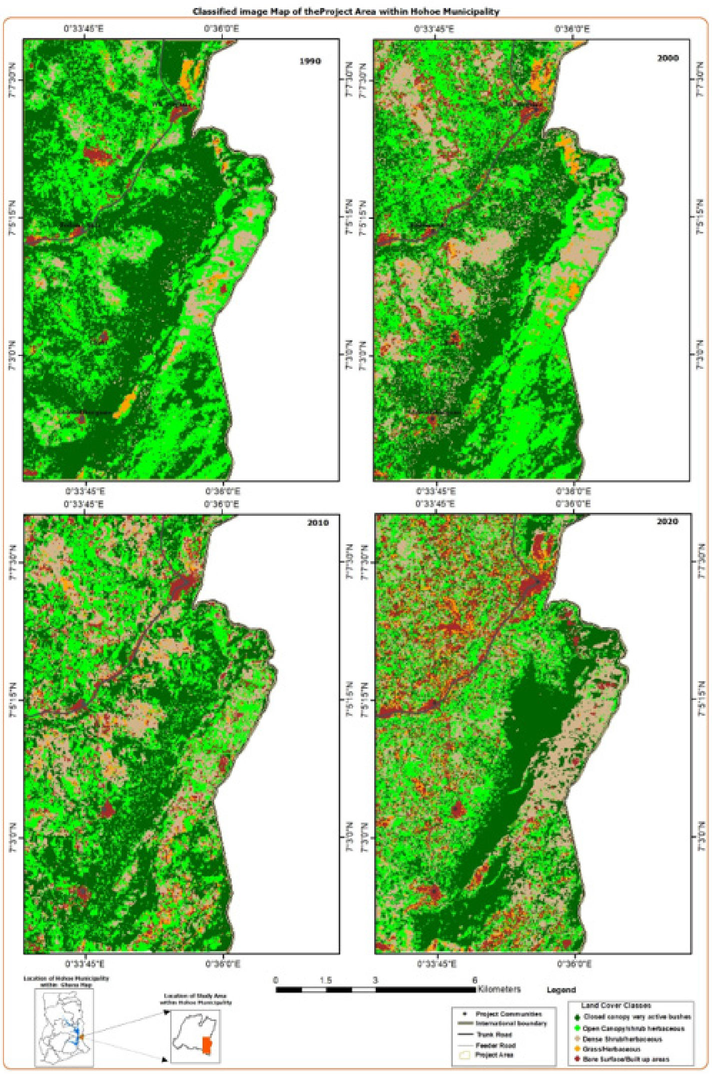

Figure 1 Change detection map of the study site

TABLE 2
Description of the LULC types maps of the study areas

Class colour	LULC type	Description
Deep green	Closed canopy, very active bushes	Areas dominated by closely-knit trees and dense vegetative tree cover. It also encompasses all vegetated areas that are not exposed to bare soil (Boahene et al., 2021)
Light green	Open Canopy/ shrub herbaceous	Areas with less continuous dense tree cover. The cover has been disturbed by anthropogenic activities and is mainly made up of regenerating forest from the past
Pink	Dense shrub/herbaceous	This class typically describes areas dominated by dense woody shrubs (height 40–60%) intermixed with herbaceous plants (grasses, forbs). It represents secondary regrowth or degraded forest, where shrubs outcompete tree regeneration due to disturbance (e.g., logging, fire, or agricultural abandonment) and grasses, forming impenetrable scrub with high biomass but low tree cover (Anderson et al., 1976; FAO, 2012)
Yellow	Grass herbaceous	This refers to open areas primarily covered by herbaceous vegetation (grasses, sedges, herbs; canopy cover <10–20% woody), with sparse or no shrubs/trees. It includes natural savannas, fallow fields, or pastures, characterised by seasonal green-up and low woody biomass. In West Africa, it encompasses guinea savanna or derived grasslands from forest clearance, supporting grazing or shifting cultivation (Anderson et al., 1976; FAO, 2012)
Red	Bare surface/built-up area	This class describes impervious surfaces such as residential, commercial, industrial areas and road networks (Boahene et al., 2021)

surface/built-up classes expanded downslope and into valley bottoms (Boahene et al., 2021; Ofori et al., 2016). In 1990, closed-canopy forest dominated the upper slopes and mid-elevations as large, contiguous blocks, but by 2020 these blocks had contracted markedly, leaving remnant stands primarily confined to higher elevations and steep, inaccessible terrain (Bergstrom et al., 2023).

The dominant transition pathway evident across the maps was the conversion of closed-canopy forest to dense shrub/herbaceous vegetation, appearing as extensive yellow/orange patches in mid-slope zones. This pattern is characteristic of post-disturbance secondary succession following selective logging and shifting cultivation, whereby removal of the canopy allows shade-tolerant shrubs and herbs to outcompete tree regeneration and establish an alternative stable state with reduced structural complexity (Chazdon, 2008; Hoffmann et al., 2010). A second prominent pathway involved direct conversion of closed-canopy forest to bare surface/built-up land, manifesting as linear and clustered red/brown patches concentrated along the upgraded trunk road in peri-urban fringes. These permanent conversions reflect infrastructure expansion and settlement growth, creating irreversible barriers to forest recovery and amplifying edge effects (Pardini et al., 2010; Rocha et al., 2021). Open-canopy to grassland/herbaceous transitions were widespread in valley bottoms, consistent with conversion to rain-fed agriculture and fallow lands, further dissecting the remaining forest matrix (FAO, 2012; Amponsah-Mensah et al., 2022).

Spatially, the maps highlight differential impacts across the disturbance gradient. The undisturbed area retained the largest remaining blocks of closed canopy, underscoring the protective role of steep, boulder-strewn slopes that deter human access (Decher et al., 2021).

In stark contrast, the most disturbed area exhibited the greatest loss, with extensive replacement of closed canopy by bare surface and dense shrub cover, particularly along road corridors and settlement edges (Ofori et al., 2016). The least disturbed area displayed moderate change, largely restricted to riparian corridors and tourism infrastructure around the waterfall, where footpaths and visitor activity generated small, localised pockets of bare surface (Boahene et al., 2021).

Collectively, the change detection maps document a net loss of closed-canopy forest from 51% to 31% and a dramatic increase in bare surface/built-up land from 2% to 18% over the 30 years. This trajectory exemplifies the classic process of forest degradation and savannisation observed across the Upper Guinea Forest Block, driven by synergistic interactions between anthropogenic pressure and biophysical feedbacks such as reduced evapotranspiration and increased fire frequency (Bergstrom et al., 2023; Forestry Commission of Ghana, 2017). By quantifying both the magnitude and spatial configuration of these transitions, the maps provide a robust empirical foundation for understanding how LULC change has reshaped habitat availability and connectivity in the Agumatsa Range, with direct implications for biodiversity conservation in this rapidly transforming montane landscape.

The concurrent expansion of bare surface/built-up areas (2% to 18%) reflects infrastructure development and settlement growth, further fragmenting forest patches, heightening edge effects, and increasing soil erosion risk (Rocha et al., 2021). Fluctuations in grassland/herbaceous cover reflect alternating cycles of reforestation initiatives and unsustainable shifting cultivation (Forestry Commission of Ghana, 2017; Bergstrom et al., 2023). These LULC dynamics interact synergistically with biophysical feedbacks: reduced canopy cover lowers evapotranspiration, reinforcing aridity and favouring fire-adapted shrubs whose flammable litter perpetuates a shrub-dominated state (FAO, 2020; Bergstrom et al., 2023). These findings have direct implications for conservation planning in the Agumatsa Range. Forest degradation and savannisation intensify habitat fragmentation and loss of biodiversity. Landscape-scale interventions, such as riparian buffers, CREMA zoning, and integration of LULC projections into REDD+ frameworks, are therefore essential to maintain ecological connectivity, preserve biodiversity hotspots, and support sustainable livelihoods in this montane system.

Conclusion and Recommendations for Conservation Planning

This study provides the first high-resolution, multi-decadal LULC analysis for the Agumatsa Range, demonstrating accelerated forest loss and fragmentation that threaten the long-term integrity of this montane biodiversity corridor. By linking quantitative change trajectories to conservation outcomes, the results offer a robust evidence base for proactive and spatially targeted management. Priority actions include: (i) protection of remaining closed-canopy cores, (ii) restoration of mid-slope shrub-dominated zones, and (iii) integration of LULC policies into planning and community-based resource management activities. Such measures will be critical to safeguarding biodiversity and the broader ecosystem services provided by the Agumatsa Range under accelerating global change.

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