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Spatio-temporal analysis of two coastal wetland systems in Ghana: Addressing ecosystem vulnerability and implications for fisheries development in the context of climate and land use changes

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ABSTRACT

Lagoons and estuaries are among Ghana's most critical habitats providing fish and other wildlife resources in support of the country's economy. In the context of climate change, it is feared that these ecosystems are faced with enormous threat. Possible impacts relate to sea level rise (SLR) that may result in widespread loss of these habitats. Land use changes around wetlands *could magnify the* impacts of climate change on these ecosystems *and may be disastrous for the welfare of coastal communities due to its potential impacts on property, water and food security. This paper addressed the question of ecosystem vulnerability in the context of climatic and land use stressors on fisheries biodiversity in two coastal ecosystems. Fish biodiversity and aquatic environmental parameters were used as surrogates of their ecological condition. Ecosystem vulnerability to possible climate and land use changes during a period of nearly three decades (1973-2010) was analyzed by the application of GIS. The Whin estuary in comparison to the Butuah lagoon generally reflects a highly productive system for fisheries development, meriting adaptation and management planning. However, the possible effects of climate change attributable to SLR could potentially frustrate these efforts due to potential increases in water surface geometry into wetland corridors with negative impacts for fisheries development. Land use changes around the water bodies if not properly managed, could exacerbate the climatic impacts. This study deployed baseline screening scenarios to provide first-hand scientific information that could inform broader vulnerability studies in support of ecosystem management for sustainable development.*

Keywords: Ecosystem vulnerability, Climate change, Fisheries, Wetlands, Land use, and sustainable development.

INTRODUCTION

Globally, lagoons and estuaries were among the first ecosystems to receive international attention through the "Convention on Wetlands of International Importance" in 1971. These wetlands are among Ghana's most valuable ecosystems since they are closely tied to salt marshes, mangroves swamps and tidal flats which constitute significant features of Ghana's coastline providing critical habitats for many fish and wildlife resources that support Ghana's economy. However, in the context of climate change, it is feared that these wetlands are faced with enormous threats, including possible impacts of sea level rise (SLR) that may result in widespread loss of these ecosystems. The loss of these wetlands would magnify the impacts of climate change and could be disastrous for the safety of coastal communities due to its potential impacts on water, food and livelihood security. Coastal wetlands have been classified as being among the most vulnerable ecosystems in the event of climate and land use changes. For example, climate change would increase the frequency and impacts of storm surges, flooding and coastal erosion, expected to be exacerbated by other hazards such as cyclones, tsunamis and by anthropogenic activity such as settlement development and an increasing number of potentially polluting industrial units located in wetland environments (ADPC, 2008). These challenges posed due to climate change have strengthened the need for coastal habitat restoration and conservation in Ghana, as a primary measure rapidly evolving as a key coastal management strategy. This is in response to concerns of various interest groups addressing issues of climate change - inter alia addressing the potential impacts of sea level rise – alongside the concerns of new major shifts in coastal resource exploitation in the country. Notably offshore oil exploration activities in the Western Region of the country. Climate change is projected to have significant impacts on Ghana. Although there will be fluctuations in both annual temperatures and precipitation, the trend for temperature over the period 2010-50 indicates warming in all regions (World Bank, 2010). Coastal areas as reported may be adversely impacted in the country. For example, a total of 1,110 km^2 of land area in Ghana may be lost as a consequence of one-meter rise of sea level, and the population at risk was estimated at 132,000 (EPA, 2008). Also, historical climatic data observed by the Ghana Meteorological Agency across the country between 1960 and 2000 (a forty-year period) progressively show discernible rise in temperature and concomitant decrease in rainfall in all agro-ecological zones of the country (EPA, 2001). In the particular instance of climate change therefore, management of coastal wetland areas would aim at providing feedback for the construction of setbacks, sustaining public interest and stakeholder participation on climate change issues, providing managed access to resources as opposed to openly public access, create opportunities for the citing of conservation or restoration areas, and satisfying the requirements that the wetlands would continue to provide their required ecological goods and services for the benefit of coastal communities. Presently, it is true that an overarching management strategy coordinating these efforts appears to be lacking constituting a major setback. Municipal zoning maps that could determine what densities and types of development to be pursued or permitted around wetland areas are lacking. Thus, creates a complex situation of grave environmental and socioeconomic concern. The situation is further constrained due to the lack of scientific data that clearly demarcates the various land uses and land cover types, as well as poor documentation of relevant information on the socioeconomic context including information on the anthropogenic stressors around wetlands. These conditions are only a part of the bigger picture largely constraining any effort seeking climate change adaptation or mitigation interventions.

This paper addresses part of the issues by assessing the ecological conditions in terms of fisheries biodiversity and aquatic environmental conditions, as well as the spatio-temporal structure of the Whin river estuary of Ghana as case studies. It evaluates data on the spatio-temporal changes of the water bodies that have occurred within a period of nearly three decades

(1973-2010) and discusses possible vulnerability implications of the ecosystems in the context of fisheries development. These aspects have been enabled by the application of Geographic Information Systems (GIS) and ecological surveys. Anthropogenic stressors and prevailing shocks to the systems that could exacerbate the potential impacts of climate change on fisheries production as well as economic activities and development being pursued are discussed. The specific objectives of the study are to document the fisheries biodiversity status and analyze the drivers of ecosystem change with reference to the spatio-temporal changes in areas of the water bodies and associated floodplains from 1973-2010 for proactive planning to adapt to impacts of climate change. This study therefore provides information intended to support programs aiming at climate change mitigation or adaptations actions relative to wetlands and coastal communities for the sustainable development.

Study area

The study was carried out in July 2010 in the Western Region of Ghana (Long. 1^{o} 42′ W and 1^{o} 48′ W; and Lat. 4^{o} 52′ N and 4^{o} 56′ N). The two wetlands are shown in Figure 1. Butuah lagoon is a classical closed lagoon because it gets cut off from the sea by sand bar for greater part of the year, but open for a short period during the rainy season (Yankson and Obodai, 1999).

The Whin estuary is a partially enclosed coastal water body with a free connection with the open sea, but whose water is diluted by fresh water from the Whin river system providing interaction between the sea, river and land. Its orientation is more or less perpendicular to the sea, funnel-shaped permitting a large seawater-freshwater interchange. The sources of the estuarine water, like some lagoon, are land drainage, direct rain and the sea (Yankson and Kendall, 2001).

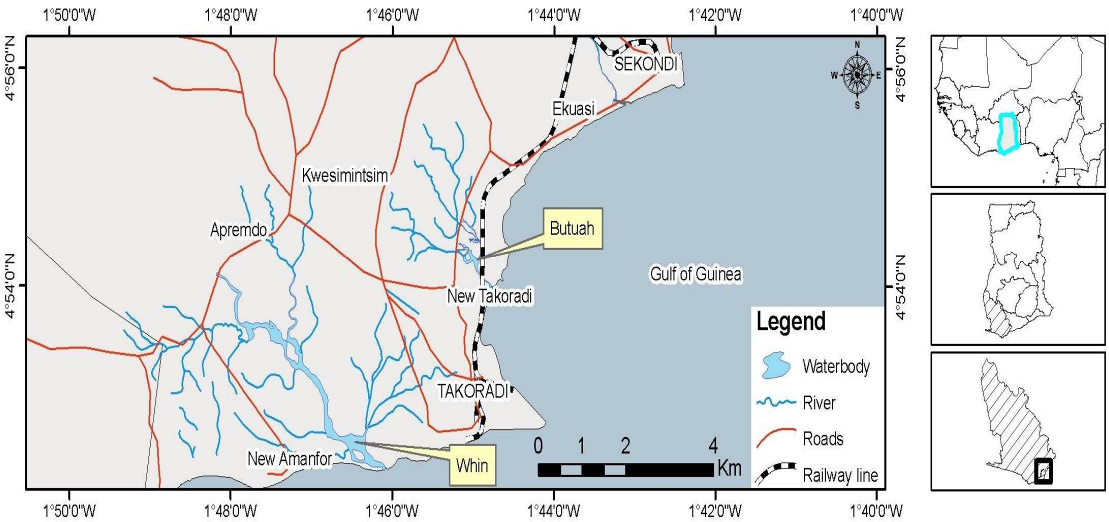

Figure 1: Map of the Butuah lagoon and Whin river estuary in Ghana

METHODOLOGY

Theoretical concept

A baseline identification of existing fisheries resources, their diversity classification and possible climatic and anthropogenic threats to these resources was assessed in this study. Sea level rise (SLR), an effect resulting from climate change was not measured empirically but whether it occurs or not was hypothetically related to the observed changes in water surface geometry between the periods 1973- 2010.

Mapping boundaries and land use change

In order to provide data on the current boundaries and land use patterns around the Butuah lagoon and estuary of the Whin river, these water bodies were mapped using Trimble Juno ST Global Positioning System Receivers (GPS). This information was complemented by data extracted from georeferenced google earth images. To provide an indication of changes in the area extent of the water bodies and also in the land use patterns within the immediate surroundings of the three water bodies, the current boundary and land use data were processed and compared with boundary and land use data extracted from a 1973 1:50,000 topographic map of the area.

Measurement of aquatic environmental factors

Water quality was assessed relative to predetermined standards for critical concentrations for certain environmental factors and pollutants. The parameters measured were: pH, Temperature, Salinity, Conductivity, Turbidity and Dissolved Oxygen (DO), and these were recorded using the Water quality checker (Model: Horiba U-10). Three replicates were recorded from seven different areas of each of the water bodies by immersing the probe into the water and recording the readings as we switched the mode from one parameter to another. The environmental data were analysed for their means, after which the Students t-test (Zar, 1999) was used to determine the statistical significance of the differences between the physico-chemical parameters of the water bodies.

Ecological and social surveys

For the fish sampling, a pole-seine net of 7 m long and 1.5 m deep with stretched mesh size of 5 mm was used for the fish sampling. Fish samples were also purchased from the local fishermen as complementary information. The fishes were preserved in 10% formalin and transported to the laboratory for further examination. The fish were sorted and identified to their various families and species using fish identification manuals (Schneider, 1990; Holden and Reed, 1991; Dankwa *et. al.*, 1999; Paugy *et al.*, 2003; Kwei and Ofori-Adu, 2005). Fish samples were analyzed for species composition, richness and diversity. Species richness was determined using Margalef index (d) given as $\frac{(s-1)}{\ln N}$, where s is number of species in the sample, and N is the number of individuals in the sample (Krebs, 1999). Diversity of the communities was ascertained by the Shannon-Wiener index (H′) given as $H' = -\sum_{i=1}^{s} P_i (\ln P_i)$, where s is the number of species in the community and P_i is the proportion of individuals belonging to species i in the community (Krebs, 1999). Information on habitat conditions, functional services and an analysis of prevailing anthropogenic threats were recorded based on Rapid Assessment of Coastal Environment (RACE) methods. The threats were rated according to level of severity on a scale of 1-10 [1= least severe; 10=most severe].

RESULTS

Spatio-temporal structure of the water bodies

The changes in the area extent of water surface of the lagoon from 1973 to 2010 are shown in Table 1. The data indicates that both the Butuah lagoon and the Whin estuary experienced some increase in their water surface area extent. The areal coverage of the Butuah lagoon in 2010 is 86,404 (sq. meters) whilst the Whin estuary spanned an area of 652,202 (sq. meters) in the same year. In 1973, the Butuah lagoon and the Whin estuary are estimated to cover an area of 73,774 (sq. meters) and 652,201 (sq meters) as shown in Figures 2 and 5 respectively. The water extent in 2010 is estimated to be 86,404 (sq. meters) and 747,911 (sq. meters) representing a percentage change of 17.12 and 14.67 for Butuah lagoon and Whin estuary respectively. Figures 2-7 indicates changes that have occurred on spatial and temporal scales from the period 1973-2010.

Table 1: Water Extent in 1973 and 2010

Water body	Extent in 1973 (sq. meters)	Extent in 2010 (sq. meters)	Percentage Change
Butuah	73,774	86,404	17.12
Whin	652,202	747,911	14.67

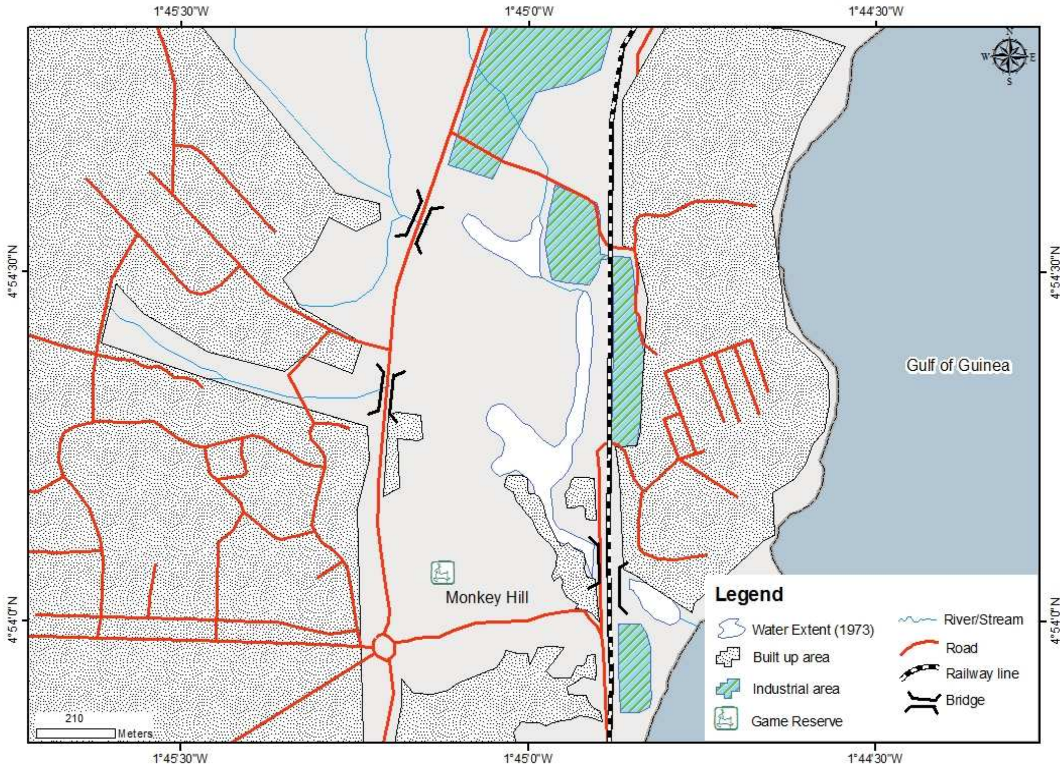

Figure 2: Spatial structure of the Butuah Lagoon in 1973

The area within the natural boundary of the Butuah Lagoon recorded natural vegetation as the largest land cover with mostly mangrove and some scattered patches of reeds, vegetation covered 44.13% of the area. Encroachment into the boundary is considerably minimal. Most of the settlements were found to be 50 feet above sea level. Consequently, 0.77% of the boundary has been settled and 7.86% for Industrial activities (Fig. 2). About 52.00% of available land around the Whin estuary is unused (Fig. 3). Vegetation and Built up areas constitute 21.06% and 25.92 % respectively. Industrial sitings makes up the least component amounting to 0.40%.

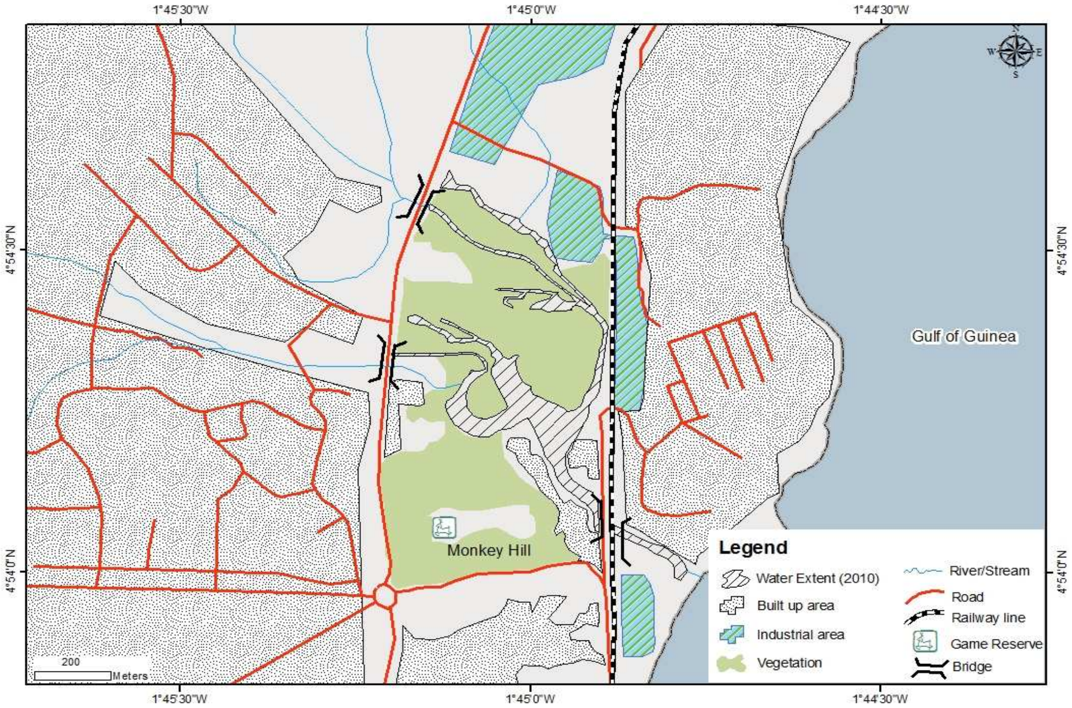

Figure 3: Spatial structure of the Butuah Lagoon in 2010

In 2010, the land use within the natural boundaries of the two water bodies shows three main cover patterns (Table 2). These patterns were identified as built up area, industrial and vegetation.

Table 2: Land use around the water bodies

Land use/cover	Area			
	Butuah		Whin	
	(sq meters)	Percent	(sq meters)	Percent
Vegetation	186887	44.13	1301206	21.06
Built up area	3265	0.77	1601561	25.92
Industrial	33276	7.86	24855	0.40
Unused/Vacant	200071	47.24	3250693	52.62
Total	423520	100	6177676	100

Aquatic environmental factors

Table 3 shows the means of the aquatic environmental parameters for the two water bodies, as well as analysis of statistical significance of their differences at the 5% level. Butuah had extremely higher temperature, averaging 32.9^{o}C ($P < 0.05$), and a significantly higher turbidity around 180 ppm ($P < 0.05$). Among the two water bodies, the Whin estuary was the most alkaline water body. Therefore, the Whin estuary generally reflects better environmental conditions.

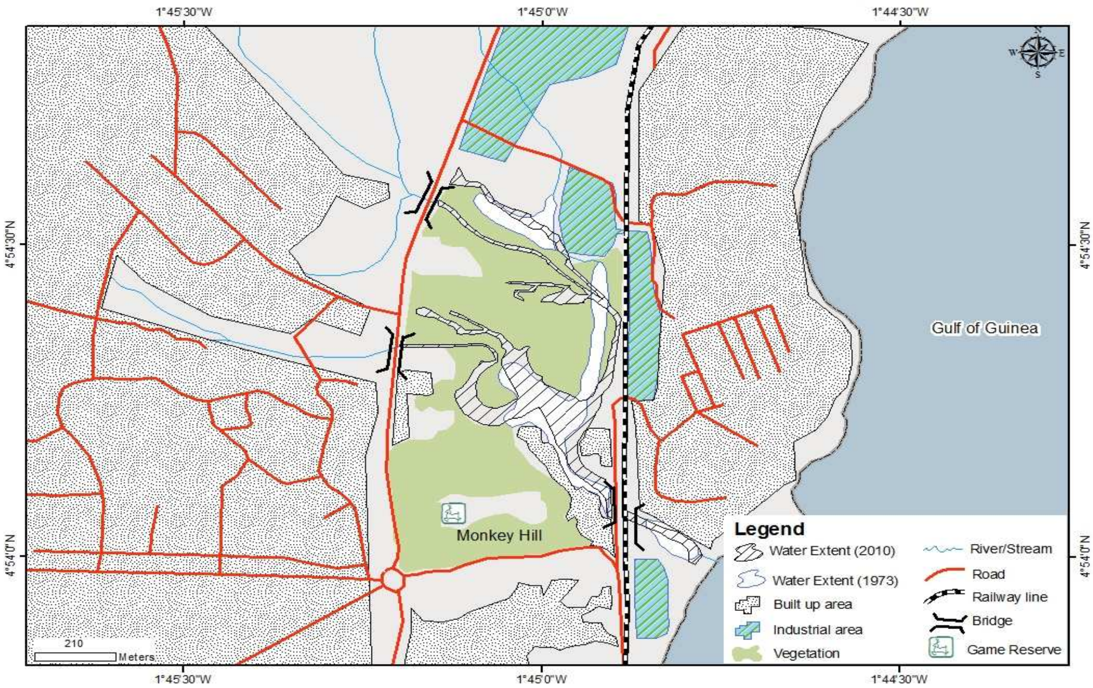

Figure 4: Spatial structure of the Butuah Lagoon comparing change in area of water body between 1973-2010.

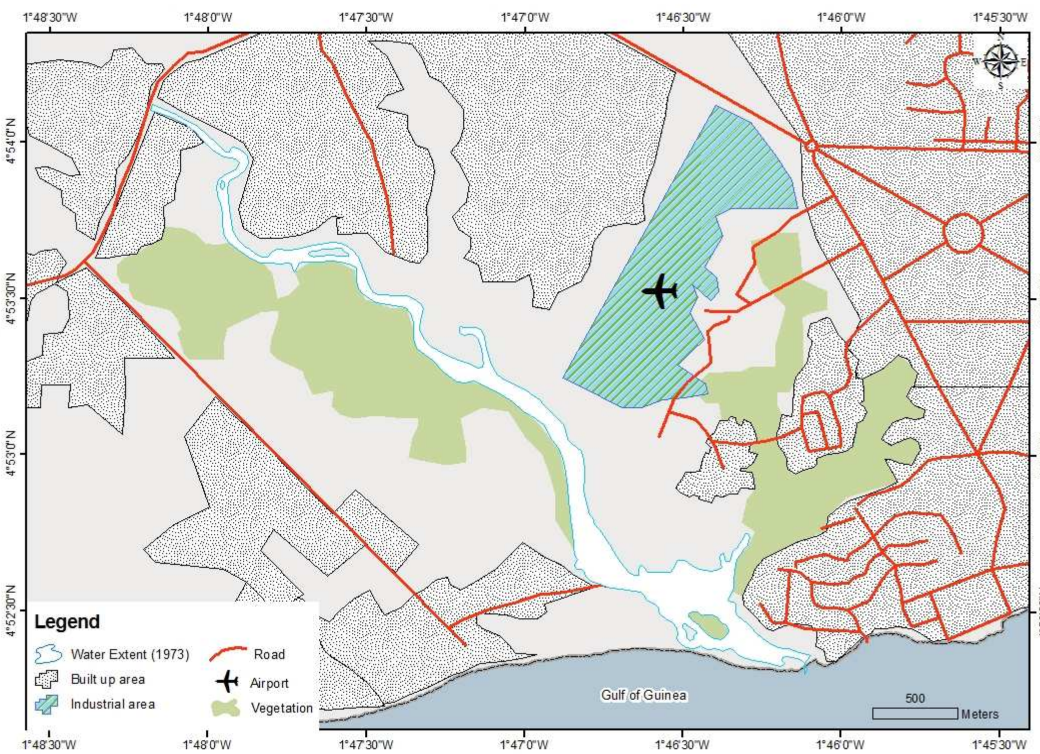

Figure 5: Spatial structure of the Whin estuary in 1973

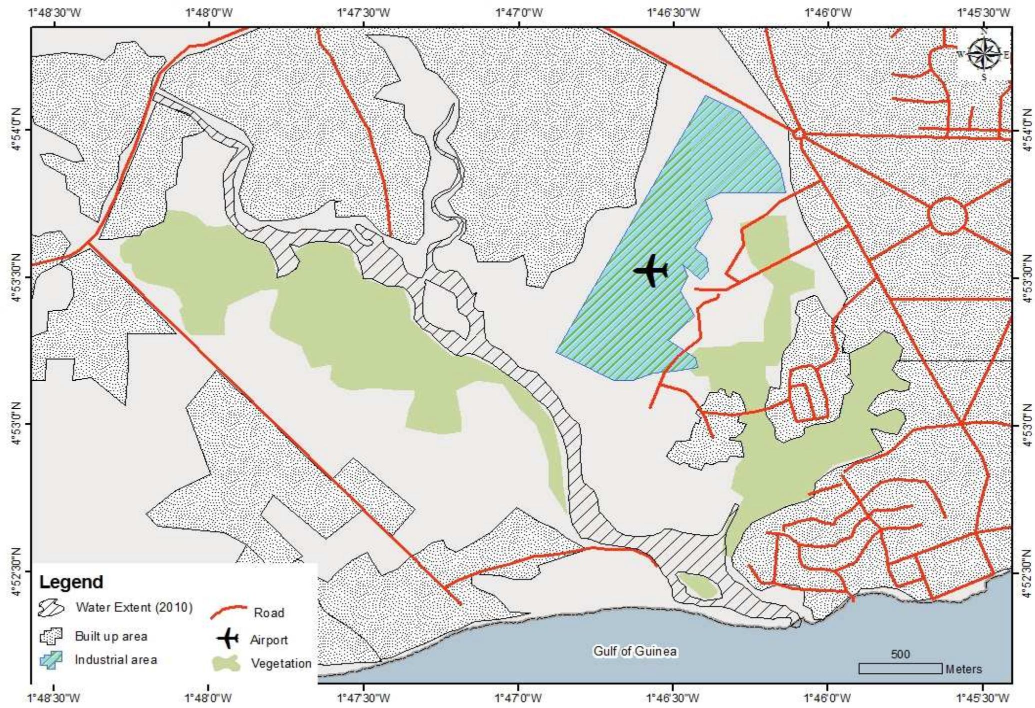

Figure 6: Spatial structure of the Whin estuary in 2010

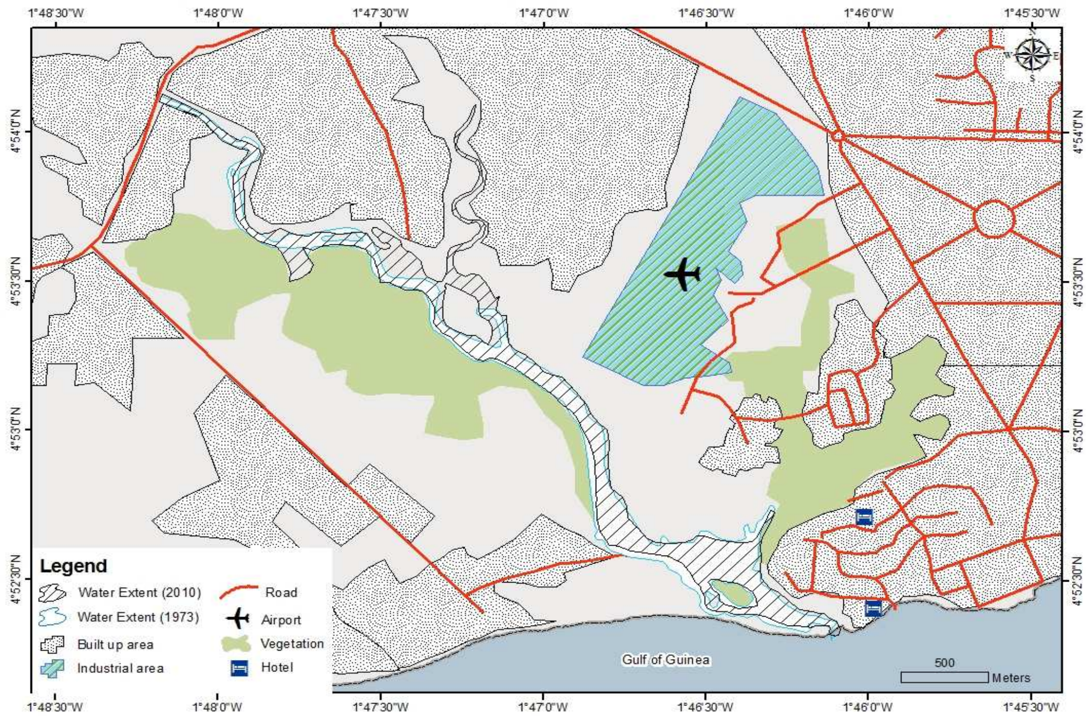

Figure 7: Spatial structure of the Whin estuary comparing change in area of water body between 1973- 2010.

Table 3: Aquatic environmental parameters of the three water bodies shown (each value is a mean of 21 measurements)

	Mean (± Standard Error)			
Parameter	Butuah	Whin	***t*-value**	$P_{(0.05)}$
pH	7.6 (± 0.05)	8.1 (± 0.04)	6.79	S
Temperature (^{o}C)	32.9 (± 0.80)	22.4 (± 0.20)	8.72	S
Salinity (‰)	1.9 (± 0.20)	3.7 (± 0.10)	6.51	S
Conductivity (mS/cm)	19.0 (± 5.60)	55.6 (± 0.17)	6.56	S
Turbidity (ppm)	180.1 (± 33.50)	42.3 (±11.50)	3.89	S
Dissolved Oxygen (mg/L)	3.7 (± 1.3)	3.1 (± 0.1)	0.50	NS

'S'- significant; 'NS'- not significant

Table 4: List of fish species identified

Family	Species
Mugilidae	*Liza dumerilii*
	Liza falcipinis
	Mugil bananensis
	Mugil cephalus
	Mugil curema
Clupeidae	*Odaxothrissa mento*
	Sardinella maderensis
Cichlidae	*Oreochromis niloticus*
	Sarotherodon melanotheron
Gobiidae	*Bathygobius soporator*
	Periopthalmus barbarus
Acanthuridae	*Acanthurus monroviae*
Labridae	*Thalassoma pavo*
Bothidae	*Scyacium micrurum*
Haemulidae	*Plectorhynhus mediterraneus*
Lutjanidae	*Lutjanus goreensis*
Eleotridae	*Eleotris senegalensis*
Gerreidae	*Eucinostomus melanopterus*
Clariidae	*Clarias gariepinus*
	Heterobranchus longifilis

The fish community and biodiversity

The fish community in Butuah was made up of 14 species belonging to 4 families, of which 10 were fishes and 4 were crabs. From Whin, 11 families were encountered of which 20 species were collected with 16 being fishes; most of which were marine species, and the remaining 4 being crabs. *Odaxothrissa mento* dominated the Butuah community (49.1 %), followed by *Sarotherodon melanotheron* (16.3 %). The Whin community was dominated by *S. melanotheron* (26.5 %) and the snapper *Lutjanus goreensis* (Lutjanidae) (13 %). Compositions of the remaining species varied between 0.5 % and 8.5 % in the communities in which they occurred.

As shown in Table 5, Whin had the most rich and diverse fish community (*d* = 3.21, *H'* = 1.62), followed by Butuah (*d* = 1.54, *H'* = 1.56). However, the distribution of the individuals among the various species was more even in Butuah (*J'* = 0.68) than in Whin (*J'* = 0.57).

Table 5: Richness and diversity indices for the fish communities of the two water bodies

Water body	Margalef's Richness (d)	Shannon – Wiener diversity (*H'*)
Butuah	1.54	1.56
Whin	3.21	1.62

Table 6: Categorization of fish species based on origin

Categories of fish species	Butuah	Whin
(a) Truly estuarine/lagoon that spend their entire lives in estuary/ lagoon.	*Periopthalmus barbarus* *Sarotherodon melanotheron*	*Periopthalmus barbarus* *Sarotherodon melanotheron* *Uca tangeri*
(b) Marine species that use estuaries and lagoons primarily as nursing and spawning grounds, spending adult life at sea and returning occasionally to estuaries and lagoons.	*Callinectes amnicola* *Liza dumerilii* *Liza falcipinnis* *Mugil bananensis* *Mugil curema*	*Liza dumerilii* *Liza falcipinis* *Mugil bananensis* *Mugil cephalus* *Mugil curema* *Callinectes amnicola* *Sardinella maderensis* *Bathygobius soporator* *Periopthalmus barbarus* *Acanthurus monroviae* *Scyacium micrurum* *Plectorhynhus mediterraneus* *Lutjanus goreensis* *Eucinostomus melanopterus* *Callinectes amnicola*
(c) Freshwater species that occasionally enter brackish water	*Odaxothrissa mento* *Oreochromis niloticus* *Clarias gariepinus* *Heterobranchus longifilis*	*Eleotris senegalensis*
(d) Occasional visitors occurring irregularly (ornamental)		*Thalassoma pavo*

Table 6 groups fish species found according to origin. In comparison to Butuah, the data indicates that the majority of fish species in the Whin estuary (nearly 80%) were marine species that use estuary primarily as nursing and feeding grounds, spending adult life at sea and returning occasionally to estuaries and lagoons.

Protection status and threats to the water bodies

The protection status of the wetlands is shown in Table 7. The data indicates minimal protection status with no well defined tenure. Responsibility for the management of the water bodies is in the hands of the traditional authorities while the role played by government in the management of the wetlands is underscored.

Table 7: Protection status of the wetlands

Coastal profile	Issues
(1) Tenure	No well defined status
	Mixed tenure between public, stool and private ownership.
(2) Protection status	Legally protected by law as a public good but not gazetted as a nature reserve or conservation area
(3) Protection measure	No fencing and free access granted
	No known managed protection of mangroves
	Traditionally, fishing activities are closed (banned) one day per week
	No known enforcement of customary laws regulating to usage of the water body
	Weak government oversight responsibility

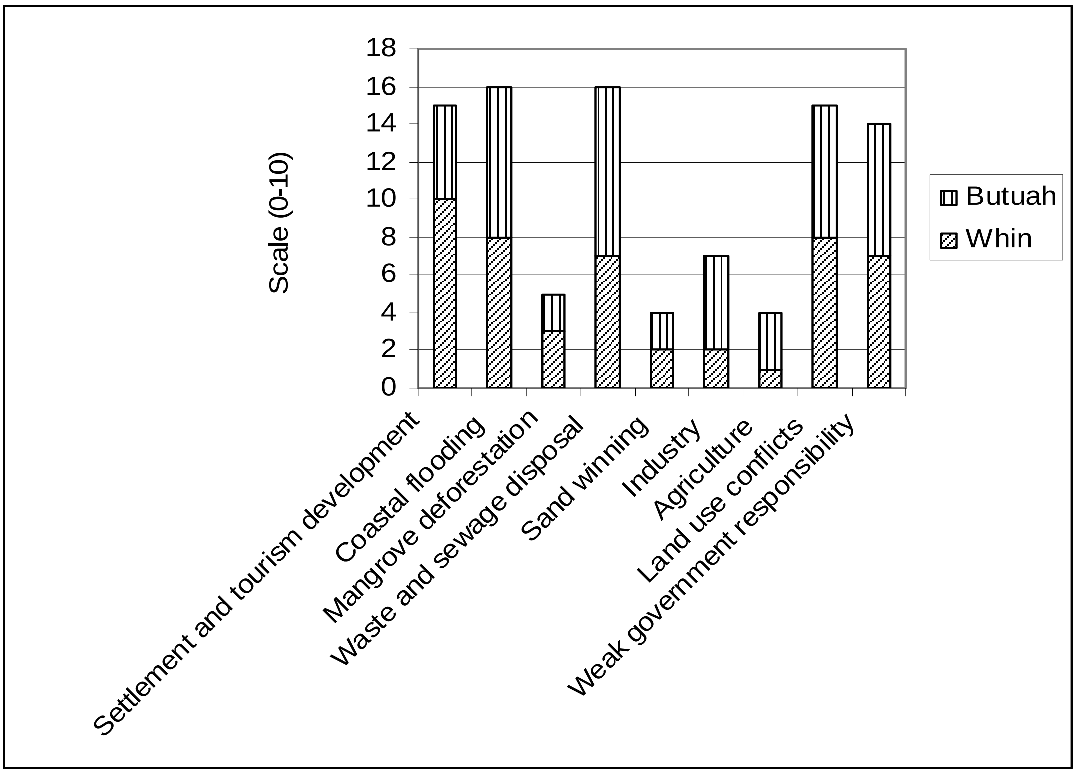

Figure 8: Analysis of associated threats to the wetlands

Figure 8 rates categories of anthropogenic threats to the wetlands. The data shows that on the whole, coastal flooding and disposal of sewage are among the most severe threats to the water bodies. Agriculture and sand wining are classified among the least of the prevailing threats. However, settlement and tourism development, land use and weak government responsibility towards the management of the wetlands are shown to be among the relevant threats.

DISCUSSION

Ecosystem vulnerability and drivers of ecosystem change

Vulnerability assessments lay the foundation for required adaptation strategy. It helps planning and in the context of climate change, help to examine what could happen as climate changes and helps to focus attention on areas, or the specific assets (people, places, buildings, infrastructure and natural resources that are vulnerable as well as associated impacts that could cause the greatest losses (NOAA, 2010). Vulnerability is used here to mean susceptibility of the ecosystems to the damaging effect of a hazard. Climate change due to global warming is a hazard that poses a level of threat to the environment, life, health, and property or environment and has already been shown to impact the Earth's biota at all scales of organization from species to ecosystems, and the rate of change is likely to accelerate in the future (Walther *et al.* 2002). This is especially so if the effects of climate change interact with other drivers like land-use change and biotic exchange (Sala *et al.* 2000). There are many aspects of vulnerability, arising from various physical, social, economic and environmental factors (ADPC, 2008). However, the data has focused on important aspects of vulnerability of the studied water bodies arising from the spatio-temporal analysis for the period 1973-2010. These refer to the overall changes in water surface areas observed to have increased by margins of 17.12% and 14.67% in the Butuah lagoon and Whin estuary respectively (Table 1) into the wetland corridors and the observed changes in shoreline features (Figs. 2-7). The changes could possibly be due to increases in sea level rise. Arguably, the effect of sedimentation processes resulting from land use impacts can not be over ruled in explaining the observed changes in water surface area. However, Hawkins et al. (2003), argued that climate is one of the key features that define the nature of ecosystems. Earlier studies conducted in Ghana reveal that the expected sea level rise will particularly result in direct inundation or submergence of low lying wetland and dry land areas, erosion of soft shores by increasing offshore loss of sediments, increases in salinity of estuaries and aquifers, raised coastal water tables and exacerbated coastal flooding and storm damage (EPA, 2008). These conditions will in turn impact on coastal habitats, biodiversity and socioeconomic activities (EPA, 2000). Land use is determined by demographic factors, including settlement and the development of tourism infrastructure and other characteristics such as mangrove deforestation, waste and sewage disposal (Fig. 8). Such land use intensity and low government overall responsibility signify limited recognition of potential risks around the wetlands in the context of climate change. Even though the wetlands are supposed to be legally protected by law as public goods, they are not gazetted and not known to have any conservation status (Table 7). This has possibly led to the resultant intense land use situation around the wetlands including sand winning and agricultural activities.

Ecosystem change and implications for fisheries development

Sea level rise could potentially cause a disruption of the ecosystems into entirely marine environment with negative consequences for several economically important fish species. Coastal inundation resulting from sea level rise will affect livelihoods such as farming but severely so on coastal and marine fisheries. Beach facilities would be endangered and some of the groundwater resources would be salinated (EPA, 2008). The studied water bodies generally indicate high diversity and richness of fish species (Table 5). However, the Whin estuary generally indicates higher diversity and richness of fish community compared to the Butuah lagoon. This may be attributed to significantly better aquatic environmental conditions (Table 3).

The fish biota is dominated mostly by marine species. These include *Liza falcipinnis, Liza dumerilii, Mugil bananensis, Mugil cephalus, Mugil curema, Sardinella maderensis* among others (Table 4). Most of these fish species e.g. *Liza falcipinnis*, *Mugil cephalus* and *Lutjanus goreensis* primarily use the estuary as nursing or spawning grounds and spend their adult life at sea and occasionally returning to the estuary in their adult life (Emmanuel and Onyema, 2007; Albaret and Lae, 2003). Such marine species live and reproduce from nearly freshwater to hypersaline conditions that are provided by brackish water environments. Therefore, the projected climatic impacts of global warming and sea level rise in Ghana (EPA, 2001), could be described as major hazards to wetlands. Consequences of such global warming and sea level rise on biotic communities include disturbance of predator-prey cycles (Frederiksen *et al.* 2007), increased risk of pathogen outbreaks (Pounds *et al.* 2006) and shifts in species distribution and phenology (Parmesan 2006; Thomas *et al.* 2004). Temperature and sea level rise would have negative effects on the productivity in areas such as lagoons and estuaries where salinity may increase and young fishes may die (EPA, 2008). Other complex effects may ensue resulting from species' interactions and may undoubtedly be a common occurrence given the high number of interacting species that form ecosystems (Ducklow *et al.* 2008; Walther *et al.* 2002). For example, the Intergovernmental Panel on Climate Change predicted changes in the abundance, distribution and species composition of fish populations, as well as the collapse of other fish species, although expansion of others is also possible (IPCC, 2001). The perceived effects of climate change are very likely to increase in the future (IPCC 2003), therefore the identity and organization of biological systems needs to be recognized. From an economic perspective, climate change is predicted to have significant impacts on the world's fisheries through losses in catch and gross revenues. The world stands to lose up to 50 percent of current gross revenues of about $80 billion per year from the world's fisheries in the face of severe climate change and continued over-fishing in global fisheries (Sumaila and Cheung, 2010).

We conclude that the studied water bodies have a vast conservation and fisheries potential. However, the observed increases in water surface area, land use intensity or conflict of interest on the part of users makes the ecosystems highly vulnerable to possible climate and non-climatic stressors leading them onto a path of potentially irreversible destruction. The effects of climate change and sea level rise has the potential to severely impact the shoreline and further weaken the resilience of coastal habitats, fish biodiversity and human communities. However, the effects of sedimentation processes attributable to the observed changes in the water surface areas need to be further investigated. This study deployed baseline screening scenarios to provide first-hand information that could inform broader climate change vulnerability studies on coastal wetlands in support of adaptation actions and ecosystem management for sustainable development. We propose that further studies should be conducted, combining topographic and economic information to identify and delineate specific areas of risks more precisely and ways to create awareness amongst civil society and policy-makers.

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