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REVIEW ARTICLE

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Mangrove ecosystems mapping in parts of Ghana and The Gambia for sustainable regeneration and utilization

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Abstract

This study was conducted in parts of Ghana and The Gambia using remote sensing and participatory geographic information system (PGIS) to map mangrove vegetation and associated land use land cover types. The selected sites support shellfishery activities, and mangrove loss threatens ecosystem functionality and local communities' livelihoods. The results revealed that mangroves are more fragmented and declining in Ghana sites, while in The Gambia, they are more extensive and stable, with a clear zonation of *Rhizophora* and *Avicennia* species. PGIS revealed that communities value mangrove species differently, informing the management systems. *Avicennia* species that were more abundant in Ghana sites were mainly used for livelihood activities such as fuelwood and the construction of fish traps. *Rhizophora* species that were more dominant in The Gambia sites have better oyster attachments due to their root systems and were more valued by the shellfishing communities. Triangulated results from remote sensing and PGIS established various drivers and threats to mangrove vegetation, including mangrove dieback, illegal harvesting, soil salinity, land use changes/conversion, waste dumping/pollution, and the effects of climate change. Lessons for sustainable mangrove area co-management included context-specific interventions based on livelihood needs, continuous community awareness, capacity development for effective mangrove restoration and conservation, and diversification of livelihood options. It is also crucial to develop the enabling environment through policies that strengthen co-management, local and national governance systems, and enforcement of existing policies. The study reiterated the value of integrated resource mapping and results validation with stakeholders who are either users or managers of these resources.

Keywords Coastal management, Remote sensing, Shellfisheries, Natural resources mapping, Mangroves, Participatory GIS, Land use land cover

1 Introduction

Mangroves are among the world's essential ecosystems, covering an estimated 14.8 million hectares (Mha) (FAO 2023), representing a linear coverage of 15 percent of the global coastline (Bunting et al. 2022). From a continental perspective, FAO (2023) estimates the mangroves cover at 8.59 Mha in Asia, 2.14 Mha in South America, 1.85 Mha in North America, 1.46 Mha in Oceania, and 0.73 Mha in Africa, with notable in-region variances of degradation, restoration, and species preferences. Further, the study concluded that Southeast Asia has the highest

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share of global mangrove cover (estimated at 44%), while Africa recorded the highest mangrove degradation and decline rates. Mangroves are present in about 123 countries, comprising over 73 mangrove species and hybrids (Numbere 2018). An estimated 75 percent of global mangroves are found in 15 countries (Giri et al. 2011), with only 7 percent of mangroves falling under protected areas for special conservation using different approaches (such as the IUCN Red List and Ramsar Convention). A study by Naidoo (2023) estimates that 20 percent of global mangroves are found in Africa and are more dominant on the West Coast (74%) compared to the East Coast (26%). Mangroves play critical livelihood and ecosystem service roles within and outside their areas of existence (Muthee et al. 2021). For example, Menéndez et al. (2020), value the flood protection services provided by mangroves at USD 65 billion annually, with 15 million more people cushioned against coastal flooding. Mangroves are also considered among the top carbon-capturing and storing ecosystems, with Choudhary et al. (2024) estimating that mangroves capture, transform, and store over four times the amount of carbon compared to terrestrial forests, contributing significantly to carbon mitigation. In addition, the decomposition of dead mangroves contributes to soil carbon accumulation for additional carbon storage.

The rates of mangrove degradation and decline remain high globally. Huber et al. (2023) estimate that over one million hectares were lost between 1990 and 2020, representing about 30 percent of the world's total. Dayal et al. (2022) establish that mangrove forests are diminishing 3 to 5 times faster than other types of forests. Although the rate of mangrove loss has declined in recent years (Arumugam et al. 2020; Lee et al. 2021), the continuing degradation and decline estimated at 21,200 ha annually (Huber et al. 2023) remains a significant challenge. These changes are associated with different context-specific drivers and threats. In Ghana and The Gambia, Duguma et al. (2022a) cite anthropogenic and natural factors as the main drivers of this change. Anthropogenic factors include urbanization, infrastructure development, salt mining, energy demand, housing demands, oyster harvesting, and aquacultural activities. Climate change and variability are the main natural factors driving mangrove degradation in the region (Harou et al. 2023). Increasing temperature and reducing precipitation patterns are associated with rising sea levels, increased atmospheric carbon, and changes in storm patterns (Ward et al. 2016), which consequently affect mangrove growth and regeneration directly or indirectly. To illustrate, mangroves are sensitive to salinity levels, increasing flood duration, and tidal range, which are all influenced by climate change (Santini et al. 2015). Ultimately, these changes lead to mangrove decline and death, as witnessed in different countries across West Africa.

Multiple approaches are recommended to promote protecting and restoring these vital ecosystems, such as adequately designing and enforcing protected area regulations to reduce encroachment. However, Diop et al. (2020) note that inadequate national and local structures to enhance such enforcement have led to mangrove loss and land use change in areas such as Densu in Ghana and Tanbi in The Gambia. In addition, most of the existing interventions are scientific, technological, and economic in nature (Muthee et al. 2022a), and largely inadequate in contextualizing the community and ecological needs and priorities (Dale et al. 2020). A study by Naidoo (2023) also recognized a lack of recent reviews of mangroves across Africa as a significant gap in mangrove restoration and conservation. This study sought to address some of these gaps by conducting mangrove mapping in parts of Ghana and The Gambia. It combined remote sensing and PGIS, bringing diverse stakeholders on board, including local communities, the private sector, research and academia, and policymakers.

2 Methods

2.1 Study sites

The study was conducted in four sites—Densu and Narkwa in Ghana and Tanbi and Bulock *bolong* in The Gambia, where the Women Shellfishers and Food Security project activities are being conducted (Women Shellfishers and Food Security Project, (2022). In the *Mandinka* language, a *bolong* (bolon) refers to a creek, tidal river, or a river tributary. The project was largely driven by the need to empower women and women groups in the sustainable management of mangrove resources, noting that traditionally they have faced bottlenecks such as disproportionate land ownership, gender perceptions, power dynamics, and social norms, as alluded to by Duguma et al. (2022b). The site selection criterion was adopted from Chuku et al. (2020) and CRC (2022). In summary, the sites selected had existing shellfishery activities driven mainly by women. Further, the mangroves and adjacent land have undergone various changes over time affecting the supported livelihoods and ecosystem functionality. The selected sites had existing baselines and a well-defined situational context from the project activities. To illustrate, Densu and Tanbi sites are urban areas, have existing shellfishery co-management plans with clear user rights, and have protected status as RAMSAR sites due to their international importance (RAMSAR 2025). In contrast, Narkwa and Bulock sites are rural areas with the potential for food crop cultivation; however, they have no documented co-management plans to guide the use of the resources.

In Ghana, the Densu Delta comprises open lagoons, dunes, saltpans, and fresh water. Scattered stands of mangroves are present in some areas around the lagoons, dominated by the white mangroves (*Avicennia germinans*), red mangroves (*Rhizophora racemosa*), and least prevalent black mangroves (*Laguncularia racemosa*) (Nunoo and Agyekumhene 2022). In Narkwa Lagoon, signs of mangrove degradation attributed to human and natural activities are evident. The lagoon plays an essential role in supporting livelihoods (including food production, salt mining, and shellfishing activities) and ecosystem functioning (such as erosion control, fish breeding and habitat, and biodiversity conservation) (Chuku et al. 2020; Duguma et al. 2022c). In The Gambia, the Tanbi wetlands complex is rich with mangrove species, including *Rhizophora mangle, R. harrisoni, R. racemosa, Avicennia africana, Laguncularia racemosa, Annona glabra,* and West Indian Alder (*Conocarpus erectus)* covering about 80% of the complex (RAMSAR 2007). On the other hand, the Bulock site has no protection status, but the mangrove forests are relatively healthy and stable, with sporadic diebacks attributed mainly to natural factors (Chuku et al. 2020; Duguma et al. 2022c). Figures 1 and 2 portray the study sites in Ghana and The Gambia, while a summary of the attributes of the four sites is presented in Table 1.

2.2 Mapping approaches

The study site mapping approach combined remote sensing and PGIS, involving different site-specific actors in shellfishery work for ground truthing. The first step involved the acquisition of satellite images from Landsat for detailed analysis to delineate different Land Use and Land Cover (LULC) types and changes between 2002–2022. The Continuous Change Detection and Classification (CCDC) algorithm by Zhu and Woodcock (2014) was used to reconstruct gap-free time series maps within the study period. CCDC was appropriate for studying remote sensing and data filing where gaps existed due to among others the cloud cover in the region. The algorithm adopts automatic LULC detection over time from a single classifier. Remotely sensed data was extracted from the Landsat 8 Operational Land Imager (OLI) sensor using different spectral bands, including blue, green, red, visible and near-infrared (NIR), and Shortwave infrared (SWIR 1 and 2) at a spatial resolution of 30 m. FAO (2007) and the international geosphere-biosphere program (FRA 2000) classifications were used to identify different land uses and land cover types within the study areas. Each class was further validated using the producer's and user's accuracies to test their reliability (Congalton and Green 2008). These metrics are essential in helping to identify areas for improvement.

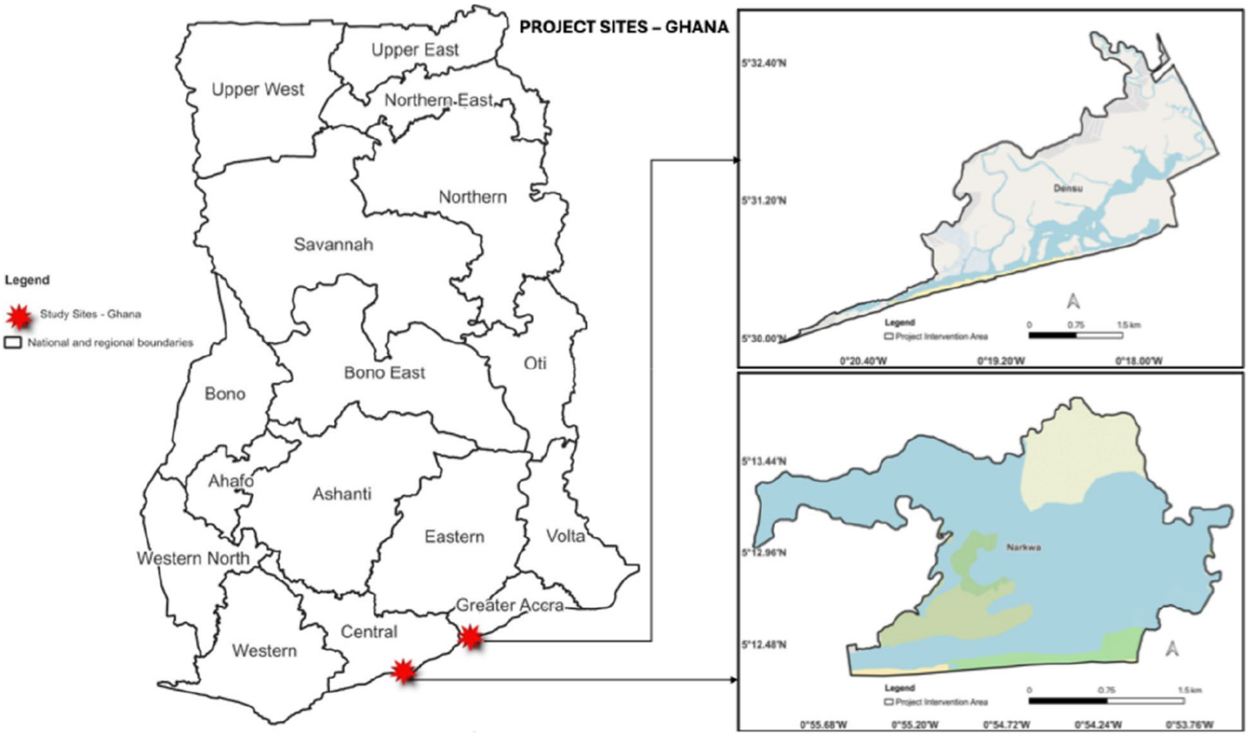

Fig. 1 Study sites in Ghana (Densu and Narkwa)

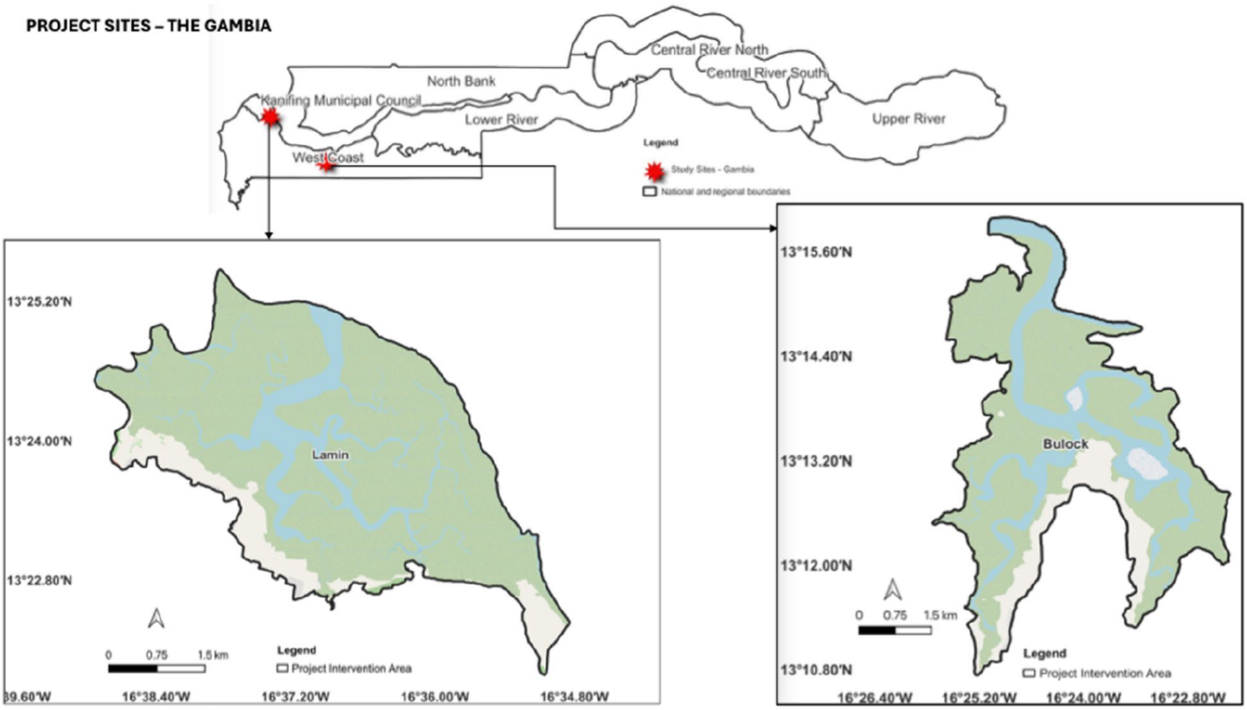

Fig. 2 Study sites in The Gambia (Tanbi-Lamin section and Bulock)

Table 1 Site-specific mangrove attributes (Adopted from Chuku et al. 2020)

Country	Site	Estimated mangrove area	Livelihood supported by mangroves	Mangroves Condition (less to highly degraded)	Threats and challenges to mangroves	Governance aspects
Ghana	Densu estuary	206 ha	Firewood collection, salt mining, fishing	Highly degraded	Land reclamation, mangrove harvesting, settlement expansion	Ramsar site, though weak enforcement
	Narkwa lagoon	110 ha	Crop farming, salt mining	Moderately degraded	Land reclamation, mangrove harvesting, settlement expansion, dieback, pollution	No clear regulations
The Gambia	Bulock	3,539 ha	Firewood collection, vegetable gardening, rice farming	Less degraded	Mangroves diebacks, overharvesting, settlement, expansion, pollution, urbanization	Local shellfisheries regulations present
	Tanbi wetland	2,550 ha	Rice farming, vegetable gardening, firewood Collection	Moderately degraded	Die backs, overharvesting, settlement expansion, pollution	Ramsar site, co-management plan for Cockle and Oyster

Producer's accuracy measures the precision of the land class identified with the ground truth data, while the user's accuracy measures the correctness of classified pixels in each class. The results yielded almost 100% accuracy, indicating that the maps correctly represented the land cover at the study time. The classification and the country where different LULCs appear are described in Table 2.

2.3 Stakeholder engagement

The PGIS brought together remote sense maps that were analyzed and validated by different stakeholders using local and national knowledge. The information was integrated into computer-based systems to visualize the spatial information provided by the stakeholders for planning and decision-making. Figure 3 illustrates the PGIS process as adopted in the study.

Table 2 Description of the LULC types mapped for Ghana and The Gambia project intervention areas (Source: Adopted from Carsan et al. 2023a)

LULC Type	Description	Ghana	The Gambia
1. Mangrove forests	All mangrove vegetation types: coastal woodland, tidal forest/ mangrove forest	√	?
2. *Rhizophora* spp.	*Rhizophora* (red mangrove species) zone: mangrove species found in intertidal areas with characteristic stilt-like roots	NM	√
3. *Avicennia* spp.	Mainly *Avicennia germinans* mangrove species zone	NM	√
4. Water	Water bodies, rivers, ocean	√	√
5. Forests	Refers to non-mangrove forest areas	√	√
6. Croplands	The area mainly under small-scale cropping with cereals (e.g. rice) and vegetables	√	√
7. Barren land	Bare areas without vegetation cover, mostly showing signs of saline soils	√	√
8. Built-up areas	Human settlement areas around the project intervention site	√	√
9. Wetland plants	Mostly perennial grasses of coastal wetlands/estuarine zones	√	√
10. Mudflats	Coastal wetland areas are characterized by fine sediment composed of mud or silt, exposed during low tides	√	√
11. Shrublands	Coastal shrubland or coastal scrub plant communities are dominated by low-growing shrubs and woody plants adapted to the coastal environment	√	√
12. Grasslands	Coastal savannas or plant communities dominated by grasses and other herbaceous vegetation	√	√

√ mapped LULC, *NM* LULC type not mapped or detected

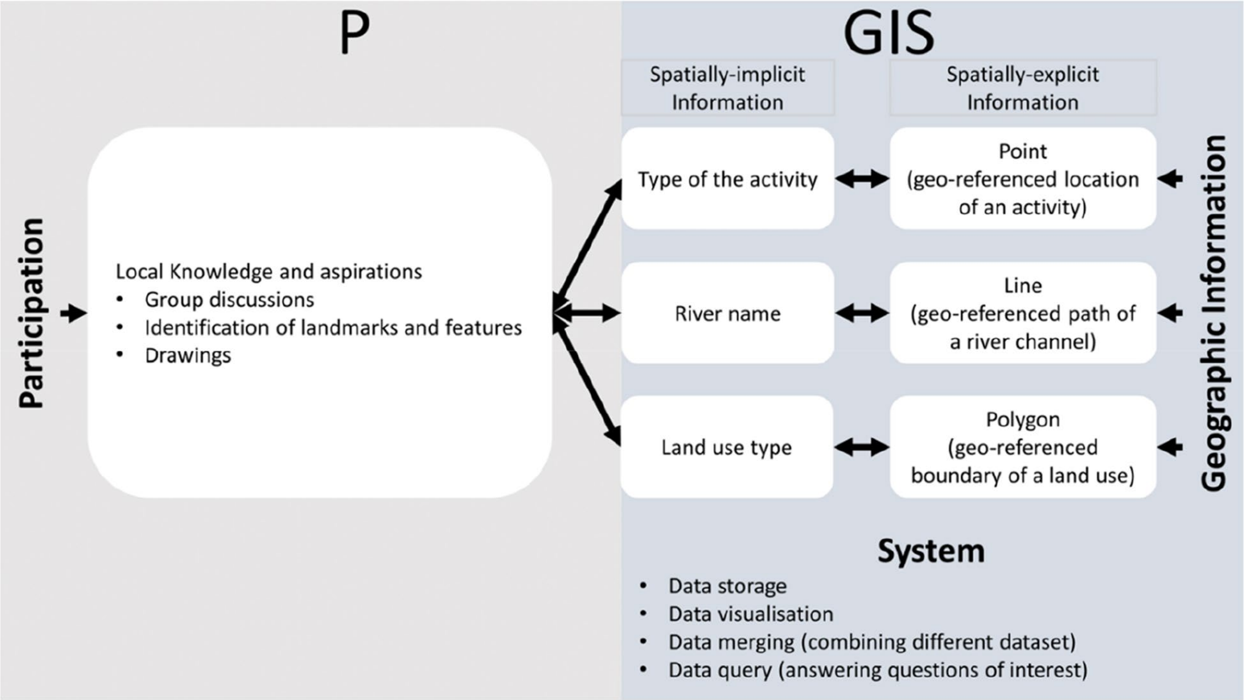

Fig. 3 Illustration of the PGIS process

Stakeholder engagements were conducted at the four sites, bringing together community and group representatives, national and local government representatives, local administration, research and academia, and development agencies. During the engagements, the previously developed LULC maps were presented to the stakeholders, describing the changes between 2002 and 2022. The purpose of the engagement included conducting ground truthing of the developed maps, sharing evidence and visioning of the mangrove changes, and developing site-specific mangrove Community Action Plans (CAPs). A total of 133 participants were engaged in

Ghana and The Gambia, respectively, as summarised in Table 3.

The facilitators took the participants through the project's objectives and the mapping exercise's mission to ensure free, prior, voluntary, and informed consent before the engagement. Consequently, community feedback was collected using site visits, transect walks, and consultative meetings, and was incorporated into the final maps shared with the communities to develop community action plans and mangrove co-management plan design (Carsan et al. 2023a, b). The entire project complied with the Institutional Review Board (IRB), which ensured the protection of human subjects during the research process. Some illustrations of this process are captured in Fig. 4.

3 Results and discussions

3.1 Site assessments in Ghana and The Gambia

The mapped sites showed unique LULC features, including mangrove forests, mudflats, shrubland, water bodies, and forested areas. These features support the livelihoods of the adjacent communities and aid ecosystem functionality. The hectarage of different land use land cover types in the four sites is summarised in Table 4.

Table 3 Gender-representation during the PGIS engagement process

Country	Site	Male	Female	Total
Ghana	Densu	10	26	36
	Narkwa	11	25	36
The Gambia	Tanbi (Lamin)	8	19	27
	Bulock	17	17	34
Total		46	87	133

The dominant features in the four sites included mangrove forests, water bodies, wetland plants, and other natural forests. Both remote sensing and community mapping work concurred that there is a depletion in mangrove resources in Narkwa and Densu, and relative stability to an increase in Bulock and Tanbi sites (Carsan et al. 2023a). In agreement, a study by Duguma et al. (2022a) demonstrated that Ghana had a net loss of about 45% of its mangrove area (estimated at 53,900 ha). This also aligns with a study by Nunoo and Agyekumhene (2022), which suggests that mangrove cover was reduced by 47.2% between 2006 and 2014, translating to 810 ha reduction annually. In contrast, The Gambia experienced a net gain of about 13.5% (estimated at 7,800 ha) between 2000 and 2020. However, even in The Gambia sites, there was evidence of mangrove degradation and decline in some areas due to human and natural factors (UNEP 2007). Evidence of degradation included the presence of mudflats and bare land, which provide ample space for restoration and diversification using mangroves and other vegetation types. The Lamin site demonstrated more signs of encroachment by settlements and crops (vegetables and rice fields). More barren lands were also noted on the fringes of mangrove areas, suggesting increased soil salinity. *Rhizophora* were more abundant compared to the *Avicennia* species in Bulock (825 ha vs. 744 ha), while the opposite was observed in Lamin (1,017 ha vs. 497 ha). The Gambia is also experiencing the loss of non-mangrove forests because of agricultural and settlement activities. The expansion of mangroves can

Fig. 4 Oyster attachment on mangroves, stakeholder's feedback and suggestions on the spatial maps, and mangrove restoration activities along River Gambia in Tanbi section. (Source: ICRAF)

Table 4 Different land use land cover types in Ghana and The Gambia sites

LULC type	Ghana			The Gambia			Combined sizes (ha)
	Narkwa (ha)	**Densu (ha)**	**Both Sites (ha)**	**Bulock (ha)**	**Lamin (ha)**	**Both Sites (ha)**	
Wetland plants	200.33	444.23	**644.56**	66.48	58.81	**125.29**	**769.85**
Grasslands	17.48	132.53	**150.01**	3.52	NM	**3.52**	**153.53**
Mudflats	137.11	104.02	**241.13**	5.98	32.29	**38.27**	**279.4**
Water	70.56	88.21	**158.78**	504.56	239.95	**744.51**	**903.29**
Barren land	10.23	78.48	**88.70**	86.87	83.67	**170.55**	**259.25**
Croplands	104.55	41.00	**145.55**	112.03	53.25	**165.28**	**310.83**
Mangrove	15.65	27.57	**43.22**	-	-	**-**	**43.22**
Red mangroves *(Rhizophora species)*	-	-	**-**	824.86	497.08	**1,321.94**	**1,321.94**
White Mangroves *(Avicennia species)*	-	-	**-**	744.16	1,016.62	**1,760.78**	**1,760.78**
Shrublands	2.47	6.98	**9.45**	15.74	NM	**15.74**	**25.19**
Built-up	0.50	6.08	**6.58**	NM	1.15	**1.15**	**7.73**
Forest	91.80	0.18	**91.97**	218.66	109.16	**327.82**	**419.79**
Site size (ha)	**650.68**	**929.26**	**1,579.95**	**2,582.87**	**2,091.98**	**4,674.84**	**6,254.79**

NM LULC type not mapped or detected

benefit livelihoods and ecosystems due to their goods and services. However, they also pose a challenge regarding conflicting land uses and changing land cover (Osland et al. 2022). For example, expanding mangrove forests compete with agricultural, aquacultural, and other food production systems (Diop et al. 2020), which may threaten food security in the affected areas.

The mangrove area decline and expansion challenges are site-specific and context-dependent based on their livelihood-ecosystem interactions. A previous study by Duguma et al. (2022a) adopted the Driver, Pressure, State, Impact, and Response (DPSIR) framework to establish the drivers and threats leading to mangrove degradation. These were broadly clustered as population-related pressures, economic and livelihood-related activities, natural and climate-related factors, and other sporadic context-related factors. Based on these findings, the current mapping process established that only a few stands of red mangroves were sighted in both Narkwa and Densu, while white and black mangroves were more dominant in different patches. From the community feedback, these species are less valued from a biodiversity perspective, especially regarding oyster attachment. However, they play critical livelihood roles in supporting fisherfolks in constructing fish traps and as a source of firewood for the local communities. This finding agrees with the study by Nunoo and Agyekumhene (2022) and presents an opportunity for red mangrove restoration for their biodiversity roles, while white and black mangroves are conserved for other livelihood roles. According to community feedback in Ghana, the depletion of mangrove resources has led to a decline in oysters and fish resources, consequently affecting their livelihood. Duguma et al. (2022c) allude that shell fishing, fishing productivity, and other coastal-related goods and services decline as the mangrove vegetation shrinks. As such, there is a need for integrated restoration initiatives of different mangrove species to meet the needs of different users and stakeholders, including red mangroves for supporting optimum shell fisher activities, and white/black mangroves to support brush park fishing activities. On the other hand, red mangroves dominate The Gambia mangrove ecosystems and have played an essential role in oyster attachment that supports the livelihoods of the women shellfishers.

3.2 Community visioning on mangrove restoration

In agreement with the spatial maps, communities in Ghana and The Gambia confirmed evidence of mangrove depletion and attributed it to the local livelihoods. Duguma et al. (2022a) have attributed the shrinkage of mangrove forests to the reduction of the available oyster and fish resources, highlighting the role that mangroves play in biodiversity conservation. PGIS activities helped identify and map opportunities to diversify livelihoods by bringing other trees into their landscapes, intensifying agricultural activities, and developing mangrove conservation plans. A summary of site-specific activities proposed to restore local ecologies and support livelihoods are shown in Table 5.

In Ghana, communities mapped much larger sites for restoration activities at 139 ha and 177 ha in Densu and Narkwa, respectively. In the Densu, an area spanning 153 ha with mangrove patches was further identified for conservation activities. To promote livelihood diversification, areas of 20.9 ha and 3.05 ha were mapped in Densu and Narkwa for coconut planting. Communities

Table 5 A summary of proposed activities identified by local communities to restore local ecologies and improve livelihoods in Ghana and The Gambia

Proposed activity	**Ghana**		**The Gambia**	
	Narkwa	**Densu**	**Lamin**	**Bulock**
Mangrove planting/conservation	X	X		
Coconut *(Cocos nucifera)* planting	X	X		
Indian almonds *(Terminalia catappa)* planting		X		
Non-mangroves forests conservation	X			
Agriculture intensification	X		X	
Improved oyster farms			X	
Fishponds establishment			X	
Buffer zones			X	X
Tree nurseries establishment				X
Salt extraction activities				X

attributed coconut values to income generation, food provisioning, coastline protection, and construction materials. Farming activities were delineated in about 53.9 ha in Narkwa, where fresh water is available. Further, mixed farming of mangroves and Indian almonds was proposed in about 24.3 ha of land in Densu. These proposed land use and cover are visualized in Annex Fig. 2.

Mangrove area development strategies in The Gambia differed slightly from those in Ghana. This is perhaps due to the relative stability of mangrove resources and extensive coverage around the study areas. In The Gambia, mangrove expansion to adjacent areas with crops and trees was in part viewed as a bio-indicator for soil salinity, especially in the Bulock area where rice farming was feared to be affected due to increased salinity. In Lamin, there was a consensus on the need for mangrove restoration through planting work to cover 48.6 ha, agricultural intensification (77.9 ha), oyster farms (123 ha), mangrove propagule source sites (78.9 ha), and fishpond development activities. Further, establishing buffer zones with diverse trees (described as social fencing) was considered critical to mitigate encroachment on the mangrove areas. In Bulock, activity mapping included agricultural intensification (76.7 ha), tree buffer zone (227 ha), establishing tree nursery sites (2.69 ha), conservation and natural regeneration of mangroves (9 ha), and establishing sites for salt extraction (4.53 ha) were identified. Bulock site emerged as a preferred site for agroforestry practices, where trees could be integrated into farmlands for multiple livelihoods and ecosystem benefits. Studies by Muthee et al. (2022a, b) and Muthee et al. (2024) have already established the existence of knowledge and practices in the areas, which is key in agroforestry development and scaling. This is crucial for livelihood diversification and reducing overreliance and pressure on mangrove vegetation. In agreement, a study by Duguma et al. (2022a) found that anthropogenic drivers, such as population growth and economic drivers, are among the main threats to mangrove decline in both Ghana and The Gambia. Bringing more livelihood activities into the landscapes, based on the community's priorities and existing socioeconomic and environmental conditions, can complement mangrove restoration initiatives. Communities suggested such activities but established the need for more financial and technical support to execute the proposed activities.

3.3 Lessons for successful mangrove area restoration and co-management

The study suggested several recommendations for successful mangrove area co-management based on remote sensing information and PGIS. First, bringing diverse stakeholders together is critical in establishing their priorities, challenges, restoration incentives and disincentives, through which an inclusive co-management plan can be developed. In the study areas, the established stakeholders included the user groups, local and national administrators, government agencies, the private sector, and development agencies. Various internal and external stakeholders present mixed interests in the mangrove areas, including income generation, conservation and management, and research and development, all of which needed to be incorporated into the restoration and co-management plan to achieve a shared vision. Different projects and studies have also reiterated the need for collaborative and participatory approaches in mangrove mapping. For example, a study by IDB (2018) in Veracruz, Mexico, noted that stakeholder engagement is essential in developing a collaborative planning model for mangroves and associated land uses. The study recommended a policy action on enhanced stakeholder engagement for sustainable planning and use of mangroves. Similarly, Sathiyamoorthy and Sakurai (2024) conducted a study to assess the effectiveness of co-managing mangroves in Northern Sri Lanka. The study noted that stakeholder participation positively enhances mangrove management and sustainable use and recommends policies geared toward enhanced participation of diverse players.

Mapping the extent of degradation, existing tenure systems, land use land cover systems, and the size of the areas that can realistically be restored within a given time emerged as critical lessons. However, restoration considerations should go beyond the land factors to consider other factors such as the costs of procuring propagules and seedlings, related inputs and equipment, required labour costs, technical knowledge and skills needed, infrastructure development, planting, and maintenance costs. The return on investment in mangroves is estimated to range from USD 1,000 to USD 9,000 per ha, varying with the context (Bayraktarov et al. 2016; Narayan et al. 2016). Such costs should be considered in advance before embarking on restoration drives. There is, however, a gap related to the economic valuation of mangroves. Dahdouh-Guebas et al. (2000) and Kirui et al. (2013), for example, used the Kenya case study to establish that mangroves are widely exploited and converted for short-term benefits due to inadequate valuation of mangroves as intact versus destructed systems. Such market failure to establish the true economic valuation necessitates accurate mapping of mangrove extent, change rate, and distribution patterns for effective management.

Diversification of livelihoods emerged as an essential lesson to ease pressure on mangroves. The entry point in livelihood diversification is conducting a comprehensive mapping of the stakeholders' prevailing environmental and socioeconomic conditions depending on the mangrove and establishing other opportunities within and outside these ecosystems that can support livelihoods. In Ghana, diversification options included introducing highly valuable tree species such as coconut and Indian almonds into the landscapes. It also involved agroforestry practices through introducing and diversifying food crops to support food security and reduce pressure on mangroves as the primary source of livelihood. Coconut was valued for its multiple benefits in supporting livelihoods and enhancing coastal stabilization and protection. Crop farming was valued in Narkwa for diversifying livelihoods, while mixed planting of mangroves and Indian almonds in Densu was identified as a possible opportunity. A clear diversification plan is, however, essential for effective implementation. In agreement, a study by Bera and Maiti (2022) in Sundarbans, India, assessed the contribution of mangroves to the livelihoods of adjacent communities. The study concluded that areas entirely dependent on mangroves faced a high degradation rate compared to areas with diversified livelihood options. As such, livelihood diversification emerged as a crucial pathway and success factor in mangrove restoration.

Lastly, awareness and capacity development emerged as a critical lesson towards successful mangrove restoration and co-management. It emerged that communities manage and use different species of mangroves based on the value that they attribute to them and their awareness level. In the Ghana sites, the community had a lower value for white mangroves, mainly used by the fisher community when constructing fisher traps. This scenario creates an opportunity to engage them in conservation since they have a directly attributable value and build more awareness of the values of black and red mangroves for supporting shellfishing activities. In The Gambia, red mangroves dominate the landscape, and communities know their value, especially regarding oyster attachment. This knowledge formed a sound basis for increased awareness and capacity to conserve the species through co-management approaches.

3.4 Policy recommendations

The study suggests the need for different policy interventions to enhance sustainable regeneration and utilization of mangrove vegetation. These included policy interventions to strengthen coastal governance and management at local and national levels. For example, enacting policies to support co-management strategies, where the communities receive the rights to access and use mangrove resources, with clear by-laws can enhance sustainable mangrove use. The co-management plans should be aligned with and endorsed through the national plans. In addition, the study established that anthropogenic factors—including population, economic, and livelihood pressures are the major drivers and threats of mangrove degradation in the study areas. To reduce land use changes resulting from anthropogenic pressures, there is a need to strengthen and enforce regulatory measures around land use and urban planning, especially in areas adjacent to mangrove vegetation. Lastly, policies and strategies to enhance awareness and support livelihood diversification in the areas adjacent to mangrove vegetation are important to reduce the pressure on mangrove areas.

4 Conclusions

The study concludes by noting the valuable provisioning, regulatory, supporting, and cultural values mangrove vegetation provides. However, they face low to high degradation rates varying with the contexts, consequently affecting their ability to regenerate and provide ecosystem services. Using remote sensing, the study found declining mangrove vegetation in Ghana and relative stability in The Gambia. The PGIS process and stakeholder feedback concurred with these findings and further suggested pathways for restoration and diversification of activities to reduce overreliance on mangroves for livelihoods. It is also noteworthy that mangrove changes and dynamics are context-specific and vary with the prevailing socioeconomic and biophysical conditions. The study was geographically limited to four sites—two each in Ghana and The Gambia, to understand these dynamics and make broad policy and practice proposals that can improve mangrove regeneration and utilization. A future study that adopts mixed qualitative and quantitative approaches can support these findings and explore in more detail how anthropogenic factors drive mangrove degradation and potentially how this can be reversed using context-based approaches. This can add more value to the mangrove mapping and address the methodological limitations of the current study.

Appendix 1

PGIS maps for the Ghana sites

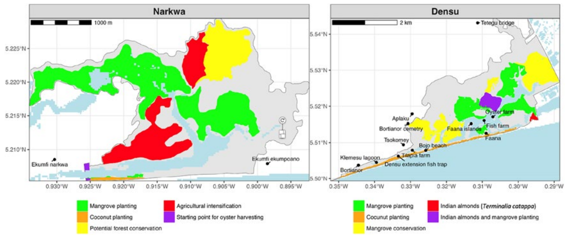

Fig. 5 Mangrove and shellfish restoration activities as part of the community action plan for Narkwa and Densu project sites. Notes: Data presented in these maps are based on participatory GIS sessions with communities in Narkwa and Densu. The light blue color (not presented in the legend) indicates the water spread on surveyed sites. The area shaded in grey color (not presented in the legend) indicates the Women Shellfishers and Food Security "project intervention area". Legends are site-specific

Appendix 2

PGIS maps for The Gambia sites

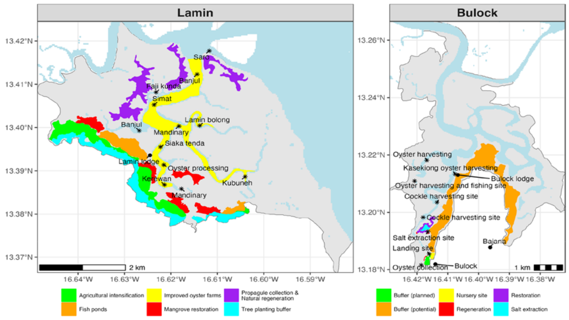

Fig. 6 Mangrove and shellfish restoration activities as part of the community action plan for Lamin and Bulock project sites. Notes: Data presented in these maps are based on community feedback during GIS sessions. The light blue color (not in the legend) indicates water spread in the bolong areas of Lamin and Bulock. Names of places are represented in solid points and project-related features are in asterisks. Banjul, Mandinary, and Simat place names in Lamin indicate sites around the bolong controlled for shellfishing by these communities. The larger grey area is the Women Shellfishers and Food Security "project intervention area". Legends are site-specific

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Authors' contributions

Kennedy Muthee: Data collection, writing the original and final draft; Sammy Carsan, Alagie Bah, Stepha McMullin, Beatrice Darko Obiri: Data collection, writing the final draft; Karen Kent, Peter Minang: funding and supervision, review the final draft.

Data availability

All data and materials are available from the references.

Declarations

Competing interests

The authors declared no potential conflicts of financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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