Two Decades of Land Use and Land Cover Dynamics: Assessing the Ecological Status of the Sakumono Ramsar Site, Ghana

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Abstract

The ecological status of the Sakumono Ramsar Site in Ghana has been significantly affected by rapid urbanization and land-use transformation over the past two decades. This study analyzes the patterns and trends in Land Use Land Cover (LULC) changes across the years 2000 to 2023, focusing on four main habitat types: Built-up, Floodplain, Vegetation, and Water. Using Landsat imagery and GIS tools, LULC changes were quantified through a supervised classification approach, validated with an accuracy assessment yielding overall accuracies of 89.13% (2000), 97.5% (2010), and 100% (2023). Further ecological analysis was conducted using the Normalized Difference Vegetation Index (NDVI) and Modified Normalized Difference Water Index (MNDWI). The results indicate that the Built-up area increased dramatically from 1.06% in 2000 to 45.26% in 2023, largely due to urban expansion from nearby Accra and Tema municipalities. Concurrently, Floodplain areas decreased from 82.22% to 21.72%, Water areas dropped from 5.62% to 2.02%, and Vegetation areas increased from 11.10% to 30.99%. These substantial changes severely compromise wetland functions. Despite national and international frameworks like the Ramsar Convention, enforcement has been minimal, and community-based initiatives have struggled with sustainability. This study underscores the urgency for active community involvement and robust stakeholder collaboration to preserve the Sakumono Ramsar Site's ecological health, highlighting the urgent need for sustainable mitigation efforts for the adverse impacts of urbanization and restore the ecological integrity of this crucial wetland ecosystem.

Keywords: Sakumono Ramsar Site, Land Use Land Cover, Ecological health, Sustainability

Introduction

Wetlands are invaluable for their ecological services, including water purification, flood control, and habitat provision for diverse species (e.g., Jisha and Puthur, 2021; Nayak and Bhushan, 2022). However, they are increasingly threatened by human activities such as urbanization, agriculture, and infrastructural development (Xu et al., 2019; Ballut-Dajud et al., 2022).

The expansion of urban areas leads to the conversion of wetlands into residential, commercial, and industrial zones. This process disrupts the natural hydrology, reduces water quality, and leads to habitat loss. For instance, Alikhani et al. (2021) highlight that urbanization reduces wetlands' hydrological functions and introduces pollutants, degrading these ecosystems. Agricultural expansion is known to be a significant driver of wetland loss globally. It often involves the drainage of wetlands to create arable land (Gardner and Finlayson, 2018). This leads to the direct loss of wetland areas and introduces pesticides and fertilizers into the water systems, causing eutrophication and loss of biodiversity. The construction of roads, dams, and other infrastructure can fragment wetland habitats and alter water flow patterns. This can lead to changes in sedimentation rates and water levels, which are critical for the survival of wetland species. Danso et al. (2021), for example, discussed how infrastructural development in the Greater Accra Metropolitan Area of Ghana has led to significant wetland degradation.

The Ramsar Convention has defined the ecological character of wetlands as a combination of ecosystem components, processes, and benefits or services that characterize the wetland at a given point in time (Hale and Butcher, 2011). The importance of wetlands is strongly linked to their key ecological characteristics, such as hydrology (the patterns of water flow, flooding regimes, and water quality), geomorphology (the physical landforms and features of the wetland, such as channels, floodplains, and basins), soil composition, vegetation, and biodiversity (Mitsch and Gosselink, 2015). Wetlands are defined by the presence of surficial water, for varying periods (e.g., Bullock and Acreman, 2023). This influences the types of plants and animals that can thrive in such an environment. Channels in wetlands significantly influence water flow and play a vital role in transporting sediments and nutrients, which are essential for maintaining the ecological balance of wetlands (Semeniuk and Semeniuk, 2016). Floodplains act as natural buffers, absorbing excess water during floods and releasing it slowly, which helps in flood control and groundwater recharge (Kundu, 2020), while wetland basins are critical for providing habitats for aquatic species and supporting various hydrological processes (Semeniuk and Semeniuk, 2016). Wetland soils are typically saturated with water, leading to low oxygen conditions and high organic matter content due to slow decomposition rates (e.g., Reddy et al., 2022).

These conditions allow wetlands to be incredibly biodiverse, supporting and providing habitat for a wide range of species, including birds, fish, amphibians, invertebrates, and hydrophytic plants, such as reeds, sedges, and mangroves (Cronk and Fennessy, 2016; Wu et al., 2021; Song et al., 2024). Wetlands often serve as breeding and nursery grounds for many species. Wetlands act as natural filters, trapping pollutants, sediments, and nutrients from runoff before they reach open water bodies. This helps maintain water quality and protects downstream ecosystems. By absorbing and storing excess rainfall, wetlands also mitigate the impacts of floods (e.g., Bullock and Acreman, 2023). Wetlands store large amounts of carbon in their plant biomass and soils, playing a crucial role in regulating the global climate. They help mitigate climate change by sequestering carbon dioxide from the atmosphere (Moomaw et al., 2018; Were et al., 2019).

The studies of wetlands in Ghana have mainly focused on understanding and managing the impact of human activities by examining the drivers and implications of Land Use and Land Cover (LULC) change on these valuable wetlands (Asmah et al., 2008; Gell et al., 2016; Lamsal et al., 2019; Ekumah et al., 2020; Baidoo and Obeng, 2023; Adarkwah et al., 2024). For example, Asmah et al. (2008) reveal the serious threats faced by these sites due to pollution from both urban and agricultural waste, leading to a decline in water quality between 1997 and 2002. Baidoo et al. (2023) also assessed the implications of LULC changes on biodiversity in the Owabi Ramsar site. Their findings reveal a decline in plant and animal species due to the disappearance of high-density forests and the expansion of Built-up areas. Adarkwah et al. (2024) investigated the drivers of LULC change in the Amanzule wetland, highlighting the negative impacts of increasing infrastructural development, mining, agricultural expansion, and oil and gas facilities on essential ecosystem services provided by the wetland. These studies have primarily explored the effects of human activities on wetland ecosystems in Ghana, often to the neglect of a comprehensive examination of the ecological character of the sites, which is crucial for setting effective conservation and management goals.

The Sakumono wetland, a coastal wetland in the Greater Accra Region of Ghana and a designated Ramsar site, is a critical wetland ecosystem in Ghana (Ramsar Convention Secretariat, 2024). It is the third most important habitat for over sixty (60) migratory shorebird species on the coast of Ghana, including six (6) internationally important ones. The lagoon also functions as a nursery for commercially important fish species, making it crucial for both biodiversity and fisheries. It has, however, been experiencing significant LULC changes over recent years (Danso et al., 2021). These changes have profound implications for the ecological balance, biodiversity, and sustainability of the site (e.g., Ekumah et al., 2020). Its proximity to two rapidly growing urban centers, Accra, the capital city of Ghana, and the Tema industrial municipality, makes it a key focus area for environmental and land use research, especially the impacts of urbanization and human activities on wetland ecosystems. Ekumah et al. (2020), in their study on four Ramsar sites in Ghana, including the Sakumono Ramsar Site, revealed accelerating transformation processes in LULC, with urbanization as the major driver, but very little or no mention of the ecological character of the site. Understanding the dynamics of LULC changes as well as the ecological character and status of a wetland is crucial for formulating effective conservation strategies (e.g., Assefa et al., 2021; Siddique et al., 2024). The conservation and preservation of wetlands are crucial for maintaining their ecological functions and the services they provide to both nature and humans.

This study, therefore, aims to assess the ecological status of the Sakumono Ramsar Site in Ghana based on two decades of LULC dynamics. The study will quantify the LULC changes in the Sakumono Ramsar Site, determine the threats and drivers influencing the changes, assess the effect of these changes on the ecological status of the Ramsar site, and make recommendations for mitigation, better management, and sustainability of the Ramsar site. The findings of this study will provide valuable insights into the specific factors driving LULC changes in the Sakumono Ramsar Site and their ecological impacts.

Study area

The Sakumono Ramsar Site is located in the coastal plains of the Greater Accra Region of Ghana, situated between the coordinates 5°35′ N and 0°03′ W (Fig. 1). It spans approximately 13.64 square kilometers and

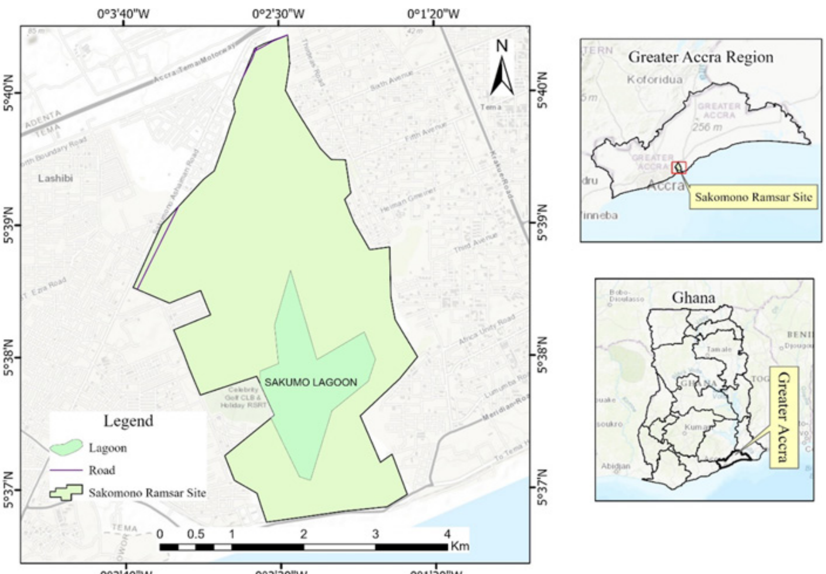

Fig. 1 The Sakumono Ramsar Site

consists of a coastal brackish-saline lagoon (the Sakumono lagoon) and surrounding floodplains, freshwater marshes, coastal savannah grasslands with thicket vegetation, and a narrow dune linking them to the sea (Ramsar Convention Secretariat, 2024). The site is bordered to the north and east by the urban municipalities of Tema and Ashaiman, which form one of Ghana's largest industrial cities. It is bordered to the west by the urban settlements of Spintex and Nungua, and to the south by the Atlantic Ocean. This coastal boundary provides a natural edge, where tidal influences affect the water levels in the Sakumono lagoon. The Sakumono community (a growing residential area) is located to the southwest of the Sakumono Ramsar Site near the coastline.

The Sakumono Ramsar Site has ecological, environmental, and socio-economic importance. It supports over 70 species of waterbirds, with an estimated 30,000 individual birds relying on its resources during migration and breeding seasons. It is also home to important marine and freshwater fish species. The wetland also provides crucial services like flood control, storm regulation, water purification, and salinity regulation. Human activities currently ongoing within the Ramsar site include farming, fishing, recreation, and urban and industrial development, including salt production.

Methods

Landsat images acquired from the freely accessible data portal of the United States Geological Survey (USGS, http://earthexplorer.usgs.gov/) were used to analyze the Land Use and Land Cover (LULC) changes within the Sakumono Ramsar Site over a period of two decades, from 2000 to 2013 and 2013 to 2023. The data description is outlined in Table 1. A systematic approach involving data collection, processing, classification, and change detection analysis was employed and is outlined in Fig. 2.

TABLE 1
Details of Satellite Images used in this study

Satellite Data	Acquisition Date	Sensor	Spatial Resolution	Collection Level	Tier
Landsat 7	04/02/2000	ETM+	30 meters	C2L2	1
Landsat 8	01/04/2013	OLI	30 meters	C2L2	1
Landsat 9	01/02/2023	OLI-2	30 meters	C2L2	1

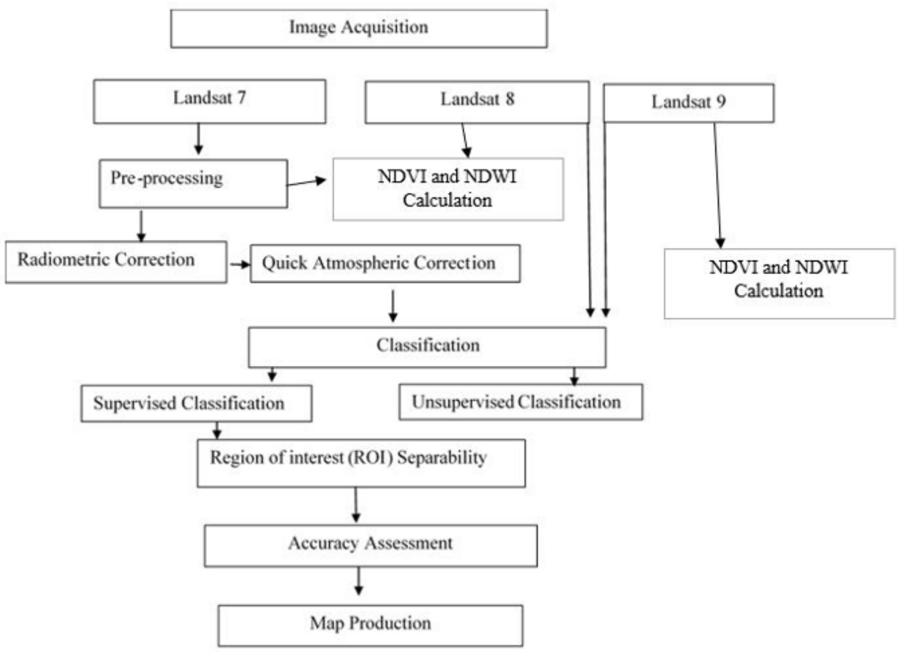

Fig. 2 Methodological Framework

The data processing and analysis tools used in this study include ENVI 5.3, ArcGIS Pro 3.3 software, and the Google Earth Pro application. The ENVI software was used for the pre-processing of satellite images and the classification of the various land uses. Pre-processing of the satellite images included radiometric calibration, atmospheric correction, and image enhancement to remove all atmospheric distortion from the images and enhance the quality for easy classification. Cloud masking was applied with a threshold allowing 10% cloud cover when downloading the Landsat 7 image. To minimize the influence of these clouds, Quick Atmospheric Correction (QUAC) was performed on the Landsat 7 imagery. Landsat 8 and 9 images were not atmospherically corrected, as the sensor already provides surface reflectance products with in-built atmospheric correction. Landsat 8 and 9 imageries (through the USGS / NASA processing chains) are typically provided as Level-2 Surface Reflectance (SR) products, which have already been atmospherically corrected. Landsat 7, with its ETM+ sensor, historically was more often delivered in less processed forms, requiring users to apply atmospheric correction. ArcGIS was used to generate the LULC, Normalized Difference Vegetation Index (NDVI), and Modified Normalized Difference Water Index (MNDWI) maps, and to carry out change detection analysis. Google Earth was used for ground-truthing (accuracy assessment).

Image Classification

A combination of both a supervised and unsupervised approach was used for image classification in this study. The initial unsupervised approach was used to help generate training samples for the subsequent supervised classification.

Up to twenty-five (25) training samples were generated per LULC class using the ENVI 5.3 software. This approach classifies satellite image pixels based on their likelihood of belonging to a given land use and land cover class. The approach requires equal probability for all the classes and a normal distribution across all input bands. False-color composite maps were created using input bands 4, 3, and 2 for the Landsat 7 ETM+, and bands 5, 4, and 3 for Landsat 8 OLI.

The spectral signature of each image pixel was then compared to the training samples and satellite images to identify and classify image features based on their representation on the ground or Earth's surface. This enabled the effective classification of four (4) LULC classes, including Built-up areas, Vegetation, Floodplains, and Water or Aquatic bodies, as described in Table 5. Also employed in this supervised approach was the Support Vector Machine Classifier (SVM), popular for its ease of use and training. The SVM used a Radial Basis Function (RBF) kernel with gamma = 0.250 and a penalty parameter (C) of 100.0; the classification probability threshold was set to 0.00. Google Earth Pro was used as a ground-truthing tool to create validation samples, which were then used for accuracy assessments to ensure that what was classified on the image was a true representation of itself on the ground. For each LULC class, 20-25 training samples were collected with a distinct independent set of samples per class. The validation sample counts were 46 for 2000,40 for 2010, and 40 for 2023. These points were selected by stratified random sampling across the four LULC classes, with the number of points per class roughly proportional to the mapped area and a minimum of three spatially distributed points per class. The Training samples were exported as ESRI shapefiles and overlaid on Google Earth imagery for visual verification. Polygon boundaries were resized where necessary to reduce overlap with the high-resolution imagery. The timestamp of each Google Earth image was checked and the image closest in date to the corresponding Landsat scene was used to mitigate potential temporal mismatch between Landsat scenes and Google Earth imagery.

Accuracy Assessment

An accuracy assessment was conducted to validate the reliability of the classification. It determined how well the mapped classes represented conditions on the ground by measuring the agreement of classified data with reference data ("ground truth") in the study area, based on high-resolution Google Earth images for the various years. The stratified random sampling technique was used to extract 40 sample points for each satellite image, based on which the generated LULC maps were compared. The classified images for all three (3) different years had four (4) land cover types. Therefore, 10 random samples were generated for each of the land cover classes, except for the Floodplain in the year 2000, for which 16 random samples were selected due to the difficulty in distinguishing it from water. From these, the confusion matrix was created for the three-year assessment. Metrics used included the overall accuracy, producer's accuracy, user's accuracy, and Kappa coefficient. The overall accuracy was

TABLE 2

Confusion matrix and per-class accuracy for 2000

Classified\ Reference	Water	Vegetation	Flood Plain	Built-up	Row total (User)
Water	7	1	2	0	10
Vegetation	0	10	0	0	10
Flood Plain	0	0	16	0	16
Built-up	0	0	2	8	10
Column total (Producer)	7	11	20	8	46
Producer accuracy: Water 100% (7/7), Vegetation 90.91% (10/11), Flood Plain 80.00% (16/20), Built-up 100% (8/8)					
User accuracy: Water 70.0% (7/10), Vegetation 100% (10/10), Flood Plain 100% (16/16), Built-up 80.0% (8/10).					
Overall accuracy = 41/46 = 89.13%. Kappa = 0.85					

TABLE 3

Confusion matrix and per-class accuracy for 2010

Classified\ Reference	Water	Vegetation	Flood Plain	Built-up	Row total (User)
Water	10	0	0	0	10
Vegetation	0	10	0	0	10
Flood Plain	0	0	10	0	10
Built-up	0	0	1	9	10
Column total (Producer)	10	10	11	9	40
Producer accuracy: Water 100% (10/10), Vegetation 100% (10/10), Flood Plain 90.91% (10/11), Built-up 100% (9/9)					
User accuracy: Water 100% (10/10), Vegetation 100% (10/10), Flood Plain 100% (10/10), Built-up 90% (9/10)					
Overall accuracy = 39/40 = 97.5%. Kappa = 0.933					

TABLE 4
Confusion matrix and per-class accuracy for 2023

Classified\ Reference	Water	Vegetation	Flood Plain	Built-up	Row total (User)
Water	10	0	0	0	10
Vegetation	0	10	0	0	10
Flood Plain	0	0	10	0	10
Built-up	0	0	0	10	10
Column total (Producer)	10	10	10	10	40
Producer accuracy: Water 100% (10/10), Vegetation 100% (10/10), Flood Plain 100% (10/10), Built-up 100% (10/10)					
User accuracy: Water 100% (10/10), Vegetation 100% (10/10), Flood Plain 100% (10/10), Built-up 100% (10/10)					
Overall accuracy = 40/40 = 100%. Kappa = 1.00					

determined by summing the diagonal of the matrix and dividing it by the total number of sampled points, and this was 89.13%, 97.5%, and 100% for the years 2000, 2010, and 2023, respectively. The Kappa coefficient derived accuracies of 0.85, 0.93, and 1, respectively (see Table 2).

Land Use Land Cover (LULC) Change Detection

To determine the geographical distribution of LULC and the dynamics of change (shape, extent, and spatial features) in the study area, ArcGIS Pro 3.3 was used to generate a change matrix that identifies quantifiable (statistical and graphical) changes in LULC types. The change detection analysis was used to identify various locations in the study area that transitioned from one LULC type to another during the specified period.

Results

Quantification of Land Use Land Cover (LULC) Changes

Land use and land cover (LULC) changes have been analyzed and quantified to understand the

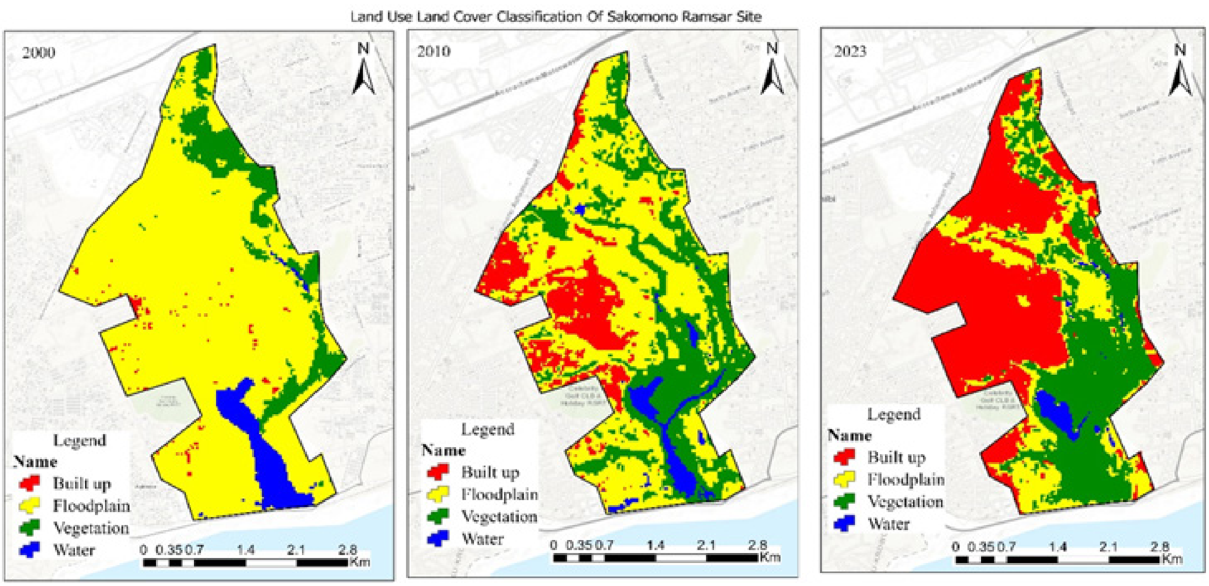

Fig. 3 LULC classification of the Sakumono Ramsar Site for the years 2000, 2010, and 2023

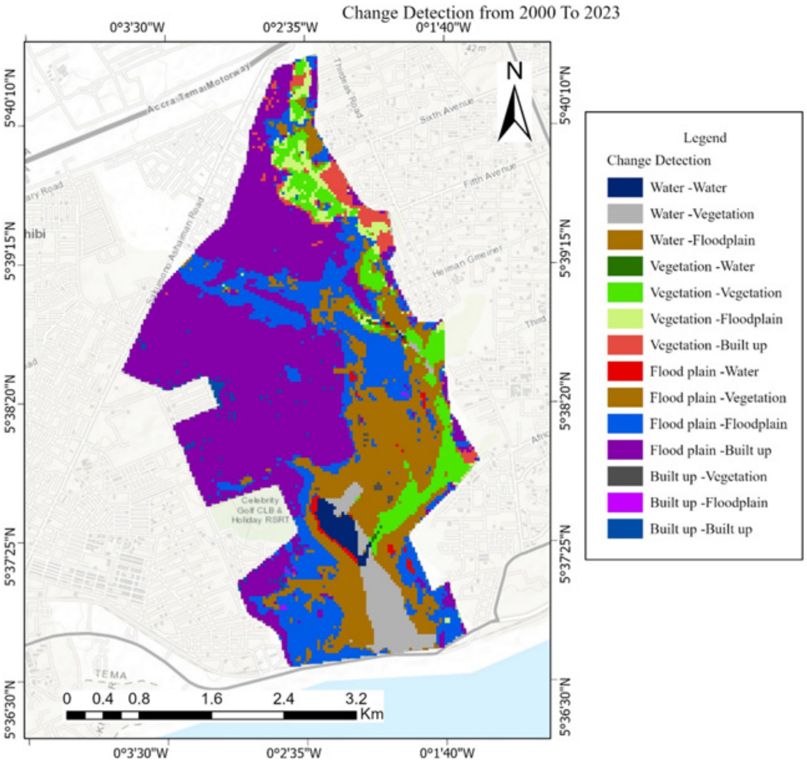

Fig. 4 Change Map of the Sakumono Ramsar Site from the year 2000 to 2023

patterns and trends in the Sakumono Ramsar Site, and the results are presented in Tables 3 and 4 and Figs. 3 and 4.

Table 3 shows the quantified values of LULC changes in the site for the years 2000, 2010, and 2023, based on the four (4) LULC class types: Built-up, Floodplains, Vegetation, and Water. It can be observed that, out of a total area of 13.62 km² occupied by the Sakumono Ramsar Site, the Built-up LULC type occupied the least area of 0.14 km² (1.06%) in 2000, followed by Water at 0.77 km² (5.62%), Vegetation at 1.51 km² (11.10%), while Floodplain occupied the largest area of 11.20 km² (82.22%). In 2010, the areas occupied by Built-up and Vegetation increased to 2.09 km² (15.34%) and 4.01 km² (29.45%), respectively, while the areas of Water and Floodplain reduced to 0.55 km² (4.02%) and 6.97 km² (51.19%), respectively. In 2023, the Built-up and Vegetation classes increased to occupy the largest areas of 6.17 km² (45.26%) and 4.22 km² (30.99%), respectively, while the Floodplain and Water classes experienced a continuous reduction in areas, with Floodplain shrinking to occupy an area of 2.96 km² (21.72%) and Water also shrinking to occupy an area of 0.28 km² (2.02%).

Figure 3 shows three (3) LULC classification maps generated for the years 2000, 2010, and 2023, respectively, based on the four (4) LULC class types: Built-up, Floodplains, Vegetation, and Water. In 2000, the Floodplain was seen to have occupied an extensive and continuous area from north to south and east to west of the Ramsar site, while Built-up covered much smaller areas scattered around the central and southwestern parts of the site. Water mostly occupied the area in the south-central portion of the site, and Vegetation occurred as a narrow strip along the eastern boundary of the site, extending from north to south. The 2010 map shows that the area occupied by the Floodplain has been reduced and fragmented,

TABLE 5
Land Use Land Cover (LULC) type description

	LULC type	Description
1	Built-up Areas	Areas that have undergone major changes due to the activities of humans and infrastructural development. These places are usually denoted by high-density structures, which include residential, commercial, industrial, and institutional buildings, among others.
2	Vegetation	Refers to the various forms of land cover that are dominated by natural or cultivated plant life. This category is usually made up of woods, grasslands, agricultural fields, and parks.
3	Flood plains	Refers to low-lying, flat areas of land adjacent to rivers, streams, or other water bodies that are subject to periodic flooding. These areas are formed and continuously reshaped by the natural processes of sediment deposition during flood events.
4	Water Bodies/Rivers	Refers to all surface water features, whether natural or man-made. This category includes rivers, lakes, ponds, reservoirs, and coastal waterways.

Source: Anderson et al. 1976

while the area of Built-up is sprawling over areas that used to be Floodplains, particularly on the western margin and parts of the central portions of the site. The area occupied by Vegetation has also expanded towards the western boundary of the site, covering previous areas of Floodplain and interspersed with Built-up areas. Water is seen to have shrunk and is now fragmented as well. From the 2023 map, the area occupied by Built-up has grown extensively compared to previous years and relative to the area occupied by Floodplains, which now appears fragmented in bits due to Built-up and Vegetation activities. The area of Vegetation is now prominent mainly in the south-central portions of the Ramsar site, which used to be covered by Water, and also along the eastern margin of the site. Water has drastically reduced to a small area in the south-central portion of the site.

Threats and Drivers of Change

The change detection technique was employed to compare differences among the three (3) classified images of the Sakumono Ramsar Site to track the transitions between different LULC type classes, providing insights into how land has been transformed over time and the drivers of such transformations. The results are presented in a transition matrix in Table 4 and on a change map in Fig. 4.

Table 4 shows the changes in the quantified area in square kilometers (km²) that transitioned from one LULC type class to another over the period under study (i.e., 2000–2023). From the change detection transition matrix, no area occupied by Built-up transitioned to Water, and vice versa. The Built-up and Vegetation classes retained more

TABLE 6
Land Use Land Cover (LULC) changes from 2000-2023

LULC Type	Area 2000 (km^2)	Area 2000 (%)	Area 2010 (km^2)	Area 2010 (%)	Area 2023 (km^2)	Area 2023 (%)
Built-up	0.14	1.06	2.09	15.34	6.17	45.26
Floodplain	11.20	82.22	6.97	51.19	2.96	21.72
Vegetation	1.51	11.10	4.01	29.45	4.22	30.99
Water	0.77	5.62	0.55	4.02	0.28	2.02
Total	**13.62**	**100**	**13.62**	**100**	**13.62**	**100**

TABLE 7
Transition Matrix from 2000-2023

LULC Type	Built-up km²	Floodplain km²	Vegetation km²	Water km²
Built-up	0.09 (75.62%)	0.01(5.44%)	0.02 (18.94%)	0.00 (0.0%)
Floodplain	5.75 (51.35%)	2.60 (23.22%)	2.77 (24.74%)	0.08 (0.69%)
Vegetation	0.29 (19.58%)	0.31 (20.85%)	0.88 (58.73%)	0.01 (0.84%)
Water	0.00 (0.0%)	0.02 (2.42%)	0.56 (74.01%)	0.18 (23.57%)

than 50% of their original areas, while less than 30% of the areas that were occupied by Floodplain and Water remained as such. The drastic reduction in the area occupied by the Floodplain class was due to about 51.35% of Floodplains being converted to Built-up and about 24.74% of the area of Floodplain being invaded by Vegetation. However, unlike the Floodplains, whose conversion was due to anthropogenic activities, the conversion of Water was primarily natural, with about 74.01% of the area of Water having been invaded by Vegetation, including cultivated areas and natural plant communities. Fig. 4 presents a map of the spatial patterns of these transitions.

Effect of these changes on the ecological status of the Sakumono Ramsar Site

To assess the ecological status of the Ramsar site, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were employed to analyze vegetation health and map water bodies, respectively. The results are shown in Fig. 5 and Fig. 6, respectively.

The NDVI values range from -1 to +1. Fig. 5 uses a color gradient scheme with higher values represented by yellow to green, indicating dense, healthy vegetation, and lower values represented by orange to red colors, indicating sparse vegetation or non-vegetative surfaces such as water bodies, bare land, or urban areas. For the year 2000, Fig. 5 reveals a predominance of low NDVI values (-0.17 to -0.3) across the site. This indicates sparse vegetation or significant areas of bare land and the presence of water on the land surface.

In 2010, however, the NDVI map shows

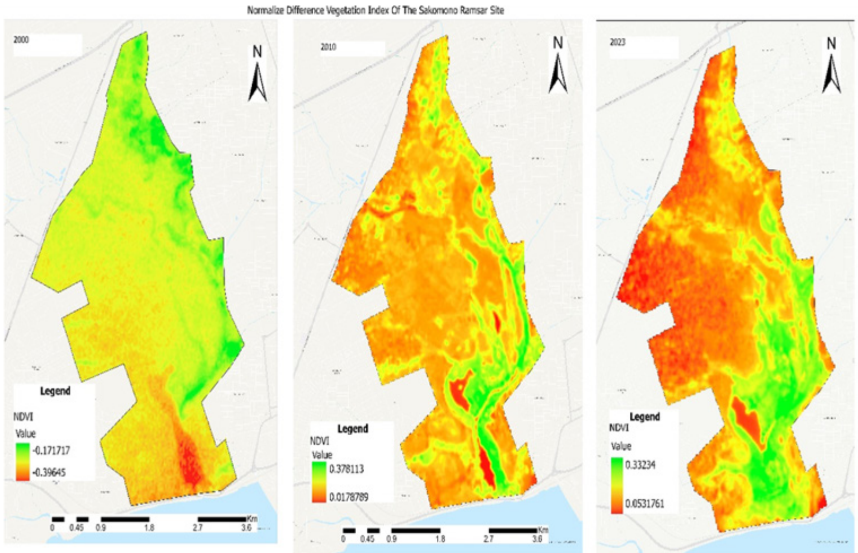

Fig. 5 Normalized Difference Vegetation Index (NDVI) of the Sakumono Ramsar Site for the years 2000, 2010, and 2023

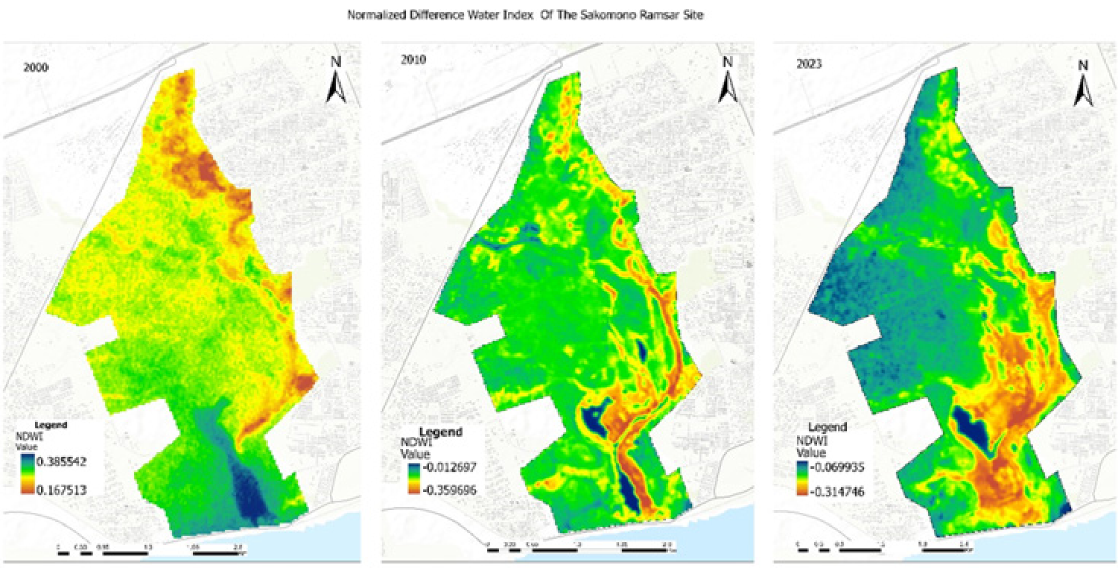

Fig. 6 Normalized Difference Water Index (NDWI) of the Sakumono Ramsar Site for the years 2000, 2010, and 2023

a significant increase in overall vegetation health and density compared to 2000, with values ranging from 0.017 to 0.378. In 2023, the area of Vegetation appears to have expanded compared to 2010, as indicated by values ranging from 0.053 to 0.332.

NDWI is a remote sensing index specifically designed to highlight water bodies, with higher NDWI values generally corresponding to open water surfaces. Fig. 6 uses a color scale ranging from blue to red, with blue representing high water abundance and red representing low water abundance or land. The map for the year 2000 shows a relatively high abundance of water within the site, indicating a larger extent of water bodies. The NDWI values are seen to have decreased in 2010 compared to 2000. There are fewer areas with high NDWI values, suggesting a reduction in the extent of open water bodies. This decrease in NDWI values can also be seen in 2023 compared to 2010. The NDWI map for 2000 reveals high moisture content, indicating a significant presence of water, particularly in the south-central portions of the study area, with values ranging from 0.167 to 0.385. The year 2010 shows a noticeable decrease in moisture content, with signs of water fragmentation and dried areas where there used to be moisture. The NDWI values now range from -0.0129 to 0.359. In 2023, NDWI values are generally negative and range from -0.314 to -0.069, indicating dried areas that used to be covered with water.

Discussion

The ecological status of wetlands has been defined based on a combination of the ecosystems' components, processes, as well as the services or benefits derived from the wetland (Hale and Butcher, 2011). Following Asmah et al. (2008), the Sakumono catchment comprises four main habitat types with distinct dominant vegetation: open lagoon (dominated by *Typha australis*), mangrove floodplains (dominated by *Avicennia africana*), freshwater marsh (90% dominated by the succulent forb *Sesuvium portulacastrum*), and coastal savanna grassland (characterized by *Paspalum vaginatum*, *Sesuvium portulacastrum*, and *Philoxerus vermicularis*).

Previous studies have revealed a significant shift in LULC within the Sakumono Ramsar Site in Ghana. Willoughby et al. (2001) revealed in their study that human-induced LULC categories grew at the expense of natural LULC categories, and such expansion could be threatening, particularly if uncontrolled. Ekumah et al. (2020) reported that, in 1985, marshes dominated the landscape, covering 9.1 km² or 63.6% of the total site area. However, by 2017, Built-up land had become the dominant LULC category, occupying 4.8 km² or 33.8% of the site. This trend of urbanization has continued, with Built-up land now covering approximately 45.26% of the total area, as seen from this study.

The hydrology of the Sakumono lagoon, defined as a brackish-water coastal wetland, is influenced by the Atlantic Ocean, the Weija Dam, rainfall, runoff, and other agricultural and domestic discharges. With the increasing trends of urbanization and environmental changes, the vulnerability of the Sakumono Ramsar Site has increased (Willoughby et al., 2001; Asmah et al., 2008; Kondra, 2016). While untreated sewage and solid waste have been discharged through open drains and sewage channels from domestic sources, pollutants from fitting mechanics and pesticides have been carried into the lagoon by rain and agricultural runoff. The result is siltation and overgrown weeds, as well as the presence of water hyacinth, according to Agbeti (2023), which is manifested in the reduction in the size of the Water area from the year 2000 (5.62%), through 2010 (4.02%), to 2023 (2.02%). These highlights explain the reason why about 74% of the area of Water was converted to Vegetation in the present study.

Rapid urbanization can be associated with the proximity of the two rapidly growing urban municipalities of Accra, the capital city of Ghana, and Tema, the largest industrial municipality in Ghana, to the Ramsar site. Ekumah et al. (2020) emphasized that the main livelihoods of the surrounding communities of the Ramsar site, including fishing, farming, and industrial activities, are contributing factors as well. The significant transition from natural land cover categories to Built-up areas in the Sakumono Ramsar Site indicates continuous growth of human settlements and infrastructure within the wetland ecosystem. Thus, urbanization is interpreted as the primary driver of these land-use changes, particularly for the expansion of Built-up areas, as found by Ekumah et al. (2020). As urban centers expand, the demand for land for housing, infrastructure, and other urban uses increases, leading to encroachment upon surrounding natural areas, including wetlands.

The reduction of the floodplain area from 82% in the year 2000 to 51% in 2010 and to 22% in 2023 implies a varied and significant impact on the ecosystem services provided by this important site. This reduction in floodplain extent can result in decreased inundation and altered seasonal water regimes, which can compromise the health and extent of crucial wetland vegetation, such as floodplain forests and marshes. This, in turn, directly impacts the habitat and survival of fauna that rely on these areas for feeding, breeding, and shelter (Hale and Butcher, 2011). Floodplain soils are significant sinks of organic carbon, so reduced floodplain area can lead to less carbon sequestration, which can jeopardize the crucial role it plays in supporting biodiversity and providing valuable ecosystem services. This can negatively impact floodplain productivity, affecting nutrient cycling, sediment deposition, and the overall health of the ecosystem (Gell et al., 2016). Such problems and others, including altered salinity, reduced fish populations, and increased health risks, have been reported by several authors in various contexts (Asmah et al., 2008; Kondra, 2016; Ekumah et al., 2020; Singh and Sinha, 2021; Agbeti, 2023).

Even though the LULC analysis portrays relatively positive changes in the area occupied by Vegetation, the results of the NDVI and NDWI indicate that not all four vegetation types existing within the Sakumono Ramsar Site are experiencing these positive changes. While the NDVI results for the year 2000 show healthy vegetation around the open lagoon, coastal savannah, and floodplain areas, the NDVI results for 2023 show relatively dry, fragmented, and unhealthy vegetation around these same areas. Furthermore, the northeastern portion of the site, occupied by freshwater marsh, appears both healthier (as indicated by NDVI) and more expanded and wetter (as indicated by NDWI) in 2023 compared to 2000.

These declines and changes in Water and Vegetation have been documented as having the potential to cause blackwater events, reduce carbon sequestration, disrupt breeding events, and lead to a loss of biodiversity (Hale and Butcher, 2011; Baidoo et al., 2023).

Conclusion

Overall, this study documents persistent degradation of the Sakumono Ramsar Site, with a marked decline in the extent and condition of wetland habitats between the study years. Although Ghana is party to international instruments including Ramsar Convention, Convention on Biological Diversity (CBD), and UNFCCC, and has national legislation relevant to wetland protection (Environmental Protection Act, Fisheries Act), enforcement has been weak, and past projects (e.g., the Ghana Coastal Wetland Management Project, CEPA) lacked long-term sustainability. Current management by the Wildlife Division faces political and community pressures and limited capacity, but new local restoration efforts (e.g., Lions Club initiative, 2023–2028) offer partnership opportunities. To halt and reverse degradation, the study recommends empowering local communities through formal community-based rules, incentives, and penalty mechanisms to encourage stewardship. Furthermore, strengthening the enforcement and institutional capacity of the Wildlife Division is paramount. Finally, securing sustained funding and multi-stakeholder partnerships for long-term restoration, monitoring, and adaptive management, and prioritizing community ownership combined with sustained support from government and partners will be essential to protect the ecological functions and services of the Sakumono wetland.

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