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Full Length Research

Spatio-temporal analysis of shoreline movements along the coast from Keta to Kedzi in the Volta Region-Ghana

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ABSTRACT: In response to the inadequacy of traditional mitigation methods along Ghana's eastern shoreline and other eroded coastal areas, this study investigates the spatio-temporal dynamics of shoreline movements along the coastal stretch from Keta to Kedzi, in the Volta Region of Ghana. The research spans the period from 1990 to 2020 and employs shoreline data derived from high-resolution aerial imagery, alongside Landsat 7 and 8 images. Utilising Digital Shoreline Analysis System (DSAS) software 5.1 and ArcGIS/ArcMap 10.8.2, the analysis incorporates key metrics such as Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), and End Point Rate (EPR). The findings reveal a nuanced pattern, with approximately six out of eight kilometres experiencing moderate to high accretion, while the remaining stretch faced significant erosion. Specifically, Keta exhibited an average NSM of 99.98 metres and an EPR of 5.26 metres per year. Vodza recorded an average NSM of 130.21 metres and an EPR of 6.85 metres per year. Conversely, Kedzi displayed an average NSM of -73 metres and an EPR of -3.87 metres per year. This study underscores the necessity for periodic monitoring, recommending a five-year interval for researchers and relevant stakeholders, including the Ministry of Water Resources, Works, and Housing. Additionally, it emphasises the imperative for targeted intervention, especially Kedzi, due to the pronounced and pervasive nature of erosion in that area.

Keywords: Accretion, keta, sea defence, shoreline, sea erosion.

INTRODUCTION

Coastal areas, where the land meets the sea, are highly dynamic interfaces, shaped by intricate interactions between terrestrial and marine processes. These regions have significant geomorphological and ecological importance and act as central hubs for various socio-economic activities, including fishing, agriculture, urbanization, oil and gas exploration, transportation, tourism, and more (Bulleri and Chapman, 2010; Lakshmi and Rajagopalan, 2000; Pelling and Blackburn, 2013; Weinstein *et al*., 2007; Reed *et al*., 2009; Xu *et al*., 2016). Moreover, the increasing population density along coastlines (Archiniega *et al*., 2001) driven by economic opportunities has heightened the need for a deeper understanding of the complex dynamics that exert influence in these areas (Anim *et al*., 2013).

Coastal environments are constantly shaped by the interaction of erosion and accretion processes (Anim *et al.,* 2013; Dadson *et al*., 2016). These processes are driven by factors like tidal waves, storms, near-shore currents, and human activities (Angnuureng *et al*., 2013; Dadson *et al*., 2016; Jonah, 2015). Weinstein *et al.* (2007) posited that this dynamic nature leads to coastal erosion, posing a significant threat to communities and ecosystems worldwide. When the shoreline temporarily or permanently retreats, it becomes a hazard for human activities along the coastal zone (Bulleri and Chapman, 2010; Cheong, 2008; Morton, 2003). That is why a periodical understanding of the extent of erosion and accretion dynamics, especially in Keta, is essential to recognize the harshness of these issues.

Tidal waves primarily generate currents that lift and transport sediments in both cross-shore and alongshore directions (Bulleri and Chapman, 2010; McGranahan *et al.,* 2007; Morton, 2003; Thompson *et al.,* 2002). These processes are significant in breaking swash zones. Accretion occurs when sediment replenishes faster than it washes away, while erosion happens when sediment moves faster than it can be replenished. Both erosion and accretion play a crucial role in shaping coastal environments, affecting shoreline position, sediment transport, and landform evolution (Anim *et al*., 2013; Dadson, 2021). Consequently, coastlines are inherently dynamic and continually moulded by erosion and accretion processes.

In the south eastern coastline of Ghana, especially in the Volta Region, shoreline movements are influenced by a complex interplay of natural and human factors. Coastal environments are highly vulnerable to various factors, including sea-level rise, global warming, waves, and storms (Appeaning Addo *et al.,* 2008; Appeaning Addo *et al.,* 2020; Dadson *et al.,* 2016; Mann *et al.,* 2023). Human activities like urbanization, infrastructure development, and sand mining also cause coastal vulnerability (Appeaning Addo, 2015; Bolle *et al.,* 2015; Jonah, 2015; Dadson *et al*., 2016). These factors interact and contribute to changes in coastal ecosystems, such as shorelines, estuaries, wetlands, coral reefs, and ocean margin ecosystems.

Of particular concern is the threat of sea-level rise caused by global warming (USGS, 2022; FitzGerald *et al*., 2008). This is why Morton (2003) revealed that projections indicate that increased greenhouse gas concentrations in the 21st century will result in higher air and ocean temperatures, leading to the melting of glaciers and polar ice caps and causing sea levels to rise. This nevertheless results in shoreline erosion, coastal flooding, and the loss of important habitats like wetlands and coral reefs. Lakshmi and Rajagopalan (2000) advised that in order to adapt to current coastal impacts, manage future coastal risks, and prevent further acceleration of sea-level rise beyond 2050, immediate action must be taken to mitigate and adapt to the effects of global warming. For Weinstein *et al*. (2007), coastal communities must urgently implement strategies like coastal protection measures, careful land use planning to avoid development in vulnerable areas, and the restoration and conservation of coastal ecosystems. However, understanding the patterns and rates of shoreline changes is crucial for developing effective coastal management strategies to mitigate erosion and ensure sustainable development of coastal areas, especially the vulnerable coast of Keta, Kedzi and its environs.

While coastal erosion and accretion have always played a role in shaping coastlines, human activities have significantly intensified coastal erosion in recent years, leading to severe land loss and a significant financial burden. According to Olympio and Amos-Abanyie (2013), coastal ecosystem management requires reliable information and robust analytical technologies for monitoring and modelling. The researchers further advanced that by incorporating geospatial methods into the study of shoreline changes, a comprehensive understanding of the spatio-temporal dynamics of the coastline can be achieved. Thus, the significance of accurate shoreline change analysis and prediction cannot be overstated in today's rapidly changing world (Appeaning Addo and Lamptey, 2012; Jonah, 2015). Remote sensing and GIS technologies have emerged as crucial tools for coastal management, providing cost- effective and technologically sound methods for monitoring and analysing coastal environments (Abbiati and Basset, 2001; Appeaning Addo *et al.,* 2008). These technologies support decision-making processes by creating environmental indicators (Appeaning Addo, 2015; Amoani *et al.,* 2012; Francis and Torell, 2004; Lakshmi and Rajagopalan, 2000).

Moving forward, continuous monitoring and studying of shoreline movements in this region are essential. This will help to adapt and refine management strategies in response to evolving coastal dynamics. The integration of scientific knowledge with practical coastal management is crucial for addressing the challenges posed by coastal erosion and ensuring the sustainable development of the coast along the study area. To this end, the main objective of this study was to analyse the movements of the shoreline along the coast from Keta to Kedzi in the Volta Region of Ghana between 1990 and 2020.

LITERATURE REVIEW

The sea is inflicting a catastrophic impact on the lives of the coastal inhabitants because of its advancement. The rates of erosion experienced and recorded annually are adversely affecting coastal resources. Thus, the current erosion rates globally pose an ad hoc response from World Leaders, World International Organizations, and in West Africa, other partners are joining efforts to protect the West African coast (World Bank, 2018; Almar *et al*., 2022).

In France, Hanson and Lindh (1993) revealed that between 1952 and 1969, the retreat was approximately 150 metres. Meanwhile, during the years 1881 to 1922, the retreat in the lowland area of Cape Breton, in the Bay of Biscay, was as much as 700 to 800 metres. In the United States of America, 30 of the states have a coastline. All 30 coastlines are facing erosion (Hanson and Lindh, 1993). They noted that during that time, 68 per cent of the coastal beaches have moderately degraded, while 53 per cent have been severely damaged. The remaining 12% are classified as stable coastal beaches. For Central Portugal, baseline results show that coastal erosion could lead to losses of 850 hectares projected to 2050 (Roebling *et al*., 2011).

Almost, 28% of the coastal area in Greece is under retreat and more specifically, 6.1% in Thrace and East Macedonia, 10.3% in Central Macedonia, 2.3% in Thessaly, 14.7% in the North Aegean Islands, 10.8% in Attica, 25.9% in the Cyclades and the Dodecanese islands, 3.8% in Peloponnesus and 6.1% in the Northern coast of Crete (Alexandrakis *et al*., 2010). Contrary to that, the sea-cliff erosion rate computed for Oregon State recorded a relatively long-term rate of 10 centimetres/year. In Mozambique, Palatane *et al.* (2016) indicated that strong coastal retreat rates exceeding one (1) metres/year were noticeable in some places, as compared to 0.4 metres/year due to natural causes. To add further, at three observation stations in the Kragan Village region, according to data collected via image interpretation, observation, interviews, and questionnaires, Kragan Village has suffered dynamics, with a total land loss of 46 metres from 2003 to 2020, according to this study (Hamid *et al*., 2021).

In China's Qinhuangdao Region, research by Xue *et al.* (2009), using mooring hydrodynamic observation, a cross-shore profile, and a topographic map coupled with satellite-image comparisons, found severe coastline erosion from 1986 to 2000 that averaged 3.7 metres per year. Meanwhile, between 1996 and 2003, the retreat rate dropped to 1.5 metres per year, and substantial coastal erosion was discovered along river mouths such as the Tang, Dai, Yang, Dapu, and Renzaohe Rivers, as well as Qilihai Lagoon, with a maximum of (less than) 7.0 metres/year. According to Marfai (2011), considerable erosion occurred along the coast of Semarang (Indonesia) between 1937 and 1972, with 500 metres of coastline fast eroding in numerous areas. A partial change in the shoreline between 1992 and 2001 suggested that there was significant erosion. The coastline has been altered because of erosion. In 1972–1992, for example, coastal erosion extended 461 metres into the land, resulting in land loss. Fauzie (2016) also reported on the debilitating effects of sea erosion in the same country, where the study found that the sea erosion of 2007, 2008, and 2013 inundated about 13 thousand, 16 thousand, and 15 thousand hectares of coastal productive regions, respectively. Coastal erosion has resulted in an annual loss of about 14 acres and a 4 metres retreat of the shoreline.

A study by Mohamed Rashidi *et al.* (2021) also indicated bizarre situations on Malaysian coasts through the report of the National Coastal Erosion Study. That's 1348 kilometres (or 15%) of the shoreline, out of a total of 8840 kilometres, that are now rapidly eroding, with three levels of severity: critical, substantial, and tolerable erosion. Critical erosion accounted for 4% of the overall eroded length, severe erosion accounted for 28%, and tolerable erosion accounted for the remaining 68%. A study by Zhang *et al*. (2004) revealed that during the last 100 years, about 86 per cent of the United States east coast barrier beaches have eroded. In California, the same report indicated widespread erosion. While using satellite imagery and field surveys, Thampanya *et al.* (2006) studied coastal erosion in southern Thailand, where 50 per cent of mangrove forests have been found lost since 1961, and discovered that between 1967 and 1998, coastlines eroded by 0.01 to 0.32 square kilometres per year.

According to a recent European study on coastal geomorphology and erosion (EUROSION, 2004), the coast of the United Kingdom is under severe and catastrophic threat from the sea. The erosion rate of the United Kingdom documented includes East England (30.3%), North-east England (27%), Wales (23.1), and North-west England (18.5%), Yorkshire and Humber (56.2%), England (29.8%), East Midlands (9%), South-east England (31%), South-west England (31.7%), Scotland (11.6%), and Northern Ireland (19.5%).

In 1983, a study of coastal erosion in West and Central Africa discovered that the main driver of erosion was anthropogenic activities (Quelennec, 1987). The report noted that since the turn of the 19th century, there has been significant coastline erosion in Ghana. Thus, between 1964 and 1975, the recession averaged approximately 6 metres per year. In the case of Togo, the coast has receded 150 to 200 metres east of the port of Lomé in 20 years, at a maximum pace of 25 metres per year. In Nigeria, erosion rates east of the Lagos harbour have ranged from four (4) to thirty (30) metres per year. Hanson and Lindh (1993) maintained that the erosion in Monrovia (Liberia) has been around 2 metres per year, mostly due to harbour measures that stop the littoral drift. According to Appeaning Addo (2009), the sea claimed about 1.5–2 metres of the stretch of 560 kilometres of coastline annually in Ghana. This is amazing! The report went further to uncover the most severely impacted hotspot areas of Ada-Foah and the Eastern part of Keta with a recorded rate of 4 metres yearly. Another study by Anim *et al.* (2013) discovered that the capital city (Accra) is suffering from coastal erosion at a rate of 1.13 metres yearly due to illegal sand mining, which puts 82% of the coastal beach in danger. Another study by Jonah *et al*. (2016) identified medium-term coastline erosion rates of -1.22 metres per year ± 0.16 metres and a short-term erosion rate of -0.86 metres per year ± 0.77 metres for the Elmina, Cape Coast and Moree areas. Angnuureng *et al.* (2013) undertook a comprehensive study of the impact of defence structures. In the findings, the mean erosion rate before the construction was 3.20 ± 0.3 metres/year; it increased to about 17.00 ± 0.3 metres/year after the construction of the defence structures.

In summary, studies from different regions of the world report varying rates of sea erosion, with some areas experiencing more severe erosion than others. These highlight the importance of continued research and monitoring of sea erosion globally to develop effective strategies to mitigate its impacts on coastal communities and ecosystems.

MATERIALS AND METHODS

The study area

The study was conducted along three coastal communities:

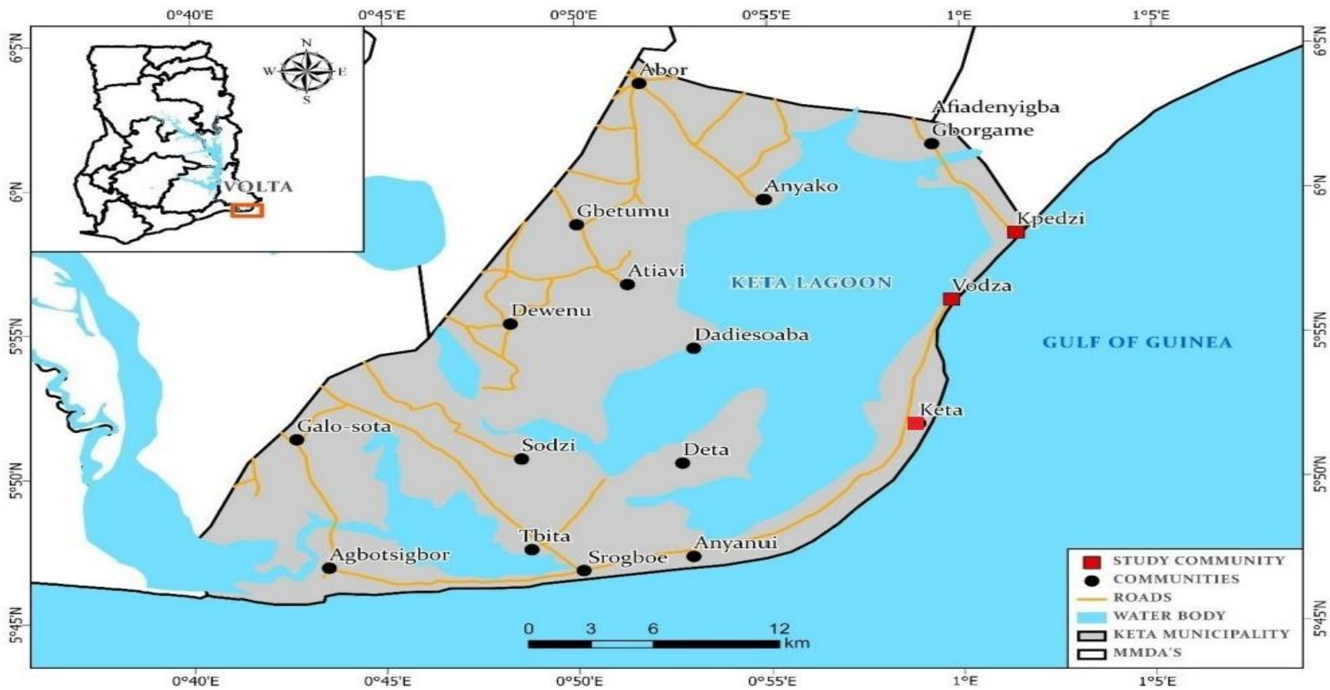

Figure 1. Coastal stretch from Keta to Kedzi (Source: Adapted Adikah et al., 2020; Cartographic Unit, University of Cape Coast).

communities: Keta, Vodza-Adzido, and Kedzi in the Volta Region of Ghana, as shown in Figure 1. The coastline studied is about 8 kilometres long, which lies between longitudes 0.30 and 1.05°E and latitudes 5.45 and 6.05°N. It is located to the east of the Volta estuary, about 160 kilometres from Accra. Keta, Vodza-Adzido, and Kedzi townships have the lowest point at about 1–3.5 metres below sea level (Boafo, 2018). The highest point of the municipality is about 53 metres above sea level indicated by Boafo (2018) around Abor in the Northern part. It shares common borders with Akatsi South District to the north, Ketu North and Ketu South Districts to the east, South Tongu District to the west, and the Gulf of Guinea to the south.

The total surface area of the municipality is 753.1 square kilometres. The largest of the water bodies is the Keta Lagoon, which is the largest lagoon in Ghana. Thus, the entire coastal stretch of the study area is approximately 8 kilometres (that is, from Keta to Kedzi).

The town of Keta is situated on the eastern end of a narrow littoral strip, extending from the Volta estuary to the Keta lagoon. The municipality is low-lying, with the northern plains being gently undulating. The area is vulnerable to tidal waves and sea erosion, leading to the construction of a sea defence wall. The town is situated on the west side of the Keta Lagoon inlet, offering water transportation and potential for commercial fishing.

The district, located in Ghana's Dry Equatorial climate zone, experiences an average annual rainfall of under 1,000 mm, making it one of the driest regions along Ghana's coast. The primary rainy season lasts from March to July, while the secondary season begins in September and concludes in November, aligning with the main and minor cropping periods, with daily temperatures reaching 30°C.

Keta Municipality is divided into five vegetation zones, including coastal strands, blackish water vegetation, freshwater vegetation, Guinea savannah vegetation, and salt flat vegetation (MOFA, 2021). The coastal strands consist of sparse grassland and woody shrubs, while blackish water vegetation includes common grass species found along lagoons and streams. Mangroves are a major source of fuel wood and livelihood for the region's people. Freshwater vegetation, located on the northern side, contains grasses used for mats and bags. Guinea savannah vegetation consists of tall grasses scattered throughout the region.

This study area was selected for this research due to its vulnerability to sea erosion emanating from the low-lying terrain, about 1–3.5 metres below sea level (Boafo, 2018). Due to its vulnerability to sea erosion, it has also attracted a number of researchers over the years. It is, therefore, important to track the most current situation in terms of erosion and movements of the shoreline to help inform policy formulation and implementation with regards to sea erosion, shoreline movements and control mechanisms.

Data preprocessing, acquisition and analysis

Shoreline position determination and change detection relied on a dataset comprising Landsat 7 and Landsat 8

Table 1. Details of imagery characteristics.

Data	Date	Resolution	Row/Path	Sensor	Source	Cloud Cover
Landsat 7	1990/01/03	30m	192/56	TM	USGS	0%
Landsat 7	2000/05/07	30m	192/56	TM	USGS	0%
Landsat 7	2010/10/05	30m	192/56	TM	USGS	0%
Landsat 8	2020/11/05	30m	192/56	OLI/TIRS	USGS	0%

images. The detailed summary of these images includes acquisition data, spatial resolution, row and path information, imaging sensor details, and the image source, as shown in Table 1. Four Landsat images, spanning 30 years, 1990, 2000, 2010 and 2020, were utilized for shoreline change analysis. These images were acquired from the United States Geological Survey, Earth Resources Observation and Science Center. This period and years were selected to analyse and understand the short to medium-term condition of the coastline in relation to sea erosion and shoreline movements. This is in line with what Gibeaut *et al.* (2001) classified shoreline movements as long term, short term and episodic.

The pre-processing of satellite images for analysis involved several sequential steps. Initially, the images underwent radiometric calibration, stacking, and conversion to the ENVI standard image format. The tools employed for this study included ENVI 5.3 (32-bit) and ArcGIS Desktop 10.7.1. The Gram-Schmidt pan sharpening algorithm in ENVI which is based on principal component analysis was used. For improved image quality and differentiation between water and land, the panchromatic band of the Landsat images played a pivotal role in pan-sharpening. This entailed bilinear resampling, resulting in a refined resolution of 15 metres. To ensure the proper alignment of all images, a geometric registration process was executed, with the 1990 image serving as the reference point. All subsequent images were aligned to its coordinate system, guaranteeing that corresponding pixels accurately represented identical objects without biased application.

Employing unsupervised classification, the images were dichotomized into two classes: water and land. The output was saved as a shapefile and subsequently exported to ARCGIS Desktop for in-depth analysis. The shapefile underwent a transformation from polygon to line, accentuating the shoreline, and was saved as a distinct shapefile. ArcGIS editing tools facilitated data refinement, while the Digital Shoreline Analysis System (DSAS) version 5.1, an ArcGIS add-on software, was employed for subsequent data processing. Attributes such as date, uncertainty, shape length, and shoreline type were incorporated into the shoreline data, along with default system attributes like shape and object ID. Fields such as date and shape length were populated, and all shorelines were amalgamated into a unified feature class within a personal geodatabase.

The amalgamated shoreline data underwent a 150-meter buffer, employing a flat line-end type due to the shoreline land-water interface exhibiting minimal to no change in elevation over the study distance. The onshore segment of this buffer was delineated using ArcGIS editing tools. Subsequently, with the shoreline and baseline data stored in a personal database, default parameters of the DSAS add-on were established. The seaward intersection option was implemented to generate 139 transects, featuring a maximum search distance of 200 metres from the baseline, and transect spacing set at 100 metres. The DSAS workflow is shown in Figure 2.

Change statistics were then computed based on the generated transects, encompassing metrics such as Net Shoreline Movement (NSM) and Endpoint Rate. For EPR, the formula used was;

$$\text{EPR} = \frac{\text{Change in shoreline position}}{\text{Time period}}$$

The Shoreline Change Envelope (SCE) was employed to quantify the overall change in shoreline movement, capturing the distances of all available shoreline positions, irrespective of their specific dates. Satellite images covering such periods were derived for each of the selected areas. The study assessed the longitudinal profile of accretion and erosion along the study coastline.

ANALYSIS AND DISCUSSION OF RESULTS

The study area was divided into three locational segments for easy analysis of the shoreline change results. This division was done based on the orientation of the coast to enhance easy comparisons for better understanding, as shown in Figure 3: The divisions are [I] Keta, [II] Vodza and [III] Kedzi.

SEGMENT 1: Shoreline movement from 1990 to 2020 along the coast of Keta

The shoreline positions and changes for Keta in 2001, 2010 and 2020 are shown in Figure 4. The entire stretch of the Keta coastline experienced low accretion to high accretion throughout the study period rather than erosion. This is reflected in the general shoreline position from the year 1990 as the base year through to 2020. As indicated in Figures 4 and 5, extreme western side of Keta

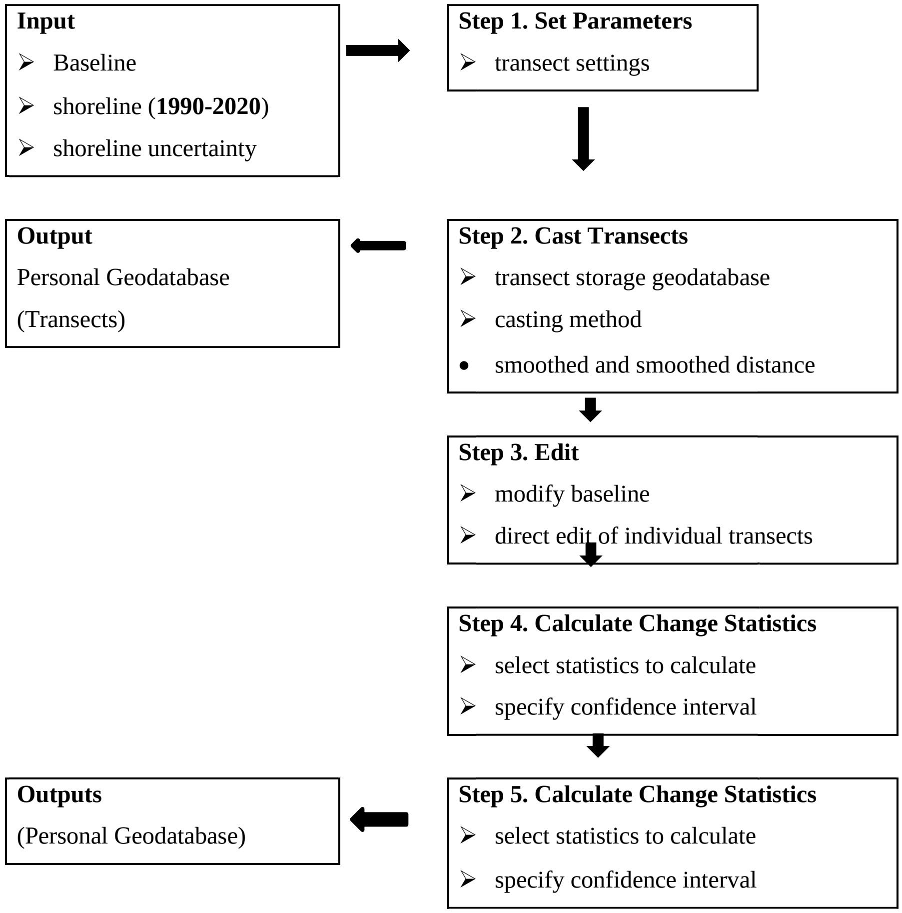

Figure 2. Digital Shoreline Analysis System Workflow (Himmelstoss, 2009).

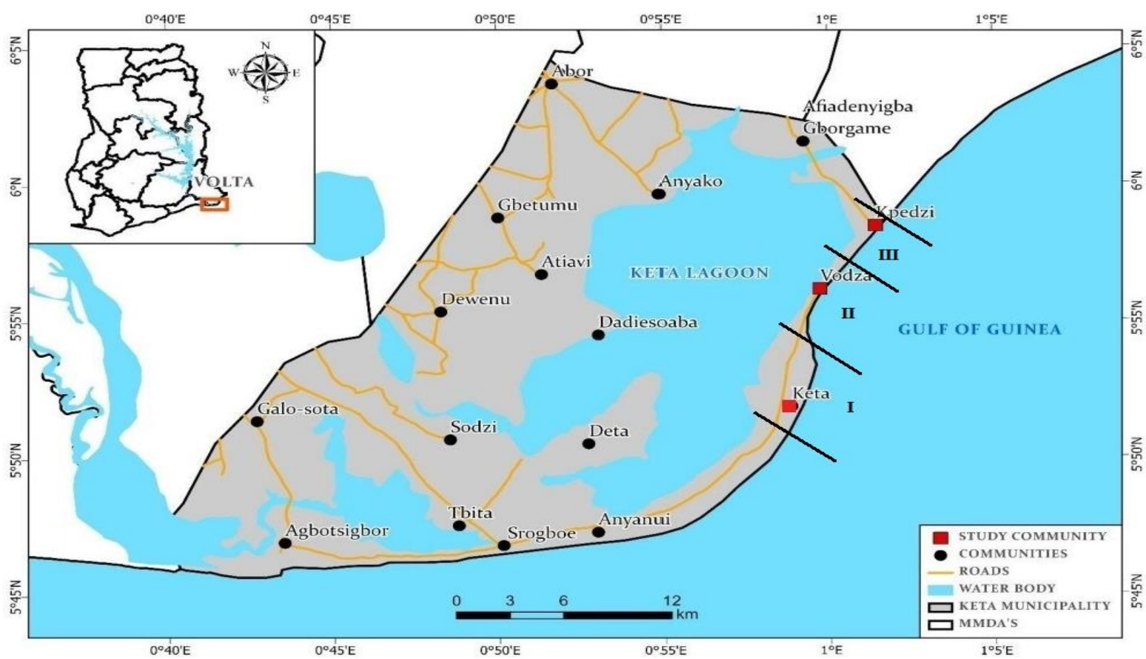

Figure 3. Study area showing Keta, Vodza and Kedzi coastline.

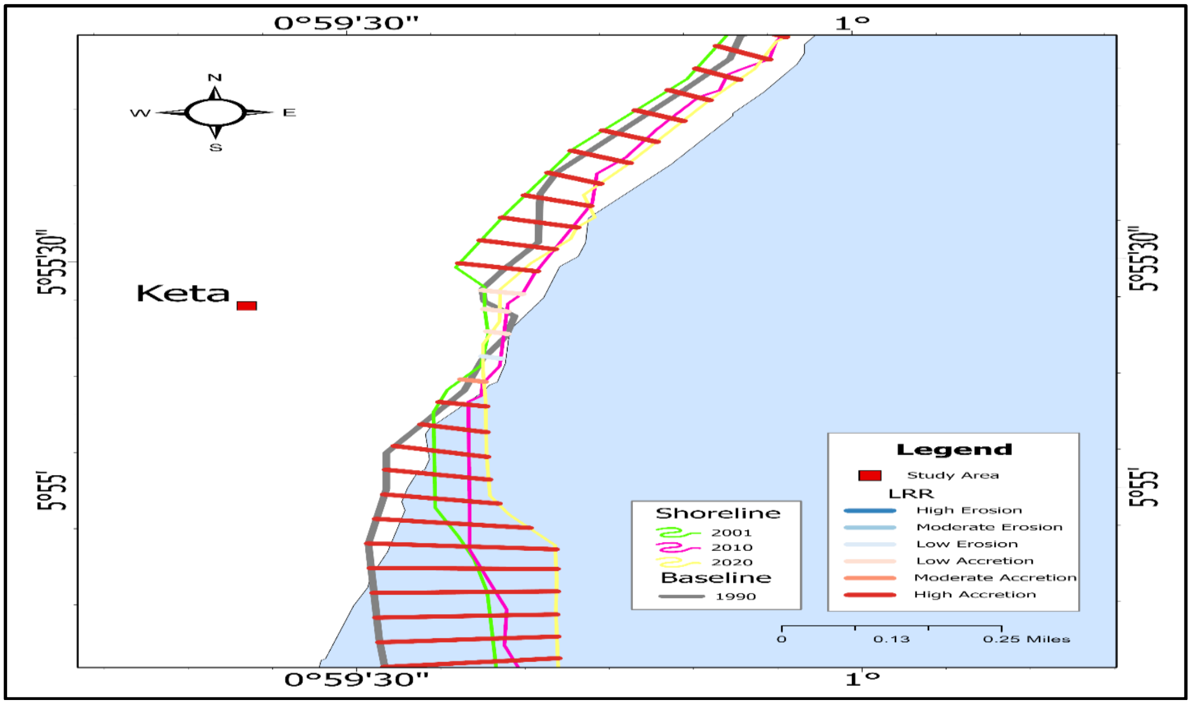

Figure 4. Shoreline Movement along Keta Coastline over the Period of 1990-2020.

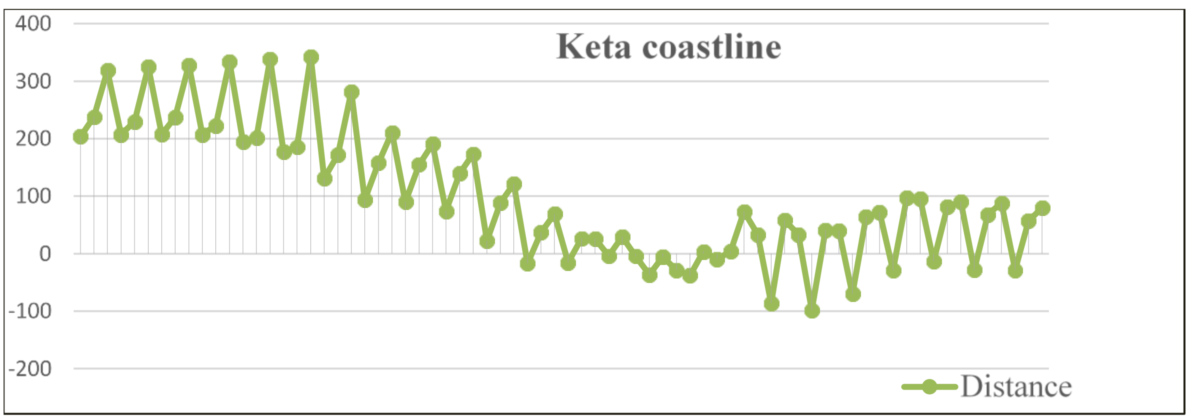

Figure 5. EPR and NSM for Keta coastline**.**

experienced a high accretion rate, while the eastern stretch of the town also witnessed a high rate of accretion. Despite the high accretion rate, Keta experienced low erosion with EPR -0.01 while NSM was - 0.28m/y between the years 1990-2020. During the study period, the average NSM was 99.98 m while the EPR was 5.26 m/y (Table 2). This indicates that between 1990 and 2020, there was a 99.98 metres variation in the shoreline, mostly due to accretion. However, the average pace of shoreline movement, or shoreline retreat, was 5.26 metres per year, notably starting in 2001. The reason for the high accretion rate, as Dadson (2021) pointed out, could be the presence of vegetation that may serve or act as a barrier on one hand and flat coastal terrain or beach, which causes the waves to spread and break off. In addition, the presence of sea defence structures could also have contributed in part. As indicated by Jonah *et al*. (2016), the rocky coast dissipates full waves of the sea; an implication of this was the possibility that the groynes have been slowing the waves before they reach the shore, which is partly responsible for the high rate of accretion along the coast. In all, Keta boasts of a generally flat sandy coastal beach which is open, devoid of trees, with a limited number of coconut trees, sparsely along the coast, which is not enough to break waves off. Hence, the high accretion recorded during the study period can be largely attributed to the

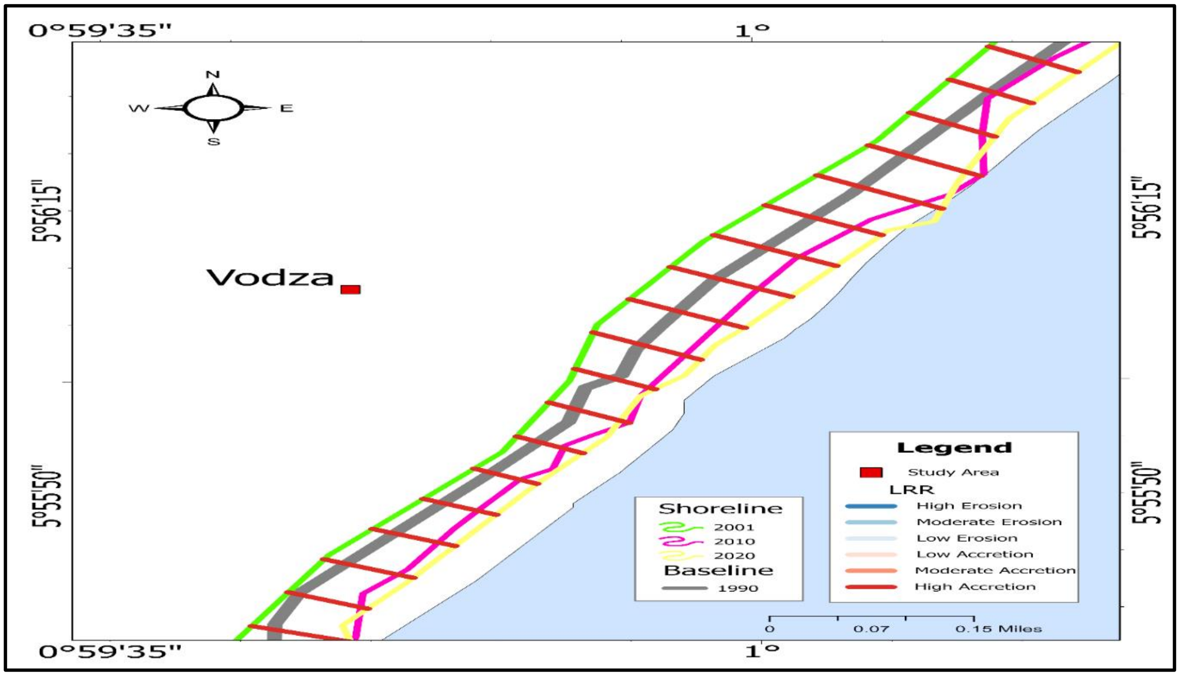

Figure 6. Shoreline Movements along Vodza Coastline over the Period of 1990-2020.

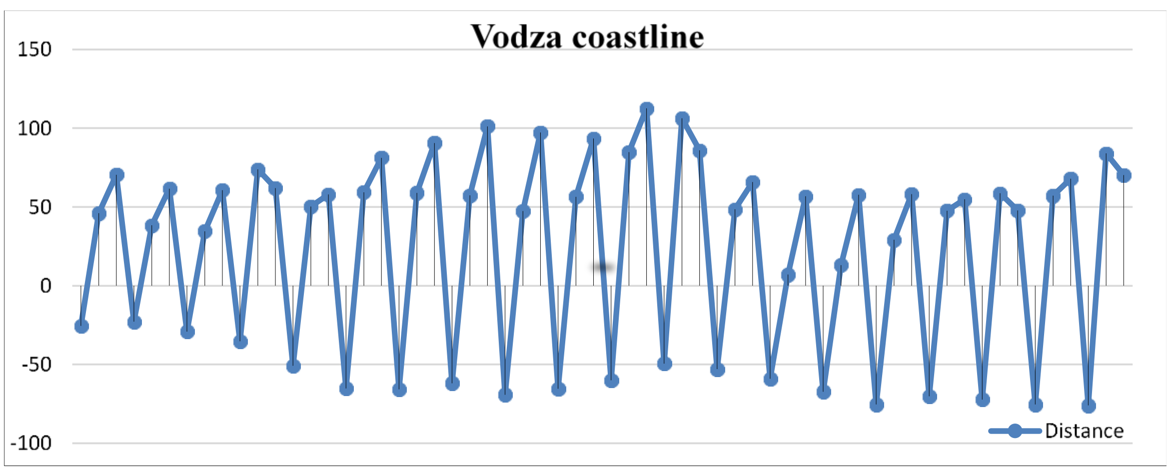

Figure 7. EPR and NSM for Vodza coastline.

presence of the groynes. This is also in line with findings by Ankrah *et al*. (2023), who posit that the transformation of shorelines and the occurrence of coastal erosion are driven by natural processes such as rising sea levels and human activities, thus posing significant challenges in coastal regions worldwide.

SEGMENT 2: Shoreline movement from 1990 to 2020 along the coast of Vodza

The shoreline positions and changes for Vodza in 2001, 2010 and 2020 are shown in Figures 6 and 7. Here, there was generally high accretion along the coast. The coastline of Vodza is not different from that of Keta as they share close features with nearness as geographical relativity. This segment is widely characterised by high retreat without any massive advancement. The entire coastline experienced high accretion, notably in 2001 with NSM of 121.06 m and EPR on the other was 8.88 m/year which occurred along the entire coast with unprecedented recession. Thus, generally, the average NSM was 130 m, and the EPR was 6.85 m/years. Vodza shares the same reasons for the high accretion as Keta. Thus, the flat coastal terrain or beach causes the waves to spread and break off (Dadson, 2021), and the presence of hard

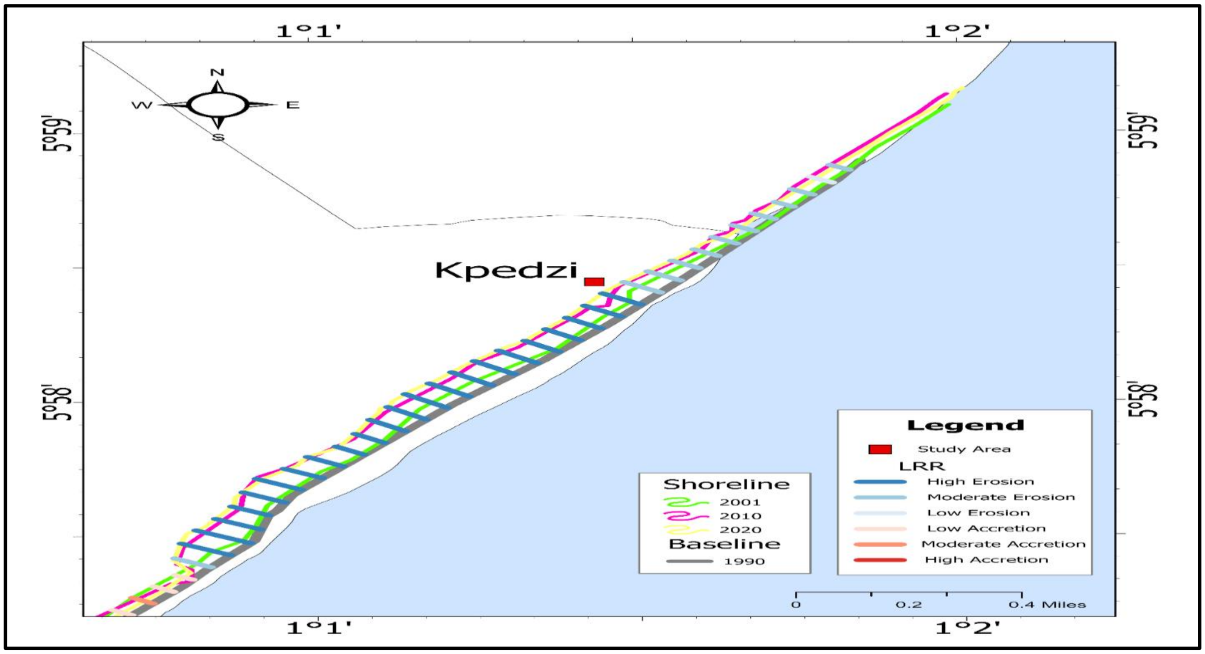

Figure 8. Shoreline Movement along Kedzi Coastline over the period of 1990-2020.

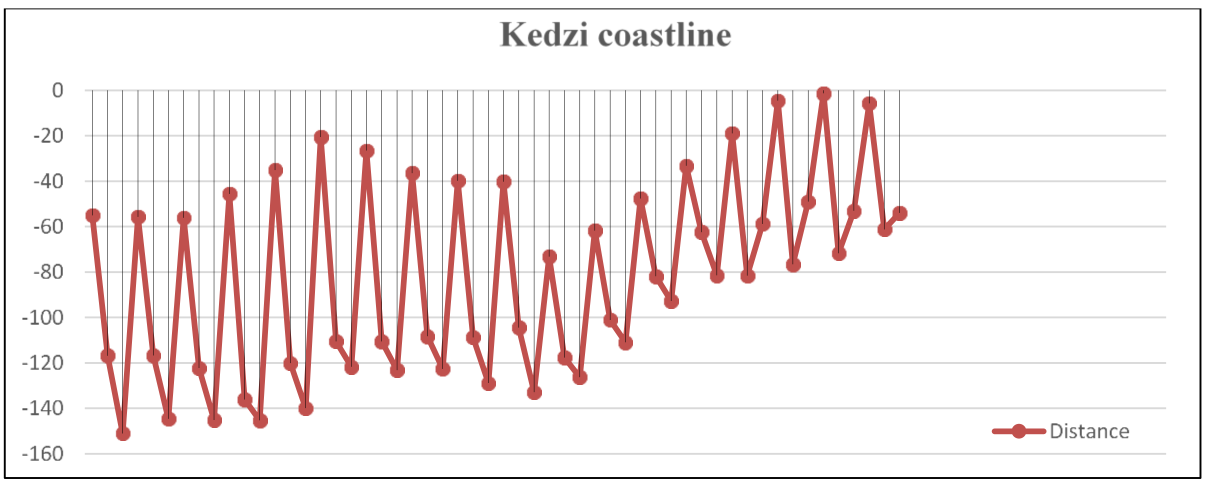

Figure 9. EPR and NSM for Kedzi coastline.

structures, such as rocky coasts (Jonah, 2016), greatly contributes to high accretion. Hence, the coastline started retreating due to the completion of the Keta Sea Defence Project, which has succeeded in breaking the waves and redirecting them to adjoining sister towns' downdrift (Angnuureng, 2011).

SEGMENT 3: Shoreline movement from 1990 to 2020 along the coast of Kedzi

The shoreline positions and changes for Kedzi in 2001, 2010 and 2020 are shown in Figures 8 and 9. This coastline is associated principally with a high rate of erosion, that is, from the township of Vodza. At the far or extreme west end of the Kedzi coastline, which can be said to be closer to the boundary between her and Vodza, there was moderate accretion to low accretion. That is, the only area to record accretion from 1990-2020. However, the entire coastline, apart from the accreted west end, witnessed a high erosion to moderate erosion at the eastern side. The coastline experienced NSM -73.56 metres, while EPR was -3.87 metres/year. The greatest net loss was experienced in 2001, with NSM of -104.88 metres and EPR of -5.52 metres/year (Table 2). This could be attributed to the construction of the sea defence project,

Table 2. Average EPR and NSM rates for Keta, Vodza and Kedzi, 1990-2020.

Shoreline segment	EPR (m/yr)	NSM (m/yr)	Description
Keta	99.98	5.26	High Accretion
Vodza	130.21	6.85	High Accretion
Kedzi	-73	-3.87	High Erosion

as was posited by Angnuureng (2011), which links the Keta Sea Defence Project to erosion at the downdrift. Again, Dadson *et al*. (2018) agreed perfectly with Angnuureng (2011) when the researcher noted that hard structures are responsible for redirecting the waves to adjoining communities that are unprotected. Although the presence of the groyne did not promote accretion, results should be interpreted with caution. The reason is that only one groyne existed principally at Kedzi next to the one located at Vodza. Here lies the issue: the waves redirected from Keta and Vodza were strong enough that the only groyne at Kedzi could not handle the feed. Hence, Kedzi will need more successive groynes in order to halt the situation.

Average EPR and NSM rates, 1990-2020 (Keta, Vodza and Kedzi)

The averages for the extent of sea erosion were computed in relation to shoreline movements. This was calculated for the entire period from 1990-2020 per each zone. The results indicated both high accretion at Keta (EPR: 99.98; NSM: 5.26) and Vodza (ERP: 130.21; NSM: 6.85); however, Kedzi (EPR: -73; NSM: -3.87) experienced high erosion.

From Table 2, it could be deduced that the coastal locational segments under study from Keta experienced a moderate to high rate of accretion and, hence, reduced erosion. Hence, the shorelines experienced retreat, with the highest occurring at Vodza. This can be attributed to the construction of the Keta Sea Defence Project. This has also been confirmed in a study by Angnuureng *et al.* (2023), which revealed that erosion has been reduced considerably in some areas that have coastal protections, such as the beaches at Keta, Mumford, Axim, and Dixcove, all in Ghana. However, the third segment (Kedzi coastline) experienced high erosion that could be seen as severe despite the presence of the groynes. This can also be attributed to strong waves redirected from Keta and Vodza, which means the groyne at Kedzi could not withstand the force of the waves, among other localized factors. Thus, sea defences such as groynes have the tendency to reduce sea erosion, but in some instances, they can aggravate the situation depending on some localized factors (Angnuureng *et al*., 2022; Mann *et al*., 2023).

Conclusions

The results of this study have been useful in revealing the trends in shoreline change, both erosion and accretion along the coast of Keta. Although aerial photographs are traditionally the main sources of data for shoreline monitoring, the study has shown that medium resolution multi-spectral satellite imagery can be used to map and monitor the large and dynamic shoreline of the three coastlines: Keta, Vodza and Kedzi. Generally, there is a continuous trend of retreat rather than advancement due to increasingly high rates of accretion, except for Kedzi. More specifically, this study found significant shoreline accretion at both Keta and Vodza while erosion at Kedzi, highlighting the dynamic nature of the Keta's coastline. Due to the retreat of the sea in the major townships of Keta and Vodza, it is not surprising that the government has decided to abandon the ongoing Keta Sea Defence Project, which is almost complete. It is worth noting that because of the variability in coastal processes, planning for coastal intervention must not be taken lightly. Hence, as a matter of urgency, the government should urge the contractor to move to the site to complete the project while adhering to the original architectural design of the project.

Policy implications

The study tried to analyze the shoreline positions and the rate of movements between the selected years and the selected locations. The dynamics that lead to fluctuations in the position and movements of shorelines were identified as erosion and accretion. Out of the three coastlines understudied, two of them (that is, Keta and Vodza) remain stable due to retreat, except Kedzi, which experiences severe erosion. This information is important since it helps to inform policy makers on the nature of the coastlines, their dynamics and the kind of actions that need to be taken. There is the need for constant monitoring of these coastlines since there is the tendency to overlook it as accretion seems to be more accommodating to coastal dwellers and policy makers than erosion. For this reason, areas identified with high erosion need swift attention from major stakeholders such as the government to assist in ameliorating the impact of this phenomenon so as to protect lives and properties. This, therefore, calls for the development of sustainable coastal management policies that incorporate local community involvement and scientific research.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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