Heliyon 10 (2024) e39824

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessment of coastal flood risk scenarios on infrastructure in the Keta municipality in Ghana using a GIS approach

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ARTICLE INFO

Keywords:
Coastal flooding
Climate change
Coastal zones
GIS
Ghana
Keta
Sea level rise

ABSTRACT

Coastal flooding and erosion, caused by climate change-induced sea level rise, pose significant threats to low-lying coastal areas worldwide. The African continent, including Ghana, has experienced severe impacts from these hazards, affecting the socio-economic development of coastal communities. This research focuses on the Keta municipality in Ghana. The Keta municipality is highly vulnerable to coastal flooding and erosion due to its low elevation and the construction of the Akosombo hydroelectric dam. This research aims to predict the impact of coastal flooding on infrastructure in the Keta municipality using different flood scenarios. It also fills the existing knowledge gap in understanding how future flood risk can impact on critical infrastructure and consequently on other vital socio-economic sectors in the coastal community of Keta. The study utilizes a Geographic Information System (GIS)-based approach, combining various datasets, including topographic data, administrative shapefiles, field survey points, and infrastructure data. Two flood scenarios were considered to assess areas at risk: a 2.5-m sea level flood scenario representing potential climate change events and a worst-case 5-m sea level flood scenario. The findings reveal that 3.3 km^2 (9 %) of coastal land area, 3.9 km of roads, and 69 structures are at risk under a 2.5m sea level rise scenario, increasing to 7.1 km^2 (19.4 %), 13.6 km of roads, and 667 structures under a 5m scenario. The study highlights the urgency of addressing these risks to protect coastal communities' socio-economic development and livelihoods. Recommendations include implementing appropriate coastal management strategies, improving infrastructure resilience, and promoting sustainable land-use practices. By understanding and addressing the future impact of coastal flooding, decision-makers can mitigate climate change's adverse effects on coastal areas and ensure the region's long-term sustainability.

1. Introduction

1.1. Background

Increased climate change, especially in the 21st century has exacerbated the frequency and intensity of environmental hazards such as coastal floods and coastal erosion [1]. The common understanding is that rising average sea levels are a known consequence of

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https://doi.org/10.1016/j.heliyon.2024.e39824
Received 19 February 2024; Received in revised form 22 October 2024; Accepted 24 October 2024
Available online 25 October 2024

climate change [2,3]. Sea level rise has been linked to a number of processes, including iceberg melting and thermal expansion brought on by an increase in global temperature. Coastal flooding is the result of the melting of the iceberg and thermal expansion which are linked to the rise in global temperature [4]. In most parts of the world, the receding of coasts induced by increasing sea levels, severe storm surges, and heaving rains continue to pose severe risk to the socio-economic activities of residents in coastal communities and community infrastructure [5]. Most research tend to focus on the rate and magnitude of average sea level rise. However, it is the occasional storm surges and wave setups that have a much bigger impact on the dangers of coastal flooding and erosion [2]. Furthermore, coastal flooding is more severe in low-lying coastal zones across the world [6].

It is estimated that about 600 million people across the world live in low-lying coastal areas and generate a total gross domestic product of about $1 trillion [2,7]. In 2018, the African continent received approximately $300 billion in gross domestic product (GDP) from the coastal economy [8]. However, all these contributions of the coastal economy to the global economy are threatened by climate change extreme events such as sea level rise, unpredictable storm surges and tidal waves [9]. It is reported that ocean flooding could cost the world economy 20 % of GDP by the end of this century if nothing is done to abate the perils associated with sea level rise [10]. The African continent has also experienced its fair share of coastal flooding and erosion in recent times [11,12]. Coastal towns in Africa are regarded as the most vulnerable to the impact of climate change, such as flooding, persistent erosion, high tides and regular storms when compared to other low-elevation coastal zones across the world due to poverty, lack of understanding, poor planning, and low adaptive capacity [13,14].

In Ghana, coastal areas play a vital role in the socio-economic development of the country [1,15]. Approximately a quarter of Ghana's population resides in coastal areas, despite it only accounting for roughly 6.5 % of the country's total land area [16]. However, these coastal areas are threatened by climate change-induced hazards such as coastal flooding and coastal erosion [13]. Floods and erosion in coastal zones in Ghana as a result of high tides and storm surges have led to the destruction of buildings and other infrastructures [6,17]. The housing shortage in Ghana is estimated to be over 1.8 million units, and the erosion and flooding caused by rising sea level and storm surges make the issue worse in coastal areas [16,18]. The issue of coastal flooding is more critical in the eastern coastal zone of Ghana, that is, the Volta Delta area and the Keta Lagoon Zone, due to the low elevation and the soil type in the area [19,20].

Coastal flooding and erosion have been studied worldwide, including Ghana. For instance, Yankson et al. [21] found that coastal communities in Ghana are vulnerable to flooding and that environmental hazards like heavy rainfall have impacted their socioeconomic activities. Similarly, Cudjoe and Alorvor [1] assessed the impact of coastal flooding in the Ada East District of Ghana and found that the impacts of flooding include the permanent submergence of coastlands, the loss and change of coastal ecosystems, the loss of livelihoods, and the destruction of properties. Other studies such as Addo Appeaning and Adeyemi [22] also examined the extent to which coastal topography and geological structure increases the physical vulnerability of coastal communities to coastal floods. Furthermore, studies outside of Ghana, such as Dube et al. [11], found that coastal floods in the Western Cape, South Africa, have caused socio-economic losses to affected communities. Additionally, Croitoru et al. [12] studied the cost of coastal floods and erosion in Benin, the Ivory Coast, Senegal, and Togo. According to their report, the total cost of the flood and erosion in the four countries is US $ 964 million, or about 1.4 % of their total GDP.

For some time now, the eastern coastal zone of Ghana has received a lot of research attention on climate change-induced hazards such as coastal floods and storm surges. A number of factors, such as topography, development-related activities that increase exposure to flood risk, and high socio-economic vulnerability to floods, have been identified as significant contributors to the flood risk in this part of the country [23]. The current study area, Keta municipality, is located on Ghana's eastern coast and has experienced some of the most devastating coastal floods due to its low altitude and the construction of the Akosombo dam. The construction of the Akosombo hydroelectric dam led to the sediment starvation of the entire Keta coastal strip [24]. In recent times, climate change events such as global mean sea level rise, unpredicted storm surge, and increased tidal waves combined with reduced sedimentation have increased flood disaster prevalence [8]. According to Osisiadan [20], the most recent disaster in the area had two unique features, which included the tidal waves occurring later in the year than expected and the severity, which was described as 'unprecedented when compared to previous years.

The have been studies conducted on climate-induced hazards and their impact in the Keta areas. For instance, Adu-Gyamfi et al. [16] revealed that about half of the houses along the coastal strip of Keta Municipality are deteriorating due to coastal erosion and flooding. Likewise, Atayi et al. [19], revealed that coastal erosion in Keta has resulted in the alteration of the shape of the strip and a significant reduction in land size from the year 2000–2021. More so, Flitner et al. [5] assessed the impact of coastal flooding in the Keta Lagoon area and found that the level of destruction is beyond the capacity of the local community to deal with it, thus necessitating urgent government support. Recently, Gbedemah [23] explored the indigenous adaptation measures used by residents to cope with coastal floods in the Keta municipality.

The above studies have been very useful in providing in-depth and varied perspectives about climate-induced hazards in the Keta municipal area. However, given that sea level rise and coastal flooding will continue to be a problem in the Keta municipality and, to a greater extent, the eastern coastal enclave of the country, there is a need for studies that can provide insight on future occurrences of climate-induced hazards and their impact on critical infrastructure. This direction in research is vital for predicting the future impact of coastal floods and enhancing disaster preparedness and response. Unfortunately, there is limited research on such ex-ante assessment of climate-induced hazards in the eastern coastal enclave of Ghana, which includes the Keta municipality. This study therefore addresses this research gap by predicting the impact of coastal floods on critical infrastructure in the Keta Municipality using two future flood scenarios. Specifically, the study examines the potential coastal flood impact using the two scenarios: (1) the extent of land area that will be inundated with flood waters; (2) the extent of road infrastructure that will be at risk; and (3) the number of structures that would be impacted under different flood scenarios.

The study is significant for the following reasons: First, the need for scientific projection of climate-induced hazards such as coastal floods has become both necessary and urgent [25]. Such projections can aid in the assessment of physical exposure and vulnerability to coastal floods, as well as the development of planning measures to deal with any eventualities. By so doing, research moves from ex post analysis to ex ante analysis of climate-induced hazards, which will be very useful for disaster preparedness and response. Second, the study also responds to the recent call for the need to examine localized risk and vulnerability assessment of critical infrastructure [26] and their potential effect on communities. This is also very useful for local communities in developing climate resilience plans to mitigate risks. Third, the risk of different flood scenarios will have implications for future and existing infrastructure. Here, insights from the projected level of disruption can engender measures that will ensure adherence to protective flood standards and engineering that will be effective in withstanding floods.

2. Methodology

2.1. Study area

Keta Municipal is one of eighteen (18) administrative districts in the Volta region. Keta Municipality is located in the southern part of the Volta region [23]. The municipality is located between longitudes 0.30°E and 1.05°E, and latitudes 5.45°N and 6.005°N [16]. It shares common borders with Akatsi South District to the north, Ketu North and South Districts to the east, Anloga District to the west, and the Gulf of Guinea to the south [27]. Fig. 1 shows the map of the study area.

From Fig. 1, the map illustrates the boundaries of the Keta municipality, some major towns in the municipality, the Keta Lagoon Ramsar site, the Keta Lagoon, and the location of the Keta Municipality on the Ghana map. The topography of Keta Municipality is characterized by a low-lying elevation ranging from −33 to 43 m above sea level. Fig. 2 presents a visual representation of the municipality's elevation profile.

Analysis of this elevation map reveals that the predominant topographical feature of the municipality is its notably low elevation, with the majority of the area situated below 5 m above sea level. This topographical characteristic renders the municipality particularly vulnerable to the impacts of climate change-induced hazards. The total surface area of the municipality is 518.7 km^2, comprising a land area of 267.8 km^2 and a water or lagoon area of 251.1 km^2. Thus, the lagoon comprises 48.5 % of the total surface area of the municipality (authors' calculation using GIS).

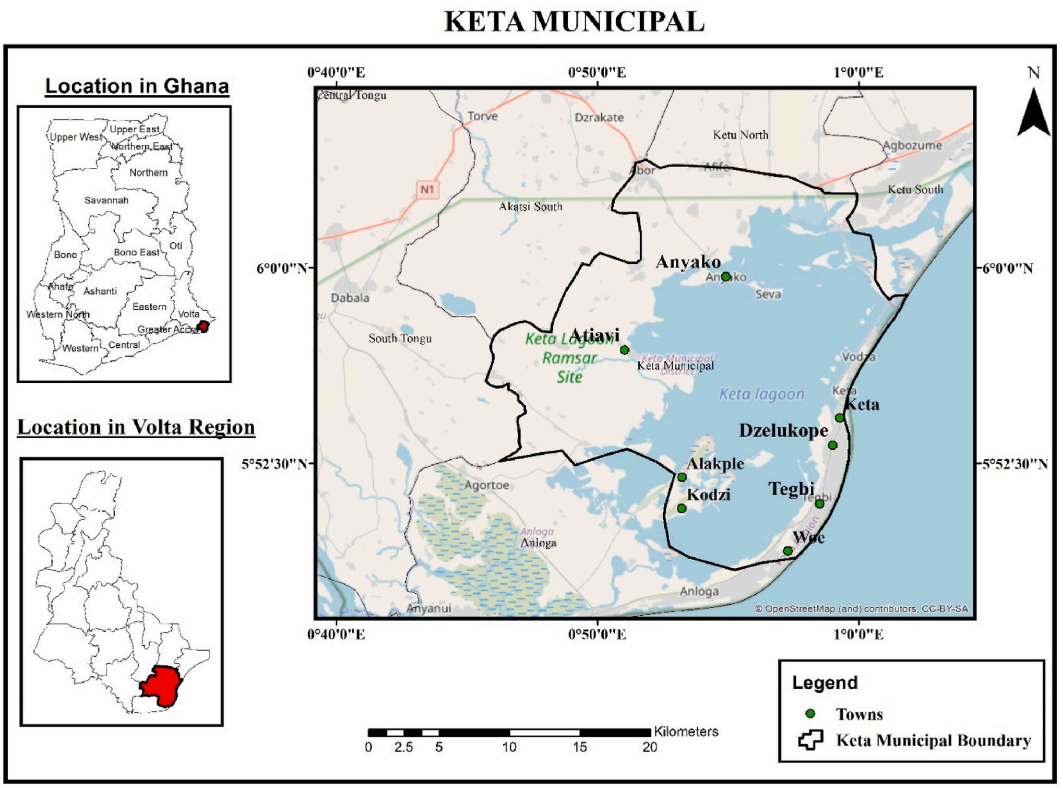

Fig. 1. The map on the illustrates the district boundary of the Keta municipality, some major towns in the municipality, the Keta Lagoon Ramsar site, the Keta Lagoon, and the location of the Keta Municipality on the Ghana map.
Source: Author's Construct

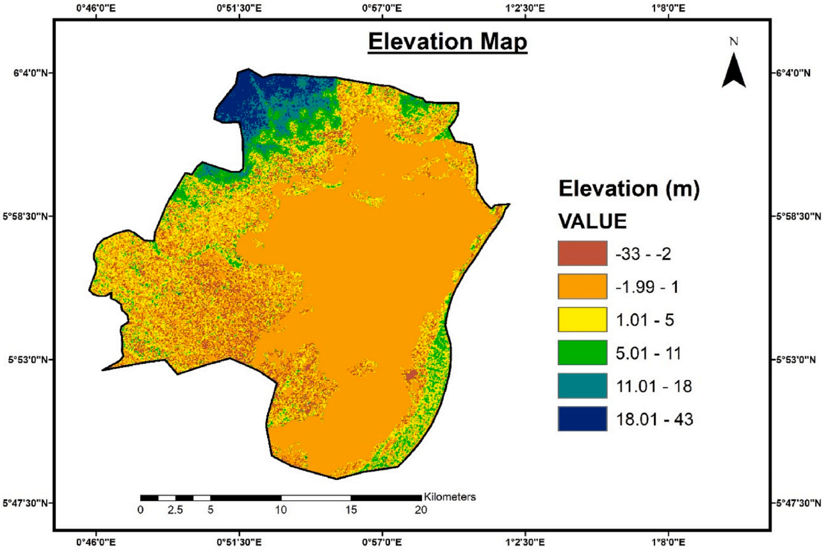

Fig. 2. The elevation map of keta Municipal.
Source: Authors' Construct

The Keta municipality experiences a Dry Coastal Equatorial climate [28]. The average annual temperature ranges from 24 °C to 31 °C [29]. The municipality has two seasons, which are the wet season and the dry season [27]. The wet season starts from April to November, and the dry season starts from December to March [29]. The annual rainfall amount received by the municipality is 1000 mm [28]. The wettest month is June, and the month with the least rainfall is January [27]. The coastal strip also receives waves from the local monsoon coupled with storms from the Atlantic Ocean [27]. The mean tidal wave height is about 1.4 m and can reach up to 1.9 or 2 m at its peak [30].

According to the 2021 census, the population of the municipality is 78,862 [31]. Keta Municipality has an annual growth rate of 1.8 per cent, which is one of the lowest in the Volta region [16,32]. The low annual population growth rate is a result of coastal flooding and erosion, which have left people with little to no land for housing and farming, making them migrate to other areas in Ghana [8,24]. The major economic activities in the municipality are fishing, trading-related activities, crop production, salt mining, and livestock

Fig. 3. Fort Prinzenstein in Keta, a historical fort built by the Danes in 1784 for the Trans-Atlantic slave trade, now partially destroyed by coastal erosion.
Source: Author (2023)

keeping [27].

Recently, Keta Municipal has become one of the major tourist attractions in the Volta region due to its beautiful and sandy beaches and historical sites such as the Fort Prinzenstein, Cape St. Paul lighthouse, and Atokor slave market [33]. Additionally, the municipality has some beautiful beach resorts and hotels [34]. The tourism industry serves as a source of income for many people and households [27]. Also, the tourism industry serves as a source of revenue for the local and central governments [34]. However, all the essential contributions of tourism are threatened by coastal flooding and erosion [35]. Fig. 3 displays what is left of the historical Fort Prinzenstein.

Fort Prinzenstein, built by the Danes in 1784 for the Trans-Atlantic slave trade, is the only fort east of the Volta River and serves as a tourist attraction, despite more than two-thirds of it being destroyed by ocean erosion and flooding [35–37]. However, three of the nine slave dungeons remain standing, making the fort a tourist attraction [36].

2.2. Study Design and data source

The study employed a Geographic Information System (GIS)-based approach to map and predict the impact of coastal flooding in Keta Municipal. GIS techniques were chosen because studies like Hadipour et al. [38], Yang [39], and Mukherjee and Singh [40] demonstrated that GIS techniques can be used effectively to map and analyse flood risk hazards.

This study used datasets including the Shuttle Radar Topography Mission 1 Arc digital elevation model (SRTM DEM), the district administrative shapefile of Ghana, field survey points data, photographs, and infrastructure (roads and structures) data shapefiles. The SRTM DEM was downloaded from the USGS Explorer website (https://earthexplorer.usgs.gov/). The SRTM Dem was selected because it is one of the few freely available and accurate topographic datasets. Furthermore, SRTM Dem has proven to be a good source of topographical data for flood risk or impact assessment [41]. The district administrative shape file of Ghana was downloaded from the University of Ghana Remote Sensing and Geographic Information System (RSGIS) lab website (http://www.ug.edu.gh/rsgislab/). The infrastructure (roads and structures) shapefile of Keta was downloaded from extract.bbike.org. The point data of the extent of the Keta Sea defence wall and the 2021 Keta floods were collected through a field survey. Photographs of the damaged structures by the 2021 floods were also collected during the field survey.

2.3. Data analysis

Two separate sets of point data were collected during the field survey. The first set of point data is for the indication of the start and end of the Keta Sea Defence wall in the municipality. The second one is the reach or extent of the most recent severe floods in 2021. The point data from the survey was imported into ArcMap for processing and analysis. The point-to-line function in the data management tool was used to create two separate lines indicating the start and end of the sea defence wall and the reach or extent of the most recent severe flooding in the municipality.

Two flood scenarios were used to determine the areas at risk of coastal flooding. The flood risk scenarios are based on a combination of tide, storm surge, wave setup, and regional relative sea-level rise [2,4]. The 2.5-m scenario represents a plausible near-term sea level rise based on IPCC projections, while the 5-m scenario represents a potential long-term worst-case scenario [42,43]. These were chosen to assess both moderate and severe flooding impacts [14,38]. The two scenarios allowed us to assess impacts under a wider range of possibilities.

The flood scenario map was created using ArcGIS desktop software. The raster SRTM Dem was mosaicked in ArcMap to form a single raster layer. The SRTM Dem raster layer was clipped with the Keta municipal shapefile by using the clip raster function. The raster calculator function in the spatial analyst tools was used to calculate or compute the areas that would fall under each flood scenario. The expressions "keta DEM raster $\leq$5 m" and "keta DEM raster $\leq$2.5 m," which were used in the raster calculator as "Keta DEM layer $\leq$5 and keta raster layer," The reclassify function under the reclass tool was used to reclassify the flooded areas into a single class and the non-flooded areas into no data. No data function was used to remove the non-flooded area pixels from the raster image display. The raster-to-polygon function was used to convert the Keta DEM raster to a polygon vector for further processing. The selection by attribute was used to correct anomalies. The polygon was then projected into a projected coordinate system (WGS_1984_UTM_Zone_31N) so that the land area of the flood area could be calculated in hectares.

To determine the proportion of road infrastructure affected by the flood, a layer of flood polygons was overlaid on the road layer. The clip function of the geoprocessing tool was used to extract the portions of the road that were affected by each flood scenario. The road risk clip feature was projected into a projected coordinate system (WGS_1984_UTM_Zone_31N) to calculate the length of the road that is at risk. The calculate geometry function in the attribute table was used to calculate the length of each road portion at risk, and the statistics function was used to get the total of the road segment at risk for each flood scenario.

To calculate the structures (building infrastructures) that will be affected by the flood, the flood polygon was overlayed on the structure layer. The select by location function was used to select structures that fall within the flood risk zone. The selection by location was used for this calculation because if a part of a building falls within the flood area, the structural integrity of the whole building is affected [16]. The selection was then used to create a new layer. The attribute table of the structures affected by the flood was exported to count the number of structures that were affected by the flood. The structure layer was also reprojected into a projected coordinate system (WGS_1984_UTM_Zone_31N) so that the area of the affected structures could be calculated in square metres.

3. Results

3.1. The present situation

The point data from the field survey was used to draw a map that indicates the current state of coastal flooding in the study area. The most recent and severe coastal flood occurred in November 2021. Fig. 4 shows the reach of the 2021 coastal flooding and sea defence wall in the municipality.

The recent severe flooding occurred in Abutiakope, Dzelukope, Tegbi, and Woe. The 2021 coastal flooding affected an estimated area of approximately 2.5 km^2 in the Keta municipality. The flood did not occur in Keta, Kedzi, and Vodza due to the seawall protection. Flooding in 2021 damaged infrastructure such as roads and structures. Fig. 5 shows buildings damaged by the flood in 2021.

Fig. 5 depicts abandoned residential buildings in Abutiakope and Tegbi and the level of damage the coastal flood can cause to a structure or building. The images show cracks and damages to the walls and structures, a situation that is attributable to the constant hits by the sea water. Even if the flood waters do not extend beyond the buildings' foundation, there is much potential and risk of creating holes in the foundation. In extreme cases, entire buildings, including the roof are inundated with water causing total collapse of the building, a situation depicted in Fig. 5.

3.2. The flood risk map

Two flood scenarios were created for the assessment of land areas at risk of flooding. The first one is a 2.5-m sea-level flood scenario, and the second one is a 5-m sea-level flood scenario. Fig. 6 depicts the flood-prone areas under 2.5 and 5-m sea-level rise scenarios.

Image A, in Fig. 6 represents A 2.5-m sea level rise flood scenario, while image B represents a 5-m sea level rise flood scenario. From image A, the communities at risk are Dzelukope, Tegbi, and Woe. The flood-prone areas in a 2.5-m sea level rise scenario are almost the same as the previous flood in 2021. However, some small areas in Dzelukope and Tegbi go beyond the course of the previous flood. The total land area prone to flooding under the 2.5-m sea level rise scenario is 3.3 km^2 which is about 9 percent of the total land area of the coastal strip of the Keta municipality which is 36.4 km^2. Additionally, the image shows that the sea defence wall protects Keta, Vodza and Kedzi from the 2.5-m sea level rise flood scenario. From image B the 5-m sea level rise scenario flood goes beyond the reach of the 2021 flood. The towns that are prone to the flood are Woe, Tegbi, Abutiakope and Dzelukope. The total area prone to the 5-m sea level scenario is 7.1 km^2 which is 19.4 percent of the total land area of the coastal strip. Furthermore, the 5-m scenario, like the 2.5-m scenario, does not cross the sea defence wall, making towns like Kedzi, Keta, and Vodza less vulnerable to coastal flooding.

3.3. Infrastructure at risk

The two flood scenarios will have an impact on infrastructure such as roads and structures along their path. Fig. 7 shows the number

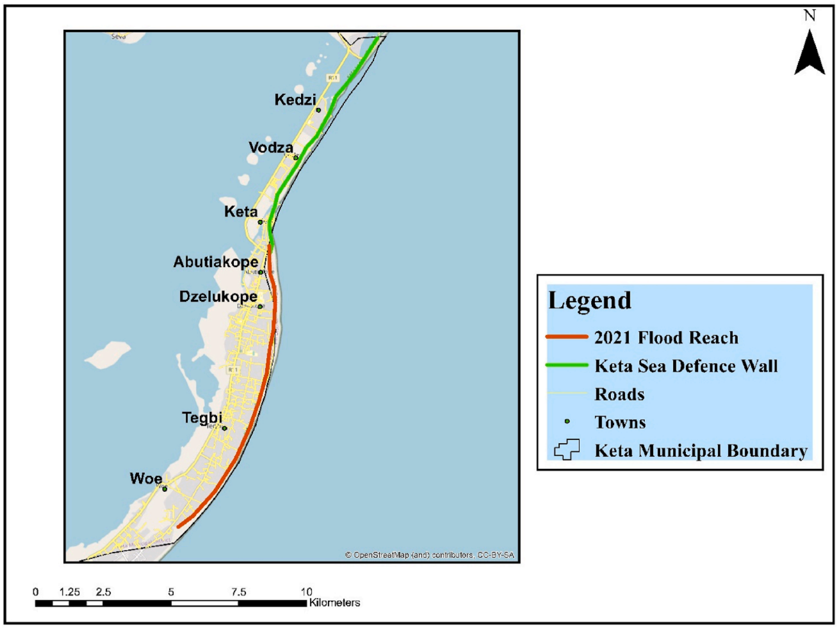

Fig. 4. 2021 flood extent and the sea defence wall.
Source: Author's Construct 2023

Fig. 5. Damaged building caused by 2021 keta coastal flood.
Source: Author 2023

of roads that will be at risk in each scenario. From Fig. 7, maps A and B represent road sections at risk under the 2.5-m scenario and the 5-m scenario, respectively.

In Fig. 7, map A represents a road at risk at 2.5 m sea-level flood scenario and map B represents a road at risk at 5 m sea-level flood scenario. Image A shows that under the 2.5-m flood scenario, 3.9 km of roads in Dzelukope would be at risk. In contrast, image B illustrates that the 5-m flood scenario would affect a more extensive area, putting 13.6 km of roads at risk across Dzelukope, Abutiakope, Tegbi, and Woe. This significant increase in affected road infrastructure highlights the potential severity of impacts under more extreme sea level rise scenarios. The length of road that would be at risk under the 5-m flood scenario is 13.6 km. The structures at risk or vulnerable to the two flood scenarios are shown in Fig. 8. Map A in Fig. 8 depicts the 2.5-m sea level rise flood scenario, while image B depicts the 5-m sea level rise flood scenario.

The structures in the Dzelukope area are vulnerable to the 2.5-m sea level rise flood scenario, as shown in Map A. In map A, the total number of structures that are exposed to this flood scenario is 69 with a land area of 29,008.76 square metres. From map B, the structures at risk under the 5-m sea level rise flood scenario are in Abutiakope, Dzelukope, Tegbi, and Woe communities. Under this flood scenario, a total of 667 structures are at risk with a land area of 245,214.8 square metres.

The structures at risk from both flood scenarios are predominantly residential buildings, with some critical community infrastructure such as schools, churches, and shrines also affected. This widespread impact on housing and community facilities could have significant socio-economic consequences. The potential displacement of residents from their homes could lead to housing shortages and increased pressure on unaffected areas. Damage to schools may disrupt education, impacting children's learning and possibly resulting in long-term effects on human capital development in the region. The risk to churches and shrines could disrupt religious and cultural practices, affecting community cohesion and social support systems. Furthermore, the extensive damage to infrastructure and buildings could lead to economic losses through property damage, reduced property values, and increased insurance costs. It may also impact local businesses, possibly resulting in job losses and reduced economic activity in the affected areas.

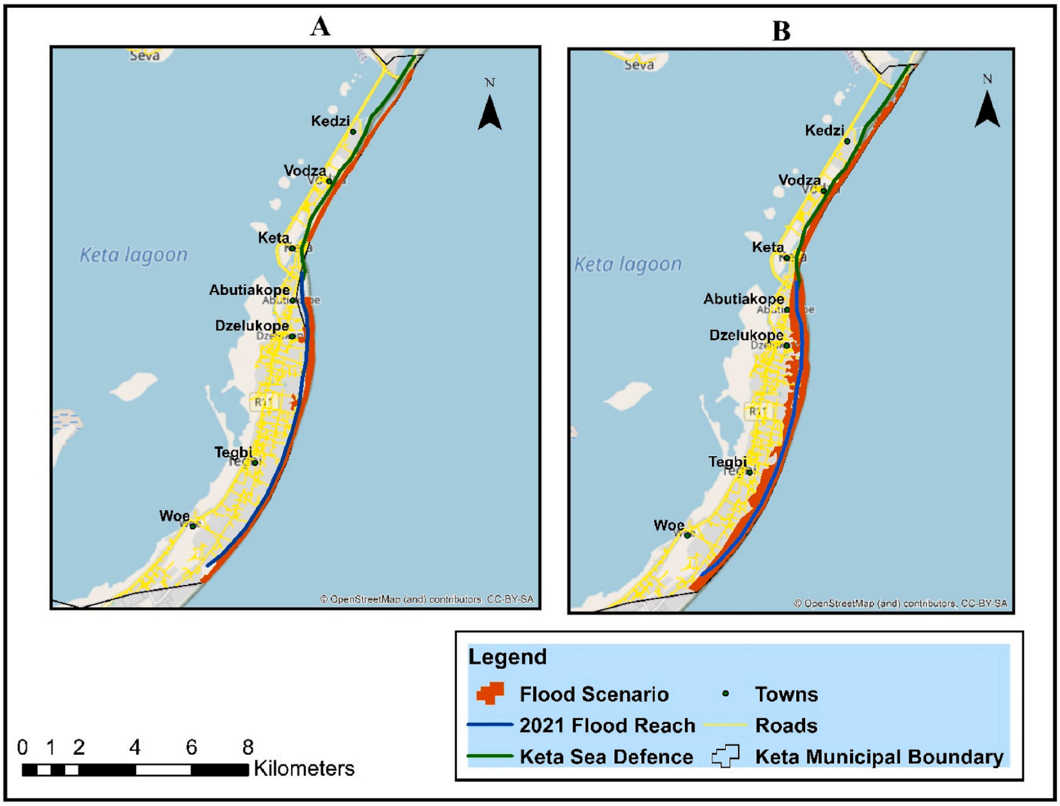

Fig. 6. 2.5 m and 5 m sea level rise flood scenario map.
Source: Author's Construct, 2023

4. Discussions

The study investigated the impact of coastal flooding caused by sea level rise in low elevations using two sea level scenarios: a 2.5-m rise and a 5-m rise. The findings highlight the significant extent of land area and infrastructure at risk in the study area, specifically in the Keta municipality. The study revealed that under the 2.5-m sea level rise scenario, approximately 3.273 km^2 of land area (9 % of the total coastline strip) is prone to flooding. This aligns with previous research by Evadzi [17] and Fitton et al. [6], which predicted that ongoing sea level rise would lead to coastal areas submerged below 10 m above sea level. Similarly, the 5-m sea level rise scenario would have a more significant impact, with 7.1 km^2 of land area (19.4 % of the coastline strip) susceptible to flooding.

These findings emphasize the increasing vulnerability of low-lying coastal regions, to rising sea levels. Additionally, the study identified specific communities and structures at risk of coastal flooding. In the 2.5-m scenario, areas such as Dzelukope, Tegbi, and Woe were prone to flooding, while the 5-m scenario expanded the at-risk areas to include Abutiakope, Dzelukope, Tegbi, and Woe. Coastal flooding caused structural damage, with 69 structures exposed to the 2.5-m scenario and 667 structures at risk under the 5-m scenario. These findings corroborate Yang [39] and Lu et al. [44], which highlighted the vulnerability of buildings and infrastructure in flood-prone zones to coastal flooding. The implications of the study's results are clear: coastal flooding resulting from sea level rise is inevitable in low-lying coastal areas. This aligns with the findings of James et al. [45] and Siegert et al. [4], indicating that coastal floods will continue to threaten life and property in these communities, including the Keta municipality.

The findings of this study revealed several policy implications which policymakers and stakeholders should consider regarding coastal floods in the environmental and coastal management sector in Keta Municipality. The first of these implications is the investment in coastal or sea defence infrastructures such as sea defence walls as the study has shown that, areas within the study area that have sea defence walls were less hit by the impact of coastal flooding. While seawalls can provide effective protection against flooding, they may also exacerbate erosion in adjacent unprotected areas and alter natural sediment transport processes, potentially leading to long-term coastal changes.

Therefore, a properly developed policy and planning measures regarding the importance of the sea defence wall for the protection of the environment and infrastructure of Keta Municipality will serve as a great starting point to salvage the Coastal strip of Keta Municipality. In addition to the sea defence wall is the conservation and restoration of coastal ecosystems such as mangroves and wetlands. It is important to note that mangroves and other forms of coastal vegetation act as a natural shield from tidal waves and storm surges and are beneficial to the protection of infrastructure as well as human life. Furthermore, the combination of sea defence wall and ecosystem restoration brings about a balance between the protection of infrastructure and the ecosystems [46].

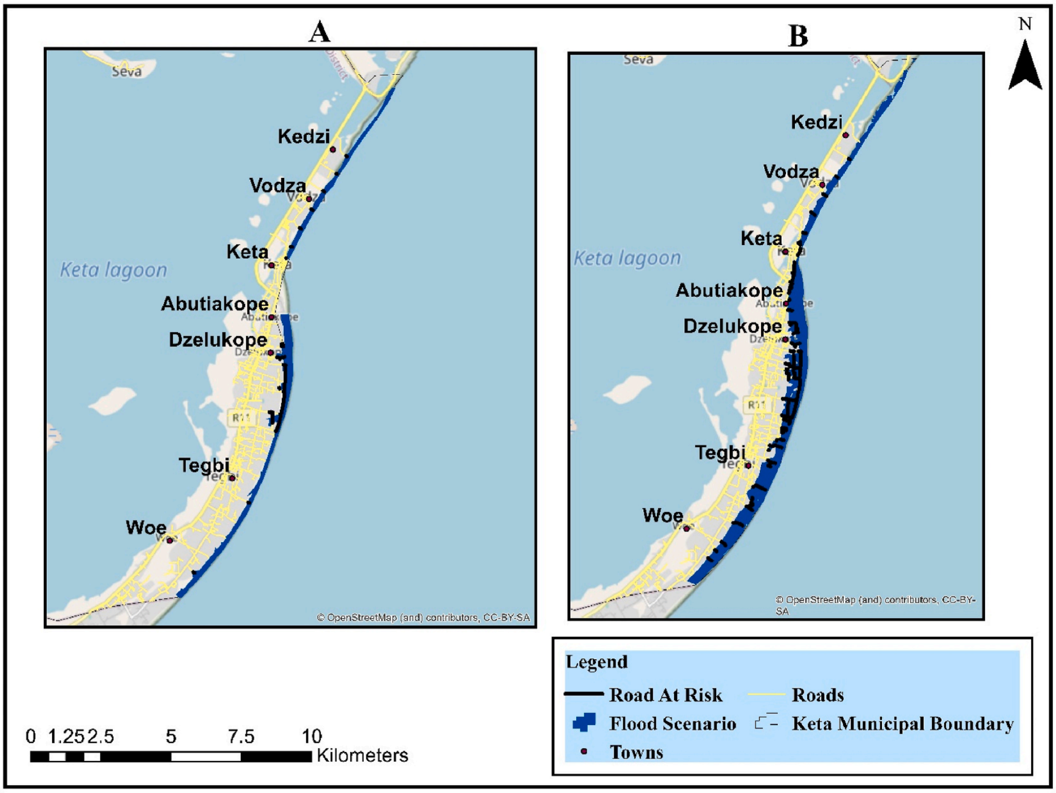

Fig. 7. Road infrastructure prone to flood.
Source: Author's Construct, 2023

Additionally, the results of the study revealed that the coastal floods in Keta Municipality have destroyed roads and buildings. Thus, there is a need for investment in resilient infrastructure such as roads and buildings. This can be done through the formulation of new building and construction codes or by updating the current building and construction codes to meet flood-resistant standards. This will enable future development such as roads and buildings to survive during floods. These building codes can also be implemented through community engagement where current house owners can be assisted by the government to upgrade their buildings to meet the new building comes. Also, government infrastructure such as current roads should be improved to meet flood-resistant standards.

Furthermore, the findings of this research revealed areas that are prone or at risk of flooding. There is a need for land use planning policy formulation that will involve the community. This land use planning and zoning system is based on different sea level scenarios to mark areas that are prone or at high risk of flooding and areas that are at low risk of flooding. Consequently, the settlements that fall within the high-risk areas will be relocated to areas that are at low risk of flooding.

The decision to invest in mitigation processes, such as sea defence walls or relocation, should be informed by accurate and reliable data like the results of the current study. This should be guided by comprehensive planning. In light of these findings, local authorities and policymakers must prioritize effective adaptation and mitigation strategies. Investing in robust sea defence infrastructure, such as the sea defence wall that protected certain areas in the study, can help mitigate coastal flooding impacts. Additionally, considering the potential for relocation or managed retreat in the most vulnerable areas might be necessary to ensure coastal communities' long-term safety and well-being.

It is important to acknowledge the limitations of the bathtub method used in this study for coastal flooding assessment. While this approach provides a useful first-order approximation of flood extent, it assumes a static water level and does not account for factors such as wave dynamics, sediment transport, or local hydrological conditions. More sophisticated hydrodynamic models could provide more accurate predictions of flood extent and depth, particularly in complex coastal environments [47]. Future studies in the area could benefit from employing such advanced modelling techniques to refine flood risk assessments.

Finally, while this study focuses on coastal flooding due to sea level rise, it's crucial to recognize that climate change may exacerbate multiple, interacting hazards in coastal areas. For instance, the combination of sea level rise with more intense storms and increased rainfall could lead to compound flooding events, where storm surges coincide with extreme rainfall or river discharge [48]. These compound events could potentially result in more severe and extensive flooding than considered in our scenarios. Future risk assessments in the Keta municipality should consider these compound hazards to provide a more comprehensive understanding of climate change impacts on the region.

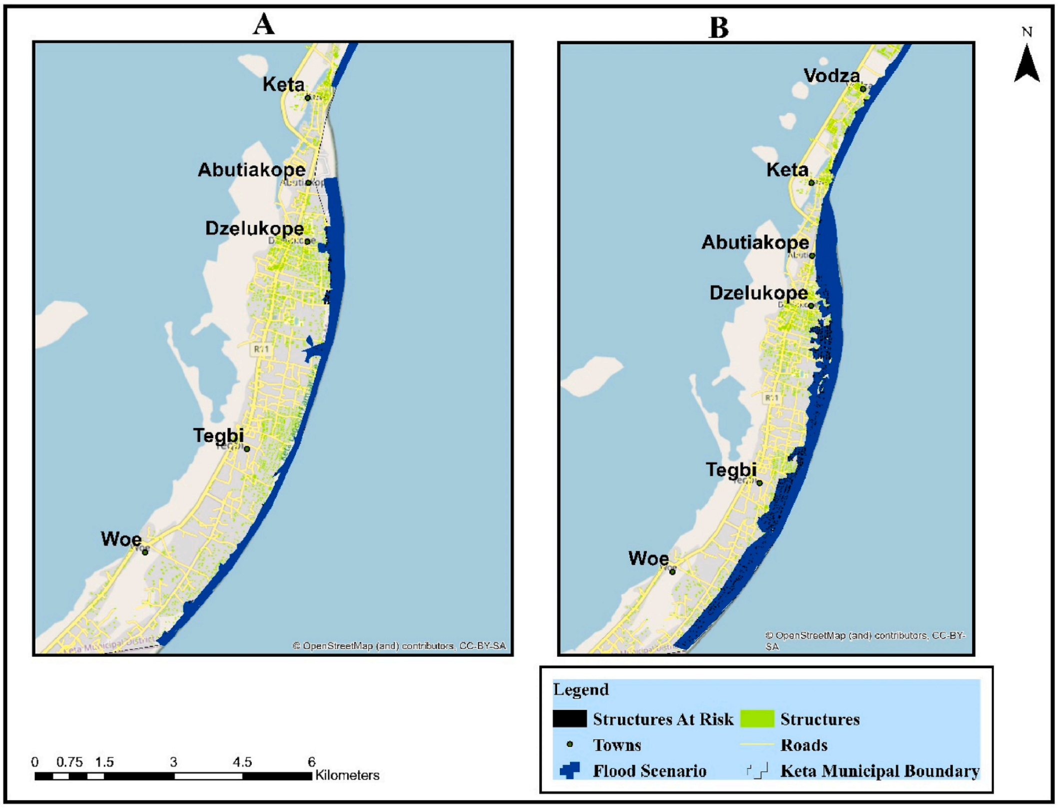

Fig. 8. Structures at Risk (A- 2.5 m flood scenario and 5 m flood scenario).
Source: Author's Construct, 2023

5. Limitations, conclusions and recommendations

This study has several limitations, the flood scenarios are based on basic topographical inundation models and do not account for complex factors such as wave dynamics, sediment transport, or future geomorphological changes. Additionally, the infrastructure data may not capture all recent developments or informal structures in the area. Future studies could incorporate more complex hydrodynamic modelling and up-to-date high-resolution data to improve predictions.

In conclusion, this study has provided valuable insights into the current state of coastal flooding in the study area and the potential impacts of sea level rise on vulnerable coastal communities and infrastructure. The findings indicate that coastal flooding resulting from sea level rise and low elevation is a significant concern for the Keta municipality and its coastal strip. The study revealed that under the 2.5-m sea level rise scenario, approximately 3.273 km^2 of land area (9 % of the coastal strip) is at risk of flooding, while the 5-m scenario increases this to 7.1 km^2 (19.4 % of the coastal strip). Furthermore, specific communities, structures, and road infrastructure were identified as particularly vulnerable to coastal flooding. These results align with previous literature and highlight the urgent need for effective adaptation and mitigation strategies.

This study recommends the formulation of a comprehensive coastal management policy framework that takes into account investment in sea defence measures such as sea defence walls and ecosystem conservation and restoration, land use planning and updating of the building and construction codes to meet modern flood-resistant standards. However, the decision to create mitigation and coping mechanisms should be informed by reliable and accurate data like the results of the current study.

CRediT authorship contribution statement

Armstrong Francis Tumawu: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **George Yao Kafu:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Gerald Albert Baeribameng Yiran:** Writing – review & editing, Visualization, Supervision. **Louis Kusi Frimpong:** Writing – review & editing, Visualization.

Data availability

The datasets utilized or generated during the course of this investigation are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to express their sincere gratitude to the residents of Keta, Ghana, for their invaluable cooperation and willingness to share information critical to the successful completion of this study. Their insights and local knowledge have significantly enriched our research findings. We extend our heartfelt appreciation to Sedinam and Precious Pearl for their unwavering support and assistance during the field survey phase of this research. Their dedication and expertise were instrumental in navigating local contexts and facilitating data collection processes. This study would not have been possible without the collective contributions of these individuals and the broader Keta community.

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