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Research article

Modelling the drivers of land use and land cover change of the great Amanzule wetland ecosystem to inform the development policy of the southwestern oil-rich region of Ghana

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ABSTRACT

This study focused on the current and future drivers of land-use change and its impact on the Amanzule wetland. It suggests policy implications for reviewing and strengthening existing policies for sustainable land use. This study employed remote sensing and GIS techniques, including participatory rural appraisal techniques. The administration of questionnaires and focus group discussions were conducted in the Ellembelle and Jomoro municipalities, where the Amanzule wetland provides economic and social services. The results showed increased land use over the last 32 years driven by various drivers, including food crop production, rubber plantations, oil and gas establishments, and infrastructure development. The study further revealed that these drivers could influence land-use change in 18 years (2018–2036). Urbanisation, cropland, rubber plantations, and shrubland will drive land-use change in the study area between 2036 and 2054. The Amanzule wetland area is expected to decrease from 272.34 ha in 2018 to 210.60 ha by 2036. The wetland area is expected to further decrease from 210.60 ha in 2036 to 174.33 ha by 2054. Other land use classes, such as mangrove and swamp forests, are also expected to decrease within the same period. The study recommends advocating for a wetland policy, enforcing the Land Use and Spatial Planning Act 925 and the Petroleum Exploration and Production Act 919 for sustainable development.

1. Introduction

This study sought to investigate the major drivers impacting the ecological conditions of the Amanzule Wetland to contribute to policy formulation to ensure the protection and sustainable use of the wetland. The wetlands provide essential ecosystem services and are rich in biodiversity, hosting various animal and plant species; plant species include mangroves, raffia palm, ironwood, and medicinal plants; and animal species such as mammals, reptiles, fish, birds, and various migrant species have been recorded [1]. These

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provisioning services make the wetland a vital livelihood source for fringing communities. The rich biodiversity of the wetland positions the wetland as a place of conservation interest nationally and globally and meets the criteria for designation as a wetland of international importance under the Ramsar Convention [1,2]. The wetland also helps mitigate climate change by sequestering carbon dioxide and other greenhouse gases [3].

Notwithstanding the enormous benefits of wetlands, land use/land cover change (LULC) has been responsible for the loss of more than 33 % of the global wetland surface area, with annual loss rates of 0.92 and 0.48 % for coastal wetlands and inland wetlands, respectively, since 1990 [4]. Danso et al. [5] showed that the rate of wetland loss poses a danger to the existence of wetlands worldwide. In Ghana, empirical studies on the rate of wetland destruction are limited [6]. However, several studies over the last decade have shown that drivers of land use change, such as increasing infrastructural development, uncontrolled mining, agricultural expansion, and oil and gas facilities, negatively impact essential ecosystem services, especially the Amanzule wetland [5,7,8]. As a result, the sustainable use of the Amanzule wetland is needed to sustain the provision of essential ecosystem services while generating adequate revenue for local authorities for development. In Ghana, even though there are several national documents, such as the National Biodiversity Strategy and Action Plan 2016, Forest and Wildlife Policy 2012, Land Use and Spatial Planning Act 925, and Petroleum Exploration and Production Act 919, that highlight the conservation of natural resources, they fail to address the challenges confronting wetlands. This could be due to the lack of a dedicated wetland policy that provides solid legal support for the protection of wetlands. The sustainability of this resource is also crucial for climate change adaptation and mitigation, in line with the Ramsar Convention, Sustainable Development Goals, Aichi Targets 5 and 14, and the Abidjan Convention. These international agreements must be upheld to ensure the effective conservation of the Greater Amanzule wetland and other wetlands in the country. Despite the importance of wetlands, little has been done in the policy dimension to protect them, even though Ghana is a signatory to the Ramsar Convention. This is evidenced by the lack of explicit wetland policy, even though numerous studies have confirmed the essential contribution of wetlands to poverty alleviation by providing vital ecosystem services to humanity [9].

Since the discovery of oil and gas in Ghana, many studies have reported its socioeconomic impact on locals. This impact is often attributed to the effect of land-use change on food security, but little attention given to the impact on the ecological conditions of the Amanzule wetland. Essentially, the Amanzule wetland covers approximately 50,000 ha of land and water areas and hosts a biodiverse mangrove ecosystem which provides livelihoods and other essential ecosystem services to more than one million people in Ghana and neighbouring Cote d'Ivoire [7]. Despite its relevance, the wetland is threatened by cumulative land use change activities, and limited measures and awareness are available for its protection. This limited attention threatens this vital ecosystem's livelihood and other services [7]. Because of these challenges bedevilling the wetland, authorities must address the driving factors of land-use change impacting the Amanzule wetland.

Land use change is an ongoing, spontaneous, or gradual process driven by human and natural factors [10]. This affects human and other organisms' access to ecosystem services and undermines ecosystem health [11]. Three types of land-use change drivers negatively impact ecosystems: human-induced, human-induced natural, and nonhuman-induced drivers [12]. Understanding the dynamics of these drivers is a significant area of research, both locally and nationally, regionally and globally [13]. LULC contributes to the rapid occurrence of climate change because it influences atmospheric carbon dioxide levels, with a cascading effect on the Earth's climate and ecosystem services. These effects could be well-managed through effective land management and policy interventions aimed at adaptation and mitigation. At the landscape level, improper management of land results in changes in the land cover structure that directly affect the flow of energy, water, and greenhouse gases [14]. For example, deforestation decreases the evaporation of water, leading to less cloud formation, less precipitation, and increased drought. Increased drought has been linked to land cover change in a simulation of deforestation in the Amazon Forest, transforming parts of the forest into grassland [15]. These transformations alter precipitation and negatively impact ecosystem services and water availability [16]. In addition, forest degradation increases the amount of suspended dust, leading to radiative cooling and reducing rainfall [17]. Forest degradation also influences the greenhouse effect by releasing greenhouse gases into the atmosphere and altering carbon deposition through land use [18]. In a related study, Ritchie's [19] showed that approximately one-third of the world's forests were lost within the twentieth century, mainly attributed to the expansion of agriculture and settlements [16]. This is of particular concern because of the loss of carbon sinks, soil, and vegetation [20,21]. In wetlands, human-induced land cover change causes soil depletion, watershed degradation, loss of vegetation, and erosion [22]. This affects people's ability to use wetlands for essential ecosystem services such as access to fish, clean water, flood control, and tourism [23], forcing indigenous people to seek alternative livelihoods. For example, the challenges of land use change have stimulated land and water conservation efforts in Niger and Burkina Faso [24]. Land use change is expected to increase the frequency of floods, droughts, heatwaves, and severe storms [25], which will negatively impact wetlands. Wetlands are particularly vulnerable to hydrological changes because they are located entirely between water bodies and terrestrial ecosystems. Over time, these changes can lead to changes in species distributions, species assemblages, and soil biogeochemical conditions. These changes could be aggravated by warming temperatures, increased atmospheric carbon dioxide concentrations, and changes in the frequency and intensity of precipitation, which alter ecological processes. Native species such as crustaceans, perch, catfish, and other fish may disappear due to climate change, affecting the livelihoods of communities [26]. These changes could also extend to the disappearance of some medicinal species and native plants. Opportunistic, adaptive, and invasive species, pests, and diseases could take advantage of land cover changes to increase their numbers and geographical range [26]. Land use change could be compounded by climate change and other stressors, such as urbanisation and pollution [26]. These stressors can undermine existing ecosystems and create new ones, further altering the benefits of wetlands.

Although the impact of human activities is familiar to all natural ecosystems worldwide, coastal wetlands have been particularly affected by land use change because of the cumulative impact of all activities in the watershed [27]. Land use change is the primary source of pollutants discharged into coastal environments. For instance, in Mexico and other South American countries, the most critical tourism infrastructure and agricultural activities along the coastal zone have modified land use patterns, resulting in the degradation and loss of ecosystem functions and declining ecosystem services to local communities [28]. In Ghana, land use change activities such as the establishment of resorts and oil and gas facilities are believed to impact wetlands along the coast. Anecdotal studies have also indicated that Ghana's oil discovery, production, and value chain activities are contributing factors to the drivers negatively impacting the Amanzule wetland ecosystem. These challenges informed the study to help advocate for policy formulation that will help in the sustainable use of the wetland in the study area.

This study adopted a modelling approach to provide an understanding of the impact of LULC over time, thereby providing valuable insights for policymakers and researchers [29]. A modelling approach has been used to study land-use change in the Albertine Rift Landscape of Uganda, revealing the impact of food insecurity fuelled by land grabbing because of oil discovery [30]. In this study, the capacity of the modelled land-use change employed to study various drivers makes it an indispensable tool for decision-making processes and sustainable land management strategies [29]. Having outlined the introduction and literature to this study, the remaining sections of this paper are structured as follows: Section 2 describes the materials and methods employed to investigate the major drivers impacting the ecological condition of the Amanzule wetland. Section 3 presents the results, and section 4 discusses the major drivers of land-use change in the Amanzule wetland. Section 5 presents the study's limitations and possible future scale-up, and section 6 provides the conclusion and recommendations.

2. Materials and methods

This study employed remote sensing and geographical information system (GIS) approaches, including social surveys, to assess the drivers of land-use change [31] in the study area. The participatory rural appraisal (PRA) technique, questionnaire administration, and focus group discussions (FGDs) were used. The selection of the drivers of the land-use change was based on satellite images showing the extent of change over time and validation of the change through interviews [31].

2.1. Study area

The study was conducted in seven communities in the Ellembelle and Jomoro municipalities in the western region of Ghana, where

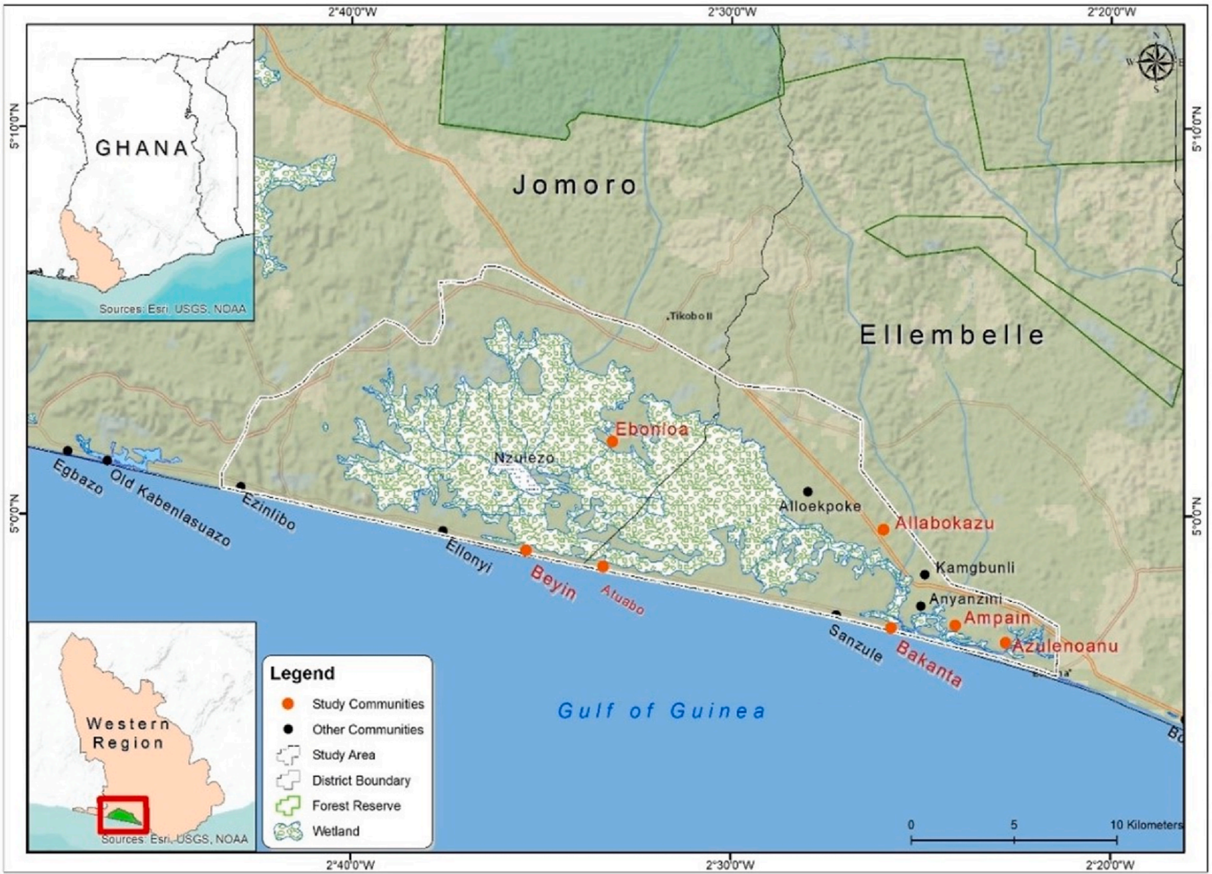

Fig. 1. Map of the study area.

the Amanzule wetland provides economic and social services, including tourism, to surrounding communities and visitors. In Ellembelle, the study communities were Azulenloano, Ampain, New Bakanta, Alabokazo, and Atuabo-Asem Nda, while in Jomoro, the communities were Beyin and Ebonloa (Fig. 1). The Amanzule wetland lies 5° 1′6″ north and 2° 32′44″ west and covers an area of more than 38,000 ha [1,7]. It stretches from the Ankobra River estuary to the Cote d'Ivoire border, covers the Ellembelle and Jomoro Municipalities coastal plains, and has an outlet that enters the sea [1,7]. Its immediate catchment area is inhabited by more than 15 communities, including Allabokazo and Beyin (Nzulezu), who depend on it for economic and recreational purposes. The wetland is critical for transportation in Ghana, Cote d'Ivoire, and between the two countries. Communities from both countries fringing the wetland depend on it for their transboundary business activities, making it essential for their economic prospects. The wetland consists of swamps, mangrove forests, birds, primates, and other essential fauna and flora [1]. It is known to hold the only peat and the largest swamp forest in Ghana [32]. The wetland is biologically rich [1], providing livelihoods (direct and indirect) for more than 50,000 people within the study area. Therefore, any effort geared towards protecting it through legislation in Ghana will stage the grounds for similar action in the neighbouring Cote d Ivoire. Hence, this study seeks to provide a basis for kickstart advocacy action.

2.2. Conceptual and theoretical framework

The framework of the study is embedded in the human ecological approach and ecosystem function, linking ecosystem system benefits and human livelihood [33]. The quantity and quality of ecosystem services provided to societies are determined by complex interactions among and within species populations, biotic communities, and abiotic environments [34]. Social-ecological systems also depend on the actions and inaction of local people and the baseline conditions of natural capital. The World Bank [35] reported that communities experiencing poverty worldwide, especially in rural areas, are dependent on renewable and cultivated natural capital for their basic needs and survival and are more vulnerable to degradation resulting from land-use change. This study sought to adopt the human ecology approach, which is part of the ecosystem-based approach widely used in many studies [33]. The rationale behind using this approach is to facilitate a broader understanding of the complex linkages between land-use change and ecosystem services,

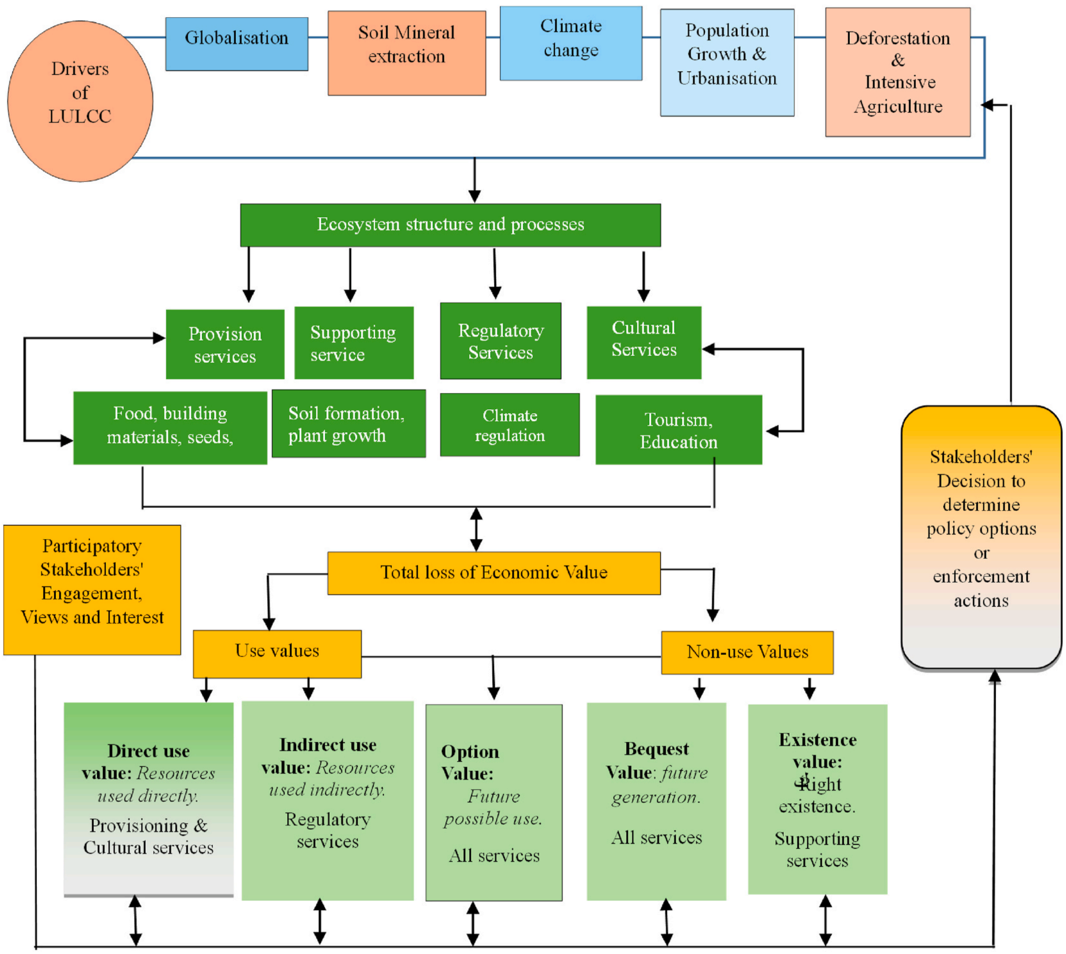

Fig. 2. Conceptual and theoretical framework.

including human livelihoods.

Human ecology studies the dynamic interrelationships between human populations and the physical, biotic, and social characteristics of their environment and the biosphere. It is an interdisciplinary subject that integrates concepts across different disciplines to holistically solve problems and enhance the complex interactions between humans and their environment. The complex interactions between ecosystem services, land-use change, and the benefits of ecosystem services demand a much broader approach to examining these linkages effectively. This will require stakeholder engagement as well as other perspectives. Therefore, this study's conceptual framework is anchored on the premise that LULC drives ecosystem structure degradation and affects wetland economic value. The effect manifests through the loss of ecosystem structure, loss of people's livelihood, and, consequently, total loss of economic value, which affects ecosystem services. Addressing such a change will require a holistic approach by engaging stakeholders and enforcing laws or policies.

This study explored the drivers of land-use change in the Amanzule wetland to provide a basis for national and subnational conservation advocacy. As illustrated in Fig. 2, the framework seeks to illustrate the linkages between drivers of land-use change and their impact on ecosystem services, how it impacts human livelihoods and the economic value of ecosystem services. Land-use change driven by human and climate change negatively affects ecosystem services, impacting communities whose primary source of livelihood is the Amanzule wetland. The conceptual framework also captures participatory stakeholders' engagement, views and interests, and measures to enforce policies for conserving wetlands and sustaining livelihoods.

2.3. Assessment of land use and land cover change

The drivers of LULC in the study area were assessed using multitemporal data from the Landsat satellite constellation [31] to analyse LULC in 1986, 2000, and 2018. For each of these periods, tiles from two dates that contained the least amount of cloud cover were selected, and the most apparent areas within each tile were combined to provide a single image for the study area. Landsat 5 Earth Explorer database systems were used for the analysis. All the processing and post-classification steps were carried out using the Earth Resources Data Analysis System (ERDAS Imagine 9.1) and ArcGIS 17.1 [36]. Before interpretation, image preprocessing, including geometric and radiometric corrections, was performed for each image. All the data were geometrically corrected and projected to the Universal Transverse Mercator (UTM) zone 30 N.

2.4. Image processing

The images were subjected to various preprocessing procedures before classification, including geometric and radiometric corrections, subset creation, and image enhancement [36]. Geometric corrections for the Landsat TM bands 1, 2, 3, 4, 5, and 7 were stacked. Band 6, which measures thermal reflectance, was not included because of its different spatial resolution of 120 m. The resultant stacked images in the global coordinate system, the UTM World Geodetic System (WGS) 84 Zone 30 N, were reprojected onto the Ghana War Office based on the Traverse Mercator Projection [37]. Radiometric calibration was carried out on satellite images before image classification and generation of spectral indices. The datasets were corrected to some extent; in particular, the 1986 Thermatic Mapper (TM) and 2000 Enhanced Thermatic Mapper (ETM+) images were quite hazy. ERDAS Imagine 9.1 was used for image processing, land use, and cover classification. ArcGIS 17.1 was used to produce the output maps. After image preprocessing, the supervised classification method using a random forest algorithm generated LULC maps for the three time points (1986, 2000, 2018). For this study, eight (8) classes were generated based on this classification to provide a basis for analysing ecosystem services. The classes were rubber plantations, mangroves, artificial areas, water bodies, croplands, shrublands, grasslands/sedges, and swamp forests. The objective of this study was to examine the driving force causing LULC; the first-level classification was performed based on the eight (8) identified classes. Sixty (60) training sets indicating the different land use and cover classes were digitised on the individual epoch images using the area of interest (AOI) tool and were named consequently in the signature editor of ERDAS imagine 9.1.

2.5. Map accuracy assessment

The map accuracy assessment compared the generated LULC maps to the ground-truthed data using 1150 sample points generated for each satellite image [31]. The accuracy was calculated for all the land cover classes. A stratified random sampling technique was used to extract random points for each land cover type. The accuracy assessment assigns a measure of validity to the generated LULC maps and allows users to understand the reliability with which the mapped classes capture conditions on the ground. It further enables potential users to determine the map's suitability for any application. The 1986 classified image had seven land cover types. Therefore, 50 random points were generated for each of the land covers. With eight land cover classes for 2000 and 2018, 50 random points were extracted for the various land cover classes, summing up to 400 sampled points. The extract values pivot tool in the GIS environment was used to extract the cell values of the land use/land cover types based on the locations of the randomly sampled points. The pivot tool was also used to construct the confusion matrix for the three-year assessment.

The overall map accuracy was determined by summing the diagonal of the matrix and dividing it by the total number of sampled points. Additionally, the kappa coefficient, which considers the difference between the reference dataset and land-use/land-cover data [36], was calculated by considering the sum of the diagonals of the error matrix and the sum of the products of the row and column totals for each land cover type. The user's accuracy was computed using the number of correctly classified pixels to the total number of pixels assigned to a particular land cover. This value represents the probability that a pixel classified into a given land cover represents that category on the ground. The producer's accuracy was also computed using the number of pixels correctly classified in a particular land cover as a percentage of the total number of pixels belonging to that category in the image. This value represents how well the reference pixels of the land cover type are classified. The producer's accuracy measures errors of omission, while the user accuracy measures errors of commission.

2.6. Change detection

The Amanzule wetland LULC was assessed using the Idrisi TerrSet edition [38]. Change vector analysis (CVA) was subsequently conducted [39] to identify areas where the Amanzule wetland might have changed between 1986, 2000, and 2018.

2.6.1. Prediction of land use and land cover change for 2036 and 2054

The integrated Markov chain and cellular automata analysis (CA-Markov) model predicted the LULC in the Amazule Wetlands. CA-Markov models have been used to predict changes and estimate variations using satellite images [12]. The CA-Markov models combine a Markov algorithm to simulate the quantity of change and a CA algorithm to simulate change allocation. The CA employs the proximity concept to show that regions closer to existing areas of the same class are more likely to change to a different class. The transition probability matrix determines the likelihood that a cell or pixel will move from a LULC category or class to every other category [12]. The LULC simulation for the study area was conducted using the Land Change Modeller (LCM) in IDRISI TerrSet 18.31 Software [38]. The purpose of the simulation was to predict the expansion of the anthropogenically induced LULC classes and other natural LULC (mangrove, swamp forest, grassland, shrubland, and waterbody) classes to anthropogenically induced LULC classes (artificial area, cropland, and rubber). The transition probability matrix was computed for 2018 using LULC maps of 1986 and 2000. The matrix for 2036 and 2054 was generated using LULC for 2000 and 2018. The transition probability matrix showed areas likely to transition to other classes. Three submodels were developed: built, farming, and plantation.

The built submodels were developed to predict the expansion of artificial areas. The farming submodel was used to predict expansion in cropland, and the plantation submodel was used to predict rubber plantation expansion. The common drivers included in the models were the LULC maps, distance from the road, digital elevation model (DEM), and slope. Distance from artificial areas was included in the built submodel. The distance from cropland was added to the farming submodel, and the distance from rubber was also included in the plantation submodel. The built submodel was developed to predict the expansion of artificial areas. The farming submodel was used to predict expansion in cropland, and the plantation submodel was used to predict rubber. The drivers were used to develop the transition of potential models. By using the transition probability matrix and the transition potential model, 2018 maps were developed. Kappa components were used to validate the predicted maps for 2018 using the 2018 LULC maps as the reference map. After the validation process, the predicted maps for 2036 and 2054 were generated. Fig. 3 illustrates the flow chart showing the methodology of the study.

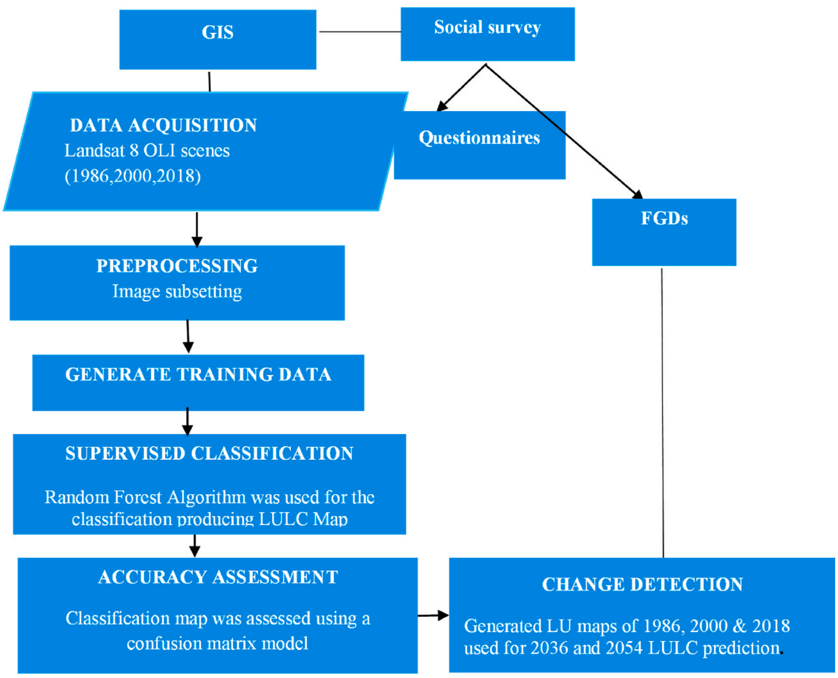

Fig. 3. Flow chart of the methodology.

3. Results

3.1. Land use change and livelihood dynamics

The different livelihood types and how anthropogenic activities impacted them over the years were studied. Fig. 4 shows that 29 % of respondents engaged in fishing as a significant source of income 15-30 years ago. Twenty-four percent (24 %) indicated coconut farming as a source of income. The tourism sector recorded the third livelihood of 21 % of the respondents. Crop farming was the fourth most common, with 18.0 %. Trading and other livelihoods (such as brewing raffia gin and harvesting raffia sticks for sale) were engaged by 5.0 % and 2.7 % of respondents, respectively. Fig. 5 shows that since 2018, there has been a change in the proportion of farmers engaged in coconut farming. The proportion of coconut farmers decreased from 24 % in the past (15–30 years ago) to 4.8 % in the present. This change represents a 19.2 % reduction in coconut farming attributed to the Cape Saint Paul's wilt disease (CSPWD) outbreak on coconut plantations [40]. Therefore, many farmers resort to rubber plantations as a more secure alternative source of livelihood.

Fig. 4 further indicates that 21 % of respondents were engaged in tourism in the past (15–30 years ago), declining to 9.8 % in the present. This shows a decline of 11.2 % of people who depend on tourism for their livelihood. The decline was attributed to the expansion of built-up areas, displacing important tourism attraction sites such as swamp forests and mangroves, which serve as bird breeding and landing sites and for educational and research purposes. Other sectors, such as fishing, crop farming, trading, and other forms of livelihoods, have expanded with a proportional increase in community members engaged in them (Fig. 5). The proportion of people fishing increased by 5.0 %, while that of crop farming, trading, and other livelihoods increased by 21 %, 2.3 %, and 2.1 %, respectively.

3.2. The extent of land use and land cover classes in 1986

Swamp forest was the most extensive land cover class in 1986, covering 22,038.14 ha, followed by croplands covering 6720.57 ha (Table 1). Artificial or built-up areas covered 2183.76 ha, occupying third place in land use. Sedge was the fourth most extensive land cover class in 1986, with an area of 1497.06 ha. The fifth and sixth most extensive land covers were shrubland and water bodies, covering 836.73 and 323.19 ha, respectively. Mangroves were the seventh most extensive land cover class, covering an area of 318.60 ha. However, there was no rubber plantation in 1986, so it had no land cover class that year (see Fig. 7).

3.3. Extent of land use and land cover classes: gains and losses from 2000 to 2018

Even though swamp forests cover an extensive area, they continue to significantly lose to other land uses (Table 1). In 2000, it lost 6160 ha to other land uses and gained only 2674 ha between 2000 and 2018 (Fig. 6). Although croplands were the second most extensive land class in 2000, they also gained 5103 ha of additional land and lost 2839 ha between 2000 and 2018. In contrast, shrubland lost 3509 ha of land cover to other land uses and gained 2489 between 2000 and 2018 (Fig. 6), even though it was the third most extensive land use and land cover class in 2000. Artificial or built-up areas occupied the fourth most extensive land use and land cover class in 2000, gaining 2911 ha of additional land and losing 1620 ha between 2000 and 2018 (Fig. 6). Sedge/grassland was the fifth most extensive land cover in 2000, gaining 2166 ha and losing 1780 to other land uses between 2000 and 2018 (Fig. 6). Although mangroves were the sixth most extensive land use and land cover class as of 2000, they lost 312 ha of land cover to other land use activities and gained only 207 ha (Fig. 6). Similarly, water bodies were the seventh most extensive land cover class, losing 278 ha to other land-use activities, gaining 87 ha, and becoming the minor land cover class by 2018. While rubber plantations emerged as the

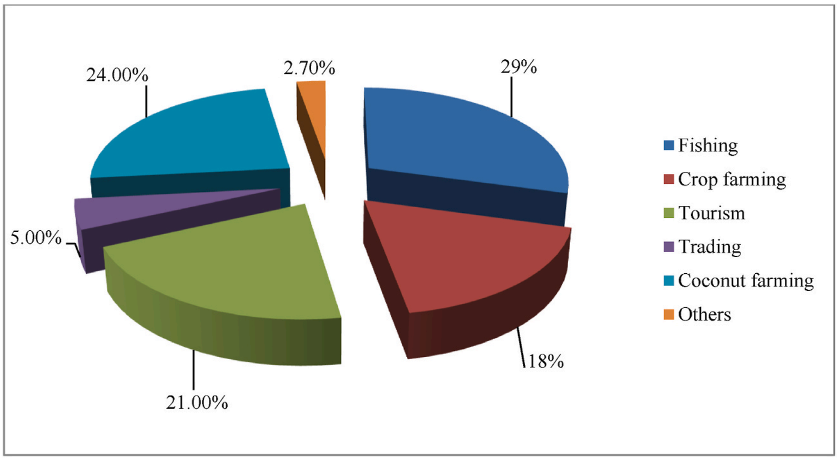

Fig. 4. Previous livelihood (15–30 years ago).

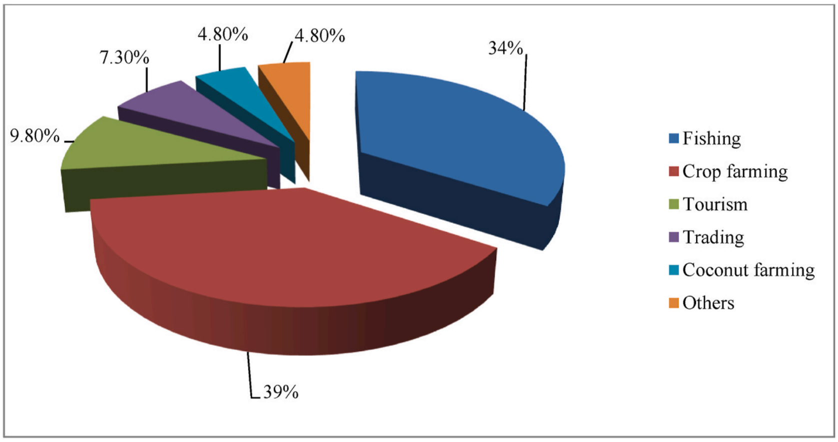

Fig. 5. Present livelihood (2018 to date).

Table 1
Percent change in land use and land cover classes (1986, 2000, 2018).

Land Use Classes	1986	2000 Area (Hectares)	2018	Percent Change (%)	
				1986–2000	2000–2018
Rubber	0	224.10	1083.06	+0.65	+2.50
Mangrove	318.60	530.91	425.97	+0.62	−3.31
Artificial/build-up area	2183.76	3181.41	4472.91	+2.91	+3.77
Water bodies	323.19	463.41	272.34	+0.41	−0.56
Croplands	6720.57	4487.67	6752.25	−6.51	+6.60
Shrubland	836.73	4119.03	3099.60	+9.57	−2.97
Swamp Forest	22,038.14	18,598.41	15,114.96	−10.02	−10.16
Sedge/grassland	1497.06	2694.42	3078.27	+3.50	+1.12

** Total average land area: 34,299.36; June 2022.

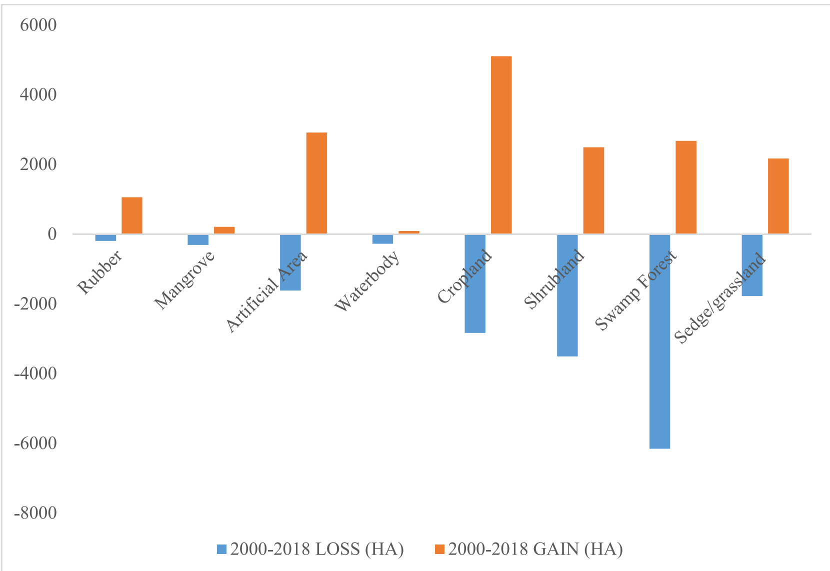

Fig. 6. Gains and losses of LULC between 2000 and 2018.

eighth and least extensive land use and land cover class, covering 244.1 ha between 1986 and 2000, they gained 1057 ha of additional land cover. It lost only 198 ha to other land use activities between 2000 and 2018 (Fig. 6) (see Figs. 8 and 9).

3.4. Percent changes in land use and land cover classes from 1986 to 2000

Table 1 presents the proportion of change in land use and land cover classes from 1986 to 2000 to 2018. From 1986 to 2000, shrubland increased more than the other land use and land cover classes. It increased from 836.73 ha in 1986 to 4119.03 ha in 2000, representing 9.57 % of the total land area. This was followed by sedge, which increased from 1497.06 ha in 1986 to 2694.42 ha in 2000, representing 3.50 %. The built-up or artificial area ranked third, increasing from 2183.76 ha in 1986 to 3181.41 ha in 2000, representing 2.91 %. Rubber plantations were the fourth largest, increasing from zero (0) hectares in 1986, when there was no rubber plantation, to 224.10 ha in 2000, representing 0.65 %. This was followed by mangrove trees, which increased from 318.60 ha in 1986 to 530.91 ha, representing a 0.62 % increase in land cover. Water bodies increased from 323.19 ha in 1986 to 463.41 ha in 2000, representing 0.41 %. In contrast, swamp forests decreased from 22,038.14 ha in 1986 to 18,598.41 ha in 2000 (10.02 % loss). Croplands also decreased by 6.51 %, from 6720.57 ha in 1986 to 4487.67 ha in 2000 (Table 1).

3.5. Percent changes in land use and land cover classes from 2000 to 2018

Croplands increased from 4487.67 ha in 2000 to 6752.25 ha in 2018, representing a gain of 6.60 % (Table 1). Artificial or built-up areas increased from 3181.41 ha in 2000 to 4472.91 ha in 2018, representing a 3.77 % increase. Rubber plantations increased in 2018 from 224.10 ha in 2000 to 1083.06 ha, representing a 2.50 % increase in the total land area. The sedge/grassland land cover area increased from 2694.42 ha to 3078.27 ha in 2018, representing an increase of 1.12 %. In contrast, swamp forests decreased from 18,598.41 ha in 2000 to 15,114.96 ha, representing a 10.16 % loss in area. Shrubland decreased from 4119.03 ha in 2000 to 3099.60 ha in 2018, constituting 2.97 % of the total land. Waterbodies showed a decrease in land cover from 463.41 ha in 2000 to 272.34 ha in 2018, representing a loss of 0.56 %. Additionally, mangrove trees decreased in land cover from 530.91 ha in 2000 to 425.97 ha in 2018, indicating a loss of 0.31 % of the total land area.

3.6. Prediction of land use and land cover change from 2018 to 2036: gains and losses

Cropland is predicted to be the primary driver of LULC between 2018 and 2036 (Table S1 and Fig. S1). It is expected to increase from 6752.25 ha in 2018 to 9899.10 ha in 2036, representing 9.17 %. Croplands are expected to gain an area of 4813 ha and a loss of

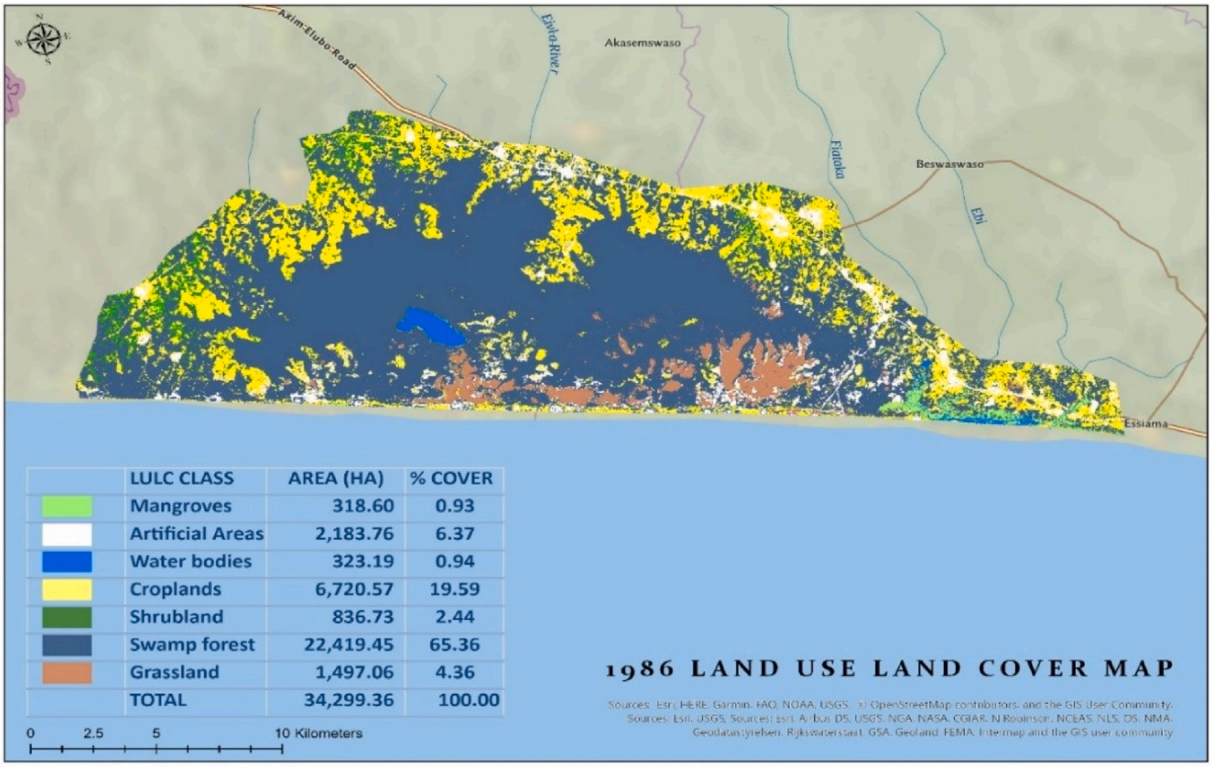

Fig. 7. Land-use/land cover map of the study area (1986).

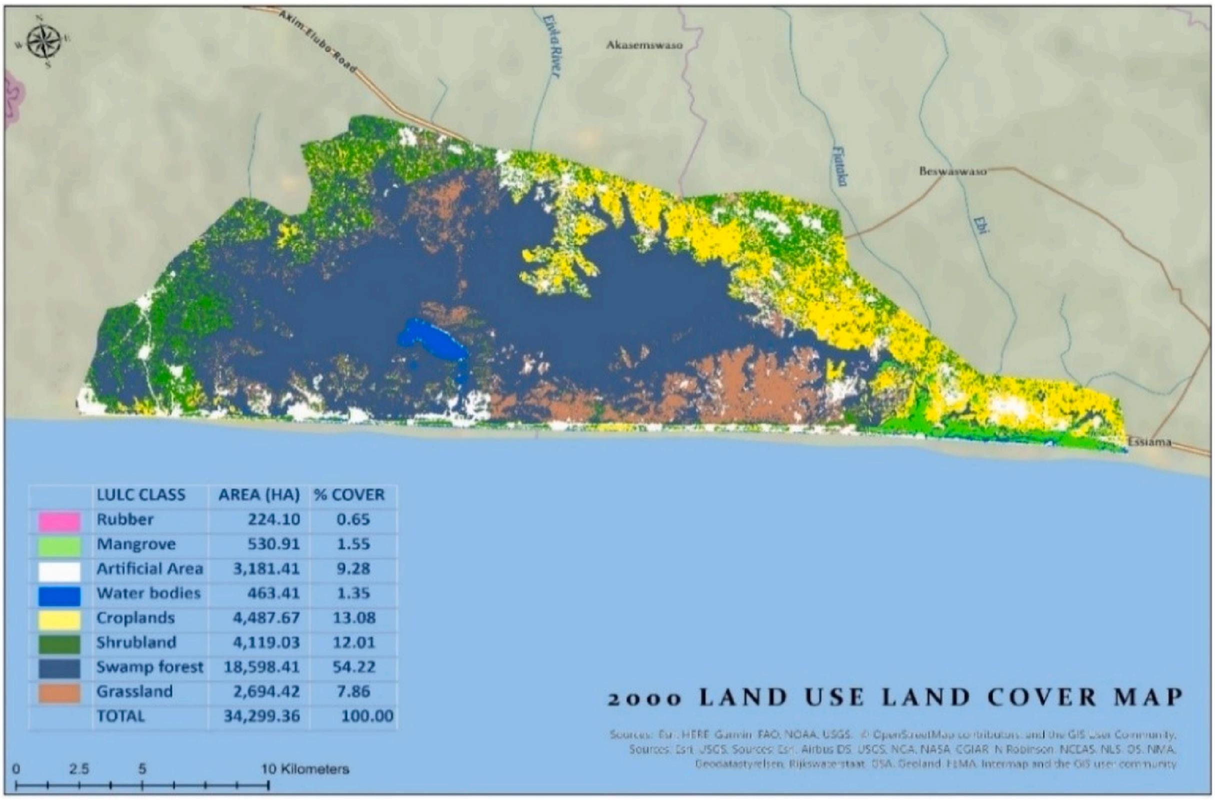

Fig. 8. Land-use/land cover map of the study area (2000).

1666 ha within the period. This will be followed by an expected increase in artificial or built-up areas, from 4472.91 ha in 2018 to 6667.83 ha by 2036, representing 6.40 %. This increase will make artificial or built-up areas the second primary driver of LULC by 2036. The artificial or built-up area is expected to gain 3062 ha and a loss of 867 ha between 2018 and 2036. Rubber plantations are expected to be the third driver of LULC and are expected to increase from 1083.06 ha in 2018 to 1677.96 ha by 2036, representing 1.73 %. Rubber plantations are expected to gain 1243 ha and a loss of 649 ha between 2018 and 2036. The other land use classes, including swamp forests, shrublands, sedges or grasslands, mangroves, and water bodies, are expected to decrease. Swamp forests are expected to decrease from 15,114.96 ha in 2018 to 12,371.58 ha by 2036 (8.0 % reduction). Swamp forests will lose 2743 ha without any gains between 2018 and 2036. The area of shrubland is expected to decrease from 3099.60 ha in 2018 to 995.31 ha by 2036, representing a reduction of 6.14 %. Sedges/grasslands are expected to decrease from 3078.27 ha in 2018 to 2153.97 ha by 2036, a reduction of 2.70 %. The mangrove area is expected to decrease from 425.97 ha in 2018 to 323.01 ha by 2036, representing a reduction of 0.30 % (Fig. S1). Water bodies are also expected to decrease from 272.34 ha in 2018 to 210.60 ha by 2036, representing a reduction of 0.18 %. Therefore, 62 ha of water bodies will be lost between 2018 and 2036 without a gain.

3.7. Prediction of land use and land cover changes from 2036 to 2054: gains and losses

Built-up areas will be the leading driving force in land-use change decisions by 2054 (Table S1 and Fig. S2). Built-up areas are expected to increase from 6667.83 ha by 2036 to 7652.52 ha by 2054, representing 2.87 %. The figure shows that built-up or artificial areas will gain 6062 ha of land and lose 1107 ha between 2036 and 2054. Cropland will be the second largest driver of land-use change by 2054 and is expected to increase from 9899.10 ha by 2036 to 10,664.55 ha by 2054, representing 2.23 %. It is expected to gain 7813 ha and lose 2366 between 2036 and 2054. Rubber plantations are expected to be the third force that will drive land-use change by 2054 (Table S1). It is expected to increase from 1677.96 ha in 2036 to 1934.01 ha by 2054, representing 0.75 %. Rubber plantations will, therefore, gain 4243 ha and a loss of 949 ha of land cover (Fig. S2). Shrubland is expected to be the fourth most important driver of land-use change between 2036 and 2054. It is expected to increase from 995.31 ha in 2036 to 1314.18 ha by 2054, representing 0.93 %. Although it is expected to increase between 2036 and 2054, there will be a loss of 2914 ha and a gain of 320 ha. The swamp forest is the primary class among all the classes that have consistently experienced a reduction and are expected to be reduced by 2054. Swamp forests are expected to decrease from 12,371.58 ha in 2036 to 10,504.89 ha by 2054 without any gains (Fig. S2). The reduction represents 5.44 % of the total area, negatively affecting space for tourism, education, researchers, and other essential ecosystem services. The area of sedges/grasslands is also expected to decrease from 2153.97 ha in 2036 to 1810.35 ha by 2054 without any gains, representing a 1.00 % reduction (Fig. S2). The number of mangrove trees is expected to decrease from 323.01 ha in 2036 to 244.53 ha

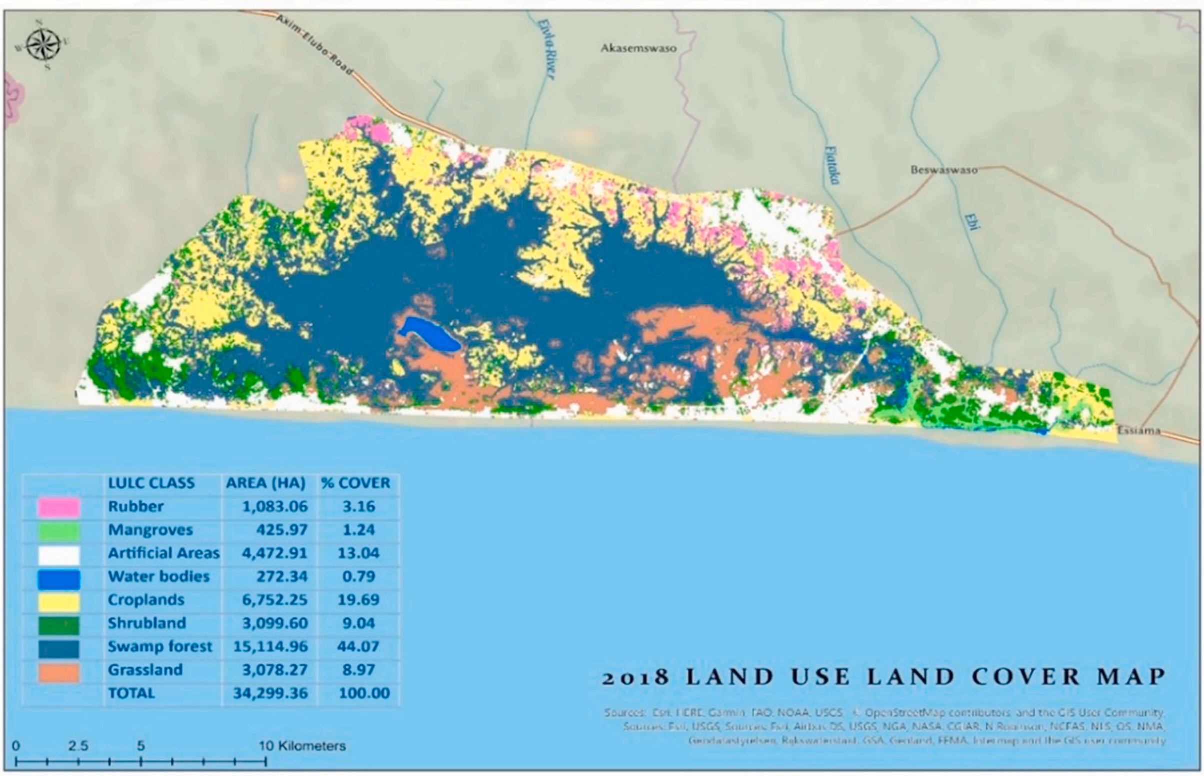

Fig. 9. Land-use/land cover map of the study area (2018).

in 2054 without any gains, representing 0.23 %. Table S1 and Fig. S2 also indicate that by 2054, water bodies are expected to further decrease by 0.11 %, from 210.60 ha in 2036 to 174.33 ha by 2054, without any gains. Figs. S3 and S4 provide the predicted land use and land cover maps showing the various land cover classes and percent coverage of the land area.

3.8. The probability of transition of land use

3.8.1. Land use and land cover class probability of changing in 18 Years (2018–2036)

Table S2 shows Markov's probability of land use and land cover class changing from one state to another in 18 years (2018–2036) in the study area. The rows represent the land use and land cover classes, while the columns represent the changes to the other classes within the 18 years. Table S2 shows that the probability of a rubber plantation changing to itself is 0.1149, that of a plantation changing to mangroves is 0.0000, and that of a plantation changing to artificial or built-up areas is 0.2193. The probability of changing to water bodies is 0.0000, that for croplands is 0.3795, that for shrubland is 0.1008, that for swamp forest is 0.1635, and that for grassland is 0.0221. The probability of mangroves changing to rubber plantations is 0.0002, that of changing to itself is 0.4121, that of changing to artificial or built-up areas is 0.0583, and that of changing to water bodies is 0.0502. The probability of changing to cropland is 0.1831, shrubland 0.2039, swamp forest 0.0298, and grassland 0.0624. The probability of changing artificial or built-up areas, waterbodies, cropland, shrubland, swamp forests, and grassland to the other land use and land cover classes follows a similar pattern.

3.8.2. Land use and land cover class probability of changing from 2036 to 2054

Table S3 shows the Markov probability of the land use and land cover class changing from one state to the other from 2036 to 2054 in the study area. The matrix showed that the probability of a rubber plantation changing to itself was 0.0679, that of a change to mangroves was 0.0064, and that of a change to artificial or built-up areas was 0.2211. The probability of changing to water bodies is 0.0021, and the probability of changing to cropland within the period is 0.2809. Again, the probability of a rubber plantation changing to shrubland is 0.1100, that of swamp forest is 0.2514, and that of grassland/sedge is 0.0601. The probability of mangroves changing to rubber plantations was 0.0344, the probability of changing to itself was 0.1783, the probability of changing to artificial or built-up areas was 0.1503, the probability of changing to water bodies was 0.0415, the probability of changing to cropland was 0.2413, and the probability of changing to shrubland was 0.1545. The probabilities of changing to swamp forest and grassland/sedge were 0.1262 and 0.0734, respectively. The probability of change of artificial or built-up areas, waterbodies, cropland, shrubland, swamp forests, and grassland to the rest of the land use and land cover classes follows a similar pattern.

3.8.3. Drivers of land use change: Amanzule wetland respondents' perspective

The respondents and stakeholders were engaged in authenticating the remote sensing and GIS results. The responses were analysed using regression analysis. The results show that food crop production, rubber plantations, oil and gas establishments, infrastructure development, population growth, weak enforcement of the Land-Use and Spatial Development Plan (Act 925), and conflict were statistically significant (95 %, F = 349, df = 11, p = 0.0002). The statistical significance shows that the above drivers influence land use in the Amanzule wetland area (Table S4). However, small-scale mining activity and climate change were not statistically significant ($p > 0.05$). The coefficient of determination (adjusted R^2) was 0.865, indicating that the drivers of change contributed to LULC around the Amanzule wetlands. The tested drivers, therefore, accounted for 86.5 % of the total drivers. However, the unaccounted variation was 13.5 %, contributing a minor variation to the land-use and land cover change.

4. Discussion

4.1. Drivers of land use change

The study revealed that cropland/food crop production, built-up areas/urbanisation, rubber plantations, oil and gas value chain activities, population growth, weak enforcement of the Land Use and Spatial Planning Act 2016 (Act 925), and conflict were the primary drivers of land-use change decisions in the study area. The results predict that rubber plantations, urbanisation, and food crop farming will influence land-use change in the next 36 years (2018–2054). According to Gomes et al. [41], LULC negatively impacts human well-being and tourism, driving global environmental change through greenhouse gas emissions and habitat and biodiversity loss. The factors facilitating LULC in the study area are being triggered by rapid transformation due to oil discovery and mining activities. Similar impacts have been confirmed in studies on the oil and gas industries in Nigeria and other developing countries, showing the effect of LULC on ecosystem services [42].

4.1.1. Food crop farming and rubber plantations

Several LULC factors might drive food crop farming and rubber plantations in the study area. These include a lack of skills available for youth to access oil and gas-related jobs, food insecurity due to population growth emanating from the influx of people and companies working along the oil and gas value chain, and high economic benefits and security in rubber plantations compared to other cash crops. Panford [43] argued that the discovery of oil in developing countries is marked by jubilation, happiness, and celebration due to the economic and other developmental benefits expected to be gained from the discovery. However, this celebration and expectation are usually met with disappointment, as oil and gas discoveries often become more of a curse than a blessing [44]. In most developing countries, skills to undertake oil-related work are often challenging, mainly when the discovery occurs far away from the main cities where most people are not skilled enough to undertake any job in the sector. Beyond these cities, rural communities are much less likely to compete for new employment and business opportunities in oil-related sectors. In this case, most community members in the study area lacked the skills to undertake oil and gas sector jobs. The FGD showed that most workers employed were expatriates or were from outside the region. However, a few indigenes were employed because they were relatives of influential people in the municipalities, such as high government officials, politicians, chiefs, or opinion leaders. The findings corroborate Masum et al.'s [45] study on the impact of political-based recruitment on public work performance in Bangladesh, which alluded that political and social power persistently give an advantage to the privileged in society and serve as major barriers to sustainable growth and poverty reduction.

It is worth noting that coconut production, the primary source of livelihood, was affected by the deadly CSPWD in the study area. As a result, many community members between 36 and 55 years of age, primarily women, go into other food crop production and rubber plantations as a livelihood. According to Pegram et al. [44], inadequate educational attainment and access to livelihood opportunities have made it difficult for young people to secure jobs. A low level of educational attainment was confirmed in the study since only 1.8 % attained a tertiary level of education. Those with primary education composed the majority (47.5 %), followed by those with junior high school (JHS) education, representing 25.7 %. Respondents without formal education formed third (21.5 %), and senior high school (SHS) represented 3.5 %. These findings were confirmed by Pegram et al. [44], who reported that low education and lack of skills in any vocation negatively affect access to oil and gas-related jobs in oil production communities. Hence, the low educational attainment in the study area made job acquisition challenging.

Considering the low educational background of the study population, it is worth recommending that using a more localised approach to advocate for wetland policy or bylaws is essential. Similarly, Botchway [46] reported a localised advocacy platform to advocate for biological diversity and ecological protection laws and policies in Ghana. Advocacy and community support could help protect the wetland for alternative livelihoods following the impact of the CSPWD on coconut yield. The solution to the impact of CSPWD on coconut yield could be achieved through awareness creation of the use of improved hybrid coconut varieties developed by the Oil Palm Research Institute of the Council for Scientific and Industrial Research of Ghana. The improved coconut varieties are early bearing, have high nut yields, are resistant to CSPWD, and can help protect the livelihoods of coconut farmers and sustain the coconut industry. To help ameliorate unemployment challenges, oil production companies (the Jubilee partners—Tullow, Anadarko, GNPC, PetroSA, and Kosmos Energy) employed corporate social responsibility (CSR) interventions to alleviate poverty. These interventions included community livelihood support projects involving cassava, orange-fleshed sweet potato, and vegetable production. The interventions in crop production were influenced by the high demand and ready market for vegetables by the oil and gas companies. This has pushed many young people to farm near water sources, further exacerbating the impact of LULC on the Amanzule wetland. Farming is usually performed close to the wetland because farmers depend on it for irrigation. This action continuously pressures the

Amanzule wetland and nearby lands, contributing to land-use change.

Rubber plantations are also gaining ground among the cash crops farmed in the study area due to their security and ready market. Ghana Rubber Estate Ltd. and other private individuals usually buy the raw material (rubber latex) across the study area, making it a major cash crop, replacing oil palm and cocoa. The cost of a tonnage of rubber latex was between GHS2,200-3500 (equivalent to USD $200–300), and the pricing varied depending on the season. The price could be between USD 300–400 during the dry season. The compensation per rubber tree was valued at GHS 290–320 (USD 25.89–28.26), depending on the tree's age. This makes rubber plantations the most secure industrial tree compared to oil palm, cocoa, and other crops with no tree compensation. These development events in the Ellembele and Jomoro municipalities cause LULC, as Sarfo et al. [47] confirmed in a similar study in southwestern Ghana.

4.1.2. Built-up areas/urbanisation

Over the years, the study area has experienced steady population growth. The results revealed that in the next 36 years, built-up areas will drive various land-use decisions across the study area due to population growth. Ellembelle municipality was separated from the Nzema East District in 2007. The 2000 Population and Housing Census [48] recorded 116,435 for both districts, with a population density of 65.1 persons per km^2. After the separation, the 2010 Population and Housing Census [49] recorded 87,501 inhabitants for the newly created Ellembelle alone, with a population density of 88 persons per km^2. According to the 2020 Population and Housing Census [50], the Ellembelle population increased to 120,893 from 87,501 in 2010, with a population density of 131 persons per km^2. Similarly, the population of Jomoro district steadily increased from 111,348 in 2000 to 150,107 in 2010, with a population density of 82.8 persons per km^2 from 2000 to 103 persons per km^2 in 2010 [48,49]. Unfortunately, the municipality witnessed a decline in population from 150,107 in 2010 to 126,576 in 2020 [50]. This decline could be attributed to the migration of the youth to Ellembele in search of jobs in the oil and gas industry and other potential businesses connected to the sustenance of the industry. This increase in population in Ellembele has put pressure on existing natural resources due to increased infrastructure development. Similarly, Mohammed et al. [51] argued that population density is an essential source of many human activities, which cause LULC in the semiarid and arid regions of Algeria.

The information gathered from experts interviewed and the literature shows that migration for job opportunities in the oil and gas industry and related companies are the main drivers of population growth that have led to changes in land-use patterns. Although Jomoro experienced a declining population in 2020, the study revealed a massive land-use change in the municipality since Jomoro was adjoining Ellembelle. Kuta [52] confirmed a sudden decline in arable land in surrounding cities and adjoining towns in the Niger Delta immediately after news about oil discovery became available to the public in Nigeria. The findings of this study in Ghana are not different, as investors secured vast arable lands from the two municipalities immediately after the oil discovery, altering the land use dynamics of the area. Kleemann et al. [53] confirmed that migration to the study area increases the demand for settlement for industrial employees and workers, leading to competition between residential and agricultural land use. The situation is exacerbated by oil and gas activities in the area, as large land covers are cleared to make way for investment in oil and gas infrastructure onshore. As argued by Wang et al. [12], oil and gas activities can attract considerable investment and development, but they can cause destruction to natural resources when poorly managed. The incursion of built-up areas resulting from population growth due to oil discovery and production affects LULC.

The study area, particularly the Ellembelle and Jomoro municipalities, has experienced numerous oil development activities since 2007. The oil and gas companies (e.g., Tullow Oil Ghana, ENI, and Ghana Gas) have been the driving force behind many land use activities in the region [54]. These land-use activities include infrastructure development, such as roads, gas pipeline construction, warehouses, and offices. The Intergovernmental Panel on Climate Change (IPCC) [55] reported that human-induced drivers (e.g., developing large-scale pipeline projects) create LULC. These increases and advancements in built-up areas significantly threaten mangrove ecosystems in the Amanzule wetland and contribute to land-use change. Ellembelle municipality, where most oil and gas companies were located, had 154 km of highways, of which 63.9 km, representing 41.5 %, were tarred [56]. These tarred roads were constructed by the Ghana Gas Company and other oil and gas companies to facilitate their activities. These infrastructure developments adversely impacted the Amanzule wetland, as bridges were constructed to move extractive products from the gas field (Atuabo Gas field). Large hectares of the Amanzule wetland in some communities were destroyed (e.g., Allabokazo, Atuabo-Asem Nda, and Sanzule).

4.1.3. Weak enforcement of the Land Use and Spatial Planning Act 2016 (Act 925)

The results show that the weak enforcement of the Land Use and Spatial Planning Act of 2016 (Act 925) contributed to land-use change. Although the Ellembelle and Jomoro municipalities have a spatial development framework (SDF) developed from 2011 to 2030 to streamline and harmonise land use to foster socioeconomic development, traditional authorities and landowners continue to drive land use decisions in these municipalities. The SDF was designed to take advantage of the opportunities offered by the oil and gas industry and take steps to mitigate the negative impacts associated with the influx of people into municipalities. However, the framework faces some challenges, such as weak enforcement of the SDF as traditional authorities continuously sell land [57]. Even though the lands are originally stool/customary lands and are under the custody of chiefs or traditional authorities, any initiative by chiefs to lease or sell land should be taken with the consent of the Land Use and Spatial Planning Authority (LUSPA). The consent of the LUSPA is needed to allow physical planning decisions as required by law to promote the sustainable development of human settlements based on the efficiency, order, security, and healthy growth of local communities. Unfortunately, traditional authorities engage in the sale/lease of lands without consulting the LUSPA for necessary planning decisions and disregarding the SDF. The influx of foreign and local investors into the municipalities to compete for agricultural lands for non-agricultural uses exacerbated the situation, leading to mixed land uses. Some traditional authorities trigger increasing land sales by increasing land valuation due to the presence of the oil and gas industry and associated value chain activities. Unfortunately, the constitution does not specify how traditional authorities should manage customary lands, worsening uncontrolled land sales. This has resulted in disagreements between the municipal assemblies and some traditional authorities.

Some indigenous and migrant farmers have witnessed evictions from their agricultural lands leased by traditional authorities for a better deal from the oil and gas value chain companies for non-agricultural use. This has deepened poverty because of the displacement of many smallholder farmers in the municipalities. As an alternative source of livelihood, the municipal assemblies have outlined in their SDF (2011–2030) a plan to generate revenue from tourism by exploiting forest resources and the Amanzule Wetland to reduce poverty in the communities. In reviewing the SDF document, the municipalities plan to exploit the full potential of the Amanzule wetland through ecotourism to create job opportunities for the youth. This includes the promotion of co-museums to support indigenous people through profit sharing. Regrettably, the environment is confronted with deforestation, originating from land-use change activities from oil and onshore gas facilities, timber companies, illegal chain saw operators, and mining and quarrying companies.

Conflict

Conflict is one of the drivers of land-use change impacting the Amanzule wetland. It arises from clashes between individuals with different thought processes, attitudes, understanding, interests, requirements, and perceptions [58]. This is triggered by the common exploitation of the Amanzule wetland resources, resulting in conflicts among various interested parties. Interested parties overexploit resources such as sedges, raffia, periwinkles, and other forest resources. Therefore, as a biodiversified wetland ecosystem, exploitation by one party has unforeseen impacts on other sectors, mainly resulting in scuffles. The ensuing conflict leads to the burning of resources, predominantly sedges and raffia, in some communities, resulting in land degradation and land-use change. Conflicts arising from resource exploitation have been a challenge for several decades. Since 1950, more than 80 % of conflicts have occurred in biodiversity hotspots worldwide, with adverse consequences for biodiversity and society. The sale of land by traditional authorities around the Amanzule wetland usually conflicts with community members who depend on it for their livelihoods, leading to the abandonment of the land for years and causing a change in the landscape. This corroborates the findings of Carrero et al. [59] that local conflicts are the leading causes of deforestation in the Brazilian Amazon Forest. Baumann and Kuemmerle [60] also reported that land abandonment following conflicts was one of the causes of land use change in the Caucasus, Columbia, Nicaragua, Bosnia, and Sri Lanka. In the Caucasus, Baumann & Kuemmerle [60] reported that approximately 30 % of abandoned agricultural land in conflict zones was replaced by new agricultural activity and that only 17 % of abandoned land was recultivated after the end of the conflict. This shows that conflicts could cause long-lasting changes in land use.

4.1.4. Study limitations

Although the scope of the study is limited to two municipalities, the results demonstrate the need for advocacy at the national and subnational levels for wetland policy dialogue to address the challenges facing wetlands and their implications for the economy. This is aimed at increasing awareness of the impact of human activities on wetlands to promote sustainability and environmental stewardship. Similar studies on land use change could be expanded across other wetland communities in Ghana and within the ECOWAS subregion (e.g., Cote d'Ivoire) to provide a broader perspective of land use dynamics and its implications.

5. Conclusion

Generally, this study shows that land-use changes around the Amanzule wetland are driven by food crop farming, built-up or urbanisation, rubber plantations, and weak enforcement of the Land Use and Spatial Planning Act 2016 (Act 925). These drivers contributed 86.5 % of the observed land use change in the area, as indicated by the coefficient of determination (R^2). These drivers are expected to cause changes to the various classes of land use in the future. The study results further show that the area of the Amanzule Wetland is expected to decrease from 272.34 ha in 2018 to 210.60 ha by 2036, representing a reduction of 0.18 %. By 2054, this area is expected to further decrease by 0.11 %, from 210.60 ha to 174.33 ha. The mangrove forest ecosystem, which is associated with the wetland, is also expected to decrease from 425.97 to 323.01 ha between 2018 and 2036, representing a reduction of 0.30 %. It is further expected to decrease from 323.01 to 244.53 ha from 2036 to 2054, representing a reduction of 0.23 %. Swamp forests are expected to persistently decrease from 2018 to 2036 and further decrease between 2036 and 2054, decreasing the tourism and carbon storage potentials of the Amanzule wetland due to the expansion of built-up areas. Built-up areas are expected to lead to land use changes between 2036 and 2054. The probabilities of the wetland/water bodies changing to built-up areas were 0.14 and 0.18 for 2018–2036 and 2036–2054, respectively. Changes in waterbodies to built-up areas will affect fishing and other provisional ecosystem services. The probability of change in the wetland to crop production could be high (0.155) between 2036 and 2054. This projection could threaten the wetland, which serves as a carbon sink and provides other essential ecosystem services. Even though rubber plantations were not a source of livelihood between 1986 and 2000, they are expected to displace food crop production between 2018 and 2036. Between 2036 and 2054, rubber plantations will be the third driving force of land use change in the study area, which could alter biodiversity composition due to monocropping. Other land use classes, such as shrubland and grasslands/sedges, are also expected to decrease between 2018 and 2036, and grasslands are expected to further decrease between 2036 and 2054. The study further revealed that land for food crops is expected to decline between 2036 and 2054 and could negatively impact food security. Even though cropland is expected to increase from 6752.25 ha to 9899.10 ha (2018–2036), this increase has implications for the Amanzule wetland, such as the wetland conversion for agriculture purposes and possible pollution from its production activities and effects on ecosystem services. The study revealed a decrease in coconut plantations attributed to CSPWD, which may cause food insecurity and could be exacerbated by climate change. Therefore, broader stakeholder consultation is imperative to address these challenges. Considering the aforementioned findings, this study draws on the following recommendations: advocating for a dedicated wetland policy in Ghana to protect the Amanzule wetland from further encroachment to conserve biodiversity and sustain carbon storage and the provision of other vital ecosystem services; the enforcement and promulgation of the Land Use and Spatial Planning Act 925 (Act, 2016) to ensure that lands designated for various land uses are strictly adhered to; and the Petroleum Exploration and Production Act 919 (Act, 2016), which, among others, is intended to explore petroleum production and ensure conservation and environmental stewardship. Concerning the decline in coconut plantations, awareness should be created about the use of improved coconut varieties developed by the Oil Palm Research Institute of the Council for Scientific and Industrial Research (CSIR) of Ghana. To help ensure the improvement of biodiversity within rubber plantations, it is recommended that there should be a policy that seeks to integrate other crops within the plantations at the early stage of growth.

6. Summary of the main findings

- The study revealed that food crop farming, built-up areas/urbanisation, rubber plantations, poor enforcement of land use plans, and conflict were the significant drivers of land use change in the study area between 1986 and 2018.
- In the next 36 years (2018–2054), it is expected that built-up areas/urbanisation, food crop farming, rubber plantations, and shrubland will drive land-use change in the study area.
- The drivers of land use change will persistently reduce the Amanzule wetland area from 2018 through 2054, which will negatively impact mangrove and swamp forests and essential ecosystem services.
- The study shows that locals and visitors have a high perception that land-use change negatively affects tourism.

Ethics declaration

Ethical approval for this research was granted by the Ethics Committee of the University of Ghana. The study was conducted following the relevant guidelines and regulations. All participants, including the authors, consented to participate in this study. All authors consented to publish this research in the Heliyon Journal.

Data availability statement

The data supporting this study's findings are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Francis Adarkwah: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stephen Awuni:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Miroslav Hajek:** Writing – review & editing, Validation, Supervision, Resources, Methodology. **Daniel Kübler:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Memuna Mattah:** Writing – review & editing, Project administration, Investigation, Formal analysis. **Christopher Gordon:** Writing – review & editing, Supervision. **Erasmus H. Owusu:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36635.

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