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SHORELINE CHANGE ANALYSIS OF THE EASTERN COAST OF GHANA BETWEEN 1991 AND 2020

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Abstract

The Eastern Coastline of Ghana is facing intense natural and anthropogenic disturbances, which pose a serious threat to the coastal community, ecosystem, and livelihoods. This study assessed the shoreline changes occurring along the Eastern Coast of Ghana stretching 149 km from Laloi Lagoon West of Prampram to Aflao, Ghana. The study utilizes satellite images from Landsat 4TM, Landsat 7 ETM+, and Landsat 8 OLI taken between 1991 and 2020. Data pre-processing techniques using ENVI 5.3 included calibration, layer stacking, mosaicking, and supervised classification. Post-classification shorelines were extracted using ArcGIS 10.7, and the DSAS tool was used to determine the rate of change over the 29-year period. The results showed that the coastline experienced an average erosion rate of 9 m/y and a maximum rate of 24 m/y, however, the accretion rate (3 m/y) was much lower, reflecting general coastline retreat. Thus, some 25 coastal communities are highly exposed to shoreline erosion. Sustaining the coastal area may require coastline re-engineering interventions. This study recommends continuous monitoring of the shorelines to ensure the protection of livelihoods. Implementation of both hard engineering and ecosystem-based adaptation strategies may be required to achieve holistic results toward sustainable coastal management.

Keywords: shoreline change, remote sensing, coastal vulnerability, coastal erosion, coastal accretion

INTRODUCTION

Globally, coastal zones are facing intense natural and anthropogenic disturbances related to sea level rise, coastal erosion, sand winning, and depletion of mangroves, which poses numerous threats to coastal regions (Appeaning Addo et al., 2011; IPCC, 2022). The threat to coastal ecosystems and coastal livelihoods has increased the awareness to accelerate efforts to assess, monitor and mitigate coastal stressors (Zhang, 2010). Monitoring spatial and temporal changes in coastal settings is one of the initiatives that can help understand the spatial distribution of erosion hazards and predict their rate and their spatiotemporal changes.

The shoreline is defined as the location of the land-water interface at any given time (Gens, 2010). Shoreline change is a highly dynamic process that serves as a predictor of coastal erosion and accretion. Globally, coastal areas have lost 28,000 km^2 and gained 14,000 km^2 of coastal land between the period of 1984 and 2015 (Mentaschi et al., 2018). This translates into the net loss of 14,000 km^2 of coastal lands for human and terrestrial habitats. Luijendijk et al. (2018) using satellite imagery between the period of 1984 and 2016 show that 31% of the world's beaches are sandy. Out of this proportion, 24% are eroding at rates of 0.5 m/yr while 28% are accreting and 48% are stable.

Shoreline erosion, coastal inundation, and coastal resource degradation are among the possible risks that Ghana's coastal communities are facing. Climate change, rapid urbanization, and accompanying anthropogenic beach modifications intensify shoreline erosion and accretion (Ekow, 2015; Appeaning Addo, 2015).

Ghana's coastline is approximately 550 kilometers long below the 30 m contour above sea level, which makes it prone to erosion (Ekow, 2015). The seashore is split into three sections based on their geomorphological characteristics. All of these have been identified to be vulnerable due to the frequency of coastal erosion, tidal waves, and sea level rise coupled with anthropogenic factors. The Eastern Coast, in particular, has suffered a variety of geomorphological events (Appeaning Addo et al., 2008; Jayson-Quashigah et al., 2021). These events are especially effective, due to the low-lying lands, unconsolidated sediments, shoreline orientation, and sediment starvation (littoral) from the Volta River after the construction of the Akosombo Hydroelectric Dam. The effects of the dam have exposed the entire coast from Laloi lagoon west of Prampram to Aflao to increased rates of erosion, tidal waves, inundation, and floods, especially from Atorkor to Keta (Ly, 1980; Appeaning Addo et al., 2011; Anthony et al., 2016).

The eastern portion of the coast is predicted to lose between 2 and 7 million m^3 of sand per year owing to continual erosion (Appeaning Addo et al., 2011; Evadzi et al., 2017). As a result, most coastal settlements have been displaced, commercial operations have been destroyed (ships no longer dock at Keta), educational, residential, and historical structures have been lost, and the lagoon basin has been silted. Other notable issues resulting from climate change (sea level rise) include the loss of agricultural land (erosion and salinization), reduced soil fertility, which results in poor yields, as well as a decrease in fish catch (both lagoon and marine), and perennial flooding of farms, which causes migration (Anthony et al., 2016).

Even though interventions have been made, such as the Keta Sea Defense Project (GLDD, 2001), the Dzita-Atorkor Sea Defence work, and the Ada Sea Defense Project to stabilize the shoreline with breakwater, these efforts have not yielded the needed results as coastal communities still suffer devastating events (Jayson-Quashigah et al., 2021).

Oceanographers, geologists, and geomorphologists have developed diverse techniques to monitor shorelines using maps and aerial photographs (Kawakubo, et al., 2011). Although these methods are effective, they are expensive and time-consuming. On the other hand, recent advances in remote sensing techniques, allow researchers to process large-scale data effectively in a low-cost manner (Berlanga-Robles and Ruiz-Luna, 2002). This is because multispectral satellites capture digital pictures in many spectral bands, including the near-infrared, where the land-water interface is well-defined. Thus, Appeaning Addo et al. (2011) highlighted the prominence of remote sensing data as the preferred choice for monitoring shorelines. Additional benefits of using the remote sensing approach include large ground coverage, relatively less time-consuming, and less expensive coupled with the ability to repeat data acquisition, and monitoring (Van and Bihn, 2008).

Distinguished studies carried out on shorelines, coastal erosion, and identifying hotspots in Ghana show that areas on the Eastern Coast, particularly the Keta shoreline is highly dynamic, with an average rate of erosion estimated to be about 2±0.44 m/y (Appeaning Addo et al., 2011). Individual rates along some transect reach as high as 16 m/year, for example near the estuary and on the east of the Keta Sea Defence. In the coastal zones of Greater Accra, the rise in sea level is influencing shoreline change (Appeaning Addo, 2009; Appeaning Addo and Adeyemi, 2013). Furthermore, studies by Dadson, et al. (2016) have shown that accretion and erosion are both active and have contributed to the fluctuations of the shorelines along the Western coast of Ghana disproportionately.

In essence, most studies conducted on shoreline change either analyze it on a spatio-temporal basis with a focus on particular hotspots (Appeaning Addo et al., 2011; Appeaning Addo and Adeyemi, 2013), or combine primary and secondary data to determine the rate of change at specified study sites (Dadson et al., 2016; Evadzi et al., 2017). Specifically, studies on shoreline changes on the Eastern Coast have mostly focused on Keta due to the presence of the Sea Defence wall (Appeaning Addo et al., 2011; Jayson-Quashigah et al., 2021), which presents a narrow scope of the challenges experienced on the Eastern Coast.

The continuous changes observed in shorelines present socio-economic problems to coastal communities. In essence, to reduce the loss of coastal livelihoods, it is crucial to understand shoreline dynamics driven by complex and uneven magnitudes of events (Chu et al., 2006, Appeaning Addo et al., 2011). Analyzing shoreline changes is essential in environmental monitoring and coastal zone management (Van and Bihn, 2008). Hence a historic assessment of the changing shorelines of the Eastern Coast will present a cumulative outcome of events and processes (natural and anthropogenic) that have altered the shoreline from 1991 to 2020 with the focus of informing coastal management practices. Thus, our aims are to (1) examine the erosion trends; (2) assess the drivers of shoreline changes; and (3) identify exposed communities along the Eastern Coast of Ghana. This will provide a basis to channel government resources in targeting coastal communities that are most vulnerable towards achieving SDG 13 (climate action), SDG 10 (reduced inequalities), and SDG 11 (sustainable cities and communities) towards the future that we want (sustainable development).

MATERIALS AND METHODS

Study Area

The study is focused on the Eastern Coast of Ghana. Ghana's coastal zone is divided into three sections (Fig. 1A): Western, Central, and Eastern based on their geomorphological characteristics (Ly, 1980; Appeaning Addo et al., 2011). Our study was conducted on the Eastern Coast, which is 149 km long and stretches from Aflao in the East to the Laloi Lagoon west of Prampram (Fig. 1B). The Eastern Coast is a sandy shoreline, and it is characterized by the eroding delta of the Volta River. The delta was formed in the Quaternary and was built of clay, loose sand, and gravel (Ly, 1980; Boateng 2012). In addition, the Eastern Coast is characterized by high-energy waves; their heights exceed 1 m in the surf zone. Along the coast, the tidal range is between 0.68 m and 1.32 m (Wellens-Mensah et al., 2002, Boateng 2012). This is because the study area is influenced by the southwest monsoon winds which blow at an orientation of 45°.

The study area is characterized by an erodible sandy shoreline with barrier beaches and lagoon-constricting bars. The area's backshore is low-lying, including marshlands, coastal plains, and water bodies (Kusimi and Dika, 2012). The area is also characterized by sand and barrier beaches and sand bars along the shore with spatially and temporally varying widths (Boateng, 2012). On the backshore of the Eastern Coast, there are two main water bodies, the Volta delta, and the Keta lagoon. The Keta lagoon is Ghana's largest lagoon, with a huge wetland that stretches to the Volta delta (Fig. 1B). Under the Ghana Wetlands Management Project, the wetland has been declared a Ramsar site, but it is one of the most vulnerable sites in Ghana. The lagoon fresh water is separated from the Gulf of Guinea sea water by a strip of land spanning from the east of the Volta estuary to the mouth of the Keta lagoon. This swath of land was formed by the deposit of river sediment from the Volta River (Ly, 1980). The prevailing unconsolidated geology along the study area's coastlines provides a significant source of sediment to the shoreline (Boateng, 2009).

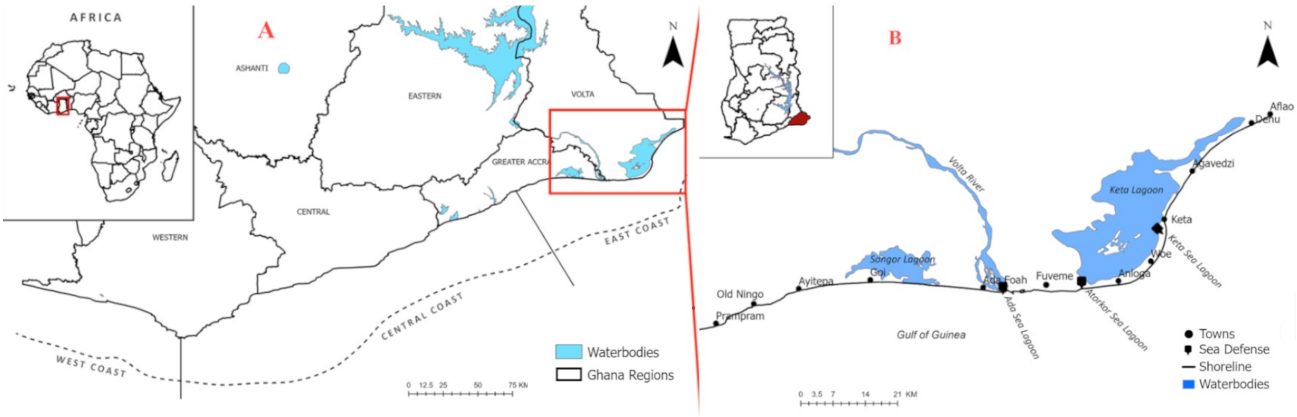

Fig. 1 The study area is in the demarcated coastal region of Ghana (A).
The study was performed on the Eastern Coast where several settlements and lagoons are located (B).

Data type and source

Landsat data series (4 TM, 7 EMT+, and 8 OLI) from 1991 to 2020 was used to track and discern the shoreline changes of the Eastern Coast. The images (taken in 1991, 2001, 2011, and 2020) were acquired from the USGS website (Table 1). Landsat images have proven to be useful for studies relevant to coastal zone management according to several authors (Pardo-Pascual et al., 2012; Liu et al., 2017; Wicaksono et al., 2019), therefore we also applied them.

Data pre-processing, shoreline extraction, and analysis

The ENVI 5.3 and ArcGIS Desktop 10.7 software were used in this investigation. Using the bilinear resampling method, the panchromatic band of the Landsat images was used to pan-sharpen the images to a 15 m resolution. This aided in sharpening the image and defining the water-land divide. All the images were registered using the 1991 image as the base image to geometrically align each image (image-to-image rectification) in the same coordinate system (Projected Coordinate System: UTM Zone 30N) so that the matching pixels represented the same item. The separation of water and land was then accomplished through the supervised classification of two classes. The final product was exported to ArcGIS Desktop as a Shapefile.

The data was cleaned using ArcGIS editing tools. ArcGIS add-on tool the Digital Shoreline Analysis System (DSAS) version 5.1 was mainly used for data processing (Appeaning Addo et al., 2011; Dadson et al., 2016; Zonkoun et al., 2022). This is a tool for calculating the rate of change of the shoreline from various shoreline positions over time. It provides a solid set of regression rates in a consistent and easily reproducible way that can be used to analyze vast amounts of data at various scales (Bheeroo et al., 2016; Nassar et al., 2019) Attribute data was added to the shoreline data extracted according to the demands of DSAS. The flat line-end type was used to buffer the merged shoreline data at 150 meters. Using ArcGIS editing tools, the onshore part of this buffer was digitized. Using the seaward intersection option, the default parameters of the DSAS add-on were set using the coastline and baseline data in a personal database. Transects were created with a maximum search distance of 1500 m from the baseline and a transect spacing of 200 m. A total of 772 transects were created at 200 m intervals throughout the entire stretch of shoreline from east to west. From the baseline, the transects were cast at simple right angles. The transect generated was used to calculate change statistics. The shoreline change rates were calculated using the Linear Regression Rate (LRR) statistical approach during the full study period (1991-2020). The LRR was preferred because it minimizes potential random error and short-term unpredictability. The LRR was chosen as the most statistically robust strategy. Scholars have used various methods to study shoreline change analyses. These methods include unmanned aerial vehicles (drones) to assess lateral shoreline change analysis (Jayson-Quashigah et al., 2019; Angnuureng et al., 2022). Others also rely on aerial photographs (Solomon, 2005; Ford, 2013;), or on field surveys (Crowell et al., 1991). But

Table 1 Characteristics of the applied Landsat images.

Year	Sensor	Date	Path and row	Spatial resolution (m)	Radiometric resolution (bits)
1991	Landsat 4 TM	03/01/1991 10/01/1991	192/056 193/056	30*30	8
2001	Landsat 7 ETM +	14/11/2001 21/11/2001	192/056 193/056	30*30	8
2011	Landsat 7 ETM+	10/01/2011 01/01/2011	192/056 193/056	30*30	8
2020	Landsat 8 OLI	01/01/2020 13/01/2020	192/056 193/056	30*30	12

in recent times, most scholars apply satellite imagery, because it is less expensive yet effective, particularly for historic studies as compared to other methods. Some studies have used a combination of multiple approaches (Appeaning Addo et al., 2011; Zagòrski et al., 2020), while others have used a single method in isolation.

Limitations

The study relied solely on satellite image analysis for assessing shoreline change over the study area. The greatest limitations of the Landsat Imagery to evaluate sub-pixel-rate erosion and accretion over time hinges on geometric and radiometric distortions associated with satellite movement and topography. However, these distortions were corrected using ground control points from the survey and mapping division of the Lands Commission of Ghana, the official government institution responsible for land mapping and survey. The study results were validated using Google Earth and point vector data of towns in Ghana, which confirmed the accuracy of the results.

RESULTS

Shoreline positions of Ghana's Eastern Coast

For shoreline analysis, a total of four shorelines were retrieved from satellite images. The findings demonstrate that major changes in erosion and accretion have occurred throughout the Eastern Coast (Fig. 2) over a 29-year period.

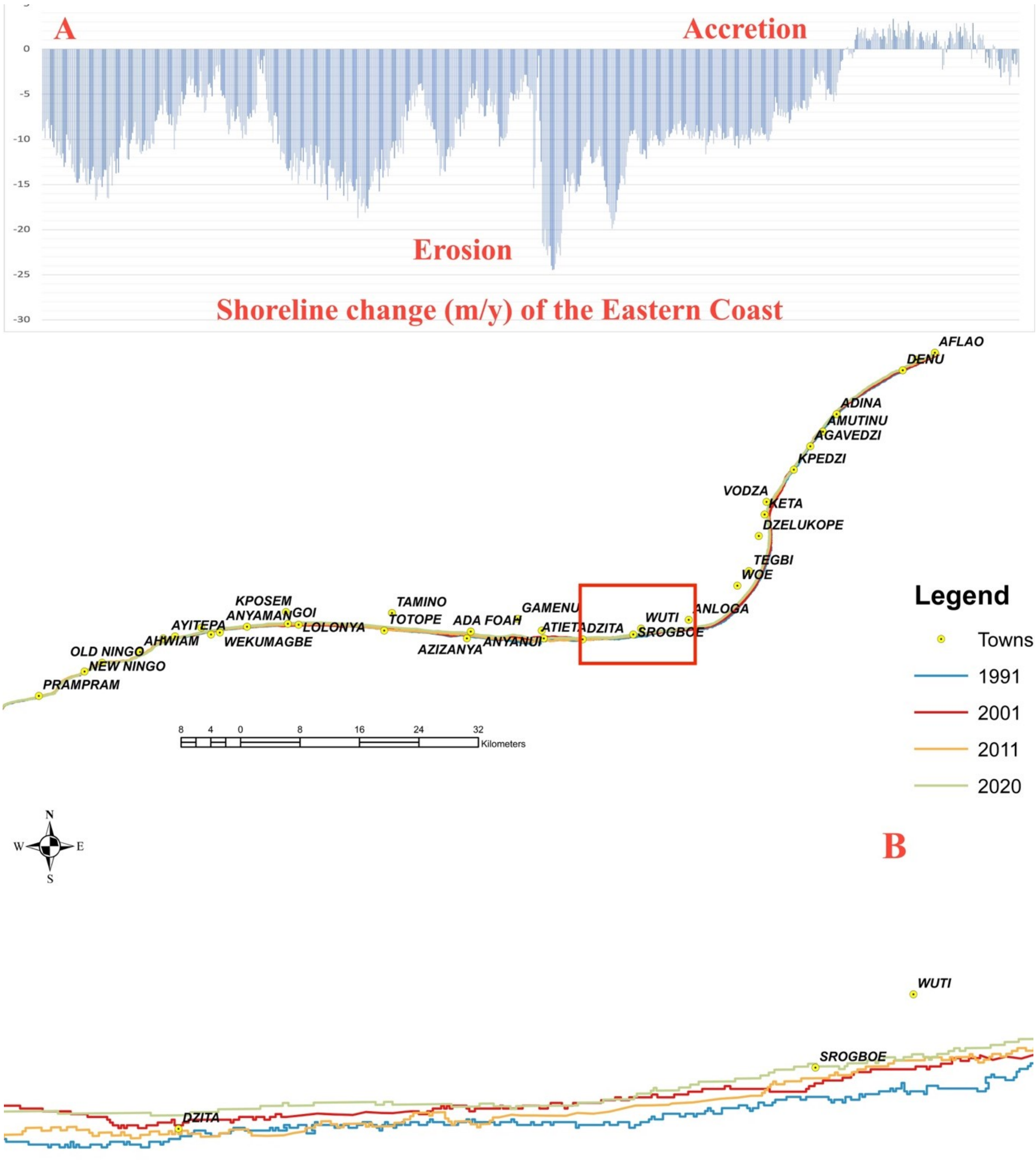

Fig. 2 Shoreline changes of the Eastern Coast (A) and a zoomed section (B) with coastal towns.

The results of the analysis show that between 1991 and 2020 the shorelines have experienced both erosion and accretion (Fig. 3). Based on the 772 transects, the average rate of shoreline change was 8.0±2.6m/y, thus in general erosion was the dominant process. Out of the 772 transects, 670 (86.79%) were erosional with 38.47% statistically significant. The highest rate of erosion was 24.5 m/y recorded at transect 405 and the lowest rate was 0.4 m/y. The mean rate of erosion at the Eastern Coast from 1991 to 2020 was 9 m/y. The number of accretional transects was 102 which represented 13.21% with 0% statistically significant accretion. The highest accretion rate was 3 m/y recorded at transect 674, and the lowest accumulation rate was 0.02 m/y. The mean rate of accretion was 1.5 m/y.

Temporal analysis showed that the period between 1991 to 2001 revealed that erosion ranged from 0.01 m to 16 m while accretion from 0.02 m to 2.9 m (Table 2). Overall, the average erosion difference between 1991 to 2001 was 4 m/y while the average accretion was 0.3 m/y. Secondly, the period from 2001 to 2011 also showed that erosion ranged from 0.8 m to 18 m while accretion from 0.4 m to 2.9 m. The average erosion for the period 2001 to 2011 was 3 m/y while accretion was 0.2 m/y.

Again, the period from 2011 to 2020 showed erosion rates from 0.7 m to 24 m accretion ranging from 0.4 m to 3 m with an average erosion rate of 2 m/y and an average accretion rate of 0.4 m/y. Finally, the period from 1991 to 2020 showed that erosion rates ranged from 0.01 m to 24 m while accretion rates ranged from 0.02m to 3m with an average erosion rate of 9 m/y and an average accretion rate of 1.5 m/y

Table 2 Temporal changes of the dynamism of the entire studied shoreline between selected years.

Period	Erosion (m/y)	Accretion (m/y)
1991-2001	4	0.3
2001-2011	3	0.2
2011-2020	2	0.4
Total: 1991-2020	9	1.5

The total change in the location of coastline between 1991 and 2020 is presented by the Linear Regression Rate (LRR). Figure 5 shows LRR of the transects for the four different years (1991, 2001, 2011 and 2020) using DSAS. The areas west of Keta generally experience erosion while areas east of Keta towards Aflao experience reduced rates of erosion and accretion.

In summary, within the 149 km long Eastern Coast, shoreline changes over the years have been observed ranging from very high erosion (24 m/y) to very low erosion (0.4 m/y). In addition, accretion rates observed also ranged from maximum accretion (3 m/y) to very low accretion (0.02 m/y).

The changing location of the coastline was merged with community locations as point data to give spatial reference and identification. The study identified 25 communities that fell in between the changing shorelines. These communities continue to suffer coastal erosion and tidal waves for 29 years (period of study).

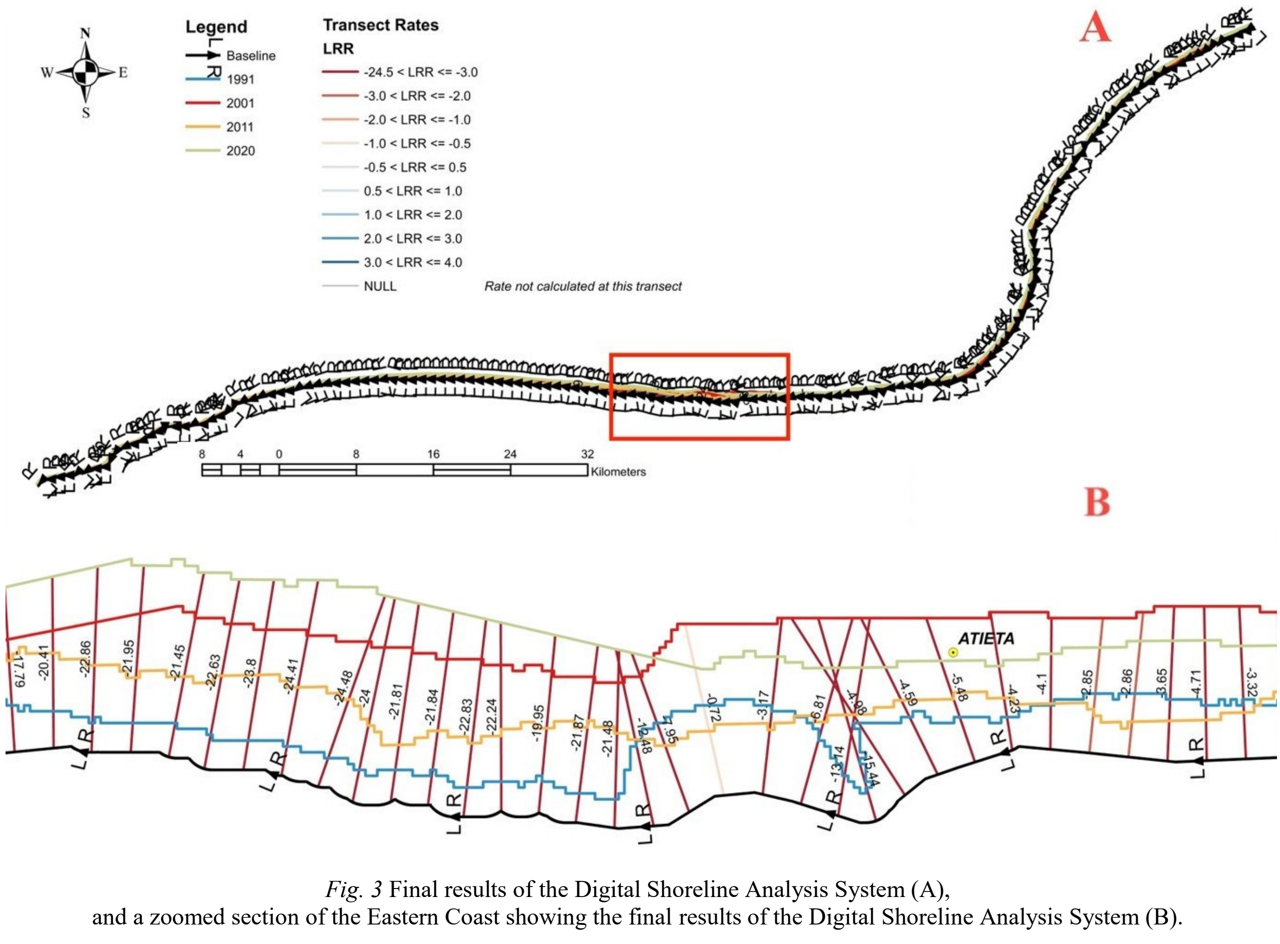

Fig. 3 Final results of the Digital Shoreline Analysis System (A), and a zoomed section of the Eastern Coast showing the final results of the Digital Shoreline Analysis System (B).

DISCUSSION

Erosion trends of the Eastern Coast

The findings from the shoreline change analysis showed that the Eastern Coast has been experiencing erosion and accretion over the past three decades. Erosion along the coast has been rapid with increasing anthropogenic activities which continues to expose coastal communities to coastal hazards. Erosion trends along the Eastern Coast are traced to the construction of the Akosombo Dam in 1962 which reduced alluvial deposits and increased erosion rates to 8 m/y as compared to 4 m/y before the construction of the dam (Ly, 1980; Appeaning Addo et al., 2011). The results of this study revealed an ongoing erosion process with pockets of accretion which has been intensified along the entire coast for the period of the study with an average erosion rate of 9m/y and a maximum rate of 24 m/y around the estuary. Pockets of accretion with an average rate of 1.5m and a maximum rate of 3 m/y were also recorded at the eastern portions of the Eastern Coastline as shown in Figure 2. The temporal changes (i.e 1991–2001) have revealed that coastal erosion has increased within the study period at different rates. The period between 1991 to 2001 recorded an

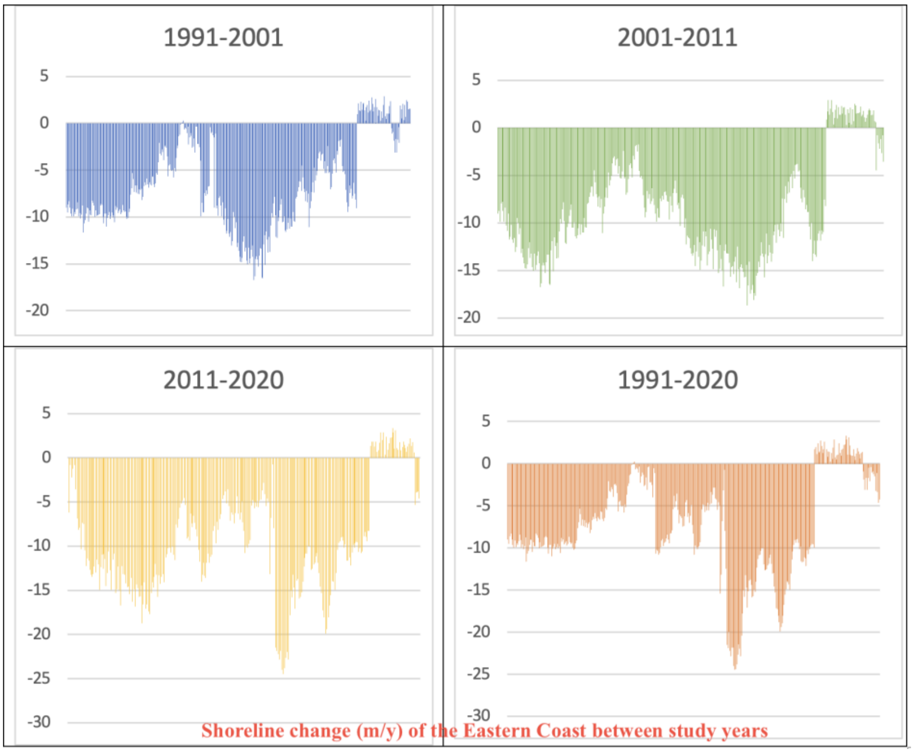

Fig. 4 Temporal changes in erosion and accumulation of the coastline between the selected years

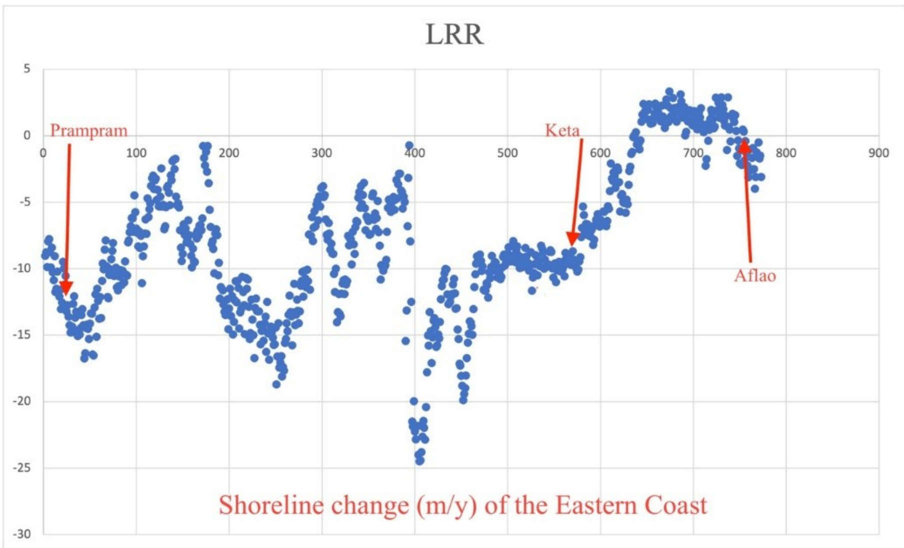

Fig. 5 The linear regression rate (LRR) of the transects represents the total change in the location of the coastline between 1991 and 2020.

average erosion of 4m/y and an average accretion of 0.3 m/y which was higher than the average erosion rate of 3 m/y and an average accretion rate of 0.2 m/y for the period 2001-2011. In addition, the period between 2011 and 2020 recorded the lowest average erosion of 2 m/y and an average accretion rate of 0.4 m/y. Finally, the period between 1991 to 2020 revealed an incremental erosion average of 9 m/y and an average accretion rate of 1.5 m/y. The wide distribution of erosion shows that the western portion of the coastline saw an increase in erosion rates from 13 m/y (1991-2001) to 16 m/y (2001-2011) and maintained the 16 m/y from 2011 to 2020. The middle portion of the coastline around the estuarine region also witnessed an increase in erosion rates from 16 m/y in 1991 to 2001 to 18 m/y from 2001 to 2011 and further increased from 18 m/y to 24 m/y from 2011 to 2020 (Figure 4). The estuarine region, given its physical characteristics of flat and unimpeded shoreline, constantly generates wave action that transports sediments eastward (Codjoe et al., 2020). In addition, the construction of sea defense projects such as the Keta Sea Defense, protected the coastal towns in Keta since the defense (barrier) breaks down the waves. However, this cause offsets to neighboring coastal towns that do not have barriers particularly west of Keta towards the estuary. The resultant effect of these erosion trends coupled with sea level rise and tidal waves cause flooding which destroys homes, schools, businesses, and livelihoods, mostly during the rainy season (Boateng, 2012). Also, the intensity of erosion rates has resulted in the retreating of the cape (Boateng, 2009). Before the construction of the Keta Sea Defense in 2001, studies carried out by Appeaning Addo et al. (2011, 2018) and Boateng (2009; 2012) show that maximum coastal erosion rates could reach as high as 15 m/y, however, after the construction of the defense, this has reduced whiles coastal erosion rates have increased west of the Keta Sea Defence. This is consistent with the findings of this study, which shows the gradual increase of 16 m/y (highest rate) from 1991 to 2001 to 24 m/y (highest rate) from 2011 to 2020 around the estuarine region.

Accretion rates on the other hand are shown at the eastern portion with incremental rates between 0.3 m/y and 0.4 m/y coupled with low erosion rates of less than 5 m. This is because given the reduced sediment deposit since the construction of the Akosombo dam, has influenced the gradual accumulation of sediments eastwards.

Furthermore, the variations in erosion rates are the result of different sea defense projects. Despite its maladaptation effects, the various types of sea defense structures built along the coast increase erosion rates, as the case of the Dzita-Atorkor Sea Defense project, which only has revetments, and the Ada Sea Defense project (Figure 1), which only has groynes, as compared to the Keta Sea Defence Project, which has groynes, revetments, and nourishment (Jayson-Quashigah, 2021). The resultant effect is increased erosion rates and tidal events in the town of Fuveme since it is found at the receiving end for excesses from the Atorkor and Ada Sea Defense Projects as compared to the Keta Sea Defense Project which enjoys relative stability (Jayson-Quashigah, 2021).

In spite of these interventions, coastal communities are still exposed to coastal hazards partly attributable to sea level rise, sandy beaches, and the lack of rocky headlands to intercept longshore drift from the western coast coupled with the destruction of wetlands and mangroves (Kusimi and Dika, 2012).

Drivers of shoreline changes

A cursory review of existing literature on coastal erosion and accretion occurring on the Eastern Coast of Ghana elucidates a number of natural causes including edaphic factors; and anthropogenic factors which are operating at different spatial and temporal scales but have colluded to shape the shoreline of the study area. The natural factors that influence the changes in the position of shorelines on the Eastern Coast include the orientation of the shoreline, waves, and tides, and the variations in sea level (Ekow 2015; Appeaning Addo, 2015). The Eastern Coast before the construction of the Akosombo Dam in 1962 used to erode at 4 m/y, even though the coast received about 71 million m^3/y of sandy deposit, and it was reduced to 7 million m^3/y (Boateng, 2012). However, other studies gave a range of 1 million m^3/y to 2.5 million m^3/y as a deposit received before the construction (Tilmans, 1993 as cited in Jayson-Quashigah et al., 2021; Anthony and Blivi, 1999). Despite the differences in the amount of deposits received, all researchers agree that since the construction of the dam, the Eastern Coast received only 10-50% of the previous sediment load. The orientation of the shoreline of the Eastern Coast as compared to the Western Coast of Ghana, which has rocky headlands that are able to break the waves (Dadson et al., 2016), is also an important contributing factor. The Eastern Coast has sandy beaches with no rocky headlands, and in addition, it is also affected by waves from the south-southwest direction, and a period of 6-16 seconds has been calculated to reach roughly 3 m (Roest, 2018). With rates ranging from 0.3 to 1.5 million m^3/year, waves approaching the coast are also responsible for some of the highest rates of unidirectional longshore sand drift (Almar et al., 2015). The southwest monsoon is one of the main winds along the Eastern Coast. It blows in a south-west direction (210°–240°) from the sea to the land, at a 45° angle to the shore, and in the same direction as the waves (Angnuureng et al., 2013). Winds occasionally blow from the northwest during the Harmattan season (December–February). Wind speed vary between 1.7 and 2.6 m/s on a monthly basis (Angnuureng et al., 2013). Furthermore, climate change coupled with sea level rise at a present rate of 3.3mm will result in a rise of 5.8 cm in 2020 with projections of 16.5 cm by 2025 and 34.5 cm by 2050 (MESTI, 2015). Also, a 1.0 m anticipated sea level rise by 2100 might result in the loss of over 1000 km^2 of land, affecting 132,000 people. Flooding and coastline erosion are particularly dangerous on the Eastern Coast (MESTI, 2015).

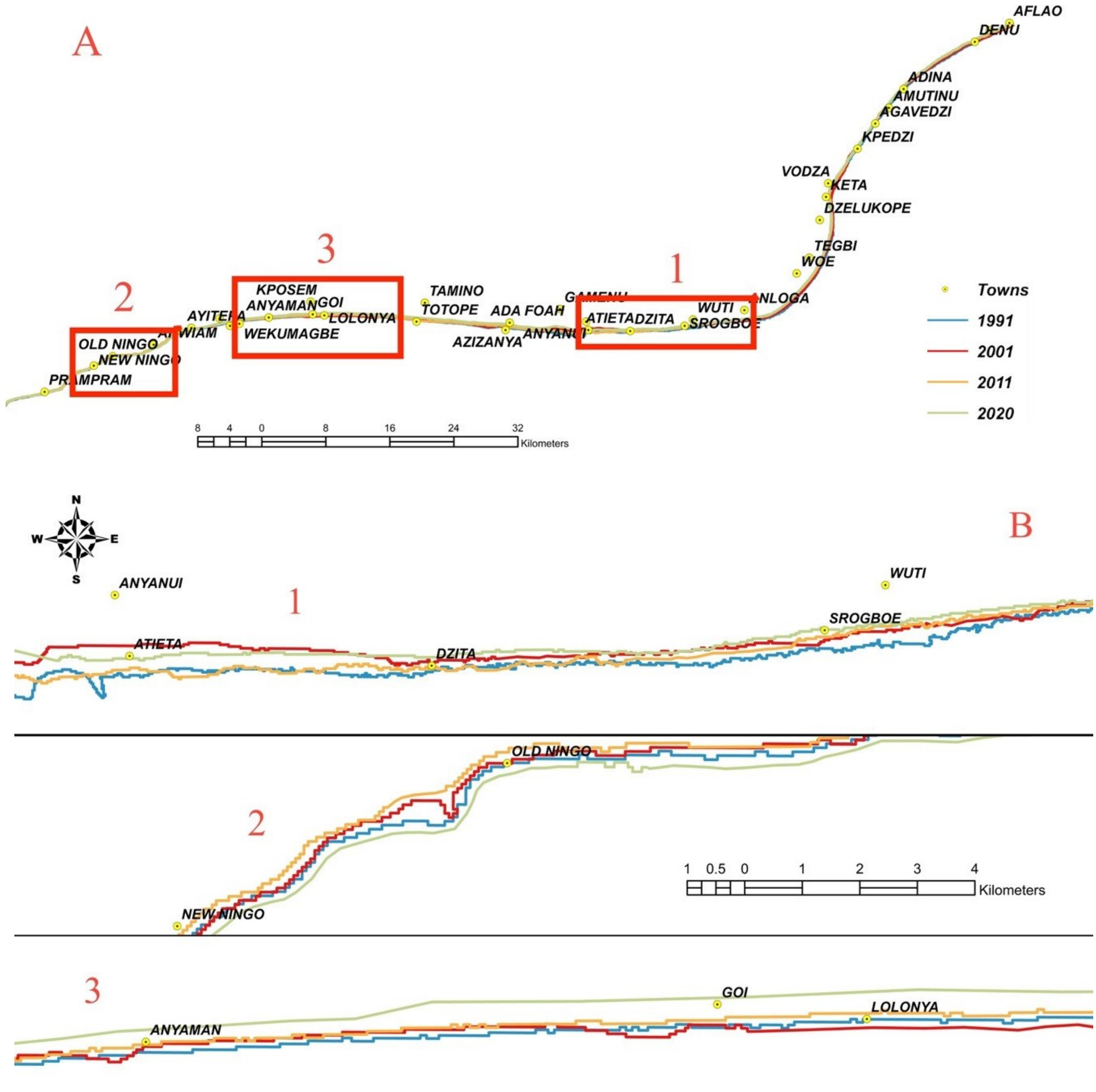

Fig. 6 Temporal changes in erosion and accumulation of the coastline between the selected years

The variation in sea level altering shorelines is a global phenomenon. In the case of Ghana, several areas near Accra are expected to be swamped between 2035 and 2065 (Appeaning Addo, 2014). IPCC reports further reiterate that climate change poses a lot of danger to coastal communities since sea levels are rising at an accelerating rate and will increase the alterations of shorelines (IPCC, 2022).

Anthropogenic activities contribute to accelerating the alteration of shorelines on the Eastern Coast of Ghana. Anthropogenic factors such as coastal engineering to reduce erosion rates further causes maladaptation and erosion continue to persist (Jayson-Quashigah et al., 2021). The temporal changes observed between the periods of 1991-2001, 2001 to 2011, 2011 to 2020, and 1991 to 2020 (Figure 4) show that in the period 1991-2001(before the construction) of the Keta Sea Defense, coastal erosion was caused predominantly by reduced sediments to the coastline due to the construction of the Akosombo dam. Subsequently, between the period of 2001 to 2011 after the Keta Sea Defence was constructed, this changed the variations in coastal erosion, particularly to the west of the Keta Sea Defense (Figure 1) which saw an increase in maximum erosion rates from 16 m/y (1991-2001) to 24 m/y (2011-2020). Despite these rates, the period between 2011 to 2020 shows a decline in average rates to 2 m/y which can be attributed to the subsequent construction of other sea defense projects at Dzita-Atorkor and Ada even though the estuarine region still recorded a maximum rate of 24 m/y (Figure 3). Other anthropogenic activities focus on environmental degradation such as the destruction of ecosystems, particularly wetlands, and mangroves. Anthropogenic factors, however, have accelerated the variation of shorelines particularly on the Eastern Coast of Ghana. In the study area, there are reports of heavy sand-wining activities (Appeaning Addo et al., 2011) and the exploitation of mangroves in Anyanui (Boatemaa et al., 2013). Recently, there are also reports of large-scale construction activities including the development of resorts along the coast. These findings are in line with studies that highlight the allure of the coast and how it leads to the alteration of coastal landscapes to serve agricultural, industrial, and residential land uses (Wu et al., 2018). Over the last century, the direct consequences of human actions have had a higher impact on the coastal zone than the impacts directly tied to observed climate change (Menstachi et al., 2018; Melet et al., 2020). Direct repercussions include the drainage of coastal wetlands, deforestation, and the flow of sewage, fertilizers, and toxins into coastal waters. Extractive operations include sand mining and hydrocarbon production, as well as the harvesting of fisheries and other living resources. The introduction of exotic species, and the construction of seawalls and other structures. Damming, channelization, and diverting coastal streams harden the coast, change circulation patterns, and influence freshwater, sediment, and nutrient delivery. Soft engineering solutions such as beach nourishment and foredune development have a direct or indirect impact on natural systems (Nordstrom, 2004). Sand mining, urbanization, commercial activity, fishing, oil and gold mining, and other human activities have all had an impact on Ghana's shorelines (Jayson-Quashigah et al., 2021).

CONCLUSIONS

This study analyzed shoreline changes on the Eastern Coast of Ghana, which stretches from Laloi Lagoon west of Prampram to Aflao (149 km), and identified vulnerable coastal communities using satellite images from the Landsat satellite mission (Landsat 4TM, 7ETM+ 8 OLI) from 1991 to 2020.

Findings revealed that the Eastern Coast has witnessed significant changes (maximum erosion: 24 m/y; maximum accretion: 3 m/y) over the studied period. The analysis further showed that some coastal communities have experienced massive erosion, thus they are highly exposed to coastal hazards. In addition, natural and anthropogenic factors continue to pose a number of threats to coastal communities.

Indeed, hard adaptation interventions such as sea defense walls have been already constructed, and further plans exist to construct new sea defense walls. The sea defense wall at the estuary/ delta area (at Keta) has reduced the rates of erosion, even though the area has suffered from short-term events such as tidal waves in recent times which have led to the displacement of thousands of households.

The climate change-driven sea level rise is coupled with population growth in coastal communities, and the erosion of the coastlines will not slow down along the coasts of Ghana. The increase in population and urbanization coupled with the exploitation of coastal resources such as sand and mangroves, continue to expose coastal communities. Since climate change and population trends, all show incremental growth, it is imperative to ensure that the coastal environment is safe, inclusive, and sustainable. The coastal region creates employment and supports livelihoods and is pivotal to the development of Ghana. Thus, the following actions are recommended: (a) The promotion of ecosystem-based adaptation using a community participatory approach is needed to ensure the cultivation and protection of mangroves, which has a triple-win benefit for nursing fisheries, serving as a breakwater for excess runoffs and the sequestration of carbon which will protect properties and livelihoods. (b) Frequent coastal monitoring is needed to ensure an up-to-date report on erosion trends in an era of sea level rise and create scenarios to predict threats that will inform policy decision-making processes such as the relocation of highly exposed coastal dwellers. (c) The implementation of integrated coastal management practices is necessary to ensure that anthropogenic activities such as the destruction of wetlands, sand wining, and destruction of mangroves are reduced to the barest minimum with community participation to build coastal resilience towards the future that we want- sustainable development.

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DECLARATION OF INTEREST STATEMENT

The authors certify that they have no known competing financial interests that may have influenced the work presented in this paper.

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