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REVIEW ARTICLES

A Biophysical and Socioeconomic Review of the Volta Delta, Ghana

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ABSTRACT

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Delta regions are dynamic and rich environments with diverse economic activities and are often densely populated. Deltas are being shaped by multiple drivers, including changes in sediment delivery to the coastal zone due to catchment changes, especially construction of dams on major rivers, intensified agriculture and/or aquaculture, mining, urbanisation, human-induced subsidence, climate change, and sea-level rise. These environmental challenges have significant implications for the livelihoods of delta residents. Thus, the integrated assessment of deltas is now attracting the attention of the scientific research community to analyse and understand deltas as coupled biophysical and socioeconomic systems. Most attention has been focussed on the major deltas. This review focusses on the smaller but regionally significant Volta delta, Ghana. Previous scientific studies are limited, with more focus upstream on the Volta River basin. Many contemporary problems are recognised in the Volta delta, especially erosion and flooding of the open coast fringe, such as at the town of Keta. However, these problems are treated independently, which may hinder identifying the root causes and the most effective solutions. Equally, the emergence of new problems might be anticipated and hence better managed or even avoided. This paper reviews the present delta with emphasis on biophysical processes and socioeconomic characteristics and considers in particular the current drivers and challenges. With this information, a research agenda will be established for a more systemic approach to understanding the Volta delta, including its residents and development.

ADDITIONAL INDEX WORDS: *Vulnerability, sea-level rise, climate change, Volta river basin, drivers of change*.

INTRODUCTION

Delta regions are often dynamic and rich environments with diverse economic activities that have some of the most densely populated areas on the Earth. Ericson *et al.* (2006) estimated that deltas contain about 7% of the world's population (500 million people) on 1% of the land area.

As shown in Table 1, multiple drivers shaping modern deltas have been identified. These include changes in sediment delivery to the coastal zone as a result of a range of human activities, including construction of dams on major rivers, deforestation, crop farming, mining, and urbanisation (Milliman, Broadus, and Gable, 1989; Walling and Fang, 2003; Woodroffe *et al.*, 2006); enhanced subsidence due to the extraction of groundwater and petroleum from the aquifer materials located within deltas that exacerbate the natural subsidence (Ericson *et al.*, 2006; Nicholls *et al.*, 2016; Pont *et al.*, 2002; Syvitski *et al.*, 2009); and eustatic sea-level rise, which is projected to accelerate during the 21st century due to ocean thermal expansion and melting of small glaciers and the Greenland and Antarctic ice sheets (Church *et al.*, 2013). These environmental challenges have significantly affected sources of livelihoods and in some instances have forced people to migrate away from or within deltas (Dun, 2011).

As a result of the issues stated above, the integrated assessment of deltas is now attracting the attention of the scientific research community to analyse and understand them as coupled biophysical and socioeconomic systems (Brondizio *et al.*, 2016a, 2016b). However, this attention has mainly been focussed on the major deltas including the Nile (Egypt), Ganges-Brahmaputra (Bangladesh/India), and the Yangtze (China) (Ericson *et al.*, 2006; Milliman, Broadus, and Gable, 1989; Woodroffe *et al.*, 2006), and smaller but regionally significant deltas are less understood. Here the focus is on the Volta delta in Ghana. Although the Volta delta is relatively smaller in size, it is undergoing changes similar to other deltas globally. Previous research mainly focussed on the Volta River basin and its tributaries: White, Main, Black, Daka, and Oti

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Table 1. *Factors driving biophysical and socioeconomic changes in deltas globally, and their relevance to the Volta delta in Ghana.*

Driver	Relevance in Volta Delta	Source
Upstream catchment management	Three dams built in 1964, 1982, and 2013; major impacts on freshwater inputs and sediment supply in particular, which has been greatly reduced	Woodroffe (2010)
Subsidence	Not measured: probably 1 to 2 mm/y based on other deltas; it may accelerate due to human effects	Syvitski (2008)
Sea-level rise	Presently 3.1 mm/y and expected to accelerate significantly	Church *et al*. (2013); Sagoe-Addy and Appeaning Addo (2013)
Coastal storms	Not subjected to local storms or hurricanes, as too near the equator	Bollen *et al*. (2015)
Energetic swell waves	Generated in the Southern Ocean—far travelled swell—can cause flood events on the coast	Almar *et al*. (2015); Bollen *et al*. (2011)
Aquaculture	Relatively minor activity at present, but large potential in the future	Adjei-Boateng *et al*. (2012)
Coastal erosion and its management	Widespread problem with erosion rates of about 4–8 m/y; over the past 40 y, several people have been forced to relocate in many locations such as Keta; more recently major defences have been constructed such as the Keta and Ada sea defence projects, providing local successes, but influencing regional sediment transport in littoral zone	Appeaning Addo (2015); Bollen *et al*. (2011); Danquah, Attippoe, and Ankrah (2014); Ly (1980)
Groundwater saltwater intrusion	Observed and locally affecting drinking water and farm irrigation, but limited regional understanding	Armah, Wiafe, and Kpelle (2005)
Population	Growing rapidly, following national trends	

(Bhaduri *et al*., 2011; Codjoe, 2004; Ibrahim *et al.,* 2016; Jung, Wagner, and Kunstmann, 2012; Kasei *et al.,* 2009; Neumann *et al.,* 2007; Oguntunde *et al*., 2006; van de Giesen, Liebe, and Jung, 2010). The lack of reliable information on the historic evolutionary trend of the Volta delta system limits understanding of its current state. This paper reviews the present delta with emphasis on biophysical processes and socioeconomic characteristics, and considers in particular the current drivers and challenges. It is hoped that this review will support the future management of the Volta delta and provide insights for the assessment of other smaller deltas.

THE VOLTA DELTA

The Volta delta is a relatively large coastal lowland located in the Keta basin, which is within the lower part of the Volta River basin. The Volta River basin is a trans-national catchment shared by six riparian countries covering about 400,000 km^2 (van de Giesen, Liebe, and Jung, 2010) (Figure 1). The watershed is 40% in Ghana, 42% in Burkina Faso, 6% in Togo, 5% in Mali, 4% in Benin, and 3% in Côte d'Ivoire (Oguntunde *et al*., 2006).

In the article, the Volta delta is defined as the land below the 5 m contour in the lower portion of the Volta River basin within the Accra-Ho-Keta Plains (Figure 2). The 5 m contour line focusses attention on the area affected by coastal processes and hazards linked to present conditions and relative sea-level rise. The Volta delta is located within latitudes 5°25′ and 6°20′ N and longitude 0°40′ and 1°10′ E along the eastern coast of Ghana and covers a total area of about 4562 km^2. To the immediate east of the Volta delta is the national border with Togo and its national capital Lomé. To the west lies Accra (the national capital of Ghana, about 40 km from the delta) and Tema (the industrial city of Ghana, about 10 km from the delta). There are nine administrative districts wholly or partially within the delta that are responsible for managing resources in the delta region shown in Figure 2.

The Volta River presently has a single outlet channel to the sea at Ada, which is associated with a large spit. The delta coast is bounded by a narrow shelf 15–33 km wide, and characterised by a fairly uniform, moderately steep shoreface with a gradient of between 1:120 and 1:150 down to 15 m, which is considered as the close-out depth for significant wave-induced sediment movement on this coast (Anthony, 2015).

The sand spits and barriers associated with the Volta delta are highly dynamic (Anthony, 2015). It also depicts the effect of human developments in the region (Boateng, 2012). The large spit of the Volta delta is a direct outgrowth of a natural change in the location of the mouth of the Volta and of a marked reduction in sand supply that predated the construction of the Akosombo Dam, but which has been strongly aggravated since the dam was constructed and the annual flood-flushing of the river mouth ceased (Anthony, Almar, and Aagaard, 2016). According to Barry *et al*. (2005); an eastward 12 km shift in the point at which the Volta River entered the sea has occurred since 1974. Radiocarbon ages from parts of the barrier front show a phased pattern of progradation from the Volta delta (Anthony, Almar, and Aagaard, 2016).

BIOPHYSICAL CHARACTERISTICS

The biophysical characteristics of a delta define how it has been formed and is being shaped today, and hence affect the environmental and ecosystem services available to delta residents.

Geological Formation

The Volta delta falls within the Keta basin (Akpati, 1978). The basin is one of several fault-controlled sedimentary basins in West Africa (Jorgensen and Banoeng-Yakubo, 2001). The geology generally comprises Quaternary rocks and unconsolidated sediments made up of clay, loose sand, and gravel deposits (Jayson-Quashigah, Appeaning Addo, and Kufogbe, 2013). The basin is underlain by the acid and basic gneisses and schists of the Dahomeyan system, which outcrop on the

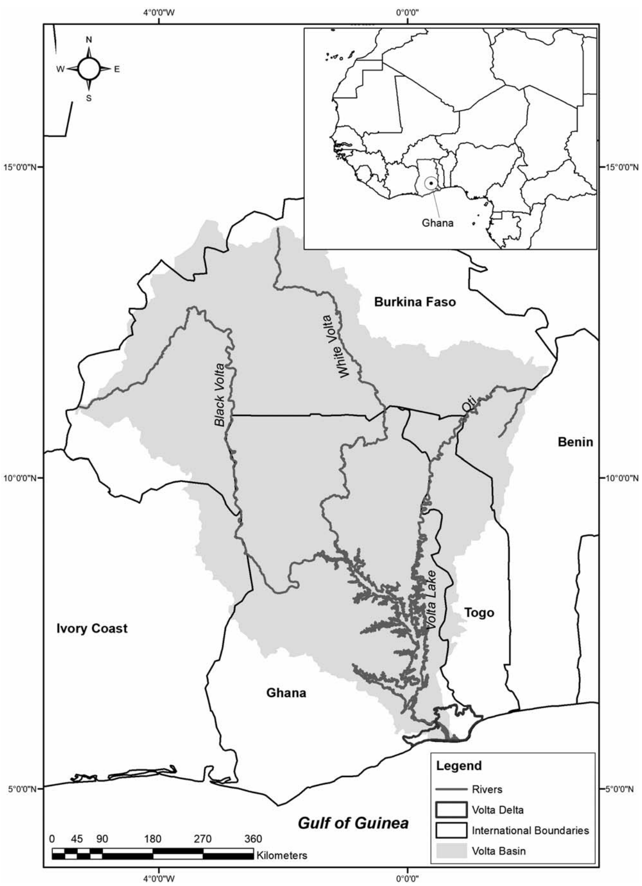

Figure 1. Part of West Africa showing the locations of the Volta delta and the three hydroelectric dams in Ghana that are influencing the delta sediment supply and morphology, and the six countries that share the water resources in the Volta Basin (Source: adapted from Rodgers *et al.*, 2006).

northern fringes of the basin (Kumapley, 1989). Geological investigations around Keta, which involved sinking of five boreholes to depths of about 20 m, revealed that the fine sand layer was only 7 m thick and is underlain to a depth of 20 m by clay and weathered shale (Kumapley, 1989). The study concluded that the soil underlying the Keta basin may be generally characterised as soft, highly compressible organic or inorganic clays overlaying fine sand to great depth (Kumapley, 1989). In addition to basement faulting, subsidence has also played a major part in the evolution of the Keta basin (Akpati, 1978). A significant portion of the landscape is characterised by the Keta Lagoon complex, the Songor lagoon, a number of creeks along the coast, and extensive marsh areas, as well as significant mangroves. Four major aquifers have been identified in the Keta basin, and they include weathered Dahomeyan gneiss along the NE rim of the basin; surficial Neogene continental deposits of unconsolidated to semiconsolidated limonitic argillaceous sands in the NE and central parts of the basin; Quaternary coastal marine sands and gravels in the Volta River estuary and Keta lagoon area; and Cretaceous–Eocene marine limestones and sandstone beds that are exploited for drinking water in the central and southern parts of the basin (Nerquaye-Tetteh, 1993). These units constitute the most important deeper aquifer in the Keta basin (Jorgensen and Banoeng-Yakubo, 2001).

Climatic Conditions

The Volta delta lies within the wet semiequatorial and the dry equatorial climatic zones (Gampson *et al.*, 2015). The climate is controlled by the movement of the Inter Tropical Convergence Zone (ITCZ) within the subregion (Dickson and Benneh, 1995). The climatic conditions of the region are influenced by the SW monsoon winds twice a year resulting in a double maximum rainfall pattern (Banoeng-Yakubo *et al.*, 2006; Gampson *et al.*, 2015): the major rain season falls between March and July, and the minor rain season is between August and November (Yidana and Chegbeleh, 2013). June is usually the wettest month of the year (Figure 3). The annual average precipitation varies significantly between 146 mm and 750 mm between years (Awadzi, Ahiabor, and Breuning-Madsen, 2008). The highest monthly mean value of 187.5 mm occurs in June, while the mean minimum value of 10.6 mm occurs in January (Yidana and Chegbeleh, 2013). From November to February is the long dry season when the NE Harmattan winds dominate in the region (Awadzi, Ahiabor, and Breuning-Madsen, 2008). This has extensive implications on the environment, water systems, health, food security, and livelihoods. Generally, the mean temperature does not fall below 25°C owing to proximity to the equator (Andah, van de Giesen, and Biney, 2003; Dickson and Benneh, 1995). The hottest months of the year are March–April (Andah, van de Giesen, and Biney, 2003). The annual evaporation is about 1785 mm, which is quite high compared with the annual rainfall in the Volta delta region (Yidana and Chegbeleh, 2013).

Catchment and Sediment Supply

The Volta River is one of the main sources of sediment supply to the Gulf of Guinea (Goussard and Ducrocq, 2014). The river drains a predominantly sandstone catchment that also includes a wide variety of lithologic terranes covering an area of about 390,000 km^2, much of which is located in the semiarid Sahel zone of West Africa (Anthony, 2015). The river's discharge varied between 1000 m^3/s in the dry season and over 6000 m^3/s in the wet season before the construction of the Akosombo Dam in 1964 (Anthony, Almar, and Aagaard, 2016). Two other dams were constructed; one at Kpong in 1982 and one at Bui in 2013 (see Figure 1). Runoff before dam construction was higher (87.5 mm/y) and more varied than the postdam period, with value of 73.5 mm/y (Oguntunde *et al.*, 2006). Given that water flow is now controlled, the natural flooding patterns of the area have also changed, and the flood plains now rely on irrigation and a reduced water supply (Corcoran, Ravilious, and Skuja, 2007). Before the construction of the dam there was regular flooding, depositing sediment, and enabling sustainable farming and vibrant fishing activities, which depended on the flood regime of the river and its subsidiary courses (Ofori *et al.*, 2016).

The yearly sediment transport before the dam construction was about 7.5 million m^3/s (Bollen *et al.*, 2011). Since the construction of the dam, there are no peaks in flow discharge, and the sediment transport is reduced to only a fraction of the

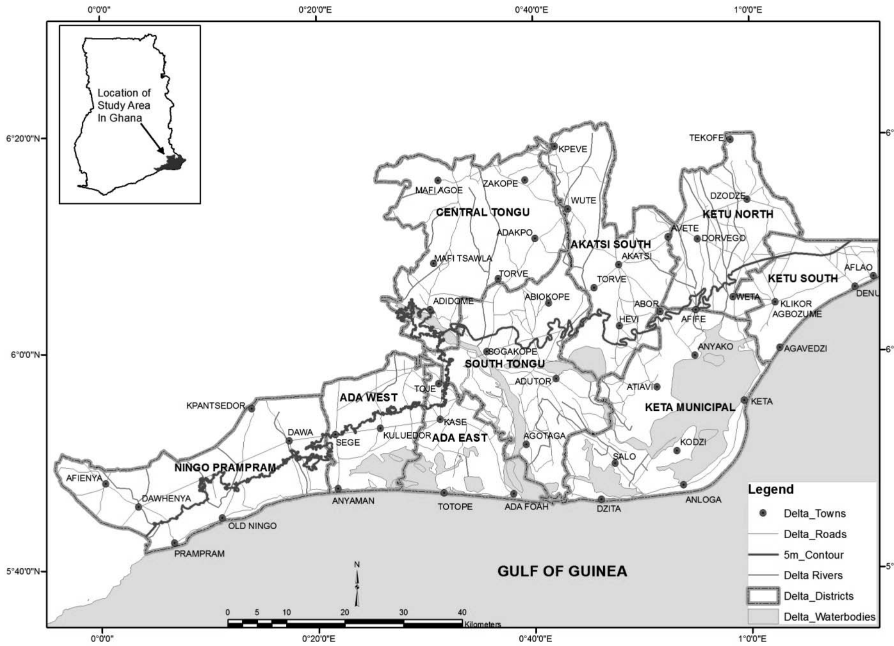

Figure 2. Map of the Volta delta region showing the 5 m contour line that defines the delta and the nine administration districts that manage resources within the delta.

original transport (Bollen *et al*., 2011). This dramatic reduction in sediment supply to the delta system has affected the evolution of the delta and resulted in significant shoreline recession (Allersma and Tilmans, 1993; Armah, 1991). Ly (1980) estimated that the shoreline in Keta was eroding at a rate between 4 and 8 m/y, while Bollen *et al*. (2011) reported that the shoreline in Totope–Ada is receding at a rate of about 6 m/y. According to Kumapley (1989), a strip of coastal land about 1 km wide has been lost to erosion since 1880s.

Oceanographic Conditions

Swell waves approach the shoreline of the delta unimpeded from the S-SW direction (Angnuureng *et al*., 2016). Waves are dominated by moderate to high energy as well as long period (Almar *et al*., 2015). The typical significant wave height is about 1.4 m with a period of about 11 seconds (Angnuureng, Appeaning Addo, and Wiafe, 2013). The waves generate significant longshore currents, which transport sediment eastward, causing one of the highest rates of annual net longshore sand drift in the world ($1–1.5 \times 10^6$ m^3/y) due to the consistent wave action and direction (Anthony and Blivi, 1999; Nairn *et al*., 1999).

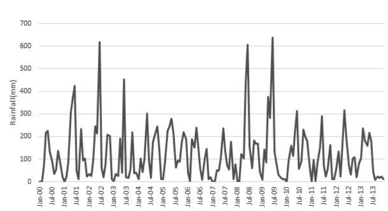

Figure 3. A graph of monthly averaged rainfall in the Volta delta from 2000 to 2013 showing the rainfall trend in the region (Source: Ghana Meteorological Agency, 2014).

Tides are semidiurnal with a tidal range of about 1 m (Appeaning Addo, Walkden, and Mills, 2008). Tidal currents are weak and have limited effect on the shoreline morphology (Wellens-Mensah, 2002). Although the environment is microtidal, a study by Angnuureng *et al*. (2016) identified that short-term evolution of the shoreline is affected by tidal cycles from neap to spring. Although the dams have greatly reduced sediment supply from the Volta River to the delta system (Ly, 1980), the strong longshore drift potential eastward is satisfied by the considerable reworking of the Holocene barrier deposits within the delta downdrift of the Volta spit (Anthony, Almar, and Aagaard, 2016; Ly, 1980). This reworking is experienced by the delta residents as the chronic erosion already described (Appeaning Addo, 2015). Figure 4 shows an example of an erosion-damaged community at Fuvemeh, within the Volta delta.

Morphology

Overall, the Volta delta has a wave-dominated form (Anthony, Oyédé, and Lang, 2002), reflecting the interplay of the sediment supply from the Volta River and sediment transport due to wave action. The delta plain is almost flat and featureless, and it descends gradually from inland to the Gulf of Guinea (Sekyi, 2004). The delta was formed by large quantities of sediment from the Volta River, including coarse-grained sand that was deposited at the river mouth (Nairn *et al*., 1999). According to Anthony (2015), the delta is asymmetric and diverted eastward over a distance of about 30 km. It is

Figure 4. Collapsed school building in Fuvemeh community, which illustrates the effect of coastal erosion on vulnerable delta communities (taken June 2016).

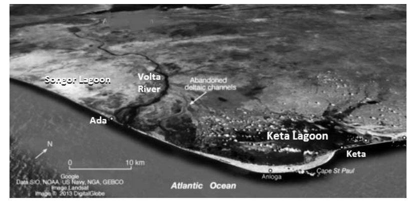

Figure 5. The Volta delta showing abandoned deltaic channels and spit in front of the Keta lagoon, which reveals the migration trend of the Volta River mouth (Source: adapted from Anthony, Almar, and Aagaard, 2016).

directly linked to the sand barrier systems of the Bight of Benin (Anthony, Almar, and Aagaard, 2016) and serves as an important source of sand for the Holocene growth of the bight shoreline (Anthony and Blivi, 1999; Anthony, Lang, and Oyédé, 1996; Anthony, Oyédé, and Lang, 2002).

The delta exhibits some natural oscillations and variations in its growth and loss (Akyeampong, 2001). According to Nairn *et al*. (1999), several thousand years ago, the river mouth of the delta was located farther east, about 20 km. However, the river mouth has migrated westward to its present location in Ada (Anthony, Almar, and Aagaard, 2016). The repositioning of the river mouth, decrease in sediment supply, and reworking of the Holocene delta plain have resulted in realignment of the delta front east of the present river mouth (Anthony, 2015; Nairn *et al*., 1999). This realignment is thought to be partially responsible for the initiation of the depositional protuberance on the delta front (Appeaning Addo, 2015; Nairn *et al*., 1999). Similar reworking of the coastal plain is seen in other deltas where sediment supply has been greatly reduced, such as the Nile (Sharif El Din, 1977). Figure 5 shows the abandoned channels of the Volta River, which shows a westward migration of the river mouth to its present location in Ada and the protruding delta front.

Vegetation and Land Use

The delta comprises extensive swamps, interspersed with short grassland mangrove areas and savannah woodland (Manson, Appeaning Addo, and Mensah, 2013). The mangrove is mainly red mangrove (Kortatsi, Young, and Mensah-Bonsu, 2005). The expanding population has altered the land cover, topography, and land use in the delta region. Figure 6 shows the land cover classes in the Volta delta in 2015. Vegetated land is increasingly being converted to agriculture and settlements (Appeaning Addo, 2015). Flood plains have been converted to both commercial and small-scale salt extraction industries (Armah *et al*., 2004). The local practice of pumping out groundwater *via* "tube well irrigation" is common in the delta region (Yaka, 2017). This has the potential to damage the fragile freshwater lenses and results in saltwater intrusion from the relatively large body of saline water underneath the aquifer (Namara *et al*., 2010). While it has not been quantified, it may also accelerate land subsidence and relative sea-level rise, as observed in other delta regions around the world (Larson, Basagaoglu, and Mariño, 2001; Woodroffe, 2010).

SOCIOECONOMIC AND DEMOGRAPHIC CHARACTERISTICS

In addition to the biophysical characteristics of the delta, it is essential to understand the socioeconomic and demographic characteristics. The socioeconomic and demographic characteristics considered in this section include gender ratio, fertility rate, language, ethnicity, religion, literacy, household, and economic characteristics.

The population of the Volta delta was 856,000 in 2010. The rural population constitutes about 64% of the total population. The gender ratio is 88 males per 100 females, which is much lower than the national gender ratio of 95.2. It has a dependency ratio of 84, meaning there are about 84 people aged under 15 and over 64 for every 100 working age people (15–64 y). The population aged below 15 years alone is about 38%. The average household size is 4.2, with about 45% of all households headed by females. The general fertility rate for the Volta delta is about 97 per 1000 females, about the same rate as the national average, and the Crude Death Rate, which is a measure of the total number of deaths per year per 1000 population within the Volta delta, is 9.5. About 24.9% of the population in the delta are migrants, *i.e*. resident in districts other than that in which they were born. This includes people from other districts within the delta area. Data from the 2000 and 2010 Population and Housing Censuses of Ghana indicate that the population of the Volta delta increased from 712,106 in 2000 to 856,050 in 2010. The population growth rate of the Volta delta over the period was 2.02%, which was lower than the national population growth rate of 2.5% (Ghana Statistical Service, 2013). The lower population growth rate in the area could partly be attributed to the high internal and international out-migration from the area due to the degradation of farmland with the construction of the Akosombo Dam in the early 1960s and declining fishing opportunities, which are the main livelihood activities of the people (Odotei, 2002; Tsikata, 2006).

The two main languages spoken in the delta area are Ewe and Ga Dangme, and they represent the two main ethnic groups in the Volta delta, which are also traditionally patrilineal. While most of the delta residents identify themselves as Christian, a sizeable proportion identify with traditional religion, and a small proportion are Muslim. Average illiteracy rate for the population aged 15 years and

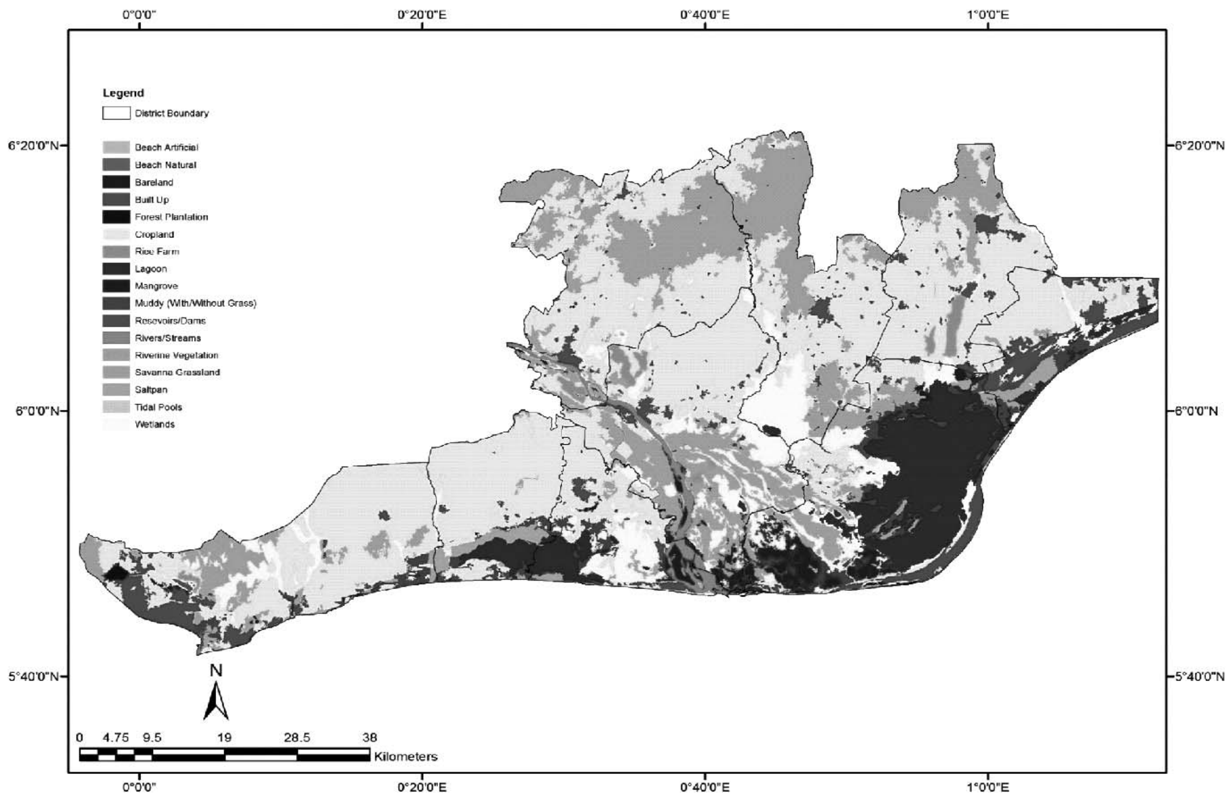

Figure 6. Map showing the various land cover classes that prevail in the Volta delta for 2015.

above is about 30%, with generally higher illiteracy among females than males (Ghana Statistical Service, 2013). The dominant types of dwelling are the compound house and separate structures, with a little over 60% of dwelling units owned by household members (Ghana Statistical Service, 2013). Outer wall materials of buildings are mainly concrete or cement block, and the main source of lighting is the kerosene lamp. This is closely followed by electricity connected to the national grid. Owing to rapid rural electrification, this pattern is expected to significantly change. Biomass (wood, charcoal, sawdust, *etc.*) constitutes the main source of cooking fuels for households. While the main source of drinking water and household water use is pipe-borne, other unimproved sources, including groundwater from wells and open water sources, are not uncommon in the delta area.

The Volta delta has a diverse economy including agriculture, fisheries, salt harvesting, and sand mining, as well as tourism. The agricultural sector is important, with the fishing sector being relatively active, and collectively they provide significant employment (Osei-Wusu *et al.*, 2016). Crop production constitutes the bigger share of agriculture, followed by livestock. Crops produced include maize, cassava, rice, and vegetables. Other economic activities include agro-industry, transportation, and tourism. The agriculture sector accounts for a higher proportion of female employment than male employment (Barry *et al.*, 2005). Women in the Volta delta region depend on the agriculture sector for securing their livelihood. Reduced fallow periods have resulted in degradation of the soil, while livestock production is becoming a source of concern, since growing livestock use exceeds the carrying capacity of the ecosystem (Barry *et al.*, 2005). Coconut production was a major cash crop in the delta in the 19th century. However, owing to economic recession in the 1930s, the coconut production was affected by Cape Saint Paul Wilt disease (a lethal yellowing type disease of coconut), which led to the collapse of the industry (Eziashi and Omamor, 2010). In addition, the growing population has forced more intensive agricultural systems over coconut production (Awadzi, Ahiabor, and Breuning-Madsen, 2008). This led to the production of shallot and other horticulture products in the area using organic manure and irrigation. Land ownership is very crucial in farming, and because of the nature of the vegetation of the delta, farmers apply organic manure and other agro-chemicals to enrich the fertility of the soil. In the past, families generally acquired lands through occupation and use of the land for farming activities (Kludze, 1973). However, owing to population growth, almost all space in the delta is now occupied or belongs to some family.

Although aquaculture practices are presently relatively minor in the delta region, they have a large potential to supplement the declining marine fish stock in the future (Amponsah *et al.*, 2015). Other emerging economic activities in the region are charcoal burning, which involves cutting of wood (Akrasi, 2005), and salt production (Barry *et al.*, 2005). Coastal sand mining is a major activity practiced along the entire coast of Ghana and more widely in West Africa (Angnuureng, Appeaning Addo, and Wiafe, 2013; Anim, Nkrumah, and David, 2013; Appeaning Addo, Walkden, and Mills, 2008; Jonah *et al*., 2015; Wiafe *et al*., 2013). Although the practice is illegal, lack of enforcement has failed to stop this activity. Beach sand is mined for the construction industry, providing a ready market (Mensah, 1997). The construction sector in coastal areas relies heavily on coastal sand and pebbles in the building of houses, bridges, and roads, and it is an important source of employment (Anim, Nkrumah, and David, 2013). The sand is either packed into bags before transport or used to mould 'sandcrete' blocks on the beaches and sold. Sand mining has contributed significantly to the increased erosion along the delta coast, since it negatively influences the sediment budget (Appeaning Addo, 2015).

The availability of fertile soil, water, and ready markets has influenced the development of small-scale agricultural industries, mainly farming and fishing, and positioned agriculture as a major economic driver (in terms of employment) in the delta region (Osei-Wusu *et al*., 2016). Such activities usually result in over exploitation of resources and generate long lasting negative interactions between the population and the environment (Ishimaru, Kobayashi, and Yoshikawa, 2014). The fishing industry supplies both dried and salted fish to other parts of the country. Unemployment is lower in the delta at 4.3% compared with the national average of 5.3% and is generally higher among females than males (Ghana Statistical Service, 2013).

DRIVERS OF CHANGE

The Volta delta, like most delta regions globally, is a dynamic and rich environment that is constantly changing in time and space (Dada *et al*., 2016). These changes impact the socioeconomic indicators in the delta region significantly. Various factors, which combine to drive the changes, can be classified as either natural or anthropogenic. In most instances, the anthropogenic factors tend to exacerbate the natural effects.

Climate change related events such as rainfall variability, flooding from both marine and riverine sides, drought, sea-level rise, storm surge, and increased temperature that have influenced the physical and biological conditions are some of the natural drivers of change in the delta system. The human-induced changes mainly occur as a result of interruptions in the hydrology and the landscape.

Energetic swell waves and storm surge facilitate flooding events on the coast from the marine side, exacerbated by erosion due to multiple causes and relative sea-level rise. Flooding from the riverine side is also experienced after heavy rainfall. According to van de Giesen, Liebe, and Jung (2010), although the onset of the rainy season has changed due to climate variability, rainfall intensity within the rainy season has increased, which has resulted in more frequent flooding. The floods impact livelihoods, threaten lives and properties, and result in migration of the displaced households.

The relatively high longshore sediment transport rate (Anthony and Blivi, 1999) and the dams on the Volta River partly account for the increased erosion in the vulnerable areas of the delta region. Mining of beach sand for the construction industry has further increased the sediment deficit and thereby increased erosion problems. The construction of the Akosombo Dam modified the Volta River hydrology. This resulted in waterborne diseases such as schistosomiasis (Ofori *et al*., 2016) and the introduction of water plants that affected aquatic life in the Volta River (Gyau-Boakye, 2001). Extraction of underground water for irrigated farming practices has resulted in subsidence. Although subsidence in the Volta delta has not been measured, it is projected to be 1 to 2 mm/y based on other deltas (Syvitski, 2008). Plans for prospecting for oil and gas within the delta region are advancing (Setordzi and Nyavor, 2015), which usually increases subsidence rates (Syvitski, 2008). Figure 7 summarises the environmental and social characteristics of the Volta delta as well as the factors that combine to drive changes in the delta system.

DISCUSSION

Human activities in the Volta delta region have resulted in significant biophysical and socioeconomic changes in the deltaic environment. The relatively high illiteracy rate, increasing population, overharvesting of vegetation for charcoal production, and coastal sand mining in the delta region coupled with environmental stressors have adversely impacted the delta environment. This has resulted in considerable changes in the land cover/use pattern in the region. Agriculture as the main source of livelihood and an avenue for employment in the delta region is climate dependent. A prolonged period of drought, increased temperature, and variability in rainfall pattern has affected the agriculture sector. This has implications for the economic and social life of the inhabitants in the delta region. The high dependency ratio in the delta region poses social, cultural, and economic risks, since this could reduce economic growth (Pettinger, 2012). This means that the economically active proportion of the population will need to provide the social and economic needs of the nonworking population (Ingham, Chirijevskis, and Carmichael, 2009). Although the female population in the region has a lower literacy rate compared with the male population, their role in the delta community is significant, since they constitute about 45% of household heads. Since the household is regarded as the fundamental social and/ or economic unit of society (Zarhani, 2011), the role of women in influencing the economic, social, and political interactions in the delta region is key (Sanni, 2006).

The dams on the Volta River, coupled with rainfall variability over the Sahel region of West Africa, have affected the freshwater and sediment input into the delta system and the sea. This has potential effects on water and food security in the future. Changes in the natural flooding pattern of the flood plain have negatively impacted agricultural production, which employs a greater proportion of the female population in the delta region. Farmers practice either rain-fed farming, which is affected by changing climatic conditions, or irrigated farming, which increases the cost of production. Methods of clearing the land for farming through bush burning and shortened fallow periods have degraded the soil and increased vulnerability in the delta region. This, coupled with increased population growth in the delta region, has led to agricultural intensification and also promoted migration of people to other places in search of alternative sources of livelihood.

Reduced sediment discharge rate has affected the sediment budget regime, altered the natural evolution trend in the delta system, and increased erosion. Reworking of the sediments of the coastal plain to sustain the longshore drift dynamics and beach mining has further worsened the erosion situation. Coastal erosion has destroyed properties, reduced livelihoods, displaced households, and widened gender gaps as women often bear a disproportionate share of the social costs (Boateng, 2012; Ofori *et al*., 2016). Climate change and its associated sea-level rise pose major challenges to the sustainability of deltas globally (Nicholls and Cazenave, 2010; Syvitski, 2008).

While erosion is a major process, other trends are less quantified. Ground water extraction for irrigation and domestic use may have increased the rate of subsidence. The frequency and intensity of the flooding events appears to have increased in recent times (Gakpo, 2016). Saltwater intrusion is locally important, which has significant consequences for coastal farming. In the future, flooding and saltwater intrusion have a huge potential impact on future food production and other coastal activities in the delta region.

Managers of erosion and flooding in the coastal zone of Ghana have adopted the hard engineering approach option. The approach uses rock groynes, or revetments, or a combination of the two methods. Although the method has been effective in solving localized erosion problems, *e.g*., in Keta, they have also transferred erosion problems downdrift (Appeaning Addo, 2015). Communities along the downdrift coast such as Kedzi and Hlorve, which were not experiencing severe erosion before the Keta sea defence project, are now eroding at faster rates (Wiafe *et al*., 2013). Angnuureng, Appeaning Addo, and Wiafe (2013) estimated the rate of erosion in these communities and identified erosion of up to 17 m/y in some locations. This suggests that sectoral management of erosion problems has not been successful. There is the need for a critical review of the effectiveness of the hard engineering ('hold the line') approach and the possibility of adopting new methods such as relocation (*i.e*. a managed retreat or 'managed realignment') in managing erosion and flood problems in the delta (Nicholls *et al*., 2013). Lack of effective coastal erosion management policies has also prevented adoption of an integrated approach in managing erosion and flood problems (Boateng, 2012).

In the past, major economic activities such as farming, fishing, salt production, services, and construction have attracted migrants to the delta region. The prospects of producing oil in commercial quantities in the region will probably further increase the rate of migration to the delta region. Although agriculture related activities and fishing are major sources of livelihood and have employed a significant percentage of the population, they are also associated with several problems. Some of these problems include the high cost of agricultural inputs, lack of access to credit facilities, inadequate extension officers from the government, postharvest loss, rainfall variability, saltwater intrusion, and reduced marine fish stock. These problems partly explain why coastal sand mining activity and harvesting of mangroves have become important industries despite their negative effect on the environment. Measures to enhance the delta communities' stewardship toward improving the sustainability of coastal resources need to be investigated through research to help reduce negative practices in the deltaic region. This is significant since the current trend in resource exploitation will result in increased uncontrolled hydrological, ecological, and landscape changes in the future, which will pose great threats to the sustained provision of delta services.

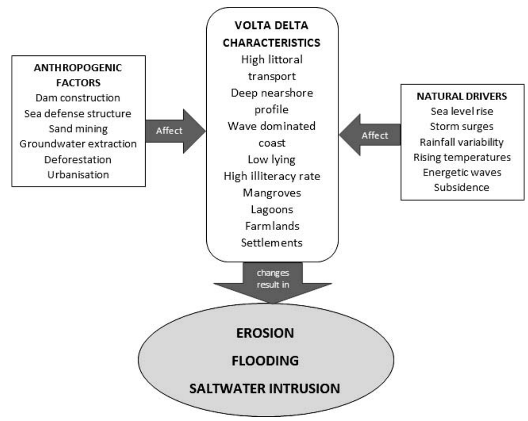

Figure 7. Volta delta characteristics and factors that drive change in the delta system.

CONCLUSIONS

This review of the evolution of the Volta delta highlights the influence of physical processes and human activities over the last 50 years. The complexity and the diversity of the problems that affect the Volta delta clearly require a multidisciplinary and an integrated approach to interpret the dynamic relationships. Particularly, there will be the need to be concerned with understanding the physical response of the area to the effects of expected climatic changes and the influence of human activities to these responses. As the delta population increases and the delta economy develops, the impact of sea-level rise as a result of climate change and subsidence in the vulnerable delta communities will be significant. The pressure on the delta will call for a new approach to increase the resilience of the delta. The concept of 'green' adaptive planning, which will ensure sustainable use of the vegetation and limited restrictions on the natural dynamics of the water bodies in the delta environment, should be encouraged. There is therefore a need to consider the historic evolution trends of the delta system to enable a better understanding of how it might evolve in the future under climate change and other drivers of change. An effective monitoring system combined with modelling efforts to explore past and possible future changes should be developed to generate early warning systems strategies to inform the communities and prepare for adaptation as needed.

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