



Forest loss and land-use transformation in the Ashanti Region of Ghana: Integrating remote sensing, political ecology and socio-ecological perspectives

 **Addo Koranteng¹⁺**
Emmanuel Donkor²
Lydia Opoku
Acheampong³
Isaac Adu-Poku⁴
John Agyei⁵

^{1,2}Kumasi Technical University, Institute of Research, Innovation and Development, Kumasi, Ghana.

¹Email: addo.koranteng@kstu.edu.gh

²Email: john.agyei@kstu.edu.gh

³Resource Management Support Centre of Forestry Commission, Ghana.

²Email: emmanueldonkor484@gmail.com

³Wesley College of Education, Science Department, Ghana.

³Email: lydia@wesco.edu.gh

⁴Kwame Nkrumah University of Science and Technology, Geomatic Engineering Department, Kumasi, Ghana.

⁴Email: iadupoku05@gmail.com



(+ Corresponding author)

ABSTRACT

Article History

Received: 27 August 2026

Revised: 25 September 2026

Accepted: 6 October 2026

Published: 22 October 2026

Keywords

Forest loss

Land-use/land-cover change

Political ecology

Remote sensing

Socio-ecological systems.

This study examines forest loss and land-use/land-cover (LULC) change in Ghana's Ashanti Region from 1990 to 2020 using remote sensing, socio-ecological systems (SES), and political ecology frameworks. Landsat images from 1990, 2000, 2010, and 2020 were classified into seven LULC types: Closed Forest, Open Forest, Cropland, Grassland, Settlement, Water, and Mining, using Maximum Likelihood Classification. Classification accuracy was validated with confusion matrices and statistical metrics. Spatial trends were interpreted within SES and political ecology contexts, drawing on demographic and governance data. Results show a 26.6% decline in Closed Forest and an 8.1% decline in Open Forest over 30 years, alongside pronounced gains in Cropland (119.8%) and Settlement (approximately 767%). Mining emerged as a distinct category by 2020, occupying 13,077.11 ha. Major transitions were observed at the intersection of forest, agriculture, settlement, and extraction areas. Although statistical causal relationships between LULC changes and factors such as population growth, agriculture, mining, and governance were not established, these drivers are discussed as influential. The Ashanti Region has experienced extensive landscape changes driven by shared ecological, socioeconomic, and governance pressures. The study advocates multidimensional forest governance strategies that merge digital monitoring, participatory process socio-ecological systems, sustainable agriculture, land-use planning, and institutional cooperation. Recommendations include routine spatial monitoring, integrated policies, and greater community involvement to mitigate forest loss and resolve land-use conflicts.

Contribution/Originality: This research advances the literature by linking multi-temporal remote-sensing evidence with SES and political-ecology perspectives, and by translating these insights into a comprehensive governance framework. It provides a nuanced understanding of landscape change and offers policy-relevant recommendations for sustainable forest management in Ghana and similar contexts.

1. INTRODUCTION

Forests provide ecological, economic, and social benefits such as biodiversity conservation, climate regulation, water regulation, soil conservation, carbon storage, timber, and non-timber forest products. Such services are

particularly important in the tropics, where rural livelihoods and agricultural production are closely tied to natural-resource systems (Peng, Li, Peng, & Zhang, 2025; Swamy, Drazen, Johnson, & Bukoski, 2018). Agricultural expansion, cocoa production, logging, mining, infrastructure development, urbanisation and population growth have continuously pressured Ghana's forest landscapes (Assede et al., 2023; Awotwi, Anornu, Quaye-Ballard, & Annor, 2018). The Ashanti Region is of particular importance because it is located within the High Forest Zone of Ghana and possesses landscapes used for agriculture, settlement, forest resources, and mineral extraction (Asibey, Agyeman, Amponsah, & Ansah, 2020; Manu, Takyi, Amponsah, Yeboah, & Lotsah, 2022).

Forest change is thus not only a biophysical phenomenon. It occurs in linked systems where ecological processes interact with resource users, institutions, markets, land-tenure arrangements, governance systems and livelihood strategies. The SES perspective provides a framework for analysing these interactions, while political ecology draws attention to power relations, economic interests, institutional arrangements and unequal access to land and natural resources.

Previous studies have documented forest and LULC changes in the Ashanti Region, Ghana (Koranteng, Adu-Poku, Donkor, & Zawila-Niedźwiecki, 2020; Koranteng & Zawila-Niedźwiecki, 2015). Other studies have explored forest governance, institutional arrangements, and community participation (Duguma et al., 2019; Kouassi, Gyau, Diby, Bene, & Kouamé, 2021). However, these lines of research are often pursued in isolation. The combination of multi-temporal remote sensing with SES and political ecology perspectives potentially allows us to link the observed landscape transformations with the institutional and socioeconomic context in which land-use decisions are made.

Therefore, this study evaluates LULC changes in the Ashanti Region from 1990 to 2020 and interprets the observed patterns through the lenses of SES and political ecology. The study aims to: (1) evaluate LULC changes between 1990 and 2020; (2) investigate temporal changes in forest, agricultural, settlement, water, and mining classes; (3) identify major landscape transition patterns associated with forest depletion; and (4) develop an innovation-oriented framework for sustainable forest governance.

Importantly, the study does not statistically estimate the causal effects of socioeconomic or governance variables on LULC change. These factors are therefore viewed as contextual and plausible explanatory influences based on literature and secondary evidence. This distinction is important so as not to attribute causal effects to variables that were not explicitly modelled.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1. Forest Loss and Land Use Change

Tropical forests are under pressure from a variety of interrelated forces, including agricultural expansion, mining, logging, infrastructure development, urbanisation and population growth. Such pressures may cause forest fragmentation, biodiversity loss, and a decline in ecosystem services (Boyle et al., 2025; Kumar, Kumar, & Saikia, 2022; Velastegui-Montoya, Montalván-Burbano, Peña-Villacreses, de Lima, & Herrera-Franco, 2022). Research in Ghana has highlighted agricultural expansion and cocoa production as major drivers of forest change, with mining and timber extraction possibly worsening forest degradation (Abugre, Asigbaase, Kumi, Nkoah, & Asare, 2025; Ashiagbor, Asante, Forkuo, Acheampong, & Foli, 2022; Kalischek et al., 2023; Peprah, 2025). Demographic growth and urban expansion also create more competition for land, particularly around fast-growing urban centres (Ankrah, Takyi, Biliyitorb Liwur, & Amponsah, 2026; Ayeni, Aborisade, Aiyegbajeje, & Soneye, 2025).

Remote-sensing studies provide important evidence of the spatial and temporal dimensions of these processes (Ababio, 2023; Koranteng et al., 2020). But knowledge of the spatial pattern of forest loss does not explain why certain land-use transitions occur. Interpretation therefore depends on economic incentives, land tenure, institutional arrangements, policy implementation, and livelihood strategies.

2.2. Forest Management and Sustainable Development

Forest governance has progressively shifted from purely state-centred management towards arrangements involving communities, customary authorities, civil society and multiple public institutions (Bamidele, 2026; Kyere-Boateng & Marek, 2021). Community participation can provide greater stewardship and incorporate local ecological knowledge. Governance may also be hindered by insufficient institutional capacity, weak enforcement, inadequate resources, divided responsibilities, and competing land-use priorities. Policies for agriculture, mining, forestry, housing and infrastructure can thus create conflicting demands on the same landscape (Atampugre et al., 2024; Chirwa et al., 2024).

Thus, sustainable forest governance in the Ashanti Region requires cross-sectoral and cross-scale coordination. Remote sensing can provide spatial evidence for monitoring, but monitoring needs to be connected to institutions that can act on that evidence. Thus, governance innovation needs to combine technological, institutional and social interventions.

2.3. Political Ecology and Socio-ecological Systems

SES theory conceptualises landscapes as coupled systems of interacting resource users, institutions, ecological processes and socio-economic activities (Cockburn, Cundill, Shackleton, & Rouget, 2018; Okpara et al., 2018). Political ecology adds to this by looking at how power, economic interests, institutional structures, and access to resources shape environmental outcomes (Makwinja, O'Farrell, Kimengsi, & Guenther, 2025; Nyengere et al., 2026). Together, these perspectives offer a useful interpretive frame for understanding why the same landscape may simultaneously experience agricultural expansion, settlement growth, forest degradation, and mineral extraction (Ali, 2023; Chirwa et al., 2024).

In this study, the structural contextual factors are population growth, agricultural expansion, mineral extraction, urbanisation, infrastructure development, consumer demand, and dependence on energy sources. These factors interact with governance conditions such as land tenure arrangements, forest regulations, enforcement capacity, institutional collaboration, and community participation. There are also ecological processes such as forest degradation, fragmentation, and conversion associated with the land-use decisions that follow. These relationships are interpretive, not statistically tested causal pathways.

2.4. Research Gap

LULC change and forest dynamics have been documented through research conducted in Ghana (Dembélé et al., 2024; Larbi, 2023; Peprah, 2022). Other studies have focused on governance and socio-ecological dimensions of environmental change (Bennett, Larson, Zamora Ríos, Monterroso, & Sheila, 2023; Shiri, Le, Ouerghemmi, & Rejeb, 2025). Another opportunity is to combine multi-temporal Landsat evidence with SES and political ecology perspectives and then translate the combined interpretation into an innovation-oriented governance framework. This study addresses that opportunity by linking remotely observed landscape transformation with the governance and socioeconomic context and suggesting intervention points for sustainable forest management.

3. MATERIALS AND METHODS

3.1. Study Area

The study area is illustrated in Figure 1, showing the location in Ghana. The study was carried out in the Ashanti Region of Ghana, which is an area of approximately 24,389 km² in the High Forest Zone of Ghana. The region is characterised by humid semi-deciduous forest conditions, with annual rainfall of approximately 1,200–1,600 mm and mean temperatures of approximately 24–30°C (Adeoti, Barry, Namara, Kamara, & Titiati, 2007). The main economic activities are agriculture and the cultivation of cocoa and food crops. Artisanal and small-scale gold mining and rapid urbanisation put pressure on forest ecosystems (Ghana Statistical Service (GSS), 2022).

3.2. Data Source

Landsat images for 1990, 2000, 2010, and 2020 were downloaded from USGS Earth Explorer for Path/Row 194/55 and 194/56. Images were selected based on acquisition date, availability, and cloud cover of less than 10%. Ancillary datasets included a 2012 topographic map, 2010 aerial photographs, a 1986 land-cover map, a 2010 land-cover map, and training/reference information from the Forestry Commission and other secondary sources. Table 1 shows the satellite data and other ancillary data employed in the study.

3.3. LULC Classification Scheme

The study used seven LULC classes: Closed Forest, Open Forest, Cropland, Grassland, Settlement, Water, and Mining. Table 2 gives a description of the seven LULC classes.

3.4. Image Pre-Processing

Image preprocessing included layer stacking, geometric correction, and radiometric correction. The original pixel values were preserved by nearest-neighbour resampling. The study used WGS 84 UTM Zone 30N and the Ghana Datum Office projection. Individual bands were stacked to create composite images for each year, and the study-region boundary was applied.

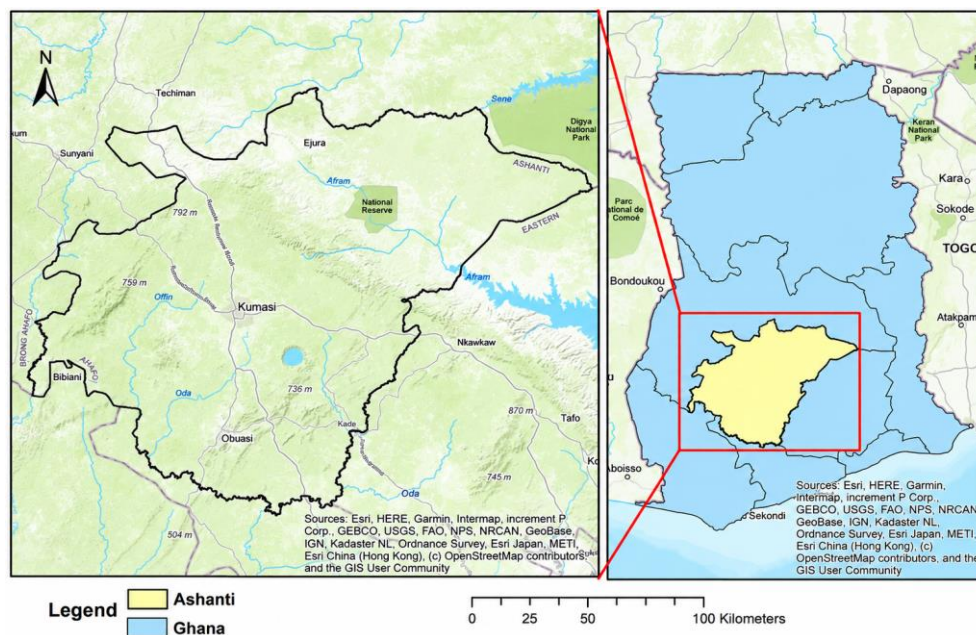


Figure 1. Location and study area of the Ashanti Region, Ghana.

Table 1. Datasets of satellite and ancillary data used in the study.

Dataset	Date	Resolution	Source
Landsat TM	December 1990	30 m	USGS EROS Centre
Landsat ETM+	April 2000	30 m	USGS EROS Centre
Landsat ETM+	March 2010	30 m	USGS EROS Centre
Landsat OLI	January 2020	30 m	USGS EROS Centre
Topographic map	2012	1:50,000	Survey & Mapping Division
Aerial photographs	2010	1:10,000	Survey & Mapping Division
Land-cover map	1986	30 m	CERGIS, University of Ghana
Land-cover map	2010	30 m	RMSC, Forestry Commission
Training data	2012	—	RMSC, Forestry Commission

Table 2. LULC classification scheme used in this study.

Land use Class	Feature
Closed Forest	Land with dense woody trees covered with closed canopy and forest patches
Open Forest	Land with dense woody tree cover without closed canopy. Forest land in the national greenhouse gas inventory that is degraded
Cropland	Cultivated land and harvested croplands and pastures
Grassland	Areas that are mostly covered by natural or managed grass and other herbaceous plants.
Settlement	Land with non-natural surfaces such as roads and highways, built-up areas, bare grounds, and human settlements
Water	Rivers, Streams, reservoirs, ponds, and lakes
Mining	Areas of active or abandoned surface mineral extraction, including open-pit mines, quarries, spoil heaps, tailings, and associated bare or sparsely vegetated surfaces, characterized by exposed soil or rock, irregular excavation patterns, and high spectral contrast relative to natural land covers

3.5. Image Classification

The Landsat imagery was classified using supervised Maximum Likelihood Classification (MLC). The seven LULC classes were delineated using training and validation/reference data. The same classification framework was used in the four observation years to enable comparisons of temporal patterns.

3.6. Accuracy Assessment

Overall accuracy (OA) and the Kappa coefficient were used to assess classification accuracy. The overall accuracy and Kappa coefficient of the 2020 classification were 89.20% and 0.850, respectively. The producer accuracies were 85.71% for Closed Forest and 87.50% for Open Forest. Cropland and Grassland showed lower producer accuracies (77.50% and 77.70%, respectively), indicating more spectral ambiguity between these classes. The overall accuracies reported for 1990, 2000, and 2010 were 92%, 94%, and 91%, respectively.

Table 3. Summary of classification accuracy by year.

Year	Overall Accuracy (%)	Kappa
1990	92.00	0.95
2000	94.00	0.97
2010	91.00	0.94
2020	89.20	0.850

3.7. Demographic and Contextual Information

Population statistics were derived from Ghana Statistical Service census reports. Contextual information on land-use pressures and governance was sourced from Forestry Commission reports, small-scale mining records, cocoa production statistics, and government, NGO, and other secondary documents. These sources were used for interpretation, not as statistically modelled predictors of LULC change.

3.8. Change Identification

LULC areas were compared for the four years of observation. Absolute change was calculated as the difference between the later and earlier areas, and relative change was calculated as a percentage of the initial area. The temporal patterns were interpreted using the SES and political ecology framework.

3.9. Workflow

Figure 2 reiterates the methodologies employed in this study, which are further detailed in the subsequent subsections.

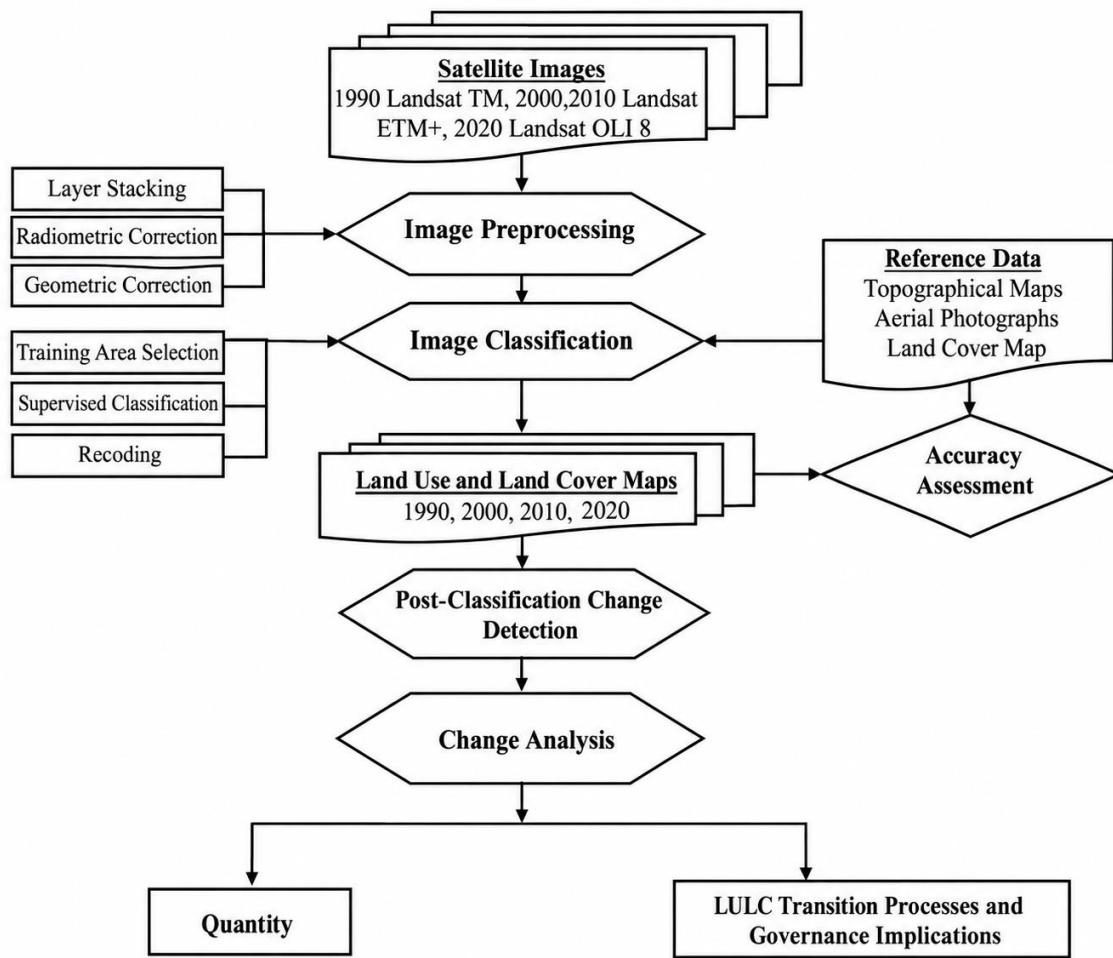


Figure 2. Methodology flowchart adopted in the study.

4. RESULTS

4.1. Classification Accuracy of LULC

In the 2020 classification, the overall accuracy was 89.20%, and the Kappa coefficient was 0.850. The historical classifications reported overall accuracies of 92% for 1990, 94% for 2000, and 91% for 2010 (Table 3).

4.2. Area and Temporal Dynamics of LULC

Closed Forest decreased from 475,552.58 ha in 1990 to 349,170.24 ha in 2020, a decrease of 126,382.34 ha, or 26.6%, in 30 years. Open Forest showed a decrease from 1,155,636.35 ha to 1,062,133.73 ha (8.1%) over the study period but an increase in area from 2010 to 2020. The cropland area increased from 164,025.46 ha to 360,590.73 ha, which is equivalent to a 119.8% increase. Settlement increased from 15,140.09 ha to 131,304.46 ha, about 767%. Water increased from 7,104.60 ha to 12,259.56 ha. In 2020, a separate category of mining was identified, with an area of 13,077.11 ha (Table 4).

Table 4. Area coverage of LULC classes, 1990–2020.

LULC class	1990 (ha)	2000 (ha)	2010 (ha)	2020 (ha)
Closed Forest	475,552.58	445,250.69	433,680.75	349,170.24
Open Forest	1,155,636.35	1,108,609.37	995,806.01	1,062,133.73
Cropland	164,025.46	304,397.12	606,611.50	360,590.73
Grassland	620,442.70	540,222.17	325,956.98	509,365.93
Settlement	15,140.09	32,419.22	65,940.01	131,304.46
Water	7,104.60	7,003.19	9,906.52	12,259.56
Mining	0.00	0.00	0.00	13,077.11

4.3. LULC Change by Period

Table 5 and Figure 3 show the LULC change over the study period. The biggest reduction in Closed Forest occurred during 2010–2020, when the class decreased by 84,510.51 ha. Open Forest declined over the years 1990–2000 and 2000–2010, but grew by 66,327.72 ha over the years 2010–2020. Cropland increased substantially in the first two periods but declined by 246,020.77 ha in 2010–2020. Settlement increased in all periods, with the largest increase between 2010 and 2020. The mining category, as a separate mapped category, only appeared in 2020.

Table 5. LULC change by period, 1990–2020.

LULC	1990–2000	2000–2010	2010–2020	1990–2020
Closed Forest	−30,301.89	−11,569.94	−84,510.51	−126,382.34
Open Forest	−47,026.98	−112,803.36	66,327.72	−93,502.62
Cropland	140,371.66	302,214.38	−246,020.77	196,565.27
Grassland	−80,220.53	−214,265.19	183,408.95	−111,076.77
Settlement	17,279.13	33,520.79	65,364.45	116,164.37
Water	−101.41	2,903.33	2,353.04	5,154.96
Mining	0	0	13,077.11	13,077.11

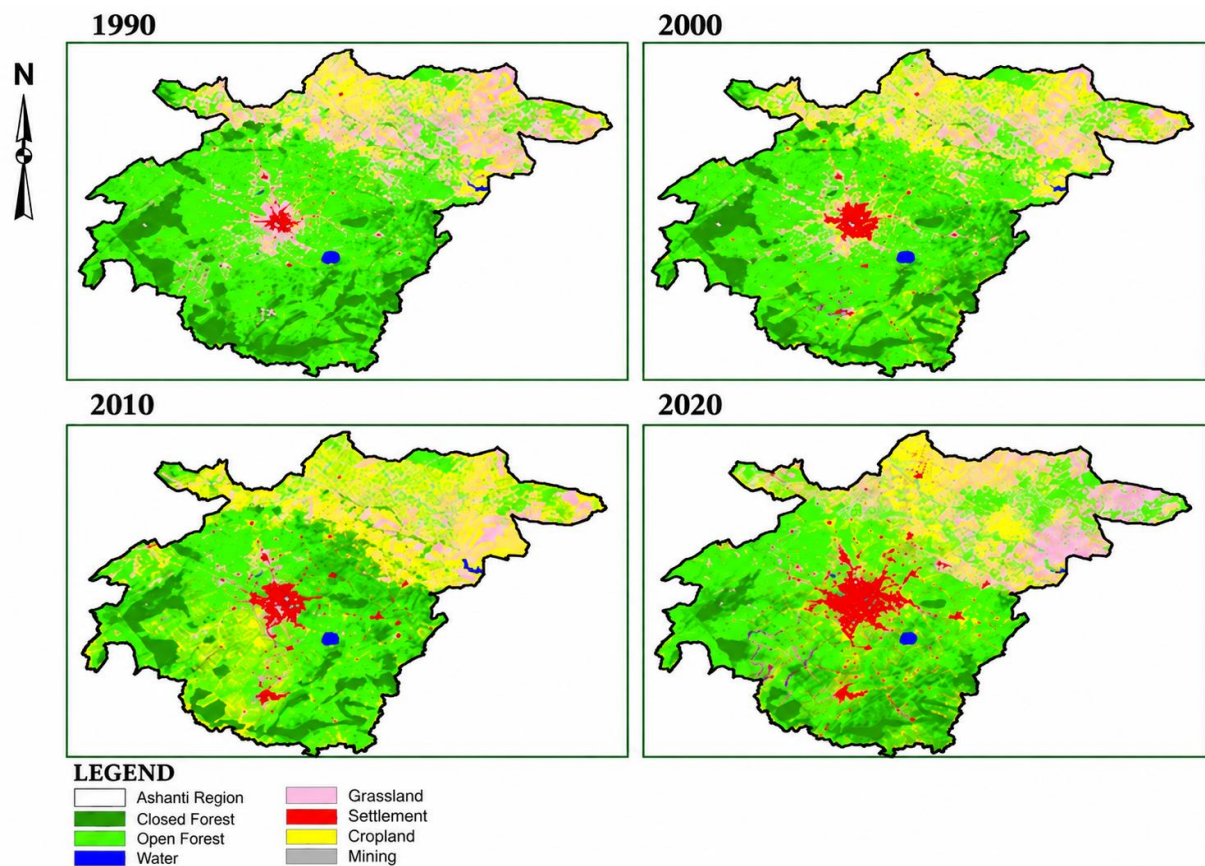


Figure 3. LULC maps for the epoch years.

4.4. Observed Shift Patterns

The study identifies several transition patterns: forest to agricultural land, forest to settlement/community areas, agricultural or timber-related land to extraction areas, and woodland to pasture to farmland pathways. Such patterns are interpreted as evidence for landscape transformation. Because the analysis presented here does not produce a transition matrix at the pixel level, these pathways should be regarded as observed or inferred patterns rather than quantified transition probabilities.

5. DISCUSSION

5.1. Forest Dynamics

Closed Forest decreased by 26.6% and Open Forest decreased by 8.1%. This indicates a large change in forest between 1990 and 2020. The growth of Open Forest from 2010 to 2020 suggests that forest change was not linear in its nature. Such a pattern may be associated with secondary vegetation, plantation development, selective disturbance, or spectral classification differences. The increase should therefore not be automatically considered as ecological forest regeneration without ecological evidence to back it up. These results largely agree with studies conducted by Ababio (2023); Abugre et al. (2025) and Ayesu, Agbyenyaga, Barnes, Gyamfi, and Asante (2024).

Unlike most previous studies in Ghana that have generally focused on shorter periods or combined forest classes, this study presents a detailed analysis of forest dynamics (both closed and open forests) in the study area for a period of three decades. In this study, we distinguish between closed and open forests and point out the nonlinear growth of open forests after 2010, showing subtle trends such as secondary regrowth and plantation development often missed in national-scale assessments. This subtle difference in time and type helps us understand more than the broad strokes of forest loss reported in previous studies.

5.2. Growth of Agriculture

Cropland area increased 119.8% from 1990 to 2020. The broader literature identifies agricultural expansion, including cocoa production, as a major driver of forest change in Ghana (Kalischek et al., 2023). However, cocoa is not distinguished from other forms of cropland in the LULC classification in this study. Thus, while the results show expansion of agricultural land, they do not quantify the contribution of cocoa or any specific crop to forest loss in isolation. The results of LULC alone cannot determine the precise effect of cocoa, food crops, or other agricultural activities on the observed transformation. Thus, these should be considered potential or documented influences from corroborative literature and socioeconomic data, rather than direct causal evaluations from the satellite classification.

Agricultural expansion has been reported as a driver of deforestation in previous studies on land-use/land-cover changes in Ghana (Acheampong, Macgregor, Sloan, & Sayer, 2019; Ampim, Ogbe, Obeng, Akley, & MacCarthy, 2021; Asibey et al., 2020). However, our study shows an unprecedented increase in cropland of 119.8% within a three-decade time frame using consistent multi-temporal remote sensing data. Contrary to previous studies that usually infer the effect of crop type, we provide a clear analysis of the limitations of the LULC classification in differentiating cocoa from other agricultural products. The transparency, scope, and accuracy of our results provide a more sophisticated basis for future studies that aim to elucidate crop-specific determinants, a shortcoming in much of the existing literature.

5.3. Growth of Settlements

Settlement increased by approximately 767%, which is the greatest relative increase of the mapped classes. This pattern is consistent with major urban and peri-urban transformation. Expansion of settlements can have long-term implications as developed land is often more difficult to revert to forest or agricultural use. Integrated spatial planning is therefore a pivotal aspect of landscape governance. This is consistent with earlier studies such as Agyemang, Silva, and Poku-Boansi (2019) and Abass, Adanu, and Gyasi (2018).

The study isolates settlements as a distinct category and relates this change to urban and peri-urban development by illustrating the extent and spatial arrangement of encroachment by built-up areas, which offers more practical insights for spatial planners and policymakers compared with previous studies that group settlements with other land uses.

5.4. Mining and Extractive Activities Land Use

Mining in Ghana has been a vocation for indigenes and foreigners long before it became a nation (Arhin, 1978; Ofose-Mensah, 2011). Studies have shown a surge in mining activities, especially in surface mining, over the years (Akyeampong & Xu, 2023; Gilbert & Albert, 2016; Kofi et al., 2023; Ndikumana & Cantah, 2023). In earlier LULC images, the mining class for 1990, 2000, and 2010 was not delineated because surface mining (legal and illegal) had not reached a measurable scale given the resolution of the satellite images. Mining was mapped as a separate LULC class in 2020 and accounted for 13,077.11 ha. The result illustrates the spatial distribution of surface extraction in the classified landscape. However, satellite classification alone cannot tell whether individual mining areas were legally authorised or illegal. The mining category should not be confused with illegal mining. Rather, the result suggests the need for better spatial monitoring, concession oversight, environmental regulation, and post-mining rehabilitation.

Unlike previous LULC studies in Ghana that either ignore mining or combine it with bare land or disturbed areas, our study defines mining as a separate LULC class at this scale. This allows us to clearly delimit more than 13,000 hectares of mining territory, setting a new spatial basis for future regulation, monitoring, and restoration activities – a pioneering development.

5.5. Interpretation of Socio-Ecological and Governance

Figure 4 explains the Socio-Ecological Forest Governance Framework Oriented to Innovation. The observed LULC transformations can be interpreted as a coupled socio-ecological system. Agricultural demand, population growth, urbanisation and extraction pressures interact with land-tenure arrangements, institutional co-ordination, enforcement capacity and community participation (Cotula, Toulmin, & Hesse, 2004; Kyere-Boateng & Marek, 2021). Political ecology also shows how land-use outcomes reflect competing interests and unequal access to resources (Adams, Kuusaana, Ahmed, & Campion, 2019; Kumeh, Kyereh, Birkenberg, & Birner, 2021). These interpretations show how governance might mediate environmental outcomes but should not be taken to represent statistically established causal relationships, as the current study did not estimate such effects.

Most of the land-use/land-cover studies (Addae & Oppelt, 2019; Ampim et al., 2021; Dembélé et al., 2024) in Ghana provide descriptive results without much consideration of governance or socio-ecological factors. By contrast, this study analyses landscape changes from the perspective of socio-ecological systems, directly associating land-use/land-cover changes with governance elements, tenure arrangements, and institutional cooperation. This multidisciplinary perspective is a big shift from the previous emphasis on biophysical or economic aspects.

5.6. A Forest Governance Framework for Innovation

The study proposed a four-tier innovation-oriented framework. Tier 1 consists of structural drivers such as population growth, agricultural development, mineral extraction, urbanisation, consumer demand and energy dependence. Tier 2 consists of governance and institutional mediators, namely property rights, organisational collaboration, environmental governance, law-enforcement capacity, civic participation, and spatial development strategy. Tier 3 comprises land-use transformation processes: forest degradation, forest fragmentation, agricultural transformation, settlement expansion, and extractive expansion. Tier 4 includes ecological and socioeconomic consequences, such as loss of biodiversity, decline in ecosystem services, soil degradation, effects on water systems, impacts on livelihoods, and reduced ecological resilience. Innovation is implemented at all four levels through five intervention areas: (1) Digital environmental surveillance using remote sensing and GIS; (2) Improved local and participatory governance; (3) Climate-resilient agriculture and agroforestry; (4) Integrated land-use policy and spatial planning; and (5) Multisectoral interagency cooperation. The framework thus defines innovation broadly as changes in technology, institutions, policies, social arrangements, and livelihoods that may affect incentives and decision-

making processes related to unsustainable land-use patterns. The framework Figure 4 describes the conceptual links between drivers, governance and institutional conditions, land-use change processes and ecological outcomes. Arrows represent proposed pathways of influence and conceptual linkages and not statistically established causal effects. The framework suggests potential innovation-oriented interventions to inform sustainable forest governance.

5.7. Policy Implications

First, remote sensing and GIS should be used for the routine monitoring of forests and landscapes. Regular monitoring can assist in the early identification of forest degradation, agricultural expansion, settlement growth, and surface mining. Second, land-use planning needs to be integrated across forestry, agriculture, mining, housing, and infrastructure rather than implemented in isolated sectoral systems. Third, agricultural policy should focus on productivity gains on existing farmland and agroforestry approaches that can lessen pressure for further forest conversion. Fourth, community participation should be strengthened through transparent engagement, benefit-sharing, and integration of local ecological knowledge. Fifth, mining governance must include spatial monitoring, concession management, environmental compliance, and post-mining rehabilitation. Finally, there is a need for stronger coordination between forestry, mining, agriculture, local government, land-management institutions and customary authorities to reduce fragmented governance.

These recommendations should be considered policy implications arising from the observed landscape changes and the theoretical interpretation of the study. They are not proposed as experimentally tested interventions.

This study goes beyond the usual policy advice by connecting remote sensing and GIS-based supervision with actionable plans for integrated land-use planning, participatory governance, and geographically targeted measures. This systematic, innovation-driven approach is rare in the Ghanaian LULC literature and offers a broad framework for future initiatives.

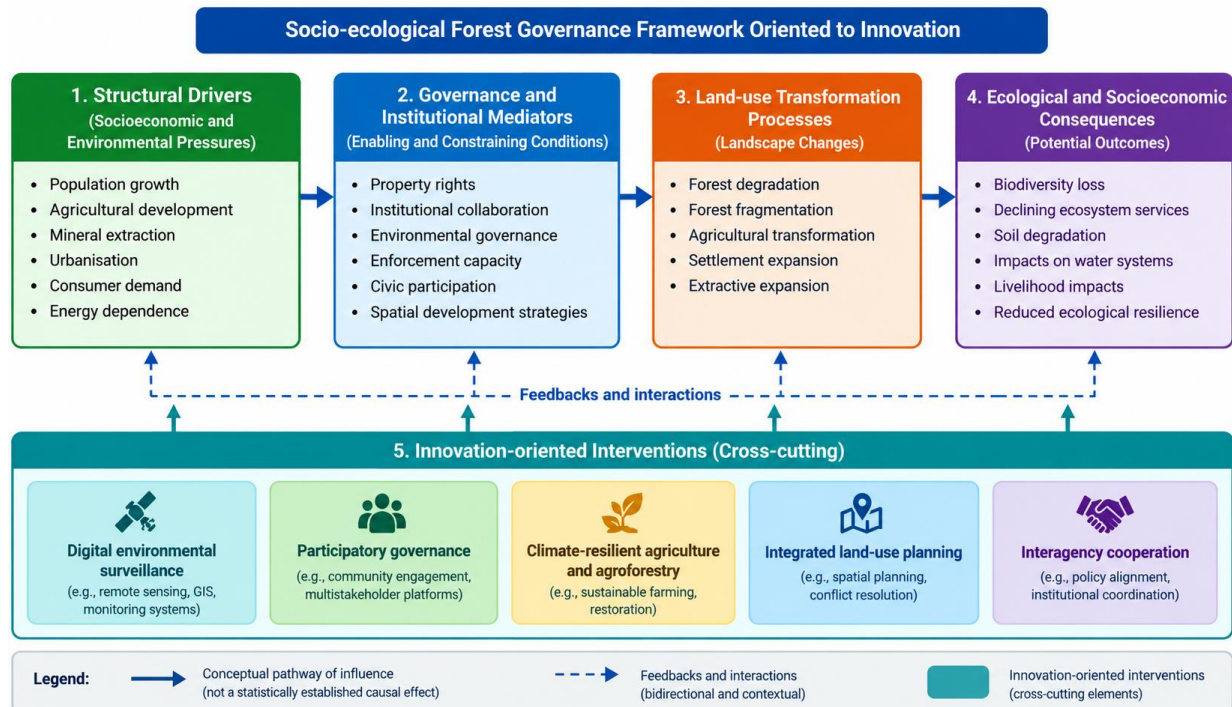


Figure 4. Socio-ecological forest governance framework oriented to innovation.

5.8. Limitations of the Study

Limitations of the study. Several limitations exist. First, Landsat imagery has a spatial resolution of 30 m, which can make it difficult to detect subtle or fragmented land-use features. Second, Cropland and Grassland had relatively

lower producer accuracy, indicating spectral ambiguity. Third, historical validation is inherently difficult because high-resolution imagery today does not provide direct evidence of land conditions in the past. Fourth, the analysis identifies temporal and spatial patterns but does not independently estimate the causal effects of population growth, agricultural development, mining, or governance on individual land-cover transitions.

Future research should incorporate higher-resolution imagery, multi-temporal change trajectories, quantified transition matrices, and spatially explicit socioeconomic and governance indicators. Where there is sufficient longitudinal data, spatial regression, panel methods, or other appropriate quantitative models could be employed to test relationships between socioeconomic/governance variables and LULC outcomes. Field validation and participatory research would strengthen the interpretation of land-use transitions and governance mechanisms.

6. CONCLUSION

The Ashanti Region experienced considerable LULC change from 1990 to 2020. Closed Forest decreased by 26.6% and Open Forest by 8.1%. Cropland increased by 119.8% and Settlement by around 767%. In 2020, mining was depicted as a distinct mapped category, including 13,077.11 ha. This indicates that a forest transformation is taking place in a broader context of agricultural, urban, and extractive expansion.

The study contributes to the literature by linking remote-sensing evidence to SES and political ecology perspectives and translating this interpretation into an innovation-oriented forest governance framework. The framework highlights that sustainable forest governance demands more than technological monitoring. Institutional coordination, participatory governance, sustainable agricultural methods, integrated land-use planning, and effective regulation are also important. Socioeconomic and governance relationships were not statistically estimated and thus are presented as contextual and plausible influences rather than proven causal effects. Future studies should quantitatively test these relationships using spatially and temporally explicit socioeconomic and governance data.

Funding: This study received no specific financial support.

Institutional Review Board Statement: Not applicable.

Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

- Ababio, B. (2023). Forest cover monitoring in Southwestern Ghana with remote sensing and GIS. Master's Thesis, NOVA University Lisbon, Portugal.
- Abass, K., Adanu, S. K., & Gyasi, R. M. (2018). Urban sprawl and land use/land-cover transition probabilities in peri-urban Kumasi, Ghana. *West African Journal of Applied Ecology*, 26(Special Issue), 118–132.
- Abugre, S., Asigbaase, M., Kumi, S., Nkoah, G., & Asare, A. (2025). Forest landscape degradation, carbon loss and ecological consequences of illegal gold mining in Ghana. *Discover Forests*, 1(1), 20. <https://doi.org/10.1007/s44415-025-00020-5>
- Acheampong, E. O., Macgregor, C. J., Sloan, S., & Sayer, J. (2019). Deforestation is driven by agricultural expansion in Ghana's forest reserves. *Scientific African*, 5, e00146. <https://doi.org/10.1016/j.sciaf.2019.e00146>
- Adams, E. A., Kuusaana, E. D., Ahmed, A., & Campion, B. B. (2019). Land dispossessions and water appropriations: Political ecology of land and water grabs in Ghana. *Land Use Policy*, 87, 104068. <https://doi.org/10.1016/j.landusepol.2019.104068>
- Addae, B., & Oppelt, N. (2019). Land-use/land-cover change analysis and urban growth modelling in the Greater Accra Metropolitan Area (GAMA), Ghana. *Urban Science*, 3(1), 26. <https://doi.org/10.3390/urbansci3010026>
- Adeoti, A., Barry, B., Namara, R. E., Kamara, A. B., & Titiat, A. (2007). *Treadle pump irrigation and poverty in Ghana*. IWMI Research Report No. 117. Colombo, Sri Lanka: International Water Management Institute.

- Agyemang, F. S. K., Silva, E., & Poku-Boansi, M. (2019). Understanding the urban spatial structure of Sub-Saharan African cities using the case of urban development patterns of a Ghanaian city-region. *Habitat International*, 85, 21–33. <https://doi.org/10.1016/j.habitatint.2019.02.001>
- Akyeampong, E., & Xu, L. (2023). Chinese technology and the transformation of the rural economy in Ghana: Evidence from Galamsey in the Ashanti and Savannah regions. *African Affairs*, 122(488), 329–351. <https://doi.org/10.1093/afraf/adad023>
- Ali, A. (2023). Linking forest ecosystem processes, functions and services under integrative social–ecological research agenda: Current knowledge and perspectives. *Science of the Total Environment*, 892, 164768. <https://doi.org/10.1016/j.scitotenv.2023.164768>
- Ampim, P. A. Y., Ogbe, M., Obeng, E., Akley, E. K., & MacCarthy, D. S. (2021). Land cover changes in Ghana over the past 24 years. *Sustainability*, 13(9), 4951. <https://doi.org/10.3390/su13094951>
- Ankrah, D., Takyi, S. A., Biliyitorb Liwur, S., & Amponsah, O. (2026). Urban sprawl, urban form, and urban land use pattern: Examining urban planning response to the causes and effects of urban sprawl in Kumasi, Ghana. *African Geographical Review*, 45(1), 79–93. <https://doi.org/10.1080/19376812.2024.2391777>
- Arhin, K. (1978). Gold-mining and trading among the Ashanti of Ghana. *Journal Des Africanistes*, 48(1), 89–100.
- Ashiagbor, G., Asante, W. A., Forkuo, E. K., Acheampong, E., & Foli, E. (2022). Monitoring cocoa-driven deforestation: The contexts of encroachment and land use policy implications for deforestation free cocoa supply chains in Ghana. *Applied Geography*, 147, 102788. <https://doi.org/10.1016/j.apgeog.2022.102788>
- Asibey, M. O., Agyeman, K. O., Amponsah, O., & Ansah, T. (2020). Patterns of land use, crop and forest cover change in the Ashanti region, Ghana. *Journal of Sustainable Forestry*, 39(1), 35–60. <https://doi.org/10.1080/10549811.2019.1608453>
- Assede, E. S. P., Orou, H., Biaou, S. S. H., Geldenhuys, C. J., Ahononga, F. C., & Chirwa, P. W. (2023). Understanding drivers of land use and land cover change in Africa: A review. *Current Landscape Ecology Reports*, 8(2), 62–72. <https://doi.org/10.1007/s40823-023-00087-w>
- Atampugre, G., Tilahun, S. A., Oke, A., Mabhaudhi, T., Cofie, O., Igbadun, H. E., & Olaleye, A. O. (2024). Social-ecological landscape sustainability in West Africa: Applying the driver pressure state impact response framework in Ghana and Nigeria. *Discover Sustainability*, 5(1), 413. <https://doi.org/10.1007/s43621-024-00602-x>
- Awotwi, A., Anornu, G. K., Quaye-Ballard, J. A., & Annor, T. (2018). Monitoring land use and land cover changes due to extensive gold mining, urban expansion, and agriculture in the Pra River Basin of Ghana, 1986–2025. *Land Degradation & Development*, 29(10), 3331–3343. <https://doi.org/10.1002/ldr.3093>
- Ayeni, A. O., Aborisade, A. G., Aiyegbaje, F. O., & Soneye, A. S. O. (2025). The dynamics of peri-urban expansion in Sub-Saharan Africa: Implications for sustainable development in Nigeria and Ghana. *Discover Sustainability*, 6(1), 290. <https://doi.org/10.1007/s43621-024-00742-0>
- Ayesu, S., Agbyenyaga, O., Barnes, V. R., Gyamfi, A., & Asante, R. K. (2024). Advancing multiple ecosystem service assessment in the tropics: Evidence from Barekese and Owabi watersheds in Ghana. *Heliyon*, 10(18), e37499. <https://doi.org/10.1016/j.heliyon.2024.e37499>
- Bamidele, S. (2026). Community-led forest management and conservation: Insights from Nigeria's Obudu and Mambilla Mountain forests. *Environmental Policy and Governance*, 36(1), 81–94. <https://doi.org/10.1002/eet.70037>
- Bennett, A., Larson, A. M., Zamora Ríos, A., Monterroso, I., & Sheila, G. (2023). Forty-year multi-scale land cover change and political ecology data reveal a dynamic and regenerative process of forests in Peruvian Indigenous Territories. *Global Environmental Change*, 81, 102695. <https://doi.org/10.1016/j.gloenvcha.2023.102695>
- Boyle, M. J. W., Bonebrake, T. C., Dias da Silva, K., Dongmo, M. A. K., Machado França, F., Gregory, N., . . . Ashton, L. A. (2025). Causes and consequences of insect decline in tropical forests. *Nature Reviews Biodiversity*, 1(5), 315–331. <https://doi.org/10.1038/s44358-025-00038-9>
- Chirwa, P. W., Kozanayi, W., Uisso, A. J., Tshidzumba, R. P., Babalola, F. D., & Amusa, T. O. (2024). Socio-economic factors, policy and governance systems influencing multifunctional landscapes. In P. W. Chirwa, S. Syampungani, & T. M.

- Mwamba (Eds.), *Trees in a Sub-Saharan multi-functional landscape: Research, management, and policy* (pp. 305–327). Cham, Switzerland: Springer.
- Cockburn, J., Cundill, G., Shackleton, S., & Rouget, M. (2018). Towards place-based research to support social–ecological stewardship. *Sustainability*, 10(5), 1434. <https://doi.org/10.3390/su10051434>
- Cotula, L., Toulmin, C., & Hesse, C. (2004). *Land tenure and administration in Africa: Lessons of experience and emerging issues*. London: International Institute for Environment and Development.
- Dembélé, F., Guuroh, R. T., Ansah, P. B., Asare, D.-C. B. M., Da, S. S., Aryee, J. N. A., & Adu-Bredu, S. (2024). Land use land cover change and intensity analysis of land transformation in and around a moist semi-deciduous forest in Ghana. *Trees, Forests and People*, 15, 100507. <https://doi.org/10.1016/j.tfp.2024.100507>
- Duguma, L. A., Atela, J., Minang, P. A., Ayana, A. N., Gizachew, B., Nzyoka, J. M., & Bernard, F. (2019). Deforestation and forest degradation as an environmental behavior: Unpacking realities shaping community actions. *Land*, 8(2), 26. <https://doi.org/10.3390/land8020026>
- Ghana Statistical Service (GSS). (2022). *Ghana 2021 population and housing census general report volume 3E: Economic activity*. Accra, Ghana: Ghana Statistical Service.
- Gilbert, D., & Albert, O.-B. (2016). Illegal small-scale gold mining in Ghana: A threat to food security. *Journal of Food Security*, 4(5), 112–119.
- Kalischek, N., Lang, N., Renier, C., Daudt, R. C., Addoah, T., Thompson, W., . . . Wegner, J. D. (2023). Cocoa plantations are associated with deforestation in Côte d'Ivoire and Ghana. *Nature Food*, 4(5), 384–393. <https://doi.org/10.1038/s43016-023-00751-8>
- Kofi, A. S., Loveridge, A. D. S., Obed, A., Oduro, N. B., David, A., & Yah, T. R. (2023). The contributions of Ghana's minerals resources to the global economy: Using bauxite as a case study. *North American Academic Research*, 6(4), 71–86.
- Koranteng, A., Adu-Poku, I., Donkor, E., & Zawila-Niedźwiecki, T. (2020). Geospatial assessment of land use and land cover dynamics in the mid-zone of Ghana. *Folia Forestalia Polonica*, 62(4), 288–305. <https://doi.org/10.2478/ffp-2020-0028>
- Koranteng, A., & Zawila-Niedźwiecki, T. (2015). Modelling forest loss and other land use change dynamics in Ashanti Region of Ghana. *Folia Forestalia Polonica*, 57(2), 96–111. <https://doi.org/10.1515/ffp-2015-0010>
- Kouassi, J.-L., Gyau, A., Diby, L., Bene, Y., & Kouamé, C. (2021). Assessing land use and land cover change and farmers' perceptions of deforestation and land degradation in South-West Côte d'Ivoire, West Africa. *Land*, 10(4), 429. <https://doi.org/10.3390/land10040429>
- Kumar, R., Kumar, A., & Saikia, P. (2022). Deforestation and forests degradation impacts on the environment. In V. P. Singh, S. Yadav, K. K. Yadav, & R. N. Yadava (Eds.), *Environmental degradation: Challenges and strategies for mitigation* (pp. 19–46). Cham, Switzerland: Springer.
- Kumeh, E. M., Kyereh, B., Birkenberg, A., & Birner, R. (2021). Customary power, farmer strategies and the dynamics of access to protected forestlands for farming: Implications for Ghana's forest bioeconomy. *Forest Policy and Economics*, 133, 102597. <https://doi.org/10.1016/j.forpol.2021.102597>
- Kyere-Boateng, R., & Marek, M. V. (2021). Analysis of the social-ecological causes of deforestation and forest degradation in Ghana: Application of the DPSIR framework. *Forests*, 12(4), 409. <https://doi.org/10.3390/f12040409>
- Larbi, I. (2023). Land use-land cover change in the Tano basin, Ghana and the implications on sustainable development goals. *Heliyon*, 9(4), e14859. <https://doi.org/10.1016/j.heliyon.2023.e14859>
- Makwinja, Y. H., O'Farrell, P. J., Kimengsi, J. N., & Guenther, E. (2025). Land cover shifts strain resource nexus in southern Africa: Evidence from Malawi. *Frontiers in Environmental Science*, 13, 1665279. <https://doi.org/10.3389/fenvs.2025.1665279>
- Manu, K. K., Takyi, S. A., Amponsah, O., Yeboah, A. S., & Lotsah, M. (2022). Location of forest reserves and sustainable natural resource management: Evidence from a Ghanaian case study. *SN Social Sciences*, 2(5), 72. <https://doi.org/10.1007/s43545-022-00381-0>

- Ndikumana, L., & Cantah, W. G. (2023). *Gold in Ghana: A story of unbalanced exchange*. PERI Working Paper No. 584. Amherst, MA: Political Economy Research Institute, University of Massachusetts Amherst.
- Nyengere, J., Tchuwa, F., Tholo, H. M., Njala, A. L., Malalu, L., Chisenga, C., . . . Mwangwela, A. (2026). Land use and land cover dynamics and its implications for agrifood systems among smallholder farmers in central Malawi. *Frontiers in Sustainable Food Systems*, 10, 1789367. <https://doi.org/10.3389/fsufs.2026.1789367>
- Ofosu-Mensah, E. A. (2011). Historical overview of traditional and modern gold mining in Ghana. *International Research Journal of Library, Information and Archival Studies*, 1(1), 006-022.
- Okpara, U. T., Stringer, L. C., Akhtar-Schuster, M., Metternicht, G. I., Dallimer, M., & Requier-Desjardins, M. (2018). A social-ecological systems approach is necessary to achieve land degradation neutrality. *Environmental Science & Policy*, 89, 59-66. <https://doi.org/10.1016/j.envsci.2018.07.003>
- Peng, J., Li, J., Peng, L., & Zhang, Y. (2025). Forest ecosystem conservation through rural tourism and ecosystem services: A systematic review. *Forests*, 16(10), 1559. <https://doi.org/10.3390/f16101559>
- Peprah, K. (2022). Drivers of deforestation, forest degradation, and management responses in Ghana. In P. Panwar, G. Shukla, J. A. Bhat, & S. Chakravarty (Eds.), *Land degradation neutrality: Achieving SDG 15 by forest management* (pp. 61–79). Singapore: Springer.
- Peprah, M. S. (2025). Land use land cover classification for Africa—a case of the republic of Ghana using systematic review and meta-analysis. *International Journal of Earth Sciences Knowledge and Applications*, 7(2), 164–192.
- Shiri, Z., Le, Q. B., Ouerghemmi, H., & Rejeb, H. (2025). Landscape approaches for sustainable land systems: A critical systematic review of frameworks, governance, and socio-ecological outcomes. *Landscape Architecture and Sustainability*, 2, 100007. <https://doi.org/10.1016/j.las.2025.100007>
- Swamy, L., Drazen, E., Johnson, W. R., & Bukoski, J. J. (2018). The future of tropical forests under the United Nations Sustainable Development Goals. *Journal of Sustainable Forestry*, 37(2), 221–256. <https://doi.org/10.1080/10549811.2017.1416477>
- Velastegui-Montoya, A., Montalván-Burbano, N., Peña-Villacreses, G., de Lima, A., & Herrera-Franco, G. (2022). Land use and land cover in tropical forest: Global research. *Forests*, 13(10), 1709. <https://doi.org/10.3390/f13101709>