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Article

Impacts of Coastal Inundation Due to Climate Change in a CLUSTER of Urban Coastal Communities in Ghana, West Africa

Kwasi Appeaning Addo [1,*], Lloyd Larbi [1], Barnabas Amisigo [2] and Patrick Kwabena Ofori-Danson [1]

[1] University of Ghana, P.O. Box LG 99, Legon, Accra, Ghana; E-Mails: lloydlarbi@yahoo.com (L.L.); ofdan@ug.edu.gh (P.K.O.-D.)

[2] CSIR Water Research Institute, P.O. Box M. 32, Accra, Ghana; E-Mail: barnyy2002@yahoo.co.uk

* Author to whom correspondence should be addressed; E-Mail: kappeaning-addo@ug.edu.gh; Tel.: +233-208-169-555.

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Abstract: The increasing rates of sea level rise caused by global warming within the 21st century are expected to exacerbate inundation and episodic flooding tide in low-lying coastal environments. This development threatens both human development and natural habitats within such coastal communities. The impact of sea level rise will be more pronounced in developing countries where there is limited adaptation capacity. This paper presents a comprehensive assessment of the expected impacts of sea level rise in three communities in the Dansoman coastal area of Accra, Ghana. Future sea level rises were projected based on global scenarios and the Commonwealth Scientific and Industrial Research Organization General Circulation Models—CSIRO_MK2_GS GCM. These were used in the SimCLIM model based on the modified Bruun rule and the simulated results overlaid on near vertical aerial photographs taken in 2005. It emerged that the Dansoman coastline could recede by about 202 m by the year 2100 with baseline from 1970 to 1990. The potential impacts on the socioeconomic and natural systems of the Dansoman coastal area were characterized at the Panbros, Grefi and Gbegbeyise communities. The study revealed that about 84% of the local dwellers is aware of the rising sea level in the coastal area but have poor measures of adapting to the effects of flood disasters. Analysis of the likely impacts of coastal inundation revealed that about 650,000 people, 926 buildings and a total area of about 0.80 km^2 of land are vulnerable to permanent inundation by the year 2100. The study has shown that there will be significant losses to both life and property by the year 2100 in the Dansoman coastal community in the event of sea level rise.

Keywords: sea level rise; adaptation; climate change; inundation; coastal erosion; Ghana

1. Introduction

Climate change, as a result of the shifts in the mean state of the climate or in its variability, has persisted for some time. The earth has warmed and cooled many times since its formation over billions of years ago [1], which may be due to both natural and human induced changes within the atmosphere and in land use. Various factors that influence these changes include volcanic eruptions which ultimately increase carbon dioxide in the atmosphere, changes in the intensity of energy emitted by the sun and variations in the earth's position relative to the sun both in its orbit and in the inclination of its spin axis [2]. Increasing levels of Greenhouse gas has led to a rise in the earth's average surface temperature by about 0.7 °C over the past 100 years from about 15 °C before the late 1800s [3]. Greenhouse gas and sulfate aerosols concentrations in the atmosphere have increased as a result of human activities such as agriculture, deforestation and the use of fossil fuels since the time of the Industrial Revolution [4]. This phenomenon has resulted in the current crisis of global warming that is projected to continue considerably in the 21st century, depending on the level of future greenhouse gas emissions. Future global emissions will depend on population growth, energy sources, regional and global economic growth [5]. This information has facilitated producing emission scenarios that are used to project future greenhouse gas concentrations. These scenarios serve as input parameters to computer generated models of global climate to provide estimates of future climate.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios of 2000 presents four families of socio-economic scenarios (A1, A2, B1 and B2) that represent different future world scenarios in two dimensions. They include a focus on economic *versus* environmental concerns, and global *versus* regional development patterns [6]. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income [5]. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis. These are fossil intensive (A1FI), non-fossil energy sources (A1T) and a balance across all sources (A1B) [6]. The A2 storyline and scenario family describes a heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines [5]. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives [5]. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels [5].

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2 and it is regarded that all should be considered equally sound. The Special Report on Emission Scenarios (SRES) do not include additional climate initiatives, which implies that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol [5]. From these model estimates using the SRES scenarios, it is projected that a globally averaged warming of 2.4 to 6.4 °C for a scenario assuming higher emissions of greenhouse gases in the century. It also projects further warming of 1.1 to 2.9 °C by the year 2100 for a scenario assuming lower emissions in which emissions grow slowly, peak around the year 2050 and then fall [2]. As global warming occurs resulting in thermal expansion of the upper ocean layer due to the increase in the world's ocean temperature, the sea level is expected to increase in the near future [7]. It is anticipated that sea level will continue to rise for several centuries, even if greenhouse gas emissions are stabilized [8], due to long lag times for the deep oceans to respond. Global warming has also resulted in the continuous melting of ice sheets or increase in iceberg calving from land-based ice sheets that has contributed significantly to sea-level rise [9]. Studies by [7] identified the impact of sea level rise on future shoreline evolution trend and concluded that remote sensing methods coupled with archival shoreline data will enable future rates of change to be predicted. Monitoring the shoreline to detect change and predict its future impact is significant since they are recognized by the International GeographicData Committee (IGDC) as one of the 27 most important features [10].

Remote sensing technology has been used to identify, monitor and assess coastal changes in various places using mapping techniques [11-13]. The mapping methods adopt techniques that extract the shoreline positions from data sources. The conventional data sources consist of historical maps, aerial photographs and repeated field measurement, while the current sources are obtained from remote sensing technologies using airborne, spaceborne and land based techniques. Remote sensing advancement has thus enabled the provision of a continuous monitoring of the shoreline globally. This enables shorelines mapped *in situ* and extracted from aerial photographs to be compared to detect, measure and analyze change. Historic rate of change information and estimated sea level rise enable the future shoreline positions over time to be estimated and its impact on the coastal environment identified. Satellite images have shown that the extent of Arctic sea ice has declined by about 8.5% per decade from its size in 1979 [2]. According to [14], if the observed increases in ice discharge rates from the Greenland and Antarctic ice sheets were to increase linearly with global mean temperature change, this would add a 0.05 to 0.11 m rise for the A1FI scenario over the 21st century. The global average rate of sea level rise for the past century has been estimated to be about 10 to15 cm, which could rise to about 1 m over the next century [15]. The effect would vary locally due to prevailing factors such as isostatic adjustment of the mantle and variations in oceanic level change [3]. Some coastal areas in the world will thus experience rise above the normal, whilst in other places sea level rise will be low. Furthermore, coasts subsidence due to natural or human induced causes will experience larger relative rises in sea level [16]. In some locations, such as deltas and coastal cities, this effect can be significant [17]. Increases of extreme sea levels due to rises in mean sea level and changes in storm characteristics are of global concern to coastal nations and local coastal environmental managers since they drive significant impact within coastal environments. Future coastal environment modeling results reveal that both tropical and extra-tropical storm intensity will increase [14], which implies additional coastal impacts than attributable to sea-level rise alone, especially for tropical and mid-latitude coastal systems [18].

Changes in other storm characteristics are less certain and the number of tropical and extra-tropical storms might reduce according to [14]. Similarly, future wave climate is uncertain, although extreme wave heights will likely increase with more intense storms [19]. Changes in runoff driven by changes to the hydrological cycle appear likely, but the uncertainties are large [3]. Human modification of the hydrologic cycle could also affect sea level rise. Sequestration of water on land in reservoirs and through irrigation losses could exceed amounts transferred seaward by groundwater mining and increased runoff due to urbanization and deforestation. The net effect of these processes could slow sea level rise by about 0.9 ± 0.5 mm/yr [20]. The future of the Antarctic ice sheet introduces a major uncertainty into sea level projections. Global climate models anticipate higher rates of Antarctic snow/ice accumulation than melting, which would remove water from the ocean and reduce sea level [21]. According to [22], a large part of the West Antarctic ice sheet is potentially unstable because it rests on land now below sea level or forms floating ice shelves, which are locally "pinned" or stabilized by submarine ridges. These prevent rapid discharge of ice from fast-moving ice streams. Ocean warming could eventually thin and "unpin" these shelves, which would accelerate the calving of icebergs into the ocean and thus increase the sea level. This process, although considered very unlikely, would have devastating consequences on low-lying coastal areas globally should it occur [23].

As sea level rises, material on sandy shorelines is eroded from the upper beach and deposited on the near-shore ocean bottom [24]. Consequently the ocean moves landwards or the shoreline recedes. It is generally accepted that the coastline will retreat horizontally 50 to 100 times the vertical sea level rise [25]. Hence, the predicted global sea-level rise would cause a coastal recession of sandy beaches of 4.5 to 88 m by 2100 in many places around the world [25]. The most obvious outcome of sea level rise is the permanent inundation of coastal areas. Over time inundation changes the position of the coastline and drowns natural habitats and human structures. Inundation can also exacerbate coastal erosion by transporting submerged sediment offshore and extend the effects of coastal flooding by allowing storm waves to act further inland. Apart from relative sea level rise, other coastal environmental factors also influence inundation. They include sediment availability, beach profile gradient and the geomorphology of the shoreline. Although both coastal inundation and beach erosion hasten shoreline retreat, they are however two distinct processes [26]. Unlike inundation, which drowns land areas, erosion redistributes sediment from the onshore to offshore areas. Sea level rise does not directly erode beaches and coastal areas. Rather, rising sea levels act as a swelling tide that allows waves to act further up the beach profile and permits larger waves to reach the coast [26]. Beach erosion is intensified in areas affected by inlets or where the construction of groins and breakwaters disrupts longshore drift [3].

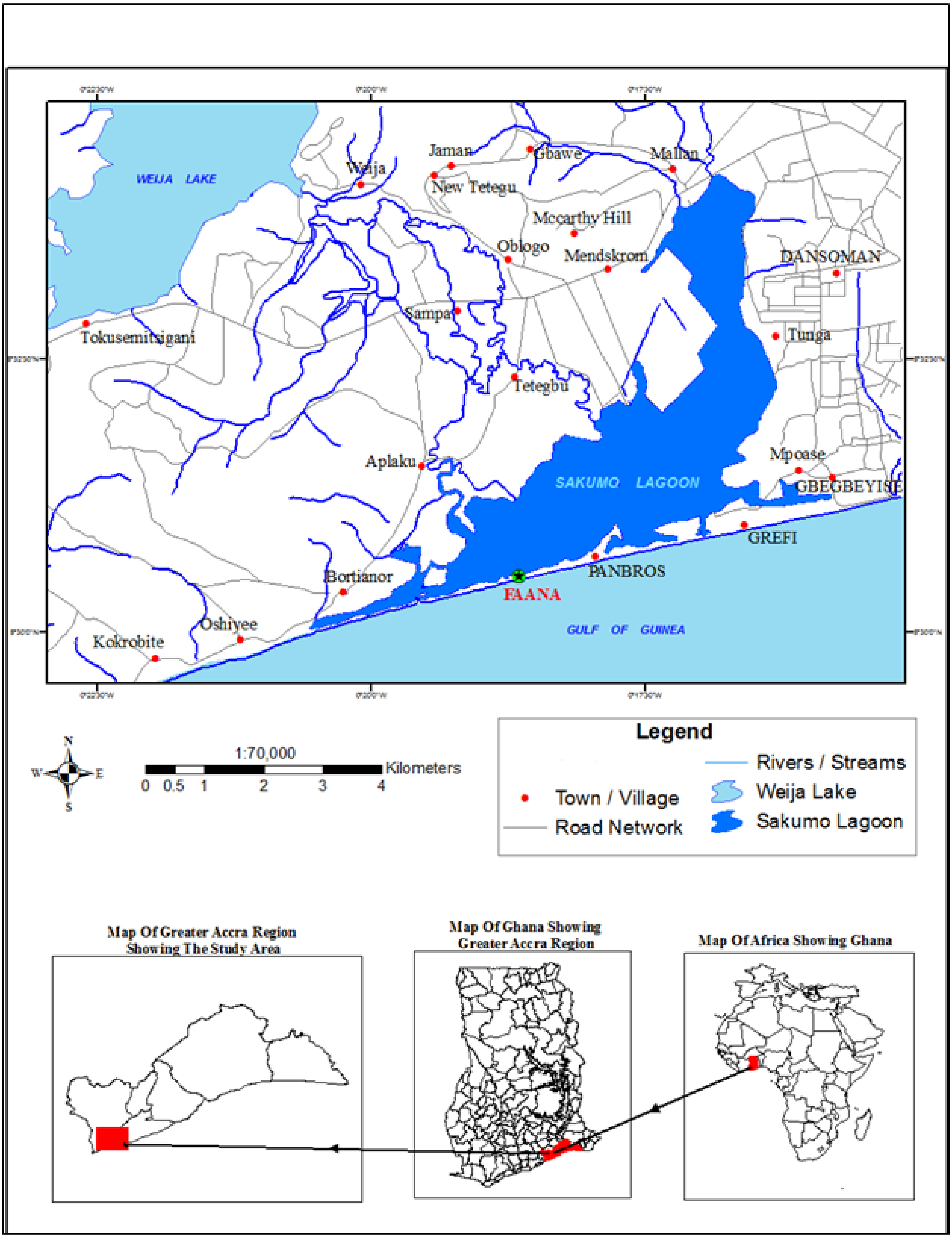
The threat of sea level rise calls for concerted efforts in the coastal communities, especially in the developing nations where geospatial data for effective coastal environmental monitoring are scarce [7], to improve their resilience to the impacts of coastal hazards. Developing pragmatic policies to sustainably manage the local coastal environment in developing nations has been influenced by the lack of reliable information on the expected impact of sea level rise on the coastal environment. This development has also affected the adaptation technique to be adopted for the coastal environment. Also, potential constraints to adaptation techniques are poorly understood [27]. This raises long-term questions about the implications of 'hold the line' *versus* 'retreat the line' adaptation policies and, more generally, how best to approach coastal spatial planning. While shoreline management is starting to address such issues for the 21st century [28], the long timescales of sea-level rise suggest that coastal management, including spatial planning, needs to take a long-term view on adaptation to sea-level rise and climate change. This paper presents results of a comprehensive assessment of the expected impacts of sea level rise within the Dansoman coastal area in Accra, Ghana.

1.1. Study Area

The study area (Figure 1), which could be described as an industrial, ecological and a residential area is experiencing coastal erosion and inundation. The area spans about 3.06 km and is located at latitude 5.3180°N and longitude 0.10010°W along the Gulf of Guinea. It is characterized by a gently sloping shoreline and sandy beach. Dansoman, similar to most parts of the Accra coast, has relatively an open coast that enables considerably strong unimpeded swell waves to reach the coast [19] and break obliquely generating longshore currents [29]. The significant wave height for 50% of the time is about 1.4 m, the period is between 10 to 15 s and spring high tide is about 1.26 m [30]. The study area comprises Panbros, Grefi and Gbegbeyise communities and experiences recurrent inundation as a result of episodic spring tides. A major salt industry that supplies salt to the entire West Africa region is located in the area as well as other small scale businesses like shops, fish landing sites, resort centers and farms. The area is an important habitat for marine and migratory birds and its destruction will affect approximately 35,000 waterfowl [31]. Flooding of the saltpans will also swell the unemployment problems in the area. It is reported that the shoreline in Accra could recede between approximately 320 m to 610 m inland by the year 2250 [7]. This is expected to affect significant proportion of coastal infrastructure and the inhabitants. However, knowledge about the effect of sea level rise on the local communities is scanty. This is because few studies have unambiguously quantified the relationships between observed coastal land loss and the rate of sea-level rise at the local scale.

Dansoman is experiencing gradual coastal submersion and periodic inundation caused by spring tides. It is unclear as to what extent these losses are associated with relative sea-level rise due to subsidence, and other human drivers of land loss, and to what extent they result from global warming. Historic sea level rise in the study area is about 2 mm/yr that is expected to rise to about 6 mm/yr in the next century [7]. Evidence of sea level rise has been reported by various authors [32-35]. The historic rate of erosion in Accra is about 1.13 m/yr ± 0.17 m/yr and future predictions for the next 250 years indicate that the extent of destruction of coastal infrastructure could be disastrous [7]. The long term erosion trend is due to relative sea level rise, deficit in sediment budget for littoral transport, orientation of the shoreline and anthropogenic influences [7]. Coastal erosion has resulted in exposed rock substratum [36], collapsed about 17 coastal buildings within a period of 26 years [37] and destroyed natural fish landing sites [38].

Figure 1. The study area (source [39]).



2. Methodology

Data for this study include digital map and 2005 near vertical aerial photographs obtained from the centre for remote sensing and GIS (CERGIS) in Ghana, 1904 bathymetric map produced for the Ghana Ports and Harbours Authority from planetable surveys (onshore) and echo sounding (offshore, last revision in 1992), 2000 population and housing census from the Ghana Statistical Services Authority, wind climate from the Svašek Hydraulics in the Netherlands, and IPCC sea level rise scenarios from [5]. The mapping methods adopt techniques that extract the shoreline on historical maps, aerial photographs and *in situ*. Selecting a particular method for mapping is influenced by factors such as the level of accuracy required, type of output desired, method of ground control point collection, availability of funding and/or equipment, and the method to be adopted to analyze the shoreline change. Studies by [7] determined the positional accuracies of the shoreline on the maps and concluded that the maps are reliable for shoreline change analysis.

2.1. Shoreline Mapping

In situ mapping of the shoreline position using physical survey methods involved determining the HWL proxy with reference to an established control point. Using the Real Time Kinematics Global Position System (RTK-GPS) method enabled the 3D coordinates of the shoreline proxy to be obtained. Two GPS receivers SOKKIA GSR2700 ISX in conjunction with an AllegroCX_36506 data logger were used for the survey. One stationary receiver served as a reference base station, while the other receiver was used as a rover. The data was collected by moving a monocycle equipped with a GPS unit directly along the shoreline at a constant speed and continuously tracking a roving antenna relative to the static base station. The coordinates were collected at specified time intervals, allowing real-time digitization of the proxy, and each epoch of data collected is processed to create a string of point coordinates representing the shoreline. The beach profile was also mapped using the RTK method to determine the dune height. This enabled topographic information obtained from [7] to be validated. Shoreline position on the 2005 digital map was digitized onscreen in Geographic Information System (GIS) environment. The identified HWL mapped facilitated the identification of the erosion trend in the study area. The revised 1992 bathymetric map was converted into digital format to facilitate analysis in GIS. The marked positions of the seabed with their spot heights on the 1992 revised bathymetric map were manually digitized. The historic map was placed on a digitizing board and the points mapped using the sensitive digitizing puck. The point mode method was adopted over the stream mode since it reduces coordinate resolution uncertainty [19] and according to [40] it is the preferred method when precise digitizing is required. The Ghana meter grid coordinate system was adopted for the maps.

2.2. Modeling Techniques

Numerical and geometric models have been developed that incorporate the laws of physics, climate data and sea level rise information. The modeled results enable various analyses that have increased scientific understanding into coastal processes. Analysis of sea level change at specific coastal locations and over short timeframes for modeling involves two components. First, there is the global component arising from thermal expansion of ocean water and the transfer of continental water reservoirs to the ocean. The second is the local component reflecting vertical land movement or subsidence due to tectonics, isostatic adjustments and sediment compactions [9].

2.3. The Bruun Rule

The Bruun Rule states that the equilibrium profile of a beach-and-dune system is re-adjusted for a change in sea level [24]. According to this rule, a rise in sea level will cause erosion and reestablishment of the equilibrium position of the shoreline further inland and described by the following equation [41]:

$$Ceq = z\, l/(h + d) \tag{1}$$

where Ceq is the equilibrium change in shoreline position, z is the rise in sea level, l is the closure distance, h is the height of the dune at the site and d is the water depth at closure distance ($l/(d + h)$ thus gives slope).

Two important drawbacks have been identified with the use of the Bruun rule to model shoreline change under a trend of rising sea level [41]. First, it gives only the "equilibrium" (or steady-state) change. However, coastal systems do not adjust instantaneously since there is apt to be some time lag in the response. Secondly, shoreline retreat, as evidenced by historical data on beach profiles, is apt to occur in "fits and starts" over time, not as a steady, year-by-year incremental change. This uneven response of the shoreline is partly a function of the chance occurrence of severe stormy seasons, which often cause erosion (in contrast, a season of very few, or mild, storms may allow the natural system to replenish the sediment supply and the shoreline to advance). Cooper *et al.* [42] also identified deficiencies in the Bruun model as a "one model fits all" approach that makes it unsuitable for a highly complex sedimentary environment with significant alongshore sediment transport. The limitations identified have resulted in the improvement of the Bruun model.

2.4. Modification of Bruun Rule

The Bruun Rule has been modified [41] to add a response time and a stochastic "storminess" factor as follows:

$$dC/dt = (Ceq - C)/T + S \tag{2}$$

where t is time, C is the shoreline position relative to that of t = 0, Ceq is the equilibrium value of C, T is the shoreline response time and S is a stochastically-generated storm erosion factor.

This study adopted the modified Bruun Rule to simulate future shoreline response to the sea level rise under plausible sea level rise scenarios. Sea level rise was projected using the CoastCLIM component of the SimCLIM model system [41] and the CSIRO_MK2_GS Global Circulation Model (GCM) pattern which is already incorporated in SimCLIM. The CoastCLIM model operates on the principle of the modified Bruun Rule and was validated and a trial experiment performed using available data.

2.5. Examining the Shoreline Response to Sea Level Rise

The state of the shore was analyzed from the surveyed results by comparing the 2005 digitized and the 2009 *in situ* surveyed shoreline positions, which revealed that the shoreline has migrated significantly inland. The CoastCLIM model was used to analyze the shoreline responses to various sea level rise scenarios. By applying selected IPCC scenarios and incorporating data such as site related parameters and storm characteristics, sea level rise projections were generated for the study area from 1940 to 2100. The study accounted for uncertainties by simulating for the extreme situation, the best estimate and the low sensitivity scenario. The site related parameters include the shoreline response time, which governs the responsiveness of the system to sea level rise in a given year; the depth of material exchange that was computed for using equations by [43] and [44] to represent the best and the worse case scenarios; the height of the dune that was obtained from [19] and validated from the RTK GPS survey; and the shoreline residual movement also from [19]. The future shoreline positions in the Dansoman coastal area were simulated for the years 2025, 2050, 2075 and 2100 with a baseline from 1970–1990 average. The 25 years intervals simulation was done to spread the predictions evenly.

2.6. Assessment of Impacts of Coastal Inundation on the Communities

Two factors were used to assess impacts of coastal inundation on the communities. These were impacts on socioeconomic systems and impacts on natural systems. These two factors were adopted due to the prevailing local economic activities and ecology as discussed in Section 1. The simulated future shoreline positions for the selected periods of 2025, 2050, 2075 and 2100 were overlaid on the aerial photographs.

2.6.1. Impacts on Socioeconomic Systems

The socioeconomic systems were grouped into two. They are the landuse pattern and the population at risk. The landuse pattern was further classified into three categories that include the built up area (defined as areas having buildings), the vegetation zone (defined as areas with vegetation) and the beach zone (defined as area from the shoreline to the built up zone). The population at risk in the study area, within a period, was estimated by visually identifying the number of buildings likely to be affected by the simulated shoreline positions overlaid on the aerial photographs. The results were used to statistically estimate the number of people at risk to coastal inundation based on the 2000 population census data using the equation [45]:

$$P_r = N_b \times P_h \times H_b \tag{3}$$

where P_r is the current population at risk, N_b is the estimated number of buildings, P_h is the average number of persons per household and H_b is the average number of households per building.

The results obtained was used to calculate an average geometric population growth rate by means of the equation below [45]

$$r = [(P_i/P_o^{1/t} - l] \times l00 \tag{4}$$

where r is the geometric population growth rate (%); P_o is the initial population (from the 2000 census data), P_i is the final population and t is the number of years for which the projection is performed.

The population was projected through the years 2025, 2050, 2075 and 2100, assuming a constant growth rate of 4.53 [46] and using the equation below [45]:

$$Pi = Po \times (1+r)^{t} \quad (5)$$

It was also assumed that it is appropriate to use the entire Accra recent growth rate and apply it to a small subset within the metropolitan area.

2.6.2. Impacts on Natural Ecosystem

The projected mangrove ecosystems under threat from sea level rise in the communities were estimated for the years 2025, 2050, 2075 and 2100 using the simulated shoreline positions overlaid on the aerial photographs. Bird species diversity was used to characterize the impacts of coastal inundation on the natural ecosystem. The key bird species at the coastal area were classified according to the [47] Red List Classifications.

2.7. Assessment of Flood Risk Awareness

The coastal community's awareness of flooding in the study area was determined from a structured questionnaire. The questionnaires were administered to 120 households in the study area projected to be likely inundated in the next 100 year scenario. Descriptive statistics method was used to analyze the results from the questionnaires that were administered.

3. Results

The input parameters for the CoastCLIM model used to simulate future shoreline positions are shown in Table 1. These were obtained from [7] and field measurements. Table 2 provides the estimated sea level rise and the shoreline positions under the SRES A1FI and B2 scenario.

Table 1. CoastCLIM model input parameter for the Dansoman coastal area.

Input	Value
Site location coordinates	Lat: 5.52, Long: 0.17
The closure distance, l, (m)	670
The depth of material exchange, d, (m)	4.19
The dune height, h, (m)	2.14
The residual movement (m/y)	−1.3
Storm surge cut mean (m)	4.5
Storm surge cut Standard deviation (m)	1.57
GCM pattern	CSIRO_MK2_GS
The shoreline response time	5

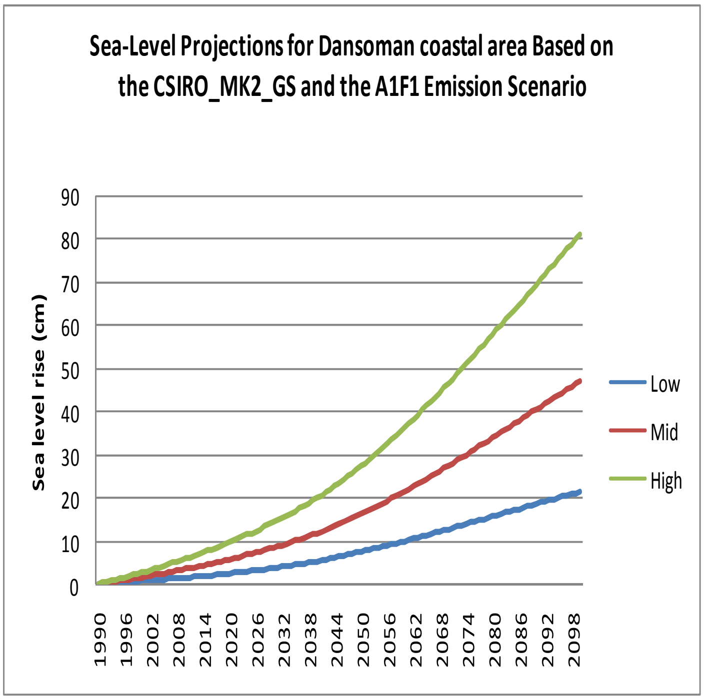
Table 2. Estimated long term sea level rise, equilibrium shoreline and the current shoreline position.

	Year	Sea level rise from SimCLIM (cm)	Equilibrium shoreline from Bruun rule (m)	Current shoreline with baseline from 1940 (m)	Shoreline position with baseline from 1970–1990 average (m)
SRES A1FI	2025	6.77	−118.96	−115.47	−63.88
	2050	15.73	−160.95	−157.08	−105.49
	2075	30.05	−208.61	−203.34	−151.75
	2100	46.41	−258.42	−253.65	−202.06
SRES B2	2025	7.17	−119.39	−115.83	−64.24
	2050	14.86	−160.03	−156.55	−104.96
	2075	23.85	−202.04	−197.75	−146.16
	2100	33.74	−245.01	−241.22	−189.63

Table 3. Projected sea level rise (cm) for the 21st century under SRES A1F1 and B2 in study area.

	Year	Low (cm)	Mid (cm)	High (cm)
SRES A1F1	2025	2.97	6.77	11.39
	2050	7.25	15.73	26.45
	2075	14	30.05	50.9
	2100	21.22	46.41	79.71
SRES B2	2025	3.18	7.17	12.05
	2050	6.46	14.86	25.6
	2075	10.14	23.85	41.99
	2100	14.04	33.74	60.27

Figure 2. Sea Level Rise Projections based on CSIRO_MK2_GS A1F1.



The shoreline response to sea level rise based on the various scenarios is provided in Table 3 below. Figures 2 and 3 are the sea level projections based on CSIRO_MK2_GS A1F1 and the B2 emission scenarios.

Figure 3. Sea Level Rise Projections based on the B2 emission scenarios.

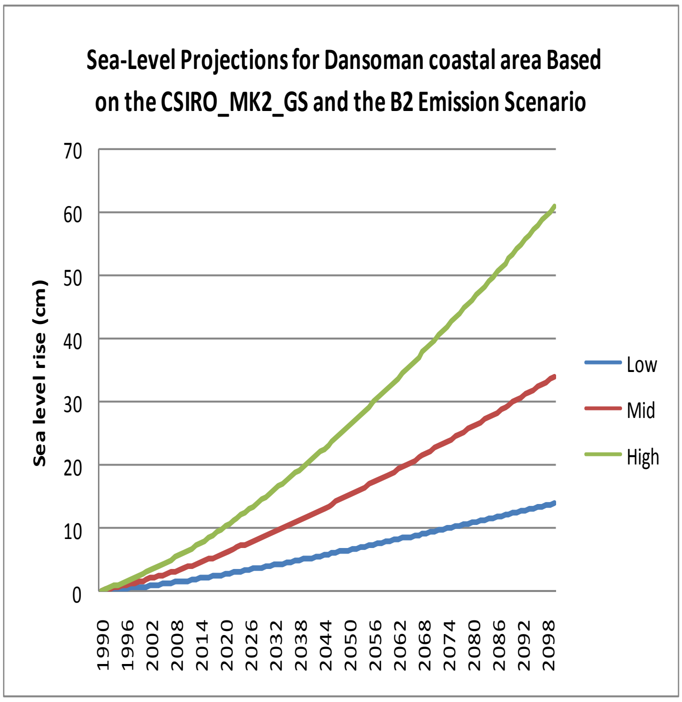


Figure 4 shows the simulated shoreline positions overlaid on aerial photographs to reveal the potential impact of flooding on the Dansoman coastal communities that are susceptible to permanent inundation in future using the various sea level rise projections. Figure 5 shows estimated settlement and vegetated areas susceptible to permanent inundation in the study area.

Figure 4. Areas susceptible to permanent inundation in the Grefi and Gbegbeyise communities.

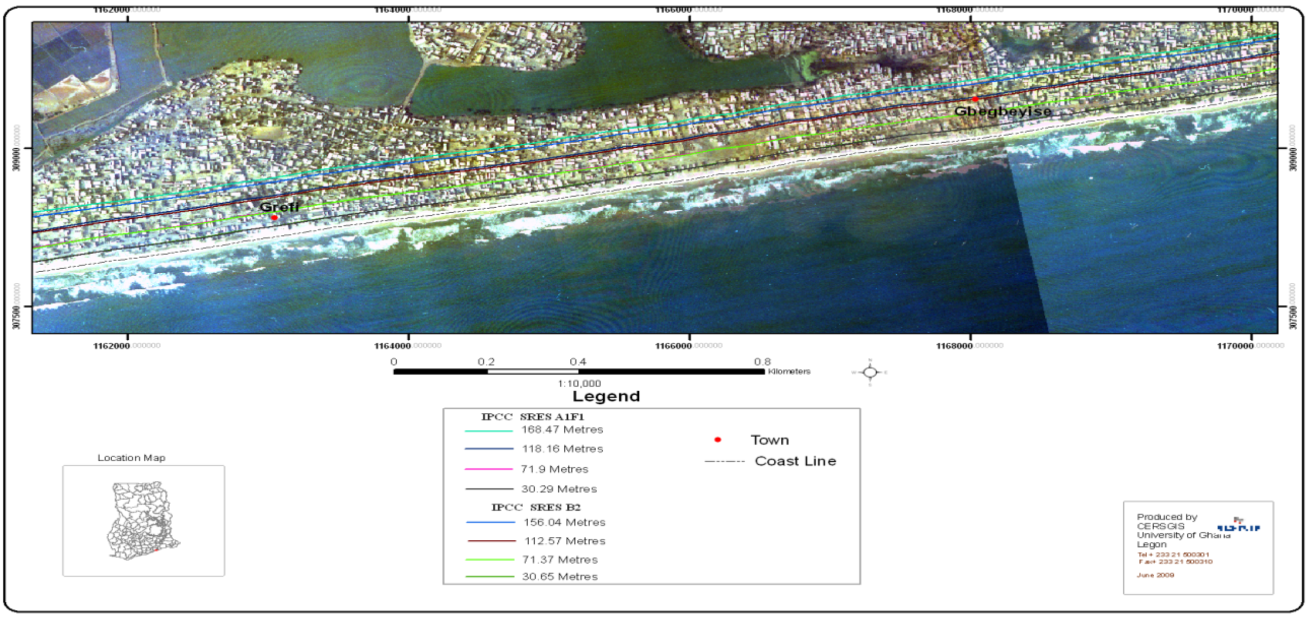


Figure 5. Settlement (red) and vegetated area (green) susceptible to permanent inundation.

Table 4 presents results on the estimated built up area and vegetation that are likely to be lost within the study area, while Table 5 shows the estimated coastal population, area and buildings that falls below various years simulated shoreline positions.

Table 4. Estimated built up area and vegetation to be lost.

Period	Landuse pattern	Number of spots on map	Sum (ha)
1990–2025	Beach	1	4.885
	Built up	14	3.732
	Vegetation	6	1.342
2025–2050	Built up	18	24.554
	Vegetation	9	5.991
2050–2075	Built up	18	25.944
	Vegetation	9	6.336
2075–2100	Built up	21	40.047
	Vegetation	11	7.815

Table 5. Estimated Population, area and buildings to be lost in the projected years.

	Year	Estimated population vulnerable	Estimated number of buildings vulnerable	Total area vulnerable (Km^2)
SRES A1F1	2025	2,135	85	0.35
	2050	28,951	381	0.48
	2075	137,114	596	0.62
	2100	645,558	926	0.78
SRES B2	2025	2,210	88	0.35
	2050	28,724	378	0.48
	2075	127,912	556	0.61
	2100	589,110	846	0.74

Tables 6 and 7 give results on the flood risk awareness of the inhabitants of the coastal communities obtained from the administered questionnaires. Table 6 presents the percentage of people who have suffered from the impact of coastal inundation, while Table 7 shows the responses to early warning signals prior to inundation.

Table 6. Residents who have suffered from the implications of coastal inundation.

	Number of respondents	Percentage
Suffered from coastal inundation implication	68	56.7
Not suffered from coastal inundation implication.	52	43.3
TOTAL	120	100.0

Table 7. Response to early warnings prior to coastal inundation.

	Frequency	Percentage
Do not receive any early warning prior to inundation	98	81.7
Receive early alarm prior to inundation	22	18.3
Total	120	100.0

Figure 6 presents a pie chart on the perceived causes of inundation sampled from the respondents to the questionnaires in the study area and Figure 7 shows the residents' estimation on the measures in place to mitigate the threat of inundation. Table 8 presents results on the implications of coastal inundation in the study area as reported by the respondents to the administered questionnaires.

Figure 6. Causes of inundation in the study area.

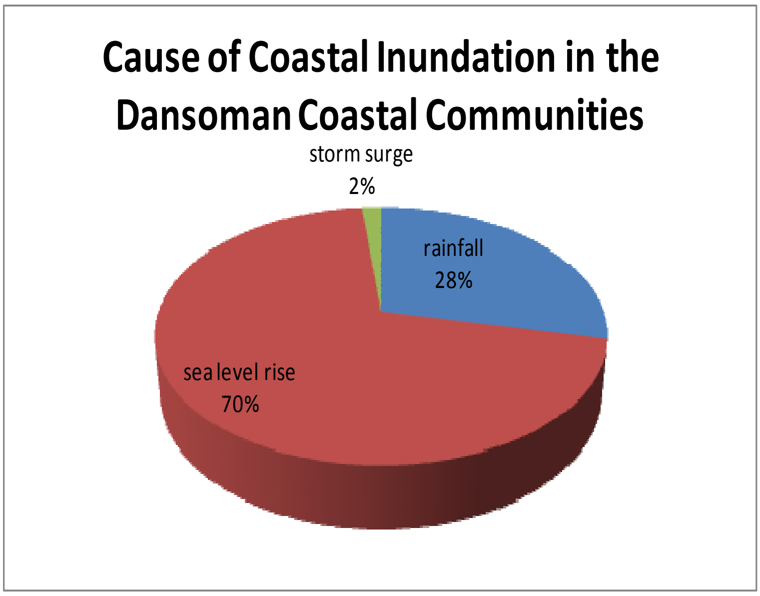


Figure 7. Adaptation measures to mitigate sea level rise.

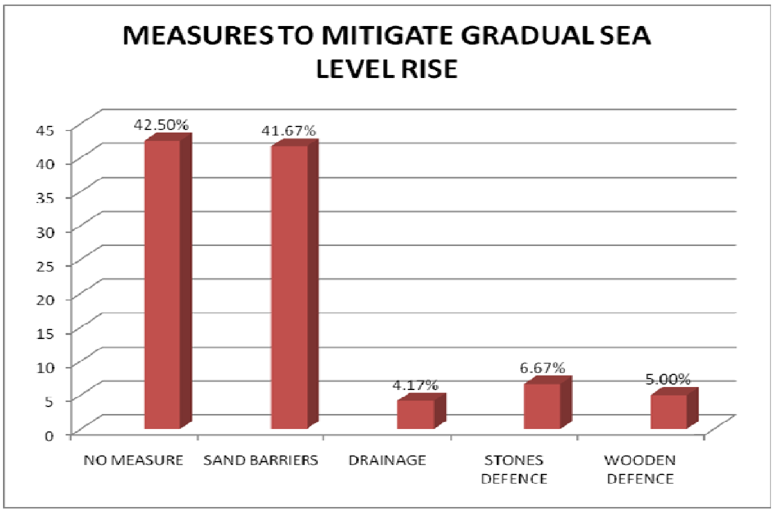


Table 8. Implications of coastal inundation in Dansoman.

Implication	Examples	Percentage of respondents (%)
Drowning		0.0
Injuries		1.7
Diseases	Respiratory, Skin and Foot Rashes, Malaria, Cholera	25.0
Population displacement		54.2
Loss of land	For Farming and Livestock rearing	2.5
Destruction of buildings	Houses and Shelters	40.0
Destruction of household chattels	Television, Furniture, Electrical Appliances.	55.0
Effects on livelihood	Decreased Fisheries Productivity, Collapse of Businesses	45.0

4. Discussion

4.1. Shoreline Response to Sea Level Rise

According to the trends shown in Figure 2, the next two to three decades are not expected to show a dramatic rise in sea level. However, the rise is expected to accelerate sharply after the year 2050 as greenhouse gases increase in the atmosphere. The B2 scenario also depicts similar trend, the projections rise remarkably in the second half of the century (refer to Figure 3). This is attributable to more greenhouse gases in the atmosphere that is anticipated to warm the earth. The likely mid-range scenarios for sea-level rise at the coastal area of Dansoman are 15.73 cm by 2050 and 46.41cm by 2100 for the worst scenario. For the best scenario, projected values of 14.86 cm by 2050 and 33.74 by 2100 are recorded. These values could be used when considering sea-level rise in projects or planning at the Dansoman coastal area.

4.2. Shoreline Changes and Coastal Inundation

Coastal inundation caused by high waves and gradual inundation by sea level rise within the Dansoman coastal communities are expected to increase. This will move the shoreline inland and thereby submerge the coastal lands and properties. From Table 2, shoreline retreat under sea level rise scenarios with baseline from 1970 to 1990 average is likely to occur at the Panbros, Grefi and Gbegbeyise communities in the Dansoman coastal area of Accra. The shoreline for the best-case scenario could recede from 64.24 m in 2025, to 104.96 m in the 2050s, and up to 189.63 m by the year 2100 (refer to Table 2). In the worst-case scenario, there could be a shoreline recession of 151.75 m by the year 2075 and a major recession of 202.06 m by the year 2100. This corroborate the study by [7], which reported that between 200 m and 600 m of shoreline will be eroded by next 250 years under sea level rise scenarios in Accra in the worst case scenario. This implies that over 200 m of coastal land could be lost in the Accra by 2100. The trend of the shoreline recession scenarios displayed by the SimCLIM system depict greater recessional rate beyond the year 2050 both for the best case and the worst case. The projections do not include the additional extent of the periodic spring tides that occur in the area. This indicates that some areas beyond the 2100 simulated shoreline position are vulnerable to inundation. The flood period could affect wide areas of land which would also adversely affect a number of small scale industries, businesses, residents and the mangrove vegetation within the area.

4.3. Impacts on the Coastal Communities and Landuse

The coastal area can be described as an important ecological, industrial site and densely populated area that extends from Panbros to Gbegbeyise. On the whole, a relatively narrow coastal strip would be permanently inundated below the 2100 simulated shoreline position. However, flooding due to storms and high spring tides could periodically engulf a much greater area.

Due to the highly populated nature of the coastal area of Dansoman as reported by [46], a large population and considerable private property and infrastructure will be potentially at risk to gradual inundation and high tidal waves. Figure 4 reveals the position of the shoreline for the years 2025, 2050, 2075 and 2100 overlaid on an aerial photograph. The shoreline indicates the baseline from 2005. Figure 5 further shows the built up areas, mangrove vegetation spots and the beach areas at risk to gradual inundation of the coast. Under the A1F1 scenario (refer to Table 4) nearly 6.0 ha of vegetated land and approximately 25.0 ha of built up area are expected to be submerged due to inundation by the year 2050. This is however expected to increase considerably by the year 2100, where about 8.0 ha of vegetation land and 40.0 ha of the built up area would be submerged.

4.4. Population

High population densities are presently concentrated near the coastline at Grefi and Gbegbeyise. The housing structure of the local population in the area is made up of sandcrete buildings which are indiscriminately built along the coast. These are likely to be destroyed in the event of coastal inundation. If population density coupled with housing habit should keep on growing at the current trend in the area, the flood periods will pose a major disaster in the future and evacuation of vulnerable people would be difficult since the few routes separating the buildings would be choked up with flood waters. From the study, under the A1F1 scenario, it can be observed that an estimated number of about 29,000 people could be displaced by the year 2050 and by the year 2100, nearly 646,000 people could be affected by inundation in the Grefi and Gbegbeyise communities (refer to Table 5).

The Densu Ramsar site is located close to the Panbros salt industry in the west. The gradual permanent inundation could destroy the wetland zone which would affect the ecological site in the coastal area. The site serves as a habitat for migratory bird species of which some are endangered.

Fishing is also likely to be affected since the remaining natural fish landing sites will be destroyed together with the breeding ground of the fishes by the inundating waters. According to the fishers, they have experienced decline in fish catch and earnings (refer to Table 8). They attribute one of the reasons to the inundation problem of the area. This is because the sea is gradually submerging the fish landing sites in the communities.

4.5. Flood Risk Awareness

From the survey, it emerged that coastal inundation is the major coastal hazard in the communities. The respondents confirmed that they really have problems of inundation in their area. According to them, inundation in the coastal community is caused by sea level rise and rainfall. However, majority of them responded that high tide as a result of sea level rise is the significant cause of inundation. The situation becomes devastating during the period when they experience spring tide in the area. During the survey, majority of the respondents emphasized that the severity of the high tides keeps on increasing every year and the coastal land is rapidly being submerged by gradual inundation.

As indicated in Table 6, about 57% of the population in the study area has suffered flood damage. The damage caused involved mainly property damage and the displacement of people from their homes. The properties include houses which are made of sandcrete materials, household chattels like furniture, television *etc.*, small scale business like bars and shops, domestic farm animals and gardens. From the respondents interviewed, no deaths were recorded in their families as a result of flooding. However, most of them reported that there have been incidences of death due to the collapse of building on some people in the area. There were some few injuries reported.

On the evacuation as a result of inundation, 70% of the respondents have evacuated before. This is mainly because the flood water inundates their houses and passage routes leaving them with no place of refuge and shelter. The respondents stressed that this usually happens during the periods when they experience spring tides. About 27.5% of them reported that they have not evacuated from the place before. However, they gave reason as living far inland not less than 50 m from the coastline. The remaining 2.5% did not respond to this question.

With regards to the possible health effects that coastal inundation could have on the residents of the coastal communities, majority of the respondents, representing 58.3% said they do not think it has some health effects at all. Their reason is that the sea water kills germs and parasites. Among the remaining 41.7% who said coastal inundation has a negative health effects, 70.5% said the health effects are parasitic. This is because the stagnant water breeds mosquitoes which cause malaria. They also reported of other skin diseases and rashes which affect children rampantly during these seasons of floods. They suspect the inundated water breeds some parasites that when children walk in them, they get infections. 22.7% said the health effects are water borne and they mentioned diseases like diarrhea and stomach aches. They gave reason that the sea water transports lots of dirt and sediments from the sea onto land. They also have refuse dumps along the coastal areas which get flooded and spread the refuse in the environment thereby affecting their drinking water and food. They stressed that during the spring tide seasons the residents especially children suffer from diarrhea, cholera and other dirt borne diseases. The remaining complained of foul air in the environment. The reason given was that the flood water is unclean, also carries along dead materials and scatters the refuse collected in the vicinity.

From the questionnaire responses, 41.7% said they build sand barriers to adapt to the gradual sea level rise. Thus, they dig sand from the coastal area and form mould barriers with stones to protect their structures. However, majority of them said they are ineffective and could not resist the impacts of the sea as it moves onshore. The barriers collapse. With regards to whether the government supports the residents of the coastal communities during flood season, most of the respondents said government does not offer any support, as 80% responded 'no' to the question. However a few people said when there are massive damages in the communities during spring tides, they only receive items like rice, canned fish and bowls as compensation to the damages caused by the flood water.

The greater proportion of the respondents said that they are expecting a massive disaster caused by coastal inundation in the near future. This is confirmed by 74.2% of the respondents with only 1.2% expecting a less disastrous future flood. When asked about the future mitigation measures they are planning to take individually, 50.8% of them said they will evacuate from the area, 32.5% said they will move to safer grounds in the same area and the rest mentioned other measures such as sea defense, mould concrete building and some not even having any plans of future mitigation measures.

5. Conclusions

It has emerged that by the year 2100, the most likely range of sea level rise in the Dansoman coastal area from model projections is between 21.2 cm–79.7 cm, considering the worst case (SRES A1F1). The best case (SRES B2) is also projected to be 14.0 cm–60.3 cm. The study concludes that under the CSIRO_MK2_GS scenario and with reference to the 1970–1990 baseline, by the year 2100, the most likely recession could be 202.06 m inland, considering the worst case (SRES A1F1). The best case (SRES B2) is also projected to be 189.63 m inland. The results corroborate the study by [7]. Coastal inundation hazard of Dansoman coastal areas are expected to increase as a result of higher sea level rise due to climate change. It is projected that about 0.48 km^2 of coastal land will be lost by the year 2050 to permanent inundation with reference the 2005 baseline. Considering the year 2100, it is likely that a maximum of about 0.78km^2 of the coastal land will be lost to permanent inundation in the coastal area of Dansoman in Accra. This would lead to the displacement of a greater percentage of the local population due to the relatively high rate of population growth in the community. The number of buildings likely to be affected by the year 2050 is about 381, while by the year 2100 a total of about 926 houses could be destroyed at the coast. Significant buildings will be destroyed as a result of the unplanned pattern of physical development. For the coastal vegetation within the study area, it is projected that a maximum of about 6.0 ha of vegetation would be lost to permanent inundation by the year 2050 and by the year 2100 the coast area might have lost about 8.0 ha of vegetation. For the built up areas, a total of about 25.0 ha of land could be permanently inundated by the year 2050. This will lead to about 378 houses being submerged and destroyed by the sea water within the coastal area. By the year 2100, approximately 99.0 ha of land in the built up areas could be inundated permanently leading to the destruction of about 926 buildings in the coastal area. Fish landing sites could also be destroyed.

The large-scale salt industry at Panbros, the Densu delta and the whole communities spanning the barrier ridge could be severely impacted. Also at risk are thousands of species of animals particularly birds whose habitats are the wetland vegetation and the Sakumo lagoon in the communities. Human health of the coastal population suffers from inundation and pollution in terms of food, water quality and sanitation. Coastal inundation may foster the spread of parasitic and enteric diseases in the communities through the stagnant flood waters. From the study, it could be realized that, people living in the Panbros, Grefi and Gbegbeyise communities are aware that the sea is rising and the beaches are eroding. This has caused some people to leave the coastal communities and many more are ready to leave. However, most of the people do not know that climate change is one of the factors leading to sea level rise. From the survey, 92.5% of the respondents confirmed that coastal inundation is the major problem at the Dansoman coastal communities and they have suffered great losses as a result of inundation in the area. The study also revealed the fact that inhabitants have no systems in place to help them adapt to the problem of inundation in the communities.

This study has revealed the significant impact of coastal inundation in the Dansoman coastal community and how it will influence economic activities. It has also exposed the level of awareness of the community on coastal flooding and the mitigation measures currently in place.

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