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*Corresponding author(s)
email: cboye@umat.edu.gh

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Assessment Of Shoreline Change Along The Sandy Beach Of Ellembelle District Of Ghana

Cynthia B. Boye[1]*, Peter E. Baffoe[1], John N. Ketibuah[1]

1. *University of Mines and Technology, Tarkwa, Ghana*

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Abstract

Sandy beaches are most popular tourists and fish landing sites, and serve as habitat for several endangered species. However, sandy beaches more vulnerable to coastal erosion, particularly those along open oceans. Assessment of shoreline change using reliable dataset aid in understanding the morphology of coastal landforms, the processes associated with their occurrence and support decision making. This paper analyzed available multi-temporal spatial dataset and field observations using GNSS techniques to assess the shoreline change along the study area. The shoreline features were extracted from 1974 topographic map and 2005 orthophotographs using the High-Water Line (HWL) in conjunction with 2020 spatial data. Shoreline change statistics were computed using DSAS. A geodatabase was created, transects were cast and the shoreline change rates computed using EPR, LRR and WLR methods. Both accretion and erosion were recorded with mean erosion rate of 0.97 m/year. It was observed that sections of the shoreline nourished by Ankobra and Amunzuri rivers were experiencing some accretion, particularly the mouth of the Amuzuri river. The estuary of Amunzuri river was found to be drifting eastwards at a rate of 5.4m/year possibly due to tides, waves and currents. The study concludes that in spite of the littoral drift eastwards, fluvial sediment supplied by coastal rivers accounts for the relative stability of shoreline in the area. Policy formulation regarding possible damming of coastal rivers by government under the 'one district one dam' agenda must be carefully considered to avert high levels of erosion along the western coast of Ghana.

1. Introduction

Shoreline change assessment is key to understanding the morphology of coastal landforms as well as the processes associated with their dynamics. This is particularly true for sandy beaches, as over 80% of the world's beaches are experiencing coastal erosion with change rates ranging from 1 cm/year to 30 m/year (Griggs et al., 2019; Nassar et al., 2019). The dynamic nature of the shoreline, which refers to the interface between land and water, makes low-lying coastal landforms highly vulnerable to erosion and flooding as a result of sea-level rise due to climate change (Nicholls et al., 2007; Pramanik et al., 2016; Woodruff et al., 2013). The position of the shoreline changes continually through time as a result of tides, waves, sea level rise and anthropogenic activities (Gornitz et al., 2001; McLean & Kench, 2015; Passeri et al., 2015; Prasad & Kumar, 2014). Sandy beaches along open oceans are more vulnerable to erosion, although they represent some of the most popular tourists and fish-landing sites, and are habitat for several endangered species in developing countries (Addo et al., 2011; Chakraborty, 2017).

Shoreline change is driven by several factors, but the three key drivers are sea-level rise (Gutierrez et al., 2007, 2011; Romine et al., 2013) change in storm climate (Duvat & Pillet, 2017; Johnson et al., 2015; Slott et al., 2006, 2010) and human interference with the coastal processes (Del Rio et al., 2013; Lazarus et al., 2011; Oyedotun et al., 2018). Other factors influencing the spatial location of the shoreline include differences in alongshore sediment transport rate (Nassar et al., 2019; Robinet et al., 2016), fluvial sediment supply (Anthony et al., 2019; Besset et al., 2019), offshore bathymetric changes (Cooper & Navas, 2004; Limber et al., 2017), beach composition (Eurosion, 2004), angle between approaching wave and shoreline (Ahn et al., 2017; Ruggiero et al., 2007), coastal material behavior (Hapke et al., 2009; Kinsela et al., 2017), and platform slope (Beetham & Kench, 2014).

The shores of Ghana stretch about 540 km long, portions of which serve as beach resorts, landing sites and preferred home to humans. Population distribution in Ghana is skewed towards the coast with about 25% of the total population living along the coastal zone and is site for about 80% of the industries in Ghana (Armah, 2011; Asante & Amuakwa-Mensah,

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2014; Jonah et al., 2016). However, most parts of the shoreline in Ghana are eroding at variable rates (Addo, 2013; Armah, 2011; Boateng, 2012; Jonah et al., 2016).

Different scientific researches have been carried out to examine some of the influential factors driving such changes in the shoreline. Some of these studies conducted in Ghana focused primarily on the analyses of shoreline change (Addae & Oppelt, 2019; Boateng, 2012; Sagoe-Addy & Addo, 2013). Other researchers analyzed the shoreline evolution to identify the causes so as to help formulate policies to support management of the coast of Ghana (Boateng, 2009; Frick-Trzebitzky & Bruns, 2019; Jonah et al., 2016), while other researches have studied the vulnerability status of the shore of Ghana (Giese & Thiel, 2014; Oteng-Ababio & Owusu, 2011; Sagoe-Addy & Addo, 2013), variability of the shoreline through time is of elemental significance, thus the past, current and future position of shoreline information is needed by both coastal managers and engineers (Addo et al., 2008; Boak & Turner, 2005; Woodroffe & Murray-Wallace, 2012). However, in regions with paucity of spatial data such as Ghana (Addo et al., 2008) shoreline change analyses are limited to available data, which is often outdated and does not provide current information to support decision making.

Though spatial data captured by remote sensing techniques could serve a good purpose, only high-resolution data, which is often expensive to procured, could provide the required accuracy for effective shoreline change analyses. Jonah et al. (2016) used available spatio-temporal data in conjunction with GPS field observations for assessment of coastal erosion in Ghana, however, the Garmin GPS device that was used has a precision of 3 m, making it unsuitable for assessment of sub-metre shoreline change. Accurate information about shoreline also helps in standardizing and authenticating numerical models (Jacobs et al., 2015; Naeem, 2020). It also helps to protect natural habitat and prevent coastal erosion.

Assessment of shoreline change through erosion and accretion have severe benefits, particularly to coastal zones in West Africa which have little or no policies on setback distances for coastal development (Fish et al., 2008; Johnsson, 2005). Coastal erosion also causes destruction to coconut plantation, turtle nesting site and fishing boats and canoes landing sites. In order to protect coastal assets and the society as a whole from the threats posed by shoreline fluctuations, seawalls or other measures are established. These shoreline protection measures, however, involves a huge financial commitment of resources which is exorbitant for most developing countries (Hilson et al., 2020; Olsen et al., 1997; Salm et al., 2000). Besides, hard protection only shifts the erosion to the lee side of coast (Hanley et al., 2014).

In view of these underlying consequences of shoreline fluctuation coupled with lack of current data for shoreline change analysis, we sought to study the shoreline of the study area by combining available data and current field data captured using satellite navigation systems techniques. The uniqueness of this study, unlike other studies within the Central zone of the Ghanaian coast (Armah, 2011), is the fact that the study site lies in the Western zone which was perceive previously to be stable (Ly, 1980) and the shores are composed of 100% unconsolidated sandy sediment making it susceptible to coastal erosion. The findings will help provide understanding of the behavior of micro-tidal sandy beach as well as aid in the formulation of policies to protect sandy beaches along the Atlantic Ocean and the western coast of Ghana in particular. Therefore, this study evaluated the shoreline change along the shores of the Ellembelle District of Ghana using field data, existing topographic datasets and DSAS, an extension of ArcGIS software.

2. Data and Methods

2.1. Study Area

Ghana is a maritime state located in West Africa which shares boundary with Togo to the east, Cote D'Ivoire to the west, Burkina Faso to the north and the Gulf of Guinea (Atlantic Ocean) to the south (Figure 1). The coastline of Ghana stretches about 540 km and it is made up of about 60% sandy beaches and 40% composite rock/sandy beaches (Boye, 2015). The ocean climate along the coast of Ghana shows an average significant wave height of about 1.2 m and a significant wave period between 10 and 12 s (Wellens-Mensah et al., 2002) Prevailing wave direction is south-southwest with a local sea level rise rate of between 2 and 3 mm/year (Boateng et al., 2017). Western Region of Ghana lies within latitudes 4°40′ and 5°10′ North and longitudes 3°07′ and 1°40′ West (Figure 1) and covers part of the Central zone and the Western zones of the Ghanaian coastal zones. The region is the second most densely populated region in Ghana next after Greater Accra with a population density of about 79 person's per-square kilometer and 63% of the region is rural.

The location for the study area as indicated in this study is actually the shores of the Elembelle district in the Western Region of Ghana which spans about 70 km of uninterrupted sandy beach. There are two main rivers along the study location, these are the Ankobra River which is to the eastern part of the study area and the Amunzuri River located on the central part of the study area. The emphasis is on the sandy beach which is known to be more vulnerable to coastal erosion worldwide and not the Amunzuri River Mouth. However, the Amuzuri estuary area is observed to have formed a barrier beach that runs parallel to the coastline and separates the estuary from the ocean except at its mouth. This imples that fluvial sediment will be retained in the estuary or along the shores except during heavy rainfall or high tides when sea water moves into the estauary. The barrier beaches along the Amunzuri estuary seems to offer protection to that stretch of the shores by breaking the impact of destructive ocean waves before they reach the estuary.

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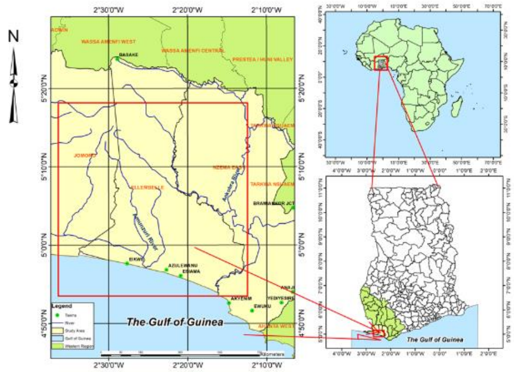


Source: SMD, Lands Commission, Ghana, 2022

Figure 1. Map of the Coast of the Western Region of Ghana

The Ellembelle District is one of the coastal districts of the Western Region of Ghana with about 70 km stretch of uninterrupted sandy beach constituting about 13% of Ghana's coastline. It shares boundaries with the Jomoro District to the West, Wassa Amenfi West District to the North, Nzema East Municipal to the Southeast, Tarkwa-Nsuaem Municipal to the East, and the Atlantic Ocean to the south. The District covers a total area of 995.8 Km2 and constitutes about 9.8% of the landmass of the Western Region. The western coast of Ghana is a low energy coast which comprises of gently sloping fine sandy beaches backed by coastal lagoon (Boateng, 2006; Ly, 1980). The shores of the study area has average exposed beach width of about 13.5 m and its nourished by numerous rivers notably the Amunsuri and the Ankobra (Boye, 2015). The sediment discharge from these rivers is distributed across the shores by the strong west to east longshore drift (Boateng, 2012). The Western Region, which lies within the Tano Basin, is underlain by Eocene and Cretaceous Appolonian sediments. The Appolonian consists of rapidly alternating sands and clays with occasional thin beds of gravel and fossiliferous limestone. The sands and clays are more compact at depth and pass into sandstones and shales (Kesse, 1985).

2.2. Materials

This study utilized both secondary and primary data. The secondary data used were multi-temporal spatial dataset comprising topographic data and orthophotos. The topographic data and orthophotos were obtained from the Survey and Mapping Division of the Lands Commissions, Ghana. The primary data was obtained based on GNSS techniques using Global Position System (GPS) receivers. The GPS receiver were validated and were found to be satisfactory before the data collection was done.

2.3. Methods

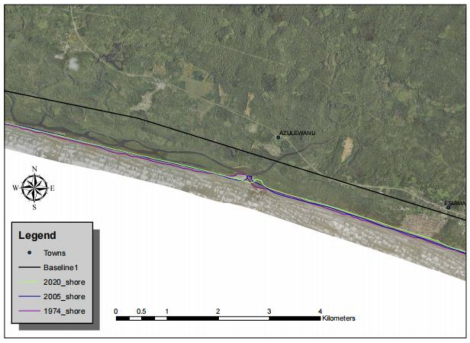
Differential GPS technique was adopted in the survey of the shoreline positions using the high-water line (HWL) mark as the shoreline indicator. Known ground control points / stations were used as reference base and closing stations; this is to enable assessment of the accuracy of the survey. The GPS receivers (rovers) was fixed on the high water marks along the shores to mark the shoreline position along the study site. The above procedures were repeated till the area of interest was covered. The data was downloaded and plotted to represent the 2020 shoreline of the study area using Topcon Tools. A personal Geodatabase was created within the ArcGIS environment to store all shorelines and the baseline. The shoreline data of the study was extracted from a topographic map of Ghana and its reliability for use was assessed (Addo et al., 2008; Boateng, 2012; Boye et al., 2018).

The 2005 shoreline was digitized from orthophotos of the study area. The data was validated by determining the positional accuracies of selected points/features which were clearly seen on the photograph as well as detected on the ground. The differences in the measured coordinates of the datasets were computed and the root mean squared error (RMSE) determined.

The multi-temporal spatial dataset projected into Leigon Transverse Mercator were merged into a single feature class. A baseline feature was also created which served as reference line for calculation of shoreline change statistics (Gibbs, 2020; Nassar et al., 2019). Digital Shoreline Analysis System (DSAS) an extension of ArcGIS was used to cast perpendicular transects across the shoreline which was used to calculate the shoreline change statistics at 50 m intervals along the study area. DSAS was used because of its advantage and suitability for shoreline change assessment compared with the traditional manual shoreline change analyses (Sheik & others, 2011). The rate of shoreline change was then calculated by using End-Point Rate (EPR), Linear Regression Rate (LRR) and Weighted Linear Regression (WLR) statistical methods. Detailed discussion on these methods could be found in Dean & Dalrymple (2004), Frazer et al. (2009), Galgano & Douglas (2000), and Dolan et al (1991). The LRR, WLR and the EPR methods were adopted because they have less positional uncertainties and the EPR allows rates could be computed where only two shorelines exist (Mullick et al., 2020). The rates were then analyzed.

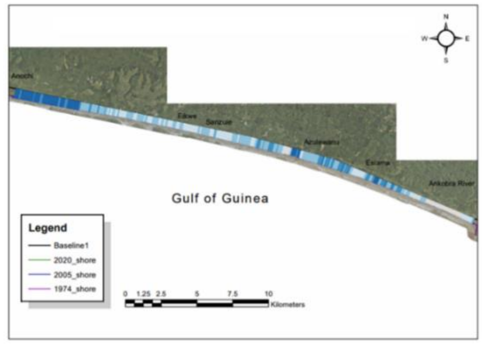
3. Result and Discussion

Figure 2a shows the shoreline multi-temporal dataset (1974, 2005 and 2020) and the baseline used. The purple, blue, and lemon green shorelines represent the position of the shore in 1974, 2005 and 2020 respectively whereas the baseline and transect cast are depicted in Figure 2b. There is a general recession of the shoreline positions along the sandy beach during the study period of 46 years stretching over 33 km length of the shore. Some accretion was observed close to the mouth of the Amunzuri River as well as along some parts of the study area.



Source: Analysis, 2022

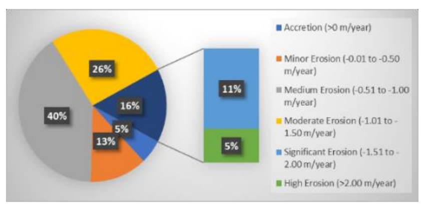
Figure 2a. Multi-temporal Dataset and the Baseline Used at the Study Area



Source: Analysis, 2022

Figure 2b. Map Produced From the Shorelines, Baseline and the Transects

Figure 3 is a pie chart showing the shoreline evolution trend taking place along the entire shore of the Ellembelle District of Western Region of Ghana. Only 5% of the shore is accreting or stable, the remaining portions of the shore is experiencing varying degrees ranging from 1 cm/year to 2 m/year. Another 5% of the shore under consideration is experiencing high erosion values exceeding 2 m/year (see Figure 3).



Source: Analysis, 2022

Figure 3. Percentage Shoreline Evolution Trend along the Study Area

Findings of this study are consistent with researches carried out in other parts of the world that indicates that over 80% of the world beaches are experiencing coastal erosion with rates varying from 1 cm/year to 30 m/year (Nassar et al., 2018). Sandy beaches are composed of unconsolidated sediment and are more easily influenced by currents, tide and waves (Oteng-Ababio & Owusu, 2011). Currents produced from breaking waves are able to transport sediment along the shore and offshore in the situation where clearly define sediment cell are non-existent (Boateng, 2006). The study area, which is part of the Western Zone of Ghana's coast is however, perceive to be low energy sandy beach backed by coastal lagoons (Boateng, 2006; Ly, 1980). Besides, micro tides are experienced along the study area with mean tide range that rarely exceeds 0.6 m due to its location along the Gulf of Guinea on the Atlantic Ocean (Boye, 2015). Erosion of the shores of the study area could be linked to climate change, induced sea level rise, as well as eastwards drift of beach sand along the shores of the study area.

The shoreline changes statistics obtained from the EPR, the LRR and WRL were considered under three different scenarios. These are: the entire study area; entire study area without the Amanzuri river estuary; and only the Amanzuri river estuary/mouth as shown in Table 1. Details of the mean change rate, maximum and minimum values of the change rates are shown for the three methods employed for the change rate determination.

An average shoreline change rate of -0.94 m/year was recorded for the entire study area, although some few portions showed accretion, greater portions experienced erosion, this confirms Wiafe, (2012) findings of an average shoreline change rate of 1 m/year for the shores of the Western of Ghana from analysis between 1974 and 2005. It could be observed that since 1974, through 2005 to 2020 the dynamics of the coast of the Ellembelle has remained quite consistent. This gives an indication that factors driving the shoreline dynamics in the area remain similar. There was neither erosion nor accretion for some part of Azulenloanu and greater part of east of the Amanzuri river estuary were found to be stable during the period under study. With the exception of the Amanzuri estuary which experienced accretion, maximum accretion of 0.89 m/year occurred west of the estuary whereas maximum erosion of -2.37 m/year was recorded at Anochi in the far west of the study area.

Table 1. Shoreline Change Statistics

Shoreline change statistics for Entire study area			
	EPR	**LRR**	**WLR**
Mean	-0.92	-0.94	-0.94
Min	-3.11	-2.99	-2.99
Max	2.68	2.82	2.82
Shoreline change statistics for study area without river estuary			
	EPR	**LRR**	**WLR**
Mean	-0.95	-0.97	-0.97
Max	0.73	0.89	0.89
Min	-2.2	-2.37	-2.37
Shoreline change statistics for only river estuary			
	EPR	**LRR**	**WLR**
Mean	0.25	0.24	0.24
Max	2.68	2.82	2.82
Min	-3.11	-2.99	-2.99

Source: Analysis, 2022

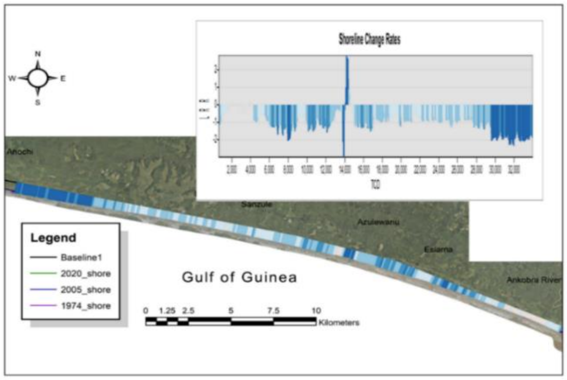
These findings are in line with results of other studies conducted along the shores of Ghana and beyond. Short to medium term analyses of shoreline along some shores of the central zone of Ghana's coast such as Cape Coast, Komenda and Sekondi showed erosion rate <-1 m/year (Dadson et al. 2016). Jonah et al. (2016) and Oteng-Ababio & Owusu (2011) also recorded mean erosion rates ranging from -<1.0 m/year and -1.5 m/year along Elmina, Moree and Cape Coast respectively. Addo et al. (2008) recorded -1.13 m/year as shoreline change rate for Accra. The results of this study confirms that shoreline erosion is taking place along the entire coastal zone of Ghana at variable rates and that few area are stable, and that the Western Zone of Ghana is no exception as perceived (Addo et al. 2008; Boateng 2012; Ly 1980; Wellens-Mensah et al. 2002). The shoreline change analysis gives an indication that the shores of the study area are undergoing natural geomorphic processes of accretion and erosion.

A careful analysis of the dynamics occurring along the estuary of the Amunzuri River at Azulenloanu reveals a trend worth noting**.** A maximum accretion rate of 2.82 m/year was recorded, while maximum erosion of -2.99 m/year and an average accretion of 0.24 m/year were recorded (see Figure 4.). Figure 2b shows a lateral shift in the position of the estuary of the Amunzuri River at an average rate of 5.4 m/year.

The rates determined by the EPR method, which considers only two shorelines at any point in time for the computation of the rates turn to vary from the regression rates (LRR and WLR). Both LRR and WLR methods gave same results (see Table 1). The regression rates yield more accurate results compared with the EPR as all the data points were used in the determination of the line of best fit, and it is also known to be the most robust method for analyzing historical trends of shoreline (Fenster et al. 1993). The linear regression method is simple to use and most commonly used by coastal planners and manager. The WLR is a generalization of ordinary LRR in which knowledge of the variance of observations is incorporated into the regression. Assumption of homoscedasticity applies in LRR whereas is the case of WLS the covariance of the error matrix is incorporated in the model. From Table 1, obtaining same values from LRR and WLR for all three scenarios suggests that the statistic assumption that shoreline movement is constant and uniform holds for the sandy beach of the study area as well as the coast of the western Region of Ghana (Jonah et al., 2016). This also implies the sandy beach of Ellembelle is homogeneous and that errors in the response variable are independent and identically distributed using the linear regression method.

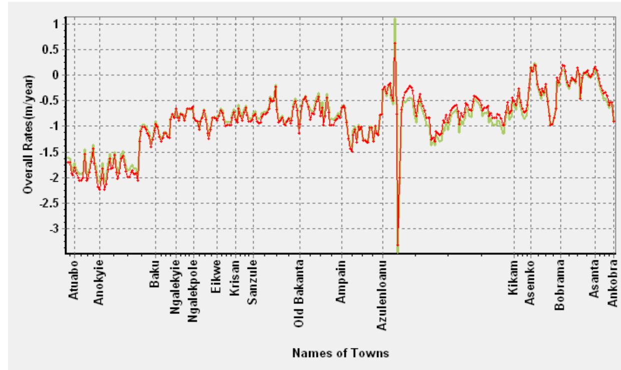
The shoreline changes statistics for study area spanning 33 km without consideration of the Amunzuri River estuary shows variation ranging from + 0.89m/year to -2.27 m/year (see Figure 5.). This observation gives an indication that although the sandy beach material behavior seems to be uniform, the causative factors driving shoreline change along the sandy shores seems to vary considerably. These driving factors may be variation in coastal processes (e.g., waves, tide or storm surge) and alongshore sediment transport (Esteves & Elírio Ernestino Toldo, 2002; Jonah et al., 2016).

However, the shore of the study area experiences micro-tides with a tidal range of about 0.6 m (Wiafe et al., 2013), besides the Boateng, (2006) and Ly, (1980) describe the Western Coast of Ghana as low energy beach, with flat and wide beach backed by coastal lagoons. Thus, the eastward drift of beach sand along the shores may be responsible for driving shoreline change in the area. Erosion rates were observed to be high at sites farther away from the fluvial sources. From the shoreline evolution chart in Figure 3, about 11% of the sandy shores are accreting possibly due to fluvial sediment supplied by the Amunzuri River at Azulenloanu which deposits its load to recharge the shores. For instance, mouth of the Amunzuri River is accreting at an average rate of 0.24 m/year. The said river which runs parallel to the shore (see Figure 2a and Figure 2b) turn to discharge sufficient load to nourish the shore, part of which may be carried away by the east-west drift along the coast of the Gulf of Guinea. This is because the Amunzuri lagoon has a relatively small drainage area and therefore has less area for sediment storage, thus its sediment yield is asserted to increase as much as sevenfold for each magnitude of decrease in the basin area (Boye et al. 2019; Milliman & Syvitski 1992).



Source: Analysis, 2022

Figure 4. Shoreline Change Analysis along Ellembelle District of Ghana



Source: Analysis, 2022

Figure 5. A graph of Overall Rate against Towns

Some accretion was also observed on the western part of the Ankobra River stretching over 1.3 km, however, moving towards the Ankobra estuary, small amounts of erosion rates to the tune of -1 m/year was observed. Even though sediment distribution from the river is not very clearly understood, rates obtained close to the Ankobra estuary are comparable to the mean rates for the study area. This could be due to the turbulence generated along the shores at the estuary as fresh water from the Ankobra River enters the sea that carries most of the sediment yield by the eastward drift or lost off shore. This finding confirms that both small and large basin coastal rivers of the study area provide significant sediment load to recharge the shores (Boye et al., 2019; Carter et al., 2012; East et al., 2021; Meidiana & Marhaeni, 2019; Milliman & Farnsworth, 2013). Nevertheless, the small basin rivers and streams provide turn to provide more of the sediment yield that stabilizes the coast of the western Region of Ghana. Thus, it can be postulated generally that, the entire shore of the study area and Ghana as a whole is experiencing east-west drift along the coast, thus sites deficient in fluvial sediment supply are likely to erode, while those sites receiving adequate supply of fluvial will accrete. The contribution of small basin rivers and streams is important for the stability of the coast of the western region of Ghana.

4. Conclusion

The dominant causes of the shoreline change in the study area are waves, alongshore currents and to a small extent tides. The shores of the study area which lies opened to the Atlantic Ocean is exposed to waves and currents generated along the shores as waves break near the surf zone. As the coast experiences micro tides with maximum tidal range of 0.6 m, the effect of tides may influence the shoreline dynamics to a small extent. The shoreline of the sandy beach in the Ellembelle district of Ghana is undergoing a natural geomorphic process of accretion and erosion in spatial and temporal scale like other open ocean shorelines. The study area is generally eroding at variable rates with an average rate of 0.97 m/year. Portions of the shores that are well nourished by fluvial sediment turn to be accreting or stable while sites deficient in fluvial supply are eroding. Shores close to the Amunzuri river are accreting much more that shores closer to the Ankobra River which has a relatively larger basin. The sediment yield from the Ankobra River may be lost off shore by the currents produced at the estuary or deposited further away from the shore of the river estuary. The mouth of the Amunzuri River is moving eastwards at an average rate of 5.4 m/year, possibly due to waves and tides. It is recommended that regular collection of multi temporal spatial data of coastal areas of most developing countries be encouraged to enable regular monitoring of the shoreline. Policy formulation regarding possible damming of coastal rivers by the government as part of one the district one dam must be carefully considered to avert high rate of erosion along the western coast of Ghana.

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