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SPATIO-TEMPORAL SHORELINE MOVEMENT OF THE AFRAM RIVER IN GHANA: THE APPLICATION OF ENDPOINT RATE AND NET SHORELINE MOVEMENT

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ArcGIS, Shoreline, Digital Shoreline Analysis System, Shoreline Erosion, Afram, Ghana

ABSTRACT

Shoreline change is a severe threat to life and property in wetland regions. Shoreline change analysis is critical for integrated wetland zone management and is accomplished through the field and aerial surveys. The Afram River is a significant source of water, food, and economic activity for Kwahu and its neighbouring communities and a form of funds for the residents. The shoreline, nevertheless, has been transforming because of erosion and accretion. This study examined a low-cost innovative approach using space-based peripheral visuals and metrics. Transects and data analysis for the riverbank were created using the Digital Shoreline Analysis System (DSAS) in the Spatial database. The study employed Landsat images from three historical years (2001, 2015 and 2022) across 22 years. End Point Rate (EPR) and Net Shoreline Movement (NSM) statistics in DSAS were used to determine the extent of change. Questionnaires and key informant interviews were administered to farmers, boat operators, fishermen, and older residents to learn more about the factors responsible for changes in shoreline position. According to the study, 24% of the shoreline erodes at a section, while 86% is stable. The survey's mean erosion rate is -0.24 m/yr, whereas the average accretion proportion is 27 m/yr. The ramifications of the Afram River channel change have affected the socio-economic livelihoods, including out-migration, farm loss and displacement of settlement. The mitigation measure employed by the residents had been relocation, and sandbags at the river shoreline have been adopted as a coping mechanism. As a result, all organisations and participants responsible for these riverbanks should work together to prevent further damage and erosion of the shoreline line and its marine life and resources. The current study demonstrates that integrating aerial photos and quantitative tools for shoreline investigations could be dependable.

INTRODUCTION

Rather than remaining stationary in shape or location, river channels naturally shift over time in response to various interconnected factors (Thompson, Ramsey, Mollhagen, Evans, & Lehman, 1997). The shape of a riparian zone can be seen as the consequence of a challenge between the valley floor materials and the river's erosive potential. The descending constituent of inertia is the key factor that causes the movement of water (Charlton, 2008). Streams change their position or shape over time to adapt to various interconnected factors. Channels have historically responded to release and deposit supply variations caused by terrestrial usage and dangerous occasions such as inundations and deficiencies in precipitation. Channels respond to tectonic uplift, landscape erosion, climate change, and other anthropogenic factors over geologic time (Montgomery & Buffinghton, 1993). According to investigations, river morphodynamics (erosion, depletion, water contamination, intertidal decline, and flooding) influence 70% of people worldwide (Nicholls & Cazenave, 2010). The importance of the Afram River cannot be overstated in this context, so its morphodynamics must be evaluated. As one of the geographic tools, remote sensing provides high accuracy, efficiency, and cost-effectiveness in monitoring a river's shoreline (Appeaning Addo, 2014). Butovsky (2011) described the underlying tenets in using Geo-information approaches for simulating shoreline morphodynamics, highlighting the significance of recognising shoreline transformation and protecting it from degradation.

Furthermore, shoreline change analysis has evolved into a powerful tool for understanding river erosion's temporal and spatial trends, shoreline changes, and accretion caused by natural and human influences (Drost, Matzke & Backhaus, 2007). River shoreline change research studies are indeed critical to understand the patterns in shoreline change, recognise the primary factors that influence it, and potentially creating scientifically verifiable frameworks that would enable prognostications (Sreenivasulu, Jayaraju, Reddy, Lakshmanna & Prasad, 2018). As per Afram Basin relevant parties, the river watershed has been confronted by various anthropogenic and natural processes, including contaminant fishery, lumbering, depletion, and inundation. These phenomena have made it challenging to achieve dynamic equilibrium and have resulted in population displacement, farm destruction, and loss of life and property. Appeaning (2009, 2014); Ali et al. (2015) and Jonnah, et al. (2015) did a study on shorelines based on a widespread scale utilising GIS. As a result, this study concentrated on the riverbanks of Nketepa, Adawso and Pitiko on a smaller scale to fully comprehend the divergent rates of shoreline changes.

Consequently, within 22 years, this research mainly located the shoreline assessment. Anfuso et al. (2007) projected a 10-year duration for shoreline evaluations. They highlighted that it provides an in-depth understanding of the occurring problem in terms of a brief review of shoreline modification. Against this background, there is a need for reliable information on the morphodynamics of the Afram River to advance appreciation of the coping strategies adopted by the community dwellers to provide a basis for formulating and applying improved shoreline change hence this study.

METHOD RESEARCH

Study Area

The Kwahu South Municipality is bordered to the north by Kwahu East, to the west by Asante-Akim South, to the south by the Kwahu West Municipality and East Akim District, and the east by the Fanteakwa District. Kwahu South Municipality is located roughly between latitudes 6°35" N and 6° 45" N and longitudes 0° 55" W and 0° 20" W. Nketepa, Adawso and Pitiko cannot be ruled out as communities under the municipality (Ghana Statistical service, 2021). The geographical coordinates of the river are 6°26'40"N, 0°48'0"W; 6°32'0"N, 0°42'40"W; 6°37'20"N, 0°37'20"W; and 6° 42'40"N, 0°32'0"W, 6°48'0"N, 0°26'40"W; 6°53'20"N, 0°21'20"W. The study area was separated into three sections to allow a fast analysis of the shoreline alteration results. As illustrated in Figure 2, this split was made based on the direction and primary activities along the Afram River. The divisions are; Nketepa, Adawso and Pitiko.

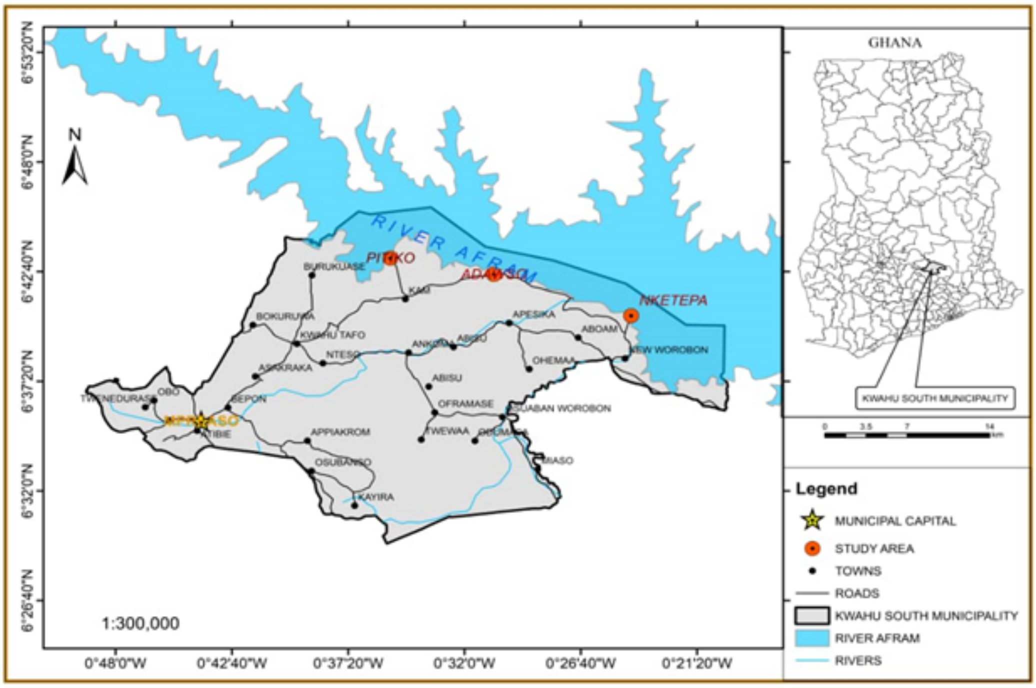

Figure 2: Study Area in Regional and National Context.

Source: Authors construct, derived from ArcGis (2020).

Material Description

There are various methods for acquiring information in research, all of which fall into one of two groups: primary and secondary data (Douglas, 2015). The study's data came from both primary and secondary sources. Primary data were collected through questionnaires and interviews to extract respondents' perspectives on the implications of shoreline change on people's daily circumstances and possible capacity to cope. For this study, the researcher relied on Landsat images as secondary data. Three-year interval periods (Landsat, 2001, Landsat, 2015, Landsat, 2022) span a 22-years frame. According to Appeaning (2011), the long-term period assessment of the shoreline provides a clear and better analysis of shoreline changes.

Because this study planned to interview key informants who gave knowledge of the River Afram shoreline, a purposive sample strategy was suited for qualitative data recovery. As a result, riverfront residents and employees shared firsthand knowledge of the causes and obstacles encountered. The paper employed an interview guide, and in-depth interviews were conducted with residents who had stayed for more than ten years. The rationale is that a 10-year timeframe assisted participants in making moral judgements on concerns like assessing shoreline alterations' impacts on people's socio-economic lives and mechanisms to address the difficulties. This study made use of Landsat images. The researchers used Three-year periods (LANDSAT TM 2001, LANDSAT TM 2015, and LANDSAT ETM 2022) that span 22 years. The year periods were chosen to aid in comparing erosion and accretion rates over different periods. The intervals between these satellite images are fourteen (14) and seven (7) years. Regarding short-term strategies, the tactics should last at least five years (Anfuso, Bowman, Danese, & Pranzini, 2016). The study's three central communities were chosen on purpose: Nketepa, Adawso, and Pitiko. These communities were selected because of their economic and social involvement in the study's focus area. The study's objectives were considered; the questionnaires were organised around three major areas. Thematic categories were local adaptation solutions and institutional implementation plans.

Shoreline Extraction

Using ArcGIS 3.1 software, the shoreline change data was derived from satellite data from 2001, 2015, and 2022. The rate of shoreline change was measured using the method described by Hanslow (Hanslow 2007, Thieler et al., 2009, Borrelli 2009, and Romine et al., 2013), which entails mapping a shoreline using spatially distributed pictures and estimating amounts of erosion and accretion.

Shoreline Data Analysis

In ArcGIS, a geo-database was generated for the digitised shoreline locations, with attribute tables for all shorelines, including year, Identifier, shape, and confidence. The historical shoreline change was examined utilising Digital Shoreline Analysis System (DSAS 4.3) software program, which is an ArcGIS extended version. The Digital Shoreline Analysis System (DSAS) uses a GIS to calculate frequency data from several previous beachfront sites (Thieler et al., 2009). The change in shoreline rates from 1969 to 2010 was calculated employing two statistical approaches. End Point Rate (EPR) and Net Shoreline Movement (NSM) were the methodologies used; in the DSAS process, EPR is computed by dividing the distance of shoreline movement by the time elapsed between the oldest and most recent shoreline Thieler et al., 2009). The NSM reported the overall distance between the oldest and youngest shoreline (Thieler et al., 2009).

Field Verification

Ground truthing operations were undertaken in the research region in 2021. Concurrently, digital photographs were acquired to understand particular spots along the Afram bank better. Extensive field validation was performed after the preliminary examination of shoreline change results in October 2021. During this period, questionnaires were distributed, and key informant interviews were conducted in Adawso, Pitiko, and Nketepa to collect data on possible shoreline change triggers and mitigating approaches. The DSAS data were juxtaposed to photographs taken along the shoreline.

RESULTS AND DISCUSSION

The magnitude of Shoreline Change of the Afram River Shoreline between 2000 And 2021

The study's average erosion rate is -0.31 m/yr, with accretion at 27 m/yr; erosion ranges from -2.51 m/yr to -0.34 m/yr; negative numbers represent erosion, while positive values represent accretion. An ArcGIS result from DSAS analysis shows an area in Adawso, Nketepa and Pitiko with historical shoreline locations and transects that allowed shoreline change statistics to be calculated. The shoreline placements of Nketepa, Adawso, and Pitiko (2001, 2015, 2022). Between 2001 and 2022, the River Afram shoreline was digitised using satellite images, as shown in (Figure 3). From 2001 to 2022, 500 transects with 10 m spacing were created, with an average change rate calculated.

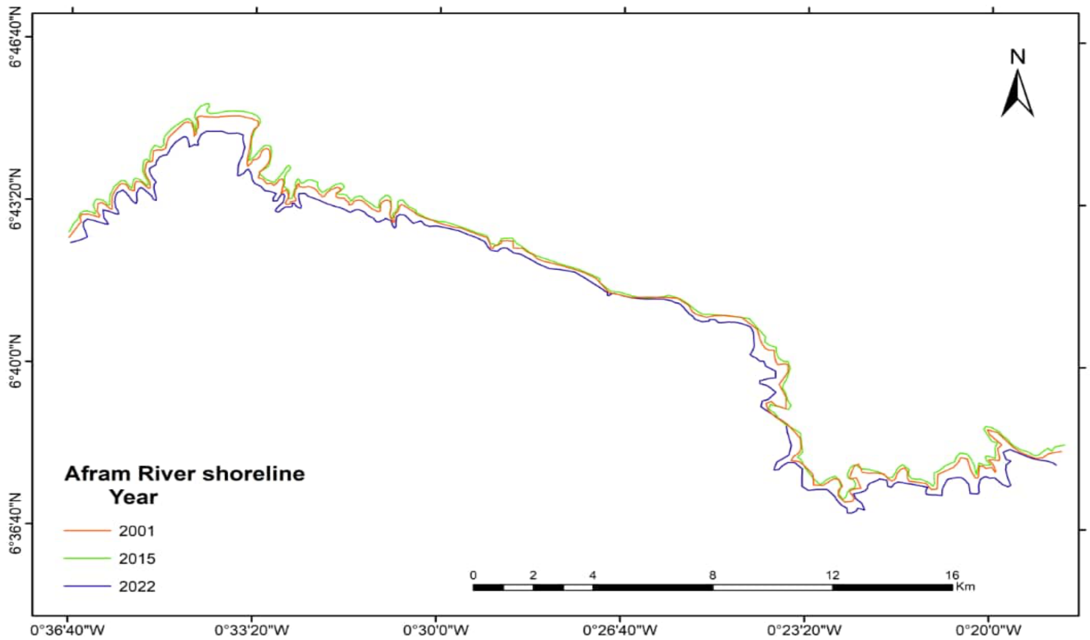

Figure 3: The rate of shoreline changes of the Afram River from Nketepa, Adawso to Pitiko between 2001 to 2022
Source: GIS Lab University of Ghana, Legon, (2022)

Erosion and accretion points along the channel of the Afram River

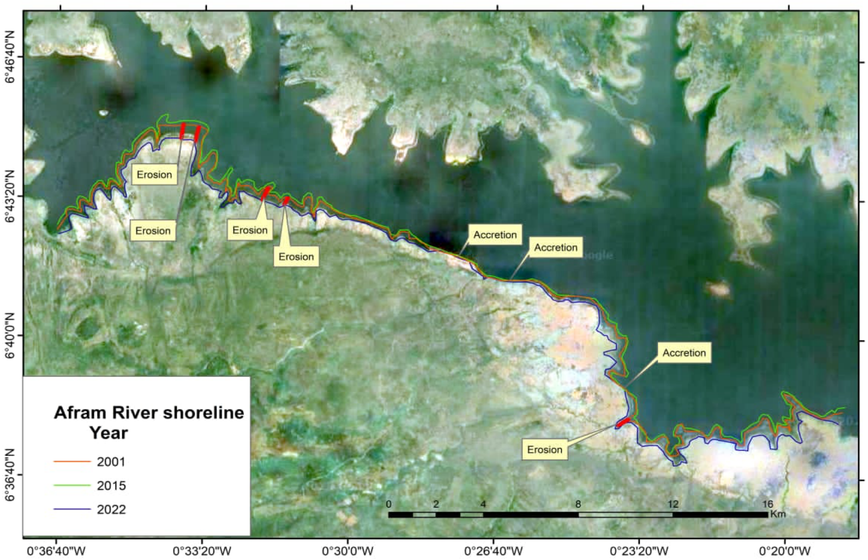

Figure: 4 Erosion and accretion points along the channel of the Afram River from Nketepa, Adawso to Pitiko between 2001 to 2022
Source: GIS Lab University of Ghana, Legon, (2022)

The shoreline along the research region is subject to a dynamic process and has a cyclical character of alternate erosion and accretion, according to the generated map shown above. The community inhabitants at Adawso, Pitiko, and Nketepa are directly impacted by some places that exhibit a high rate of erosion. The targeted locations are currently experiencing severe erosion because the erosion rate from 2015 to 2022 is much greater than the erosion rate from 2001 to 2015. The Afram River shoreline exhibits a cyclical process of erosion and it's ascribed to anthropogenic actions. Boye (2015) contends that sand mining operations caused by human activity are to blame for the area high to extremely high rates of shoreline alteration.

River Afram shoreline change between 2000, 2015 and 2022 using end Point Rate

Figure 5 shows a historical trend from 2001, 2015 and 2022 consisting of a fourteen and seven-year span depicting the shoreline's changes. Accretion dominated the entire shoreline during this era, with 86.4 per cent of the cast transects recording accretion and 24.6 per cent recording erosion at some part of the study area, to be precise Adawso and Pitiko. The annual rate of change (EPR) varied from -140 m/yr to 51.19 m/yr. The annual accretion rate (EPR) increased from 0.66 to 51.19 m/yr. The erosion rates (EPR) ranged from -0.99 to -140 meters per year. The recorded erosion was observed to be common along transects 331 - 467 and 5 - 12. The shoreline of Afram River at some sections accreted, with most transects exceeding five m/yr. The investigation of shoreline variations between 2001, 2015 and 2021 revealed that the River Afram shoreline has been accreting and eroding at specific parts of the research region.

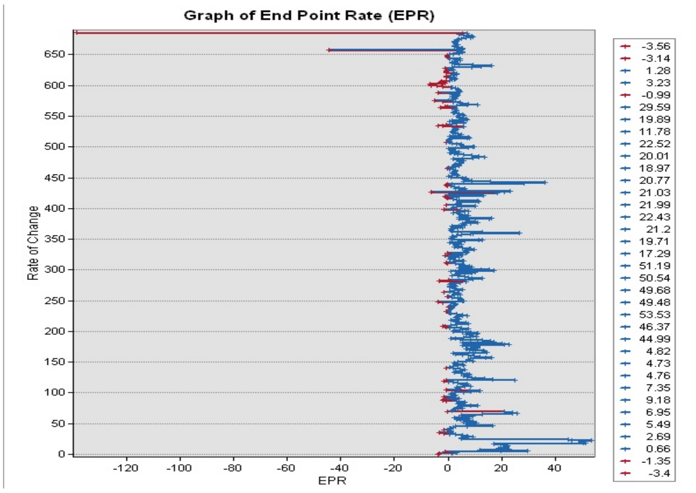

Figure 5: The Rate of Shoreline Changes of the Afram River from Nketepa, Adawso to Pitiko Using End Point Rate
Source: GIS Lab University of Ghana, Legon (2022)

Shoreline change between 2001, 2015 and 2022

As shown in Figure 6, River Afram had different erosion and accretion rates, as evidenced by the results. Generally, the rate of shoreline change calculated using (NSM) statistics showed that the rate of change varied from -13.85 to 909.37 metres. Accretion rates are calculated using (NSM) statistics ranging from 13.0 metres to 800.0 metres. The erosion rates (NSM) varied from -13.0 to -44.1 m. Erosion was rampant along the various portions of the shoreline. Transect 280 had the fastest rate of deterioration. According to the proportion of transects, accretion occurred along most of the river's shoreline line. Accretion was clustered in a particular section of the river shoreline and was most noticeable between transects 355 and 440. Again, transects 448 experienced the highest rate of accretion. Erosion was widespread along the shoreline's various portions. Transect 280 had the fastest rate of erosion. This period's shoreline modifications were more varied, with most of the shoreline experiencing accretion and just a few spots exhibiting erosion.

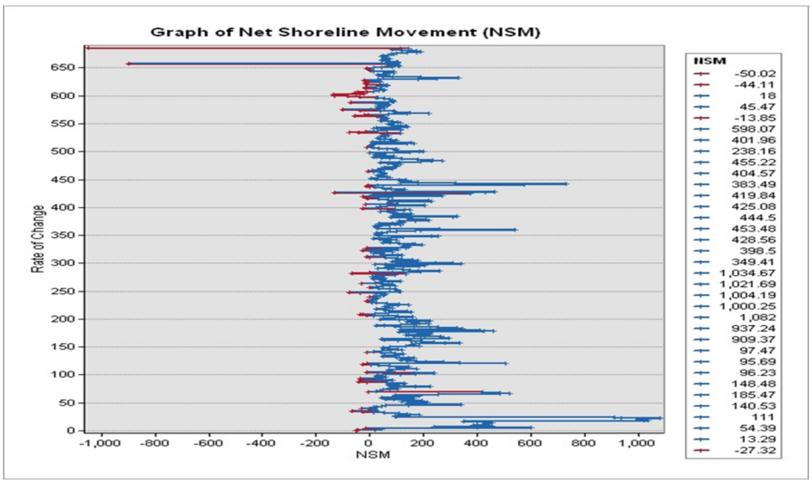

Figure 6: The Rate of Shoreline Changes of the Afram River from Nketepa, Adawso to Pitiko Using Net Shoreline Movement statistics

Source: GIS Lab University of Ghana, Legon (2022)

The increase in the volume of the Afram River is a significant factor along the River Afram shoreline, specifically Adawso, Nketepa and Pitiko. Moreover, as identified by (Páez-Osuna, Sanchez-Cabeza, Ruiz-Fernández, Alonso-Rodrguez, Pión-Gimate, Cardoso-Mohedano, & lvarez-Borrego, 2016), a rise in stream capacity has been recognised as a key trigger of shoreline movement, whether on a short or long-term dimension. The consistent erosional behaviour of the Afram River can be linked to a stable flow in the river generated by the opening of the Bagre Dam. This confirms the assertion of (Appeaning Addo *et al.,* 2011). In their investigation along the shoreline of Dansoman, an Accra neighbourhood, they classified the area as vulnerable to shoreline modification and floods because of an increased water volume.

According to Kansuk, Stephen, and Chimbar (2018), the opening of the spill gate of the Bagre Dam in Burkina Faso in 1999 was the principal cause of the River Afram volume increase. After constructing the Bagre multipurpose hydro dam on the White Volta sub-basin in Burkina Faso, numerous settlements in Ghana downstream of the White Volta River have experienced a sequence of river depth increases and storm surge disasters. These tragedies have occurred in many areas of the Afram community. A male farmer sums up this notion at Pitiko in an interview. He noted:

"The opening of the Bagre Dam in Burkina Faso is one of the primary causes of the River Afram's annual increase in volume at Adawso, Nketepa, and Pitiko. "When the river's volume is at its peak, we cannot cross to Ekye Amanfrom for a market which affects our economic activities as traders, and it also destroys a lot of town and farmland".

Policies and Coping Strategies Adopted by Adawso, Nketepa and Pitiko

The results of the respondents' coping mechanisms to the impacts of Afram River shoreline changes show that 99 respondents, representing (50%), usually use the relocating strategy to cope with the effects of Afram River shoreline changes. The study's findings revealed that natural hazards significantly impact residents. The changes in the shoreline of Afram affect the livelihoods of the various communities due to the physical damage and socio-economic losses. The effects of shoreline change on livelihoods are considered critical, particularly in the three villages where livelihoods rely on fishing, agriculture, and other landed economic activities. A very concerning issue regarding the fate of these household heads is the lack of government support, aside from some pittance relief items given to victims. Second, residents do not insure their properties, so they cannot cope with and recover from the shoreline displacement canker. This viewpoint is summed up by a remark posted by some other female discussant at Kwahu Adawso:

"When the river level increases, we must migrate to different .places". *We usually use this mechanism to protect ourselves from disaster. If we do not relocate and something bad happens, we have no one to blame, and no one is ever willing to help us in such times.*"

Asiedu and Kusimi (2019) made the case in their study that people who live in such areas want to relocate to safer places in the neighbourhood, but victims lack the financial means to do so. At the time of the study, the newly relocated area known as Domeabra at Adawso is shown in (Figure 7). Victims hoped to have some amount of money to complete their building.

Figure 7: Relocated Site is known as "Domeabra" in the Adawso community
Source: Field survey (2022)

Furthermore, most respondents used sandbags along river margins to prevent water infiltration. From the study, using sandbags is simple for community members and an effective way to keep water. According to the resident, packed and strategically placed sandbags can operate as a barricade to deflect running water around structures instead of passing through them. While sandbag construction cannot ensure a protective barrier, it is suitable for most purposes, according to the study. Sacks are the most typically used bags; however, they are not robust enough to endure the scenario and are thus permanently ruined. Figure 8 depicts this.

Figure 8: Sandbags to break shoreline change and floodwaters at Pitiko
Source: Field Survey (2022)

During an interview, a participant at Pitiku expressed the following viewpoint:
"We normally create a sandbag barrier along the Afram River's banks.". *Even so, we cannot guarantee a safe environment due to changes in the Afram River's shoreline. A wall or flood defence, in my opinion, would be preferable.* (Male participant, Pitiko)."

Other than one Opinion leader at Pitiko (pseudonym), a female discussant confirmed this during the interview at Kwahu Adawso.

"Coping with this cankerworm is incredibly difficult for the community, and therefore the only improvised approach to avert any tragedy due to changes in the river's shoreline. We

frequently organised communal labour to collect sandbags and lay them along the River Afram; despite this method, it is not very productive, but it needed to be performed in this manner because no one is addressing our concerns."

According to Musa and Usman (2013), sandbags placed in strategic locations around homes can help to mitigate the effects of flooding or shoreline change. Sandbags will not completely stop the flow of water, but they will reduce the amount of water that enters. Shoreline nourishment, floodwalls, and tree planting were documented at 5%, 5%, and 2%, respectively, as other adaptive techniques implemented by Adawso, Nketepa, and Pitiko community occupants to alleviate the vulnerabilities related to modifications in the River Afram's shoreline. Shore nourishment, which was designed to minimise long-term shoreline erosion by "filling" vast volumes of sediment into the wetlands zone, was shown to be inefficient along the Afram River. One of the stakeholders discovered a previously nourished location that has since vanished due to ineffectiveness. Sand nourishment, according to Zhang et al. (2014), safeguarded properties and structures from flooding and increased sensitivity caused by long-term shoreline erosion/recession.

The wall was constructed in Adawso, as shown in figure 9, to protect a few residents and buildings that have grown up to the river's edge. Respondents state that the wall improves the deposition process along the river and can help prevent the adverse effects of shoreline changes. The statement below summarises the views of residents concerning the situation of the wall:

"*This community has a wall along the Afram River. It is not a complete wall; it is simply an extension of the pontoon station wall designed to protect a few people along the river. It only benefits a few people. It should be well-built*". *(Female participant, Adawso)*

Figure 9: Retaining Wall in Adawso along the Afram River

Source: Field Survey (2022)

Structures such as groynes, breakwaters, and artificial headlands, according to Müller, Reiter, and Weiland (2011), assist in enhancing sediment accumulation on the beach. This help to cushion against storm surges because wave energy is expended on relocating sand particles on the shoreline instead of progressing water landward.

Adawso, Nketepa, and Pitiko adopted a riparian vegetation scheme along the Afram River for soil, water management, and restoration, as well as to sustain stream health by supplying physical stability to the earth via the plant root, following the observations. This is shown in Figure 10.

Figure 10: Riparian vegetation along the banks of the River Afram
Source: Field Survey (2022)

The Nketepa Assemblyman made this affirmation regarding the riparian vegetation strategy adopted:
"*We began work on the Afram River bank by forming a committee, the Chairman of which I am. Each community along the Afram River was assigned a representative. We began by planting trees along the river's edge. Residents have begun planting trees due to these initiatives to prevent further erosion of the riverbanks and community flooding.*"

The flora on river channel banks and bottoms affects channel morphology in various ways. It protects and strengthens the banks, and research has shown that a dense root structure can boost strength properties by a factor of 10. (Charlton, 2008). Consequently, channels with vegetated banks are usually narrower than those with non-vegetated banks under similar formative fluxes. This is especially visible on reforested banks (Hey & Thorne, 1986). The impact of riparian vegetation on hydraulic risk is critical in river planning and decision-making (Aberle & Järvelä, 2013). Baptist (2005) argued in his study that removing riparian vegetation causes ecological damage and significant changes in river morphodynamics.

Public Education and insurance policies were extremely poor. The community members iterated on the fact that; they had not heard about any insurance policy that covers them in the community. To add up, a Chief in one of the communities (pseudonym) lamented;
"*Krachi' (researcher), what policy, which government, which institution, do not get me annoyed, they do not care about our situation, whether we will sleep or not after the*

displacement, we begged on NADMO, they came to promise us. Still, I do not know if they will come tomorrow. Please, we have no insurance policy and practical education".

The researcher probed to confirm on the side of other stakeholders, and one Unit Committee member said

"*Nana is right, we have no insurance policies that cover displaced victims, and concerning public education, it is woefully minimal; we are only educated when they open the Bagre Dam seasonally, and that one, too, is not all that effective*."

Aside from the interview responses, the study found that the most common coping strategies used by Adawso and Pitiko residents were sandbag relocation and packing at the river's edge. As a result, it was common to come across sandbags and the new location where people had relocated during this study. Specifically, residents have widely adopted relocation and sandbags along the Afram River shoreline as a coping mechanism against the Afram River's morphodynamics.

CONCLUSION

The paper concludes that natural and anthropogenic factors contribute to shoreline erosion and sedimentation. Nonetheless, the contribution of human activity to escalating shoreline erosion is a significant problem. Sand winning, development, excessive grazing pressures from concentrated commercial activity and degradation of flora along the river shore have all been reported to exacerbate shoreline erosion. Compared to places with indigenous natural vegetation, in rehabilitation, and without shoreline defensive fortifications. All entities responsible for such riverine environments work together to protect the shoreline and its aquatic life and resources.. This study and others published recently, such as Jonah and Adu-Boahen (2016) and Jonah et al. (2015), clearly demonstrate the cause of shoreline change along the Afram River.

Again, the study found that the trend of shoreline modification had a direct socio-economic impact on local populations because better coping strategies have not been initiated in communities. All of the variables used as proxies to estimate the socio-economic effects, namely farm damage, out-migration, homeless, destruction of properties, and other human impact indexes, were associated with the shoreline change variable and found in the study communities. This conclusion achieves the overarching goal of the research. The current study is in line with the findings of other researchers such as Mouat, Lozano, & Bateson (2010) and Dunn, Friedman, & Baish (2000).

The study's results have helped reveal the recent morphological changes along the Afram River shoreline. Through satellite and remote sensing and GIS techniques, this study has been able to ascertain that other researchers can now monitor the morphological changes on the Afram shoreline techniques. The study also used endpoint rate and net shoreline movement to calculate the shoreline change rate for the entire study area. For these short-term analyses, the research area's shoreline is frequently accreting at some parts, with the other part eroding. The findings helped identify patterns in the Afram River shoreline change (erosion and accretion). Erosion areas identified along the Afram shoreline include the segment from

Adwaso to Pitiko because of anthropogenic activities such as construction, sand mining, and farming activities. This conclusion is consistent with the original goal of the study.

In addition, community members relocate to new sites. Still, the sad situation is that some end up sleeping in mud houses and buildings made from Raphia grass, locally known as "kaakaw". Planting riparian vegetation along the river is inadequate to alleviate shoreline threats; hence the situation is still at its peak. Adawso community Assemblyman's comment corroborates this remark,

"We have launched a mitigation approach such as growing vegetation along the river; however, the techniques are ineffective in addressing our demands.".

The community has inadequate funds for such intensive structures, leading to calamities ".Moreover, the study found that the trend of shoreline modification had a direct socio-economic impact on the local population, including unemployment, loss of farmlands, displacement of settlement pattern, low-income level, and out-migration.

Finally, according to the findings, residents of the Adawso, Nketepa, and Pitiko communities frequently employ strategies to sustain their lives and restore their losses. Still, these strategies are inadequate to the admiration of shoreline protection principles and precepts. Among the sustainable systems are that some residents use soft sacks and polyethene rubbers in building sandbags which are not strong enough and hence get soaked and destroyed when the river gets to where it has been placed.

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