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Research

Social-ecological landscape sustainability in West Africa: applying the driver pressure state impact response framework in Ghana and Nigeria

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Abstract
This study interrogates the state of social-ecological landscapes (SEL) in West Africa, focusing on two case studies: the Mankran SEL in Ghana (case study 1) and the Doma–Rutu SEL in Nigeria (case study 2). Using a mix of methods, the assessment was framed by the Drivers Pressure State Impact Response (DPSIR) model tailored for SEL evaluation (DPSIR-SEL). In the Mankran landscape, land use patterns shifted significantly from 2008 to 2018, with cash crop cultivation peaking at 30% in 2015 before declining to 14.5% by 2018. Water quality assessments in the Mankran micro-watershed indicated that several parameters, including Total Suspended Solids (TSS) at 914.41 ± 1974 mg/L, lead at 18.73 ± 17.26 µg/L, and arsenic at 53.41 ± 86.66 µg/L, exceeded World Health Organization (WHO) standards, raising concerns about potential contamination. In contrast, the Doma–Rutu landscape in Nigeria experienced land use and land cover (LULC) changes from 2000 to 2022, characterized by the expansion of residential and agricultural areas alongside modifications to natural water bodies and vegetation. Water quality issues have emerged, with elevated levels of electrical conductivity, total dissolved solids, and salinity. Furthermore, Focus Group Discussions (FGDs) revealed persistent herder-farmer conflicts in Nigeria, which have historically constrained crop production due to various environmental and social factors. The intertwined challenges faced by both the Mankran and Doma–Rutu landscapes underscore the urgent need for sustainable and inclusive resource management, adaptive land-use strategies, and proactive measures to safeguard water quality.

Keywords Sustainability · Social ecological landscapes · AgriFood systems · DPSIR-SEL · Ghana · Nigeria

1 Introduction

Socio-ecological landscapes highlight the interdependence of human activities and cultural practices with both social structures and ecological processes within a landscape [1]. Such landscapes integrate natural and human-made features, including forests, rivers, cities, and agricultural fields, illustrating how human societies both influence and are influenced by their surrounding environments. Recently, social-ecological landscapes (SELs) have garnered significant attention in sustainable development and environmental conservation. This growing recognition stems from the understanding that SELs are not just physical spaces but dynamic systems with intricate relationships between natural elements and human

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societies. They consist of natural and/or human-modified ecosystems that interact with various ecological, historical, political, economic, and socio-cultural processes [1, 2]. These landscapes are crucial for providing sustainable livelihoods and essential ecosystem services that contribute to human well-being. Sustainable SELs serve as a foundation for resilient agrifood systems, ensuring that food production remains secure and adaptable amidst challenges such as climate change, population growth, and environmental degradation. Promoting these landscapes is vital for the well-being of local communities and the stability of the global food system.

In West Africa, the factors driving changes in social-ecological landscapes (SELs) are complex and multifaceted. High population growth rates in the region have led to increased demands for infrastructure, industry, and agriculture, while multiple stakeholders at national and global levels extract natural resources in an unsustainable manner [3, 4]. This has resulted in many landscapes facing a myriad of threats, including overexploitation and misuse of resources, which are further exacerbated by the impacts of climate change [5]. The expansion of agricultural land to meet the growing food demands has been a significant driver of SEL changes in West Africa. Recent studies have shown that the increase in agricultural land use can have direct consequences on ecosystem services or reduced productivity [4]. As more land is converted for crop cultivation, the region's biodiversity and the provision of vital ecosystem services are declining at an alarming rate [4, 5]. This scenario underscores the growing importance of research and strategies aimed at the sustainable and inclusive management of these landscapes to ensure their long-term resilience and the well-being of the communities that depend on them.

Moreover, the unsustainable extraction of natural resources by various stakeholders, both at the national and regional levels, has put immense pressure on the region's SELs [3–5]. The overexploitation of resources, such as timber, minerals, and wildlife, has led to the degradation of habitats and the loss of biodiversity. This, in turn, jeopardizes the agricultural production systems and the sustainability of local livelihoods that are intrinsically linked to the health of these landscapes [3]. The complex interplay of population growth, agricultural expansion, and unsustainable resource extraction, coupled with the impacts of climate change, has created a challenging scenario for the management of SELs in West Africa [6]. Addressing these issues requires a holistic and inclusive approach that involves multiple stakeholders, including local communities, governments, and the private sector. Strategies should focus on promoting sustainable land-use practices, protecting biodiversity, and ensuring the equitable distribution of benefits derived from ecosystem services [7]. By prioritizing research and implementing evidence-based policies, West Africa can work towards the sustainable management of its social-ecological landscapes and secure a better future for its people and the environment.

In Ghana and Nigeria, SEL development often overlooks biodiversity conservation and the essential ecosystem services necessary for soil fertility, natural pollinators, and pest control in agrifood systems [8, 9]. Agricultural practices in these countries frequently prioritize short-term economic gains over long-term ecological health, resulting in significant biodiversity loss and degradation of ecosystem services. The reliance on monoculture farming and harmful agrochemicals disrupts ecosystem balance and diminishes beneficial organisms vital for agricultural productivity [10, 11]. Consequently, healthy landscapes are increasingly unable to buffer against extreme weather or support species adaptation to climate change [12]. Moreover, sectoral strategies in both countries often exclude local communities from decision-making, limit livelihood diversification, and promote unsustainable practices, perpetuating cycles of poverty and environmental degradation [8, 13–15]. Addressing these challenges requires an integrated approach that emphasizes inclusive governance and sustainable land management to restore ecosystem health and enhance biodiversity conservation.

Research on SELs in Ghana and Nigeria is gaining traction due to the recognition of the need for integrated and inclusive approaches to understanding and managing complexity for sustainable agrifood systems [8, 9, 16, 17]. This study is framed within the context of using "social-ecological systems" research to explore the sustainability of SELs, particularly in relation to Sustainable Development Goals (SDGs) 2, 6, 13, and 15. It posits that equitable access to and efficient use of land and water resources are prerequisites for fostering healthy, productive, and resilient agrifood systems. The paper emphasizes the importance of understanding synergies and trade-offs among development activities in landscapes, alongside the complex ecological resources and processes involved [18]. The development aspect involves intensive engagement with land use, organization, and spatial arrangement. The characteristics of land and space, along with their natural and produced substrata, are crucial for determining future sustainable development [19]. This research aims to connect current development trends with natural resource conservation. The Driver Pressure State Impact Response framework for SEL assessment (DPSIR-SEL) is employed in this study [16] to integrate social and ecological aspects, evaluating landscape-level phenomena through the five interrelated components that shape the benefits or trade-offs derived from landscapes. This holistic approach focuses on driving forces, pressures, state, impacts and responses that define the sustainability of the SELs [20].

Using a mix of methods, this study will analyze the sustainability of the Mankran landscape in Ghana and the Doma–Rutu landscape in Nigeria, aiming to provide an overview of how various drivers and pressures delineate the state and impacts of SELs, while highlighting institutional and stakeholder responses. The main objectives of this study include:

- Assessing the drivers and pressures that underpin landscape change
- Examining the dynamics of the social-ecological landscape state
- Exploring the impacts of landscape transitions on human well-being, biodiversity, and ecosystem services
- Investigating existing institutional and policy responses to landscape drivers, pressures, dynamic states, and impacts.

The selected study sites are ideal due to their rich ecological resources, including diverse water networks, fertile plains, and minerals, alongside multiple competing land uses and significant environmental degradation [6]. This landscape assessment will be crucial for decision-making aimed at balancing multiple goals and objectives, such as conservation, sustainable agriculture, livelihood improvement, climate change mitigation and adaptation, and social equity.

2 Conceptual framework

At the center of a sustainable SEL is the improvement of the management of land and the natural resource base in such a way that land use concurrently meets three goals: (i) provision of products (e.g., food) and services on a sustainable basis, (ii) support for sustainable livelihoods for all social groups and (iii) conservation of the full complement of biodiversity and ecosystem services. Globally, sustainable SEL approaches such as inclusive landscape management, agroecology, eco-agriculture and integrated landscape management are already being applied, with promising results in places where food production, poverty alleviation and conservation of biodiversity, water, and ecosystem services are all high priorities [21, 22]. These approaches are applied on productive landscapes with symbiotic land use (e.g., forestry, agriculture, extraction of minerals, conservation/protected areas, and settlements). Therefore, SEL state and performance assessment frameworks that focus exclusively on, for example, the conservation of natural resources on the one hand or agriculture and other land uses, on the other hand, can at best give an inadequate overview of the SEL. Considering the varied SEL goals, a comprehensive and iterative assessment framework is needed to consider the drivers of land use and the complex interactions among different land uses and interventions across the landscape.

The purpose here is not to present a new conceptual framework for analyzing SEL sustainability. The intended aim is to draw insights from the works of [20–26] and the case studies of the Satoyama Initiative [26] to comprehensively understand the driving forces and pressures that underpin changes in the state of SELs as well as their implications for human wellbeing, ecosystems services and sustainable landscape management in Ghana and Nigeria. The DPSIR-SEL assessment framework (Fig. 1) is a coupled social-ecological framework informed by systems thinking. It is a tool that can inform the assessment of landscape-level phenomena.

Essential aspects of the DPSIR-SEL include the five key components which interact at the landscape level and have a significant influence on the benefits derived from the landscape:

Driving Forces motivate human activities and fulfill basic human needs, consistently identified as the necessary conditions and materials for a good life, good health, good social relations, security, and freedom. Driving forces describe "the social, demographic, and economic developments in societies". Social determinants also have a strong influence on SEL dynamics. Therefore, for this framework, driving forces have been broadened to include socio-cultural and political factors. Accordingly, during the stakeholder workshops, focus group discussions (FGDs) and key informant interviews (KIIs), respondents were asked about what they thought motivated the type of land uses in and around their communities.

In the context of this paper, *Dynamic Pressures* are human activities derived from the functioning of natural, social and economic driving forces that induce changes in the environment or human systems. For this study, participants were asked about: (i) Land use changes resulting from alterations in the natural landscape; (ii) Discharges of pollutants that may result from the operation of industries or vehicles or the diffused distribution of contaminants from agricultural lands, mine sites, or roads through groundwater or storm-water run-off, etc., (iii) Contact uses activities that lead to a direct alteration or manipulation of the open/closed vegetation, water resources, or land, including: (iv) Physical damage—direct degradation through mining, dredging and filling, deforestation; (v) Biological addition—ballast discharge, the release of non-natives, feeding, creation of artificial habitat; (vi) Biological harvest—harvesting, fishing, accidental by-catch, clear-cutting. The State of the landscape in this work refers to the state of the natural and built environment. From respondents, information was sought on the quantity and quality

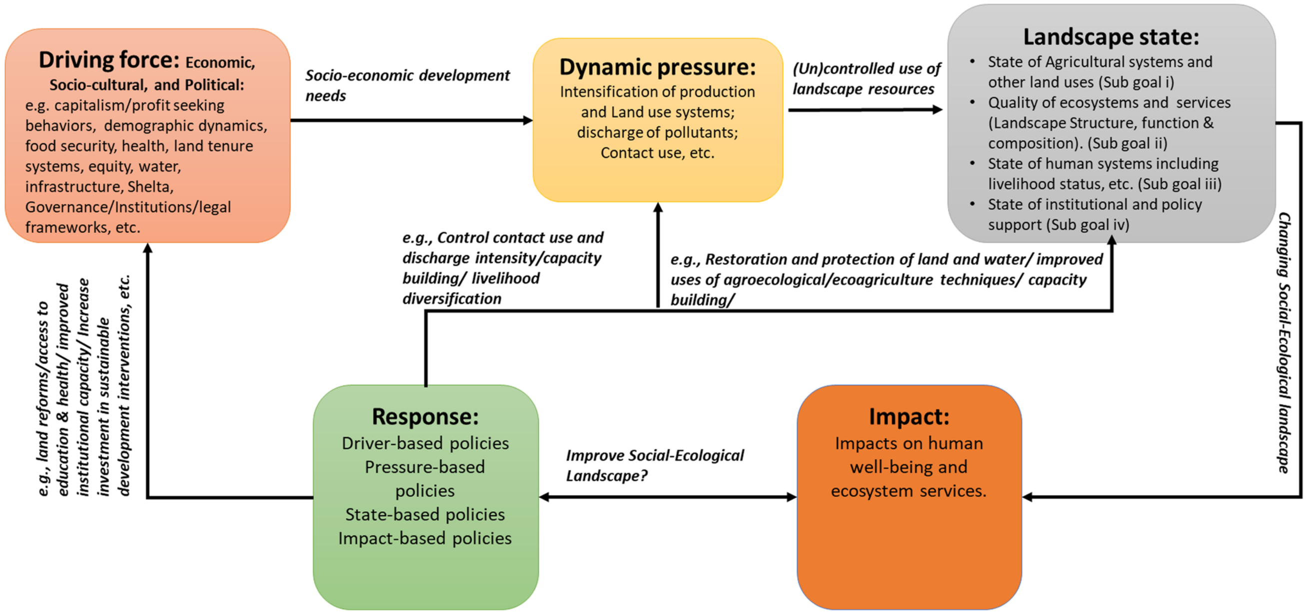

Fig. 1 DPSIR-SEL framework (Source: Adapted from [16])

of the following components of the landscape: (i) physical, (ii) chemical, (iii) biological, (iv) and human systems. With regards to impacts on ecosystems and human well-being, the notion is that changes in an ecosystem's structure, functioning and composition will impact the production of ecosystem goods and services and, ultimately, human well-being through, for example, health and food insecurity. For the impacts on ecosystem goods and services, the study sort data/information on: (i) Provisioning services, (ii) Regulating services, (iii) Cultural services and (iv) Supporting processes.

On the *impacts* on human wellbeing, as abstract as the concept is, the study tried to get qualitative information on a mixture of people's life circumstances and the degree of fulfilment of basic human needs for food, water, health, security, culture, and shelter. Human well-being reflects a positive physical, mental and social state. For this paper, human well-being includes Economic prosperity (e.g., productivity, ability to work, income), Health and safety (e.g., life span, medical or insurance costs, sick days, pain and suffering), Cultural and social well-being (e.g., "happiness", sense of belonging, community vibrancy, spiritual fulfilment).

A key benefit of using the DPSIR-SEL framework is that it explicitly includes an Action or Response component that can be taken at any level of the causal network. In the DPSIR-SEL assessment framework, responses are considered actions taken by groups or individuals in society and (non) governmental institutions to: (i) prevent, (ii) compensate, (iii) ameliorate, (iv) adapt to changes in the state of the environment, (v) modify human behaviors that contribute to health risks and (vi) directly modify health through medical treatments or to compensate for social or economic impacts of the human condition on human well-being. Responses may be directed at driving forces, pressures, landscape state, or impacts. Responses were solicited from participants and review of official reports.

3 Methodological approach

The research employed a mixed-method approach, where quantitative data were combined with context-specific qualitative data for site selection, data collection, and data analysis. These include stakeholder workshops, focused group discussions, key informant interviews, documentary research, content analysis, geospatial analysis, and water quality analysis.

3.1 Case studies

It is important to mention that this work is part of the Consultative Group on International Agricultural Research (CGIAR) initiative called West and Central Africa AgriFood Transformation (TAFS-WCA). Consequently, the criteria for selecting these target landscapes were informed by two expert workshops held in Ghana by International Water Management Institute (IWMI-Ghana team) and in Ivory Coast by the TAFS-WCA partner institutions. During these engagements, the existence of the following outlined themes guided the selection of case landscapes:

- Location of case landscape: the site must be in the forest transition zone for Ghana.
- Significant competing land uses and related degradation (e.g., Agriculture, Forestry, Mining, settlement expansion, Chain-saw operations, etc.).
- Types of crops: vegetables, sweet potato, rice, cassava, plantain, cowpea, cocoa, Yam, maize, cocoyam.
- Fishing and aquaculture
- Watersheds and related issues: quantity and quality of water and water productivity.
- Existing landscape management initiatives/Low-hanging-fruits (preferably CGIAR institutions and related projects—e.g., International Institute of Tropical Agriculture (IITA), Centro Internacional de Agricultura Tropical (CIAT), Africa Rice Center (AfricaRice), Technologies for African Agricultural Transformation, Phase II (TAAT II), Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA), Climate Change, Agriculture and Food Security (CCAFS), West Africa Agricultural Productivity Program (WAAPP), Integrated Agricultural Research for Development (IAR4D).
- Existing multi-stakeholder platforms/forums

In the context of this paper, the selected target landscapes in Ghana and Nigeria are used as cases. It is also important to state that this study is not a comparative study. This study is meant to emphasize the state of social ecological landscapes in West Africa, using cases from Ghana and Nigeria.

In Ghana, the target landscape (i.e., *Mankran landscape, case study 1*) is located in the Mankran watershed in the Offin sub-basin. Administratively, the site is in the *Ahafo Ano South West District (AASWD)* in the Forest Transition Belt of Ghana (Fig. 2). Ahafo Ano South West District is located at 6°42′ north, 1° 45′ east, and 2° 20′ west. The district, where case study-1 is located, is approximately 645.54 sq/km, about 2.6% of the total land area of the Ashanti region. It is bounded to the northeast by Tano North Municipal in the Ahafo Region, to the northwest by Ahafo Ano North Municipal, to the south by Atwima Nwabiagya Municipal, and to the east by the Offin North District in the Ashanti Region. According to the 2021 Population and Housing Census, the district's population is 65,770, with 33 641 men and 32,129 females [34].

The AASWD comprises 119 settlements, with Mankran as the capital located approximately 35 km from Kumasi. A significant social challenge within the district is the notably high poverty level. This is particularly evident in the human settlements, where rural poverty is starkly manifested. Many communities experience a lack of basic social amenities such as health, education, water, and sanitation, contributing to the overall state of poverty. This hardship is further reflected in the deteriorating infrastructure and the overall decline of the built environment. The district's physiography features numerous rivers/streams, a moist semi-deciduous rainforest, double maxima rainfall, fertile soils suitable for agriculture, and mineral-rich rock formations. However, recent illegal mining and logging activities have escalated, degrading rivers, and transforming tributaries into seasonal water systems. This alteration contributes to water insecurity, particularly in dry seasons. Despite sufficient rainfall for agriculture, its erratic and unpredictable nature poses challenges for rain-fed farming. Climate variability also leads to frequent flooding, exacerbated by river siltation. Natural vegetation is diminishing rapidly, with secondary forests replacing the original cover. Deforestation stems from excessive tree felling, primarily by illegal chain saw operators, and poor farming practices.

In Nigeria, the Doma–Rutu Landscape (case study-2) in the Nasarawa State in Nigeria is the selected case. It is located at latitudes 80 17′ 32″ to 80 26′ 48″ N and longitude 80 12′ 34″ to 80 23′ 16″ E, with altitude ranging from 73 m above sea level around the Mada River to 217 m above sea level southwest of the Doma Dam (Fig. 3). The landscape is within the Doma Local Government Area of Nasarawa State, Nigeria. The landscape covers an area of approximately 192.26 km^2 (19,226 ha). The Mada River borders the West, and the Doma Dam borders the southeast. The main river in the Doma–Rutu Landscape is the Ohina River, which originates from the Shandam Plateau hills, enters the landscape from the southeastern flange, flows through the full length of the landscape, and drains into the Mada River to the northwest. The Ohina River is dammed within the landscape (the Doma Dam) and then flows

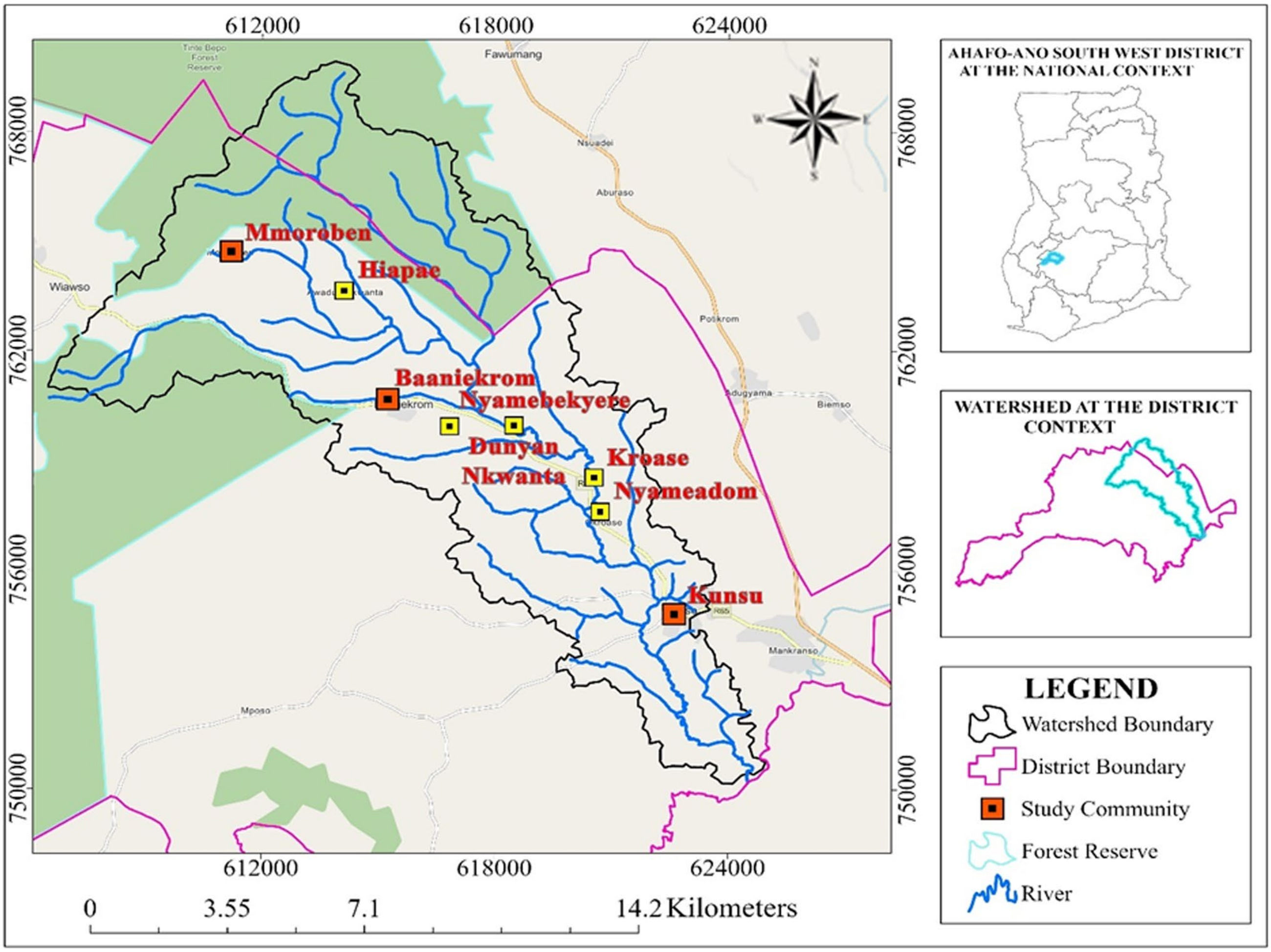

Fig. 2 Location of Offin River Basin, Ghana (case study-1) [20]

approximately 15.4 km (from the Doma Dam) to the Mada River. The Mada River is a larger river flowing from the plateau hills and passing by the border of the landscape in the northeastern part of Rutu village. The communities within the landscape include parts of Doma and Mukaiya towns in the northeast, Dogon Kurmi/Iwashi village in the north, Rutu village in the northwest, and Alagye village in the southwest [28, 29]. Records of the human population of the communities in the landscape are not within reach; however, the population of the Doma Local Government Area as of 2022 is estimated at 214,600 people at a growth rate of 2.8% per annum [30].

3.2 Qualitative data collection and analysis

In AASWD (case study 1), nine parallel FGD sessions were carried out. These sessions engaged not only community members but also community leaders. FGDs were held separately for men and women. Each group consisted of 8–12 participants. Simultaneously, a comprehensive set of 12 institutional interviews was conducted, encompassing vital entities such as the Agricultural Department, Forestry Department, Education Directorate, Health Directorate, Ambulance Services, Social Welfare and Community Development, Environmental Health and Sanitation, Judiciary (Registrar), National Commission for Civic Education (NCCE), Commission for Human Rights and Administrative Justice (CHRAJ), and the Police. Consent forms were methodically employed to ensure a foundation for informed consent before the participants' involvement. Privacy safeguards have been established by applying pseudo-identification methodologies. Participants were educated on the study's objectives to mitigate potential response biases rooted in social desirability [31]. Comprehensive records were maintained for all interviews and focus group discussions, each with the participants' explicit consent.

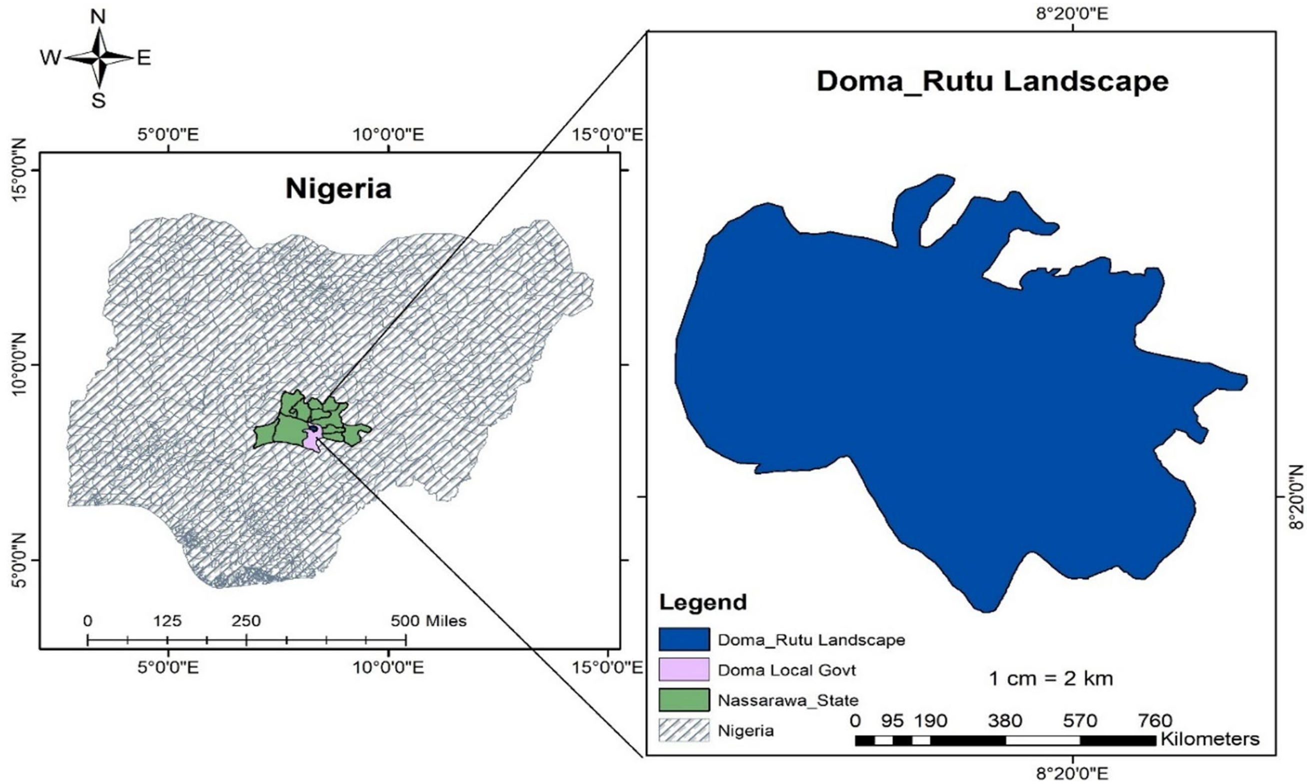

Fig. 3 Location of the Doma–Rutu, Nasarawa State, Nigeria (case study 2)

At the Doma–Rutu Landscape (DRL) (Case study-2), data was collected through a combination of nine Focus Group Discussion (FGD) sessions and key informant interviews (IKIs). These sessions actively engaged diverse community members, including men, women, youth, herders, institutions, and organizational leaders. The selection of the target population was justified by the need to include a wide range of perspectives from across three different communities and the Doma Irrigation Site, ensuring a comprehensive understanding of the local context. To achieve this, 19 Key Informant Interviews (KIIs) were purposively selected from institutions like local government, chieftaincy institutions, government ministries, and other relevant organizations. Considering the subject matter of this paper and knowledge level, these 19 key informants were nominated for the interviews by their institutions. Consent for participation was obtained through consent forms and vocal agreements, and pseudo-identification measures were employed to ensure participant anonymity. The survey design included transparent communication of the overarching research objectives to mitigate potential social desirability bias, a common challenge in such studies.

The FGDs were categorized into four cohorts (12 participants per group): men, women, youth, and herders, hailing from diverse communities. Inhabitants with a minimum of a decade's community residency constituted the FGD participants, and their extensive local experience contributed valuable and dependable insights into the landscape. The ambit of discussions encompassed an array of themes spanning food production, land use dynamics, community socioeconomic structures, food security paradigms, livelihood alternatives, conservation initiatives, and the preservation and revival of wild biodiversity and ecosystem services. This comprehensive approach reverberated consistently across the focused group. Content analysis was used to analyze the reports and transcripts from key informant interviews and FGDs [32, 33].

3.3 Geospatial data acquisition and analysis

Secondary data were mainly geospatial, sociodemographic, and economic (Table 1). Data were collected to evaluate changes in land use and land cover (LULC) in Ghana and Nigeria, utilizing data from 2008, 2015, 2018, and 2021 for Ghana and 2000, 2010, and 2021 for Nigeria (Table 2). See Fig. 4 for the workflow from data acquisition to LULC maps. The Google Earth Engine (GEE) was used to extract and process historical images of a given year. The GEE platform was used for data processing for both sites, as it provides better solutions for assessing and processing large amounts of

Table 1 Secondary data used in the study

Available data	Source	Purpose	Year
	Ghana (case study 1)		
Socio-demographic and economic data	Ghana Statistical Service [34]	Profile of study districts/communities	2021 Population Census
Satellite images	European Space Agency [35], National Aeronautics and Space Administration (NASA)[36]	Land cover/land use mapping	1986–2022
Digital elevation models	NASA	Watershed and Topographic mapping	2013–2017
Forest/Game Reserves	Forestry Commission	Protected area mapping	
Roads	Roads & Highways		2021
Streams and Rivers	Hydrological services Department [37]	Drainage Density, watershed delineation, water quantity and quality assessment	2021
	Nigeria (case study 2)		
Socio-demographic and economic data	Nigeria Bureau of Statistics [38]	Profile of study districts/communities	2021 Population Census
Satellite images	European Space Agency, NASA	Land cover/land use mapping	2000, 2010, 2022
Digital elevation models	NASA	Watershed and Topographic mapping	2021
Forest/Game Reserves	Forestry Commission	Protected area mapping	
Roads	Roads & Highways		2021
Streams and Rivers	Nigeria Hydrological Services Department [39]	Drainage Density, watershed delineation, water quantity and quality assessment	2022

Table 2 Characteristics of the satellite data used for both Ghana and Nigeria

Satellite	Sensor	Period covered	Spatial resolution (m)
Ghana (case study 1-)			
Landsat-7	TM	2008	30
Landsat-7	TM	2015	30
Landsat-8 OLI	OLI	2018	30
Landsat-8 OLI	OLI	2021	30
Nigeria (case study 2-)			
Landsat-7	TM	2000	30
Landsat-7	TM	2010	30
Landsat-8 OLI	OLI	2022	30

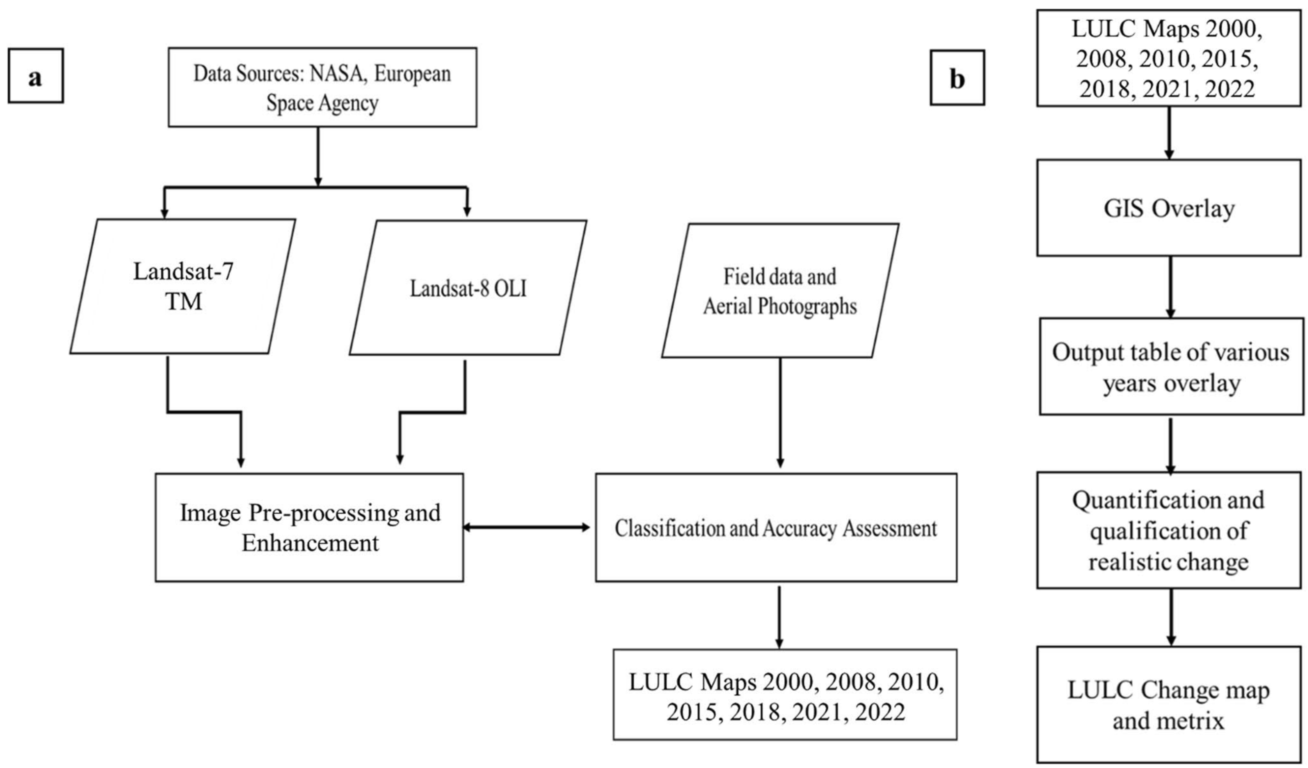

Fig. 4 Summary of a. Land Use/Land Cover Mapping procedure and b. Land Use/Land Cover change detection procedure (Source: Authors' Construct, 2024)

freely available online data [40]. GEE also offers an opportunity for more rapid analysis of LULC images using a set of pixel-based classifiers with different classification techniques for land mapping [41–43]. One of the challenges of satellite imagery in developing countries is cloud cover [44–46]; however, all images captured during the dry season were used to avoid this. Subsequently, the images were georeferenced within ArcGIS Pro version 3.0 software. To delineate the boundaries of the case study landscapes, the pour point technique was used. In Mankran case, pour points located at the southernmost confluence of the Mankran river were identified and used to delineate the watershed after a hydrologically conditioned DEM was created. Extraction of flow characteristics (flow direction, flow accumulation, stream order, flow length, stream link and stream feature) was then carried out to delineate the boundary of case study 1. Same was replicated for the Nigeria case.

For image classification, a modified version of the Food and Agricultural Organizations' land cover classification system was adopted to identify land cover and land use types in the landscapes (Table 3). Approximately 178 training points

Table 3 Adapted land use/land cover classification systems of the FAO. Source: FAO [49]

FAO land cover classification system	Adapted land use/land cover classes
Cultivated and managed terrestrial vegetation	Cash crop
	Subsistence farming
Natural—semi-natural terrestrial vegetation	Dense natural vegetation
	Sparse natural vegetation
Artificial surface	Road
	Built-up
Bare surface	Degraded areas
	Recovering mining sites
	Clear natural water body
Natural—semi-natural aquatic vegetation	Natural aquatic vegetation
Artificial aquatic vegetation	Rice
Artificial waterbody	Artificial water body (irrigation)

covering all land use land cover classes were purposefully collected from the watershed to aid interpretation. Segmented images were created from the object-based classification process. The derived image and 110 stratified and randomly selected training samples were used to identify and classify land use/land cover types. Specifically, object-based image classification with the Support Vector Machine algorithm was used. Unlike pixel-based classification, which considers only spectral information at the individual pixel level, object-based classification considers spatial and spectral characteristics of features of interest. It can produce results comparable to visually interpreted images. Object-based classification suits high-resolution images with spectrally heterogeneous features [47]. The quality of the classified image was checked using the image using the remaining 68 field samples. In measuring the accuracy of classification, the proportion correctly classified (PCC) index and the Kappa statistic, derived from an error matrix, were used. Post-classification change detection techniques were employed to account for land use/land cover transfers between the period in question (i.e., January 2008–December 2021in the case of Mankran landscape). This involved an overlay of independently classified images. It is the most used qualitative method of change detection [48]. It operates on two or more independently classified images as inputs, resulting in a change map and a change matrix. The classified thematic map of 2008, 2015, 2018 and 2021 was loaded and analyzed using tools in ArcGIS Pro 3.0 to indicate changes between the images in the form of a change map and change matrix, which was then used for the analysis.

The 'true world classes' are preferably derived from field data but sometimes sources of an assumed higher accuracy, such as aerial photographs could be used as a reference for validation [50]. Both field data and aerial photographs were employed to achieve high accuracy Proportion Correctly classified (PCC) was used in measuring the accuracy of classification (see Eq. 1).

$$PCC = \frac{\text{Number of correctly classified pixels}}{Total\ number\ of\ sampled\ pixes} \quad (1)$$

The PCC also known as Over-all Accuracy, is the number of correctly classified pixels (i.e., the sum of the diagonal cells in the error matrix) divided by the total number of sampled pixels. The confusion matrix gave an overall accuracy of 85.7%.

3.4 Water quality testing

For the ecosystem degradation assessment of the cases, we considered only the water quality of water bodies in the landscape as an indicator.

At case study 1, 17 water samples in the offshore sub-basin were collected randomly from the river systems where the questionnaire was administered between May and June 2019 similar to [51]. The precise coordinates of the sampling points were documented using a handheld Garmin Etrex GPS device. The sampling procedure adhered to the guidelines set by the American Public Health Association (APHA) [52]. Plastic bottles of 500 mL capacity were thoroughly rinsed within the river following the flow direction to collect the samples. After collection, the samples were promptly placed in a cooler box containing ice blocks to ensure preservation during transportation to the laboratory, maintaining their natural state.

Note that the parameters varied by case study, and this is informed by the dominant land use type. Case study 1 is predominantly mining and agroforestry while case study 2 had subsistence agriculture (i.e., rice farming) as the major land use. Considering that case study 1 had mining (illegal mining) as a major land use, the study conducted analysis of heavy metals, which included arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), mercury (Hg), and lead (Pb). The analysis was executed at SGS Laboratory Services Ltd in Tema, Ghana, employing an inductively coupled plasma–optical emission spectrometry instrument (Nexion 300 × ICP). Other analytical procedures were conducted at the Environmental Quality Engineering Laboratory of Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. Parameters such as total dissolved solids (TDS), electrical conductivity (EC), and pH were determined using a Palin test multimeter. Total suspended solids (TSS) were evaluated using the gravimetric method. The analysis of nitrate–nitrogen ($N–NO_3$) and ammonia–nitrogen ($N–NH_4$) was performed using a DR 3900 spectrophotometer. Acid-persulfate digestion, cadmium reduction, and Nessler methods were applied to determine these parameters. For total nitrogen (TN), the Kjeldahl method was employed using Velp 139 distillation equipment.

In case study 2, 15 water quality testing were conducted across the river system in the landscape. Rapid water quality testing was carried out using a C-600 7 digital water quality tester. Water quality testing was conducted at five key locations within the landscape. Each test was repeated three times at each test point, and the means were recorded as a reading. This was replicated in 3 places within each location. The parameters measured included pH (pH scale), temperature (°C), DO (mg L^{-1}), EC (µS/cm), TDS (mg L^{-1}), DO (mg L^{-1}), oxidation–reduction potential (ORP), Specific Gravity (SG), and water temperature. One Factor Analysis of Variance was used to compare the means across the locations for each parameter. These water quality parameters were compared with the WHO standards for drinking water [53]. Limited water quality parameters were investigated since there are no industry, mining or major polluting activities within the local government area. Farming activities in the landscape are majorly subsistent.6

4 Results

The results section of this article presents a comprehensive analysis of the state of social-ecological landscapes (SEL) in Ghana and Nigeria. Key findings include changes in land use patterns, water quality assessments, and socio-ecological challenges faced by local communities.

4.1 Mankran landscape situational analysis: (case study 1)

The landscape situational analysis (LSA) aimed at giving an overview of how drivers and pressures combine to delineate the Social Ecological Landscape (SEL) state and impacts, highlighting the institutional responses. This study contends that the unsustainable exploitation of natural resources/ecosystem services in the Mankran landscape is generally underpinned by the need for "necessities of survival" rather than the quest for "opulence". The results indicate that the driving forces behind the pressures that define the state of and impacts on the landscape are local, albeit a few national and global drivers (Fig. 5):

4.1.1 Drivers of change in the Mankran Landscape (Driving Forces-D)

This study identifies several driving forces that underpin the threats to the SEL in the Mankran landscape. These driving forces include the need for "necessities of survival" rather than "opulence," agricultural expansion, legal and illegal logging, population dynamics, and complex forest and water tenure arrangements. In addition, the need for necessities drives communities to unsustainably exploit natural resources unsustainably, leading to environmental degradation. The drivers of change in the Mankran landscape in Ghana are primarily linked to socio-economic factors, such as bad benefit-sharing mechanisms, poor gender and social inclusion, high incidence of poverty, need for agricultural extensification, population dynamics including rural–urban migration, weak governance, inadequate law enforcement, and conflicting land and forest tenure systems. These drivers collectively contribute to deforestation, degradation of water bodies, loss of biodiversity, and other negative environmental impacts in the region.

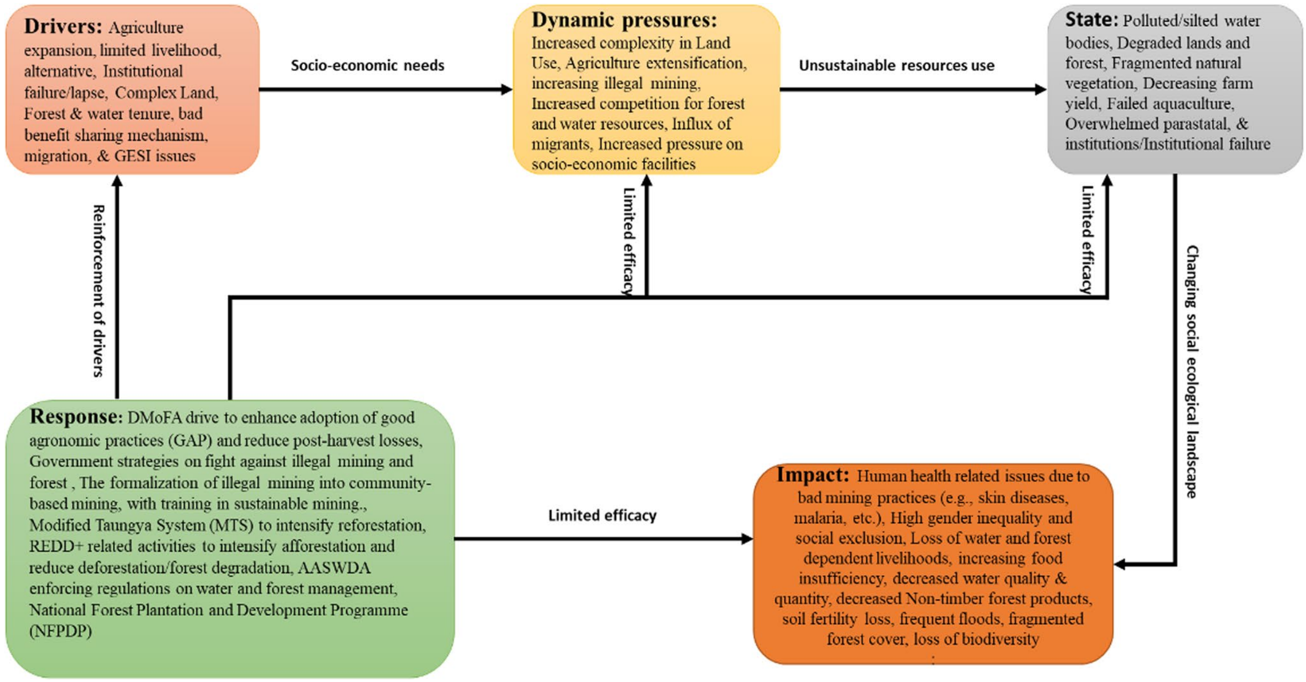

Fig. 5 Results from landscape situational analysis in Ghana (case study 1)

4.1.2 Dynamic pressures on the Mankran Landscape (pressures-P)

The identified driving forces exert pressure on the Mankran landscape. These include agricultural expansion driven by food and cash crop demand, resulting in deforestation and vegetation degradation. Galamsey and unregulated community mining contribute to land conversion, vegetation cover degradation, and water pollution. Legal and illegal logging activities exert pressure on forest ecosystems and biodiversity. Population dynamics, including migration to urban centers, increase resource demand and strain social and economic infrastructure. Complex forest and water tenure arrangements have led to resource access and use conflicts.

4.1.3 The state of the Mankran Landscape (State-S)

The current state of the environment reflects significant degradation. Water bodies and rivers are polluted and silted, leading to perennial issues. The land has suffered from soil fertility loss, deforestation, and fragmented natural vegetation. Agricultural yields remain consistently low across all crops, and aquaculture efforts have largely failed, resulting in overwhelmed parastatal institutions due to these challenges. The SEL faces significant challenges in maintaining its ecological balance and providing essential ecosystem services.

4.1.4 The consequences of the current state of the Mankran Landscape (impact)

The impacts of these drivers and pressures are profound and multifaceted. Human health has deteriorated due to poor mining practices, leading to various diseases and an inadequate healthcare system. Furthermore, there is heightened gender and social exclusion, particularly affecting women and migrant populations. The loss of livelihoods dependent on water and forest resources has contributed to increasing poverty levels, while ecosystem services have declined, resulting in decreased food sufficiency and water quality. Environmental insecurity has escalated, characterized by soil fertility loss, flooding, sanitation issues, and biodiversity loss.

4.1.5 Responses from relevant stakeholders (R)

In response to these challenges, several institutional initiatives have been implemented. The Ahafo Ano Southwest District Assembly (AASWDA) launched capacity-building programs focused on effective spatial planning and monitoring. The Department of Ministry of Food and Agriculture (DMoFA) promotes good agronomic practices, while government strategies aim to combat illegal mining. Efforts to formalize illegal mining into community-based initiatives include training in sustainable practices. Additionally, the Modified Taungya System (MTS) is being utilized to enhance reforestation efforts, and REDD+ activities are being carried out to promote afforestation and reduce deforestation. The AASWD is also working to revive traditional norms and regulations for water and forest conservation, supported by the National Forest Plantation and Development Programme (NFPDP) and Youth in Afforestation Programmes (YAP).

The above responses notwithstanding, the challenges have remained pervasive, underscoring the urgent need for integrated and inclusive approaches to address the complex interplay of social and ecological factors in the Mankran landscape. To address the challenges, various responses are required. These responses include strengthening institutional capacity, creating stakeholder platforms, regulating small-scale mining, implementing sustainable land-use practices, enforcing logging regulations, promoting afforestation initiatives, and improving benefit-sharing mechanisms. Addressing forest and water tenure issues and promoting secure land rights for communities are essential for sustainable resource management and protection.

4.2 Land use land cover (LULC) dynamics in Mankran landscape

The results showed 1,885 hectares of land were cultivated for cash crops in 2008, or 6% of the total land (Figs. 6 and 7). This suggests that a comparatively limited amount of land was set aside for income crops in the same year. In contrast, a larger area of 2,740 hectares, or 9% of the total land, was used for subsistence farming. Significant changes were observed in the acreage of these categories in 2015. The area under cultivation for cash crops increased significantly to 9540 ha or 30% of the total area. This was a significant rise over 2008, pointing to a trend towards a wider use of land to cultivate cash crops. The area used for subsistence farming decreased to 1846 ha (6% of the total land). This drop indicates that subsistence farming was less common during this period. In 2018, these categories underwent additional adjustments. The area under cultivation for cash crops decreased to 4546 ha or 14.5% of the total area. Studies on commercial crops, rice, and subsistence farming in Ghana have shown that land usage patterns have changed dramatically. From 2008 to 2015, cash crop production expanded significantly but shrank in 2018 (Fig. 6). Significant changes were observed in dense

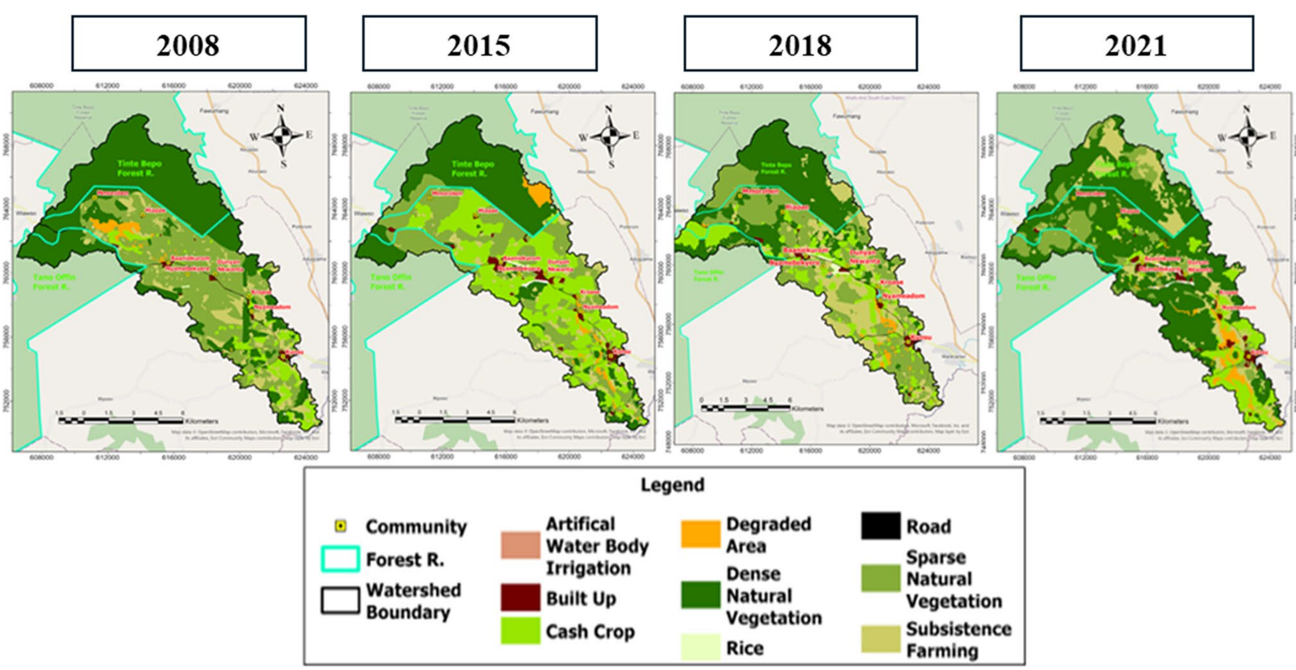

Fig. 6 Land-use land cover maps dipicting transitions in the Mankran Landscape (case study 1)

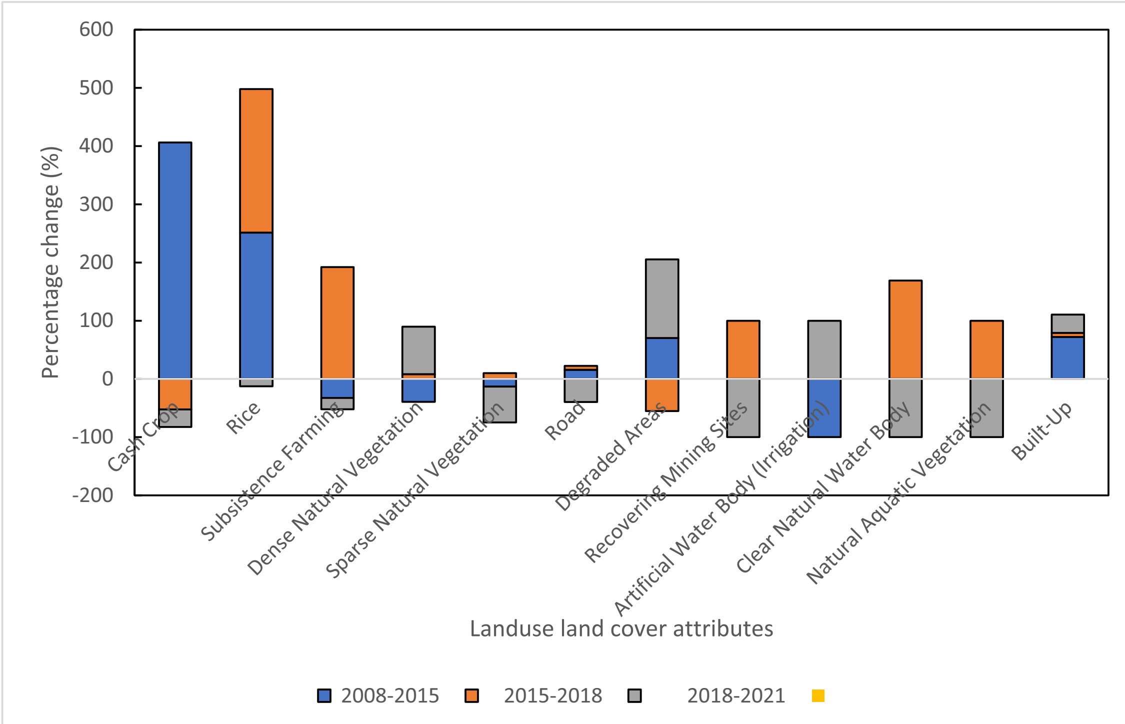

Fig. 7 Percentage change in the LULC across years at Ahafo Ano Southwest District, Ghana (case study 1)

Table 4 Water quality parameters at the Mankran (micro-watershed in the River Offin)

Parameters	Minimum	Maximum	Mean ± SD	WHO limits (drinking water)
pH	4.82	6.770	5.879 ± 0.36	6.5–8.5
TSS (mg/L)	9.00	6,790.00	914.41 ± 1,974	500.00
EC (µS/cm)	49.30	1104.00	172.21 ± 247.85	110–400
TDS (mg/L)	31.00	684.00	106.76 ± 153.66	1200.00
Total N (mg/L)	1.68	5.32	3.23 ± 1.01	10.00
Total Phosphate (mg/L)	0.090	1.14	0.339 ± 0.26	0.0001
Total P	0.03	0.37	0.117 ± 0.26	0.0001
N-NO3- (mg/L)	0.40	6.40	1.477 ± 0.65	50.00
N-NH4- (mg/L)	0.080	1.90	0.44 ± 0.44	10.00
Pb (µg/L)	0.018	68.45	18.73 ± 17.26	10.00
Hg (mg/L)	0.005	7.57	0.512 ± 1.83	6.00
As (µg/L)	0.020	294.43	53.41 ± 86.66	10.00
Cd (µg/L)	0.010	1.367	0.711 ± 0.34	3.00
Cu (µg/L)	0.036	403.79	67.95 ± 95.53	2000.00
Fe (mg/L)	0.125	429.15	50.22 ± 107.22	0.10

natural vegetation and increased cash crop areas. The percentage changes in LULC for cash crops and arable crops (i.e., rice) between 2008–2015 and 2015–2018 (Fig. 7).

4.3 State of water quality in Mankran landscape

The dataset highlights the quantified parameters within a water sample and their corresponding minimum, maximum, mean, and standard deviation metrics (Table 4). The interpretation herein is compared with the established guidelines delineated by the World Health Organization (WHO) for the quality of potable water [53]. The results for water quality return with several parameters that are much above the recommended limits by WHO, which presents a serious health concern. The mean pH of 5.88 is lower than the WHO range of 6.5–8.5, indicating that the water is more acidic than it should be, and might cause leaching through pipes to release toxic metals. The mean level of TSS is very high, 914.41 mg/L, way over the WHO limit of 500 mg/L. This may bring in reduced clarity of water, can clog filters, and can harbor some harmful pathogens. Besides, high concentration means were found for both metals for lead and arsenic: 18.73 and 53.41 µg/L, respectively, against the WHO limits of 10 µg/L. The iron concentration is 50.22 mg/L on average, way above the WHO limit of 0.10 mg/L, therefore discoloring water, making it taste metallic, and staining; more importantly, it could indicate the presence of other harmful contaminants. These findings call for immediate measures to ensure the water is safe for human consumption. This assessment exemplifies the DPSIR_SEL framework by linking quantified parameters (State) to potential contamination (Impact), prompting the need for interventions (Response) to mitigate risks and improve water quality.

Furthermore, the findings from the Ghanaian FGDs underscore the critical challenges within the Mankran landscape. Mining and unsustainable resource utilization adversely affect biodiversity, livelihoods, and ecosystem processes, including soil services. The Ahafo Ano Southwest (AASW) district relies heavily on agriculture as its economic foundation, leveraging vast arable lands and favorable rainfall patterns.

However, a pronounced agricultural focus has led to extensive deforestation and vegetation deterioration. Notably, the expansion of cash crop plantations (e.g., cocoa, palm oil, and teak trees) and food crop cultivation (e.g., cocoyam, plantain, yam, and maize) is culpable. Agricultural expansion, particularly through authorized farming in reserves (Taungya system) and non-admitted farming, significantly drives forest degradation, especially in the Mankran landscape, as observed around communities such as Barniekrom, Dunyakrom, and Mmroberm. Despite legal boundaries for admitted farms, limitations in Forest Division monitoring have enabled unauthorized expansion, leading to deforestation. Similarly, chainsaw-operated illegal logging amplified deforestation and forest degradation in the AASW district. Despite policy interventions, governance and management flaws persist, enabling illegal logging. Moreover, the Mankran landscape contends with unregulated mining, notably Galamsey (illegal mining), which results in vegetation loss, farmland-to-mine conversion, and water body degradation. While some participants highlighted purported livelihood improvements from Galamsey, the overall consequences for the environment and society are severe. This issue is compounded by ineffective law enforcement, land mismanagement, and mining-related land transactions. Socioeconomic factors encompassing income needs, unemployment, and market dynamics also fuel Galamsey. The FGD outcomes depict an intricate web of challenges in the Mankran landscape, necessitating comprehensive strategies for sustainable resource management, land use, and livelihood enhancement.

4.4 Doma–Rutu landscape situational analysis (case study 2)

4.4.1 Drivers of land use change and ecosystem degradation in Doma–Rutu (Driving Forces-D)

The increase in dry season farming in the Doma–Rutu landscape, even without proper irrigation facilities, has led to the expansion of cultivated areas, resulting in deforestation and a decrease in dense and sparse vegetation cover. The practice of open grazing by livestock after harvesting rain-fed crops has caused soil degradation, erosion, and an increase in hilly areas. There is a potential climate change effect or increased water use for dry season farming, reducing the area covered by natural water bodies, including perennial streams and wetlands. These drivers collectively shape the social, economic, and ecological dynamics of the Doma–Rutu Social-Ecological Landscape, influencing livelihoods, agriculture, land use, and ecosystem services. The drivers of change in the Doma–Rutu Social-Ecological Landscape are summarized in Table 5.

4.4.2 Pressures on ecosystems in the Doma–Rutu Landscape (Pressure-P)

The Doma–Rutu landscape is experiencing significant pressures from anthropogenic activities, categorized into four main areas. First, there is an increased reliance on wetlands during the dry season for food production, leading to environmental stress. Second, the indiscriminate felling of trees for firewood and charcoal production is altering the original vegetation and contributing to deforestation. Third, natural fish resources are being depleted due to unsustainable fishing practices, which threaten aquatic biodiversity. Lastly, the landscape is undergoing complex land use and land cover transitions driven by demographic changes, economic development, and environmental factors. Notably, forested areas are being converted into agricultural land to meet rising food demands, resulting in a decline in forest cover and

Table 5 Overview of Main and Detailed Drivers of Change the Doma-Rutu Landscape (case study 2)

S/No	Main drivers of change	Details of the drivers in the SEL
1	Agricultural expansion	• Monocropping: Cultivation of a single crop, leading to specialization, efficiency, and higher productivity, but also potentially negative impacts on biodiversity and vulnerability to pests • Mixed Cropping: Planting multiple crops together to maximize resource use, reduce the risk of crop failure, and improve soil health and productivity • Relay Cropping: Planting a second crop after the first is harvested, optimizing land and resource use, benefiting from residual nutrients, and improving overall productivity
2	Livestock production system	• Traditional Pastoralism: Raising cattle, sheep, goats, and poultry as an integral part of the agricultural system, with challenges such as disease outbreaks, conflicts over land, and inadequate veterinary services
3	Artisanal fishing	• Fishing is an economic activity, utilizing various methods such as nets and hooks, but facing challenges owing to the unwholesome use of chemicals, which leads to water contamination and health risks
4	Constraints on agricultural production and capacity development	• Decreasing Soil Fertility: Overuse and lack of proper soil management lead to poor fertility, impacting crop yields • Limited Access to Markets: Difficulty reaching markets leads to reduced income potential and agricultural investment • Climate Change: Extreme weather events affect livelihoods and cause crop losses due to changing weather patterns • Land Use Conflicts: Tensions and disputes among farmers and land users due to competing interests and differences • Lack of Access to Credit: Limited access to credit institutions hampering investment in farms and essential inputs • Urban Encroachment into Floodplains: Urban development disrupts floodplain functions, leading to ecological imbalances and health hazards
5	Livelihood status and options	• Water Resources: Rivers provide water for domestic and agricultural use and support fisheries but face erratic water flow challenges • Wetlands/floodplains: Providing water filtration, flood control, and irrigation potential but facing challenges such as pollution and reduced water regulation • Grazing land for livestock and wildlife but facing the gradual loss of biodiversity
6	State of institutional and policy support	• Limited institutional and policy support is due to limited resources, poor infrastructure, weak coordination, and capacity constraints

the loss of ecosystem services. Additionally, rapid urbanization is encroaching on agricultural land, further exacerbating biodiversity loss and soil degradation. These pressures have significant implications for the local environment, including reduced natural water bodies and increased vulnerability to climate change. Consequently, the ongoing pressure from agricultural expansion, deforestation, and grazing practices highlights the urgent need for sustainable land-use strategies and effective water management practices to protect the fragile ecosystems of the Doma–Rutu landscape.

4.4.3 The state of the Doma Dam Landscape (State-S)

The Doma–Rutu landscape is primarily agrarian, with agriculture serving as the backbone of the local economy. However, it faces numerous challenges that hinder food production and livelihoods. These challenges include decreasing soil fertility, flooding, inadequate infrastructure, limited market access, climate change, and limited access to resources, education, and institutional support. While agriculture provides income for many households, poverty remains prevalent in the region. Despite these challenges, the landscape offers opportunities for sustainable agricultural practices, such as mixed cropping and livestock production, that can enhance food security and livelihoods.

4.4.4 Impact of dry-season farming expansion on ecosystems and water resources (Impact-I)

The expansion of dry-season farming has resulted in deforestation, soil degradation, and erosion, affecting the ecological balance of the landscape. A decrease in natural water bodies due to various factors can lead to water stress and adversely affect the ecosystem. Natural resources in the Doma–Rutu landscape are facing significant threats from excessive exploitation and climate change, raising serious concerns about sustainability. The depletion of these resources adversely affects human health and well-being, highlighting the need for a holistic approach that incorporates fair and ethical values for living in harmony with nature. Effective management of natural resources is essential to maintain the supply and flow of ecosystem services (ES), which are the benefits derived from healthy ecosystems. These services play a crucial role in improving human well-being, and their inclusion in policy decision-making is vital for fostering sustainable economies. Assessing the significance and sustainability of ES can guide development planning, mitigate risks from climate change, and enhance the management of biodiversity, soil, and water resources. The intricate relationship between ecosystem services and human health necessitates a multifaceted approach to understanding their interactions. In the Doma–Rutu landscape, overexploitation of agricultural and fishing resources has led to significant degradation of savannah vegetation and biodiversity loss. This decline in ecosystem health has resulted in increased poverty, food insecurity, and limited livelihood options for the local population. Many households struggle to meet their food needs, relying increasingly on external sources as agricultural outputs diminish. The degradation of rivers and water bodies due to pollution and unsustainable fishing practices further exacerbates health risks for communities dependent on these resources for drinking water and domestic use.

4.4.5 Sustainable irrigation and land management to prevent water conflicts and protect ecology in Doma and Rutu (Response-R)

The Doma–Rutu landscape in Nasarawa State, Nigeria, is governed by various laws, policies, and institutions aimed at promoting conservation and sustainable natural resource management. A significant piece of legislation is the Forestry Law of 2007, which regulates the exploitation and management of forest resources, establishing the Nasarawa State Forestry Commission to oversee its implementation. This law aims to conserve forests, prevent deforestation, and manage forest reserves effectively. Alongside this, the Nasarawa State Environmental Protection Agency (NASEPA) ensures compliance with environmental regulations, while initiatives like the Community-Based Natural Resources Management Program engage local communities in conservation efforts. However, despite these frameworks, the impact of the Agricultural Policy for Nasarawa State (2019–2027) has yet to be fully realized, as challenges persist in achieving its objectives for food security and agricultural productivity.

There is a need for proper development and management of irrigation facilities in the Doma and Rutu Irrigation Schemes to regulate dry-season farming and avoid water-related conflicts. Implementing sustainable land-use practices and regulations can help preserve vegetation, prevent erosion, and protect the ecological integrity of the landscape. Water quality management and measures to protect water sources should be implemented to ensure the safe drinking of water for the community.

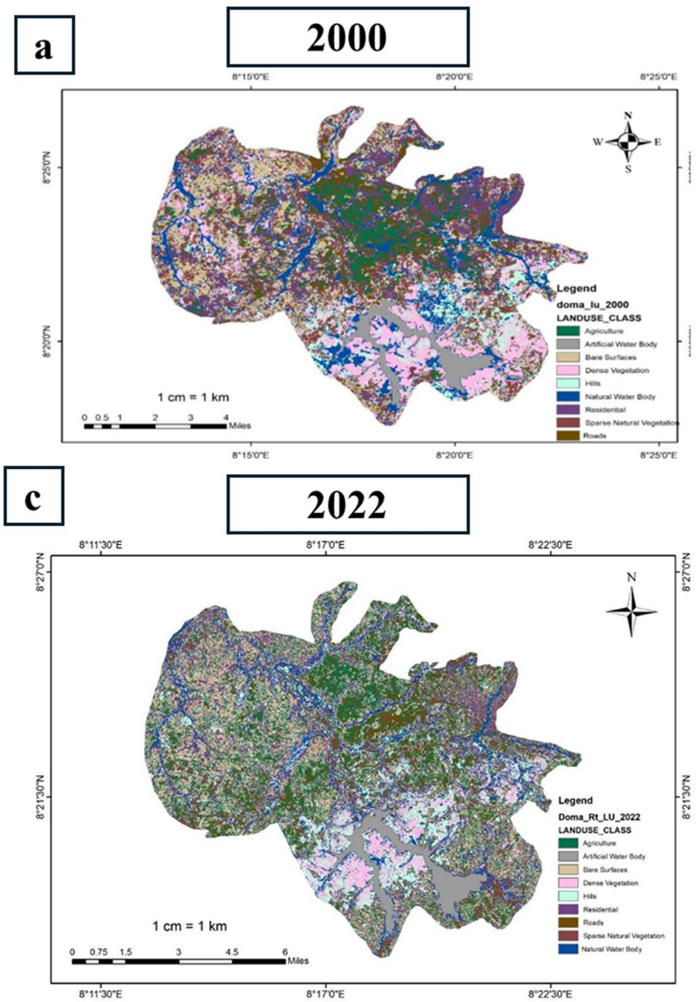

Fig. 8 Land cover/land use map of the Dome-Rutu landscape 2020, 2010 and 2022 (case study-2)

4.5 Land use land cover dynamics in Doma–Rutu landscape

According to the categorization, Doma Dam covered an area of 748 ha in 2000, or 4% of the total land area (Figs. 8 and 9). A total of 2874 ha (or 15% of the area) was covered by dense vegetation and 2465 ha (13%) by sparse natural vegetation. The categorization shows modifications in land-use patterns as of 2010. Agriculture, comprising cultivated areas and floodplains, has increased dramatically to 3245 ha. Natural vegetation covered 1,857 ha (10%), whereas dense vegetation covered 1848 ha (10%). The size of the residential areas expanded to 2374 ha, or 12% of the total area. Sparse natural vegetation covered 1446 ha (7.5%), while dense vegetation declined to 1698 ha (9%). Hills grew to 2161.0 ha (11.2%), and bare surfaces to 3589.5 ha (19%). At this site, an examination of land-use categorization for 2000, 2010, and 2022 showed that different categories are undergoing dynamic changes (Fig. 9). Land use patterns are changing, as seen by the growth of residential areas and agricultural land, variations in natural water bodies, dense natural vegetation, and sparse natural vegetation. These modifications emphasize the interaction between human activities and natural resources and reflect the changing requirements and priorities of the area.

4.5.1 State of water quality in Doma Rutu

The following results were obtained by comparing these metrics to the World Health Organization (WHO) requirements (Table 6). The values of pH at some sites, such as Alagye and Asogebe-Amutu, are out of range, recommended

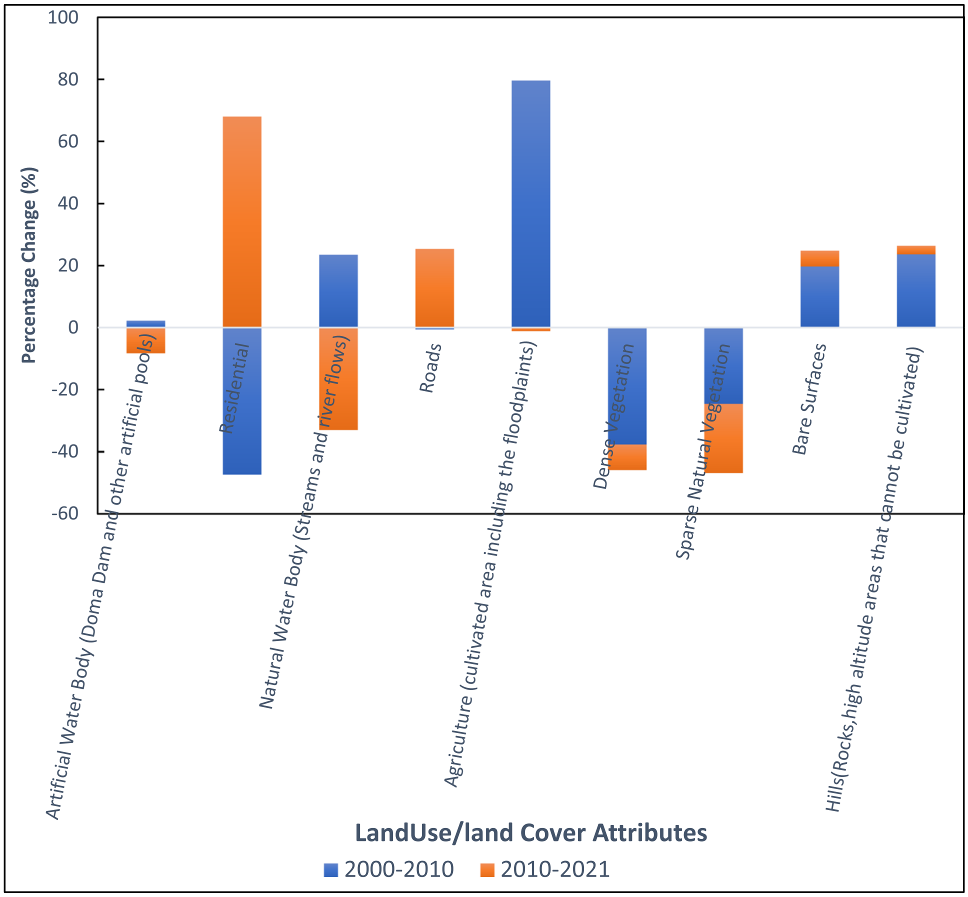

Fig. 9 Percentage change in the LULC across years at Doma-Rutu Landscape

Table 6 Water Quality Parameters at Doma-Rutu Landscape, Nigeria (case study-2)

S/No	Geographical coordinates		Locations within the DR landscape		Temperature *	pH*	EC*	TDS*	Salinity*
	Lat	Long							
1	8.4181	8.2871	Iwashi		30.6 ± 0.80	6.6 ± 0.04	78.0 ± 16.8	38.0 ± 8.6	127.0 ± 15.5
2	8.4315	8.2391	Rutu		33.1 ± 0.64	7.3 ± 0.23	78.0 ± 3.6	40.0 ± 1.0	127.3 ± 5.0
3	8.3818	8.3333	Akurku stream		34.1 ± 1.51	7.1 ± 0.76	66.0 ± 42.4	34.7 ± 24.5	169.7 ± 103.1
4	8.3581	8.2635	Alagye		34.2 ± 1.11	6.9 ± 0.59	59.3 ± 41.6	29.7 ± 20.8	107.7 ± 13.4
5	8.3747	8.2936	Rice farm Alagye I		31.2 ± 1.58	6.5 ± 0.44	82.3 ± 33.1	41.0 ± 16.8	102.3 ± 5.1
				Max	35.2	6.03	26	13	98
				Min	29.8	7.94	115	63	288
				WHO Standard for drinking water		6.5 – 8.5	110–400	1200	

*No significant difference (p = 0.05)

by WHO, at 6.03 and 6.51 respectively, indicating more acid water likely to cause corrosion and metal solubilization. The electrical conductivity is higher at Akurku stream, 115 µS/cm, and Rice Farm, Alagye I, 108 µS/cm, indicating an increased dissolved salt likely to affect water quality. Similarly, high values of TDS were obtained at Akurku Stream, 63 mg/L, and Rice Farm, Alagye I, 54.0 mg/L. These high values might give the water an unpleasant taste or make it unsatisfactory for drinking purposes. Again, there is high salinity in Akurku Stream, with a value of 288 mg/L, thus suggesting a high load of dissolved salts in the water, which no doubt will affect the quality of the water and lower its agronomic uses of the soil, although the values recorded are still below the maximum limits for drinking water The increased amounts of dissolved chemicals and salts in water bodies may be caused by agricultural operations, particularly using fertilizers and pesticides. Pollutants can also be introduced by industrial discharge and poor waste management, affecting water quality metrics even though, industrial activities are not common in the landscape. Natural processes like weathering and leaching can also influence water's mineral composition and salinity. Understanding these factors is essential for implementing effective measures to reduce pollution and safeguard water resources.

Table 6 shows the mean and standard deviation of the water temperature, pH, electrical conductivity, total dissolved solids, and salinity across the landscape. The ANOVA shows no significant difference in the water quality indicators across the five locations across the landscape.

In summary, the water quality data from different streams in the Doma–Rutu landscape (*State*) illustrate the potential environmental and health impacts (*Impact*) of water usage. The pH values, mostly within the normal range, indicate the water's slight acidity to alkalinity, but exceptions were noted in samples from certain locations. While electrical conductivity and total dissolved solids values fall within acceptable ranges for irrigation and drinking water, respectively, the oxidation–reduction potential values were below recommended levels for sanitized drinking water, suggesting the need for treatment (*Response*) to improve the water's overall quality for residents. This analysis aligns with the DPSIR-SEL framework by highlighting how water quality parameters (*State*) can lead to potential impacts on health and usage (*Impact*), necessitating responses to enhance water quality and safety (*Response*). In Nigeria, the results of the FGD showed that the issue arising from herd incursions into cultivated land and the resultant conflicts between herders and crop farmers have notably constrained the cultivation of specific crops within the landscape. Community consensus, as evidenced by the Focus Group Discussion (FGD) sessions, has indicated that yam and cassava cultivation has ceased due to heightened vulnerability to animal invasions. Herders also communicated the absence of established grazing routes (referred to as "burtali"), particularly during the rainy season, necessitating the utilization of interconnected roads in and around communities for cattle movement. Nigeria's persistent herder-farmer conflict is deeply rooted in an intricate historical context. These conflicts have ancient origins traceable to pre-colonial eras and are primarily attributed to factors such as population pressures, climate fluctuations, inadequate governance, cattle theft, and other underlying causes. This prolonged predicament engendered various socioeconomic predicaments that prominently affected agricultural productivity. Discord between herders and farmers can be perceived as a struggle for land access. The escalation of agrarian populations and expansion of cultivated areas at the expense of grazing lands have led to the unavailability of traditional herding routes, particularly in the context of global climate change. Consequently, disputes over land ownership have arisen. Furthermore, ecological deterioration, desertification, and soil degradation have necessitated modifications of herder transhumance patterns. While climate change is frequently associated with the genesis of conflict, contemporary perspectives suggest that it may not be the sole catalyst; rather, it has altered herders' migratory patterns.

The data on the quality of water from Ghana and Nigeria portray various challenges. For Ghana, key concerns are high TSS, high levels of metals like lead, arsenic, and iron, and acidic pH values, all pointing towards associated serious health risks. While some areas of the Nigerian data had lower pH, high EC, and high salinity, mainly from Akurku Stream, the case therefore points to probable problems of dissolved salts and water acidity. Both regions have water quality problems, but the case is much more one of heavy metal contamination in Ghana and one of acidity and salinity in Nigeria.

5 Discussion

In Ghana, significant shifts in land-use patterns occurred between 2008 and 2018. In 2008, only 6% of the land was used for cash crops, whereas 8.73% was dedicated to subsistence farming. However, by 2015, cash crop cultivation had surged, covering 30.4% of the total land area and overshadowing the decrease in subsistence farming to just 5.88%. By 2018, the trend was adjusted, with cash crop areas reducing to 14.5%. Concurrently, there was a noticeable decline in dense natural vegetation, primarily because of increased cash crop cultivation. This decade of study highlights a significant pivot from subsistence farming to cash crop production, with notable fluctuations and environmental impacts, emphasizing the dynamic nature of agricultural practices in the region [17, 54–59]. Similarly, between 2000 and 2022, agricultural land use increased from 9 to 17% in Nigeria, driven by a doubling of the dry season farming area. This growth occurred despite the incomplete development of local irrigation schemes, prompting farmers to utilize wetland areas to cultivate rice and vegetables during the dry season (November to March). Notably, this expansion came at the cost of forested areas, which saw dense vegetation decrease from 15 to 8.8% and sparse vegetation decrease from 12.8 to 7.5%. Deforestation for farming was particularly evident in the Iwashi floodplain, where visible tree stumps indicate land conversion for paddy rice. Moreover, vegetation loss could also be attributed to tree felling for charcoal production, serving as an energy source and profitable business for certain urban communities. The same trend has been reported by authors both within some West African countries [17, 55] and in other parts of the world [56, 58, 59].

The landscape in Ghana reflects drivers of land use and land cover (LULC) changes, including agricultural expansion, unregulated community mining, legal and illegal logging, increases in population and poverty, and complex and conflicting tenure systems for forests and water. These changes were evident in the evolving state of the landscape between 2008, 2015, and 2018, with impacts such as habitat loss, increased surface runoff, and altered microclimate [60–62]. In Nigeria, the driving forces of LULC changes include agricultural expansion, livestock production systems, artisanal fishing, agricultural production and capacity development constraints, livelihood status and options, and institutional and policy support. These activities have led to converting natural areas into built-up areas and agricultural land, with potential impacts such as habitat loss, reduced biodiversity, and increased soil erosion [63, 64].

The impacts of land use changes on water quality were significant in both case study areas. In Ghana, the case study 1 site showed higher levels of pollutants in drinking water than case study 2. These elevated levels extend beyond ecological consequences and affect the livelihoods and well-being of local communities. Addressing these challenges requires a holistic approach that integrates regulatory measures, sustainable practices, and community involvement to safeguard water resources and promote a healthy socio-ecological landscape [55, 65, 66].

The Mankran landscape in Ghana faces several significant environmental challenges primarily driven by human activities and institutional weaknesses. One of the major issues is the degradation and pollution of the Mankran River, largely due to illegal mining and logging activities. These practices have transformed perennial water bodies into seasonal streams, exacerbating water insecurity for local communities, particularly during the dry season. Additionally, the erratic rainfall patterns and climate variability have led to increased flooding and soil erosion, further complicating agricultural practices and threatening local food security. Another critical challenge is the lack of effective governance and community involvement in natural resource management. Weak institutional coordination among agencies has resulted in inadequate monitoring and enforcement of environmental regulations, allowing illegal activities to flourish. Furthermore, corruption within local governance structures has undermined accountability, leading to unsustainable resource exploitation and unfair benefit-sharing arrangements. This combination of environmental degradation, ineffective governance, and socio-economic pressures has created a complex situation that necessitates urgent and sustainable management strategies to protect the Mankran landscape and its resources.

In the Doma–Rutu landscape, the effectiveness of institutions and policies is hindered by limited resources and support. Governmental and non-governmental organizations alike face significant challenges in implementing their programs and initiatives due to a lack of adequate funding and resources. This scarcity of resources directly impacts the quality and reach of the services provided by these institutions. Furthermore, the region suffers from poor infrastructure, including inadequate road networks and limited access to healthcare facilities. This lack of basic infrastructure not only impedes institutional effectiveness but also contributes to the overall development challenges faced by the local communities. Another key issue is the weak coordination among various institutions operating in the Doma–Rutu landscape. The lack of effective communication and collaboration leads to duplicated efforts and a reduced overall impact of their initiatives. This lack of coordination is further exacerbated by limited human resources, technical expertise, and financial support within these institutions. The insufficient capacity to deliver effective services hinders the ability of institutions to address the pressing needs of the local population and effectively manage the region's natural resources.

Policy-wise, this study is very important, as it advances the DPSIR-SEL framework theoretically, showing its use in the analysis of complex socio-ecological landscapes through identification of the causal links of human activities and changes in the environment. Very insistent in the integration of social and ecological systems within landscape management, it proves that undesirable practices within uses, and degraded landscapes are becoming more commonplace when such integrative approaches are neglected. At the same time, greatly enriching theoretical discussion through making it clear that currently existing models are far from all-comprehensive enough to reflect those complicated interactions. On the score of policy, this study articulates the need for more specific and effective institutional responses—not just to environmental challenges in isolation but to deforestation and environmentally destructive practices of land use more generally. It also identifies poor stakeholder coordination as one of the main barriers that sustainable landscape management policy frameworks should address by enhancing collaboration among various stakeholder efforts. Another recommendation from this study is that the landscape management be carried out through a participatory mechanism that will ensure that the policies themselves are linked to local realities. Lastly, it identifies and calls for sustainable land-use planning and resource management policies that would mitigate adverse human activities and maintain ecological balance while supporting local livelihoods.

The study identified several limitations and gaps. Institutional responses were not specific and strong enough to make much difference in the context of the existing socio-ecological issues. Poor coordination of the stakeholders with limited capacity proved to be the major barriers to enhanced performance of integrated management and planning of ecosystem services. Efforts were further dissected due to isolation in the major sectors of production, which complicated any coherent landscape management. Besides, myths, as well as negligence of socio-ecological and participatory approaches in the landscape practices, resulted in unsustainable rural developments with an under-tapping potential of the landscape, especially that of the agrifood systems of Ghana, Nigeria, and the wider West African region. Corrective measures are necessary to take care of these landscape gaps that would wish to be managed sustainably.

5.1 Inclusive landscape management: a way forward?

Inclusive land management planning [67] can be crucial in mitigating the pressure on the Social-Ecological Landscape (SEL) in the Mankran and Doma–Rutu landscapes. By involving all relevant stakeholders, considering social, economic, and environmental aspects, and promoting sustainable practices, inclusive land management planning can address the root causes of threats and ensure the long-term health and functioning of SEL [67–71]. Some ways to practice inclusive land management planning to help mitigate the pressure on the SELs in the Mankran landscape include (i) stakeholder engagement. By incorporating diverse perspectives and knowledge, the planning process can identify and address the specific challenges faced by different groups, leading to more effective and equitable solutions, and (ii) promote sustainable Land Use Practices. This may include promoting agroforestry, organic farming, and sustainable logging practices to minimize the negative impact on forests and ecosystems while ensuring livelihoods and food security; (iii) Zoning and Land Allocation: through inclusive planning, areas can be zoned and allocated for specific purposes, such as protected areas for conservation, agricultural zones for farming, and mining zones for regulated mining activities; and (iv) promoting afforestation and reforestation initiatives. Local communities can be actively involved in tree-planting and forest restoration activities, creating a sense of ownership and responsibility for the environment, and (v) promoting capacity building and education at both local and regional levels in Ghana. Raising awareness of the importance of sustainable land use and ecosystem conservation can foster a collective commitment to protect the SEL.

Mitigating challenges in the Mankran landscape requires a multifaceted approach [72–74]. To address Agricultural Expansion, implementing sustainable farming practices such as agroforestry and organic farming can reduce deforestation and pesticide use. Strengthening land-use planning is essential. For Galamsey and Unregulated Community Mining, bolstering law enforcement, promoting responsible mining, and offering alternative livelihoods can curb the impact of illegal landscape requires a multifaceted approach [72–74]. To address Agricultural Expansion, implementing sustainable farming practices such as agroforestry and organic farming can reduce deforestation and pesticide use. Strengthening land-use planning is essential. For Galamsey and Unregulated Community Mining, bolstering law enforcement, promoting responsible mining, and offering alternative livelihoods can curb the impact of illegal mining. Tackling Legal and Illegal Logging necessitates enhanced governance, stricter regulations, and encouragement services and conflict-resolution mechanisms is crucial. Sustainable fishing practices, including community-led efforts to discourage harmful chemicals, are vital. Modernizing farming technologies, enhancing infrastructure, and providing access to credit can help overcome production constraints [75]. Habitat restoration initiatives for savanna vegetation, woodlands, and wetlands are necessary for ecosystem preservation. Empowering alternative livelihoods through vocational training, youth engagement, and women's inclusion can help address poverty [76–79]. Strengthening policies, fostering stakeholder collaboration, and optimizing resource allocation will holistically address these multifaceted issues.

6 Conclusions

The DPSIR-SEL framework was applied to assess the SEL's condition in the Mankran landscape in Ghana, revealing causal links from Drivers (e.g., agricultural expansion) through Pressures (land use change) to States (biodiversity loss) and Impacts (habitat destruction). Institutional Responses were analyzed but found to need more specificity and effectiveness. Unsustainable practices such as small-scale mining, large-scale wood exploitation, and forest conversion for agriculture were driven by local livelihood needs. The state of the SEL in the Mankran watershed has been altered, impacting the availability of ecosystem services (ES), poverty, food security, pollution, and deforestation. Poor stakeholder coordination, limited capacity, and isolated production sectors have hindered integrated management and ES planning. This study highlights the complex interactions between human activities and ecological outcomes within the Mankran landscape.

In Nigeria, using the DPSIR-SEL framework, drivers such as deforestation for expanded agriculture and inactive irrigation schemes lead to pressures on floodplains and ecosystems. This results in reduced biodiversity, eroded land, and diminished water capacity in the floodplains. These impacts include threats to floodplain extinction, agricultural sustainability, and increased flood vulnerability due to urban encroachment. Appropriate measures are required to address these challenges. Sustainable land-use planning, irrigation scheme reactivation, and urban expansion management are potential responses to counteract these negative impacts. This framework emphasizes the interconnectedness of human activities, environmental changes, and the necessity for informed actions to maintain the Doma–Rutu Landscape's ecological balance and the well-being of communities that rely on it.

It is apparent from the above that productive landscapes in Ghana and Nigeria, and by extension West Africa, are facing increasing pressure from deforestation, land degradation, poor water management, poor agricultural practices, unsustainable mining, wildlife poaching, and climate change. The agrifood systems in these areas struggle to utilize/optimize the landscape's potential. Misconceptions in landscape management practices, such as neglecting socio-ecological and participatory approaches, hinder sustainable development. Socio-ecological landscape management, which integrates social and ecological systems and promotes collaboration among stakeholders, innovation, risk resilience, resource sustainability, and community satisfaction, could be the way forward in this context.

According to the water quality assessments, there are concerns in both regions: for Ghana, lead averaged 18.73 µg/L, above the WHO guideline of 10 µg/L, arsenic averaged 53.41 µg/L above the 10 µg/L limit, and iron was well in excess at an average of 50.22 mg/L over the 0.1 mg/L limit. In some cases, the pH values were as low as 6.03 in Nigeria, which is below the WHO recommended range of between 6.5 and 8.5. At the same time, salinity reached 288 ppm in Akurku Stream, portraying possible contamination from dissolved salts. These findings underpin the need for inclusive landscape management that addresses land use and water quality in balancing economic and environmental priorities to sustain livelihoods and ecosystem health.

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Author contributions GA is the corresponding author and conceptualized the study and provided an initial draft of the literature review and findings for Ghana. IHE replicated the study in Nigeria using the conceptualization and methods in Ghana study. SAT engaged in fieldwork in Ghana and reorganized the introduction and literature review sections. AO engaged in fieldwork in Nigeria, and revised and reviewed the literature. TM reviewed and revised the first draft of the paper, revised the conceptual framework, and developed the abstract, OAO analyzed the field data and reviewed the literature. OC made revisions throughout the paper from the introduction to the conclusion.

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Data availability Data available for this study is not in the public domain but would be accessible on special request.

Declarations

Competing interests The authors declare no competing interests.

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