Chapter 5

Geodesign a Tool for Redefining Flood Risk Disaster in Developing Countries: A Case Study of Southern Catchment of Ankobra Basin, Ghana

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Additional information is available at the end of the chapter

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Abstract

Flood is a hazard with increasing number of events and damages in all parts of the worlds. Many studies and researches have been conducted in understanding the causes of flood, effects and finding solutions to reduce its occurrences. Most of the solutions proposed have failed in the light of changing climate, river morphology and human modifications of watersheds in the world. In this regard, this research adapted geodesign as a flood reduction technique in stimulating flood risk within the Ankobra lower basin. Geodesign framework by Steinitz was adopted where various physical characteristics of the study area were remodelled. The results indicated that increasing building foundation above 88 m reduced flood risk. Also, further simulations by increasing drainage and connectivity reduced flood area size of extreme flood risk zone and high risk zones.

Keywords: geodesign, spatial multi-criteria evaluation, flood risk

1. Introduction

Man's life through centuries has been engulfed within diverse risk. Manifestation of these risks to reality is term disaster and it brings untold hardship. Flood-related disasters are one of the oldest disasters experienced by man since the dawn of time. A translation of cuneiform symbols of the Weld-Blundell Prism shows that flood occurrences go way back in antiquity during the Sumerian civilisation with both negative and positive effects [1]. In modern times, flood disasters are increasing with huge tolls on people and governments. Flood disasters are working against the attainment of Sustainable Development Goals as destructions levels are increasing human insecurity and poverty levels. According to the International Strategy for Disaster Reduction [2], there has been an increase in flood disasters with over 3455 reported cases between 1980 and 2011. Increase in flood disasters have puts over 24 million people and an estimated $2203.97 billion worth of assets at risk in the world [3]. In Ghana, it is estimated that floods have affected over 4 million people and brought about damages to the tune of US$ 78 hundred million between 1990 and 2014 [4].

Based on the destructive effects of flood, greater attention has been devoted to studying the causes and finding possible solutions to flood. Diverse research has been able to document numerous causes of flooding for all terrains in the world. But, solutions for curbing the occurrences and effects of flood have been limiting. Most proposed flood solutions have been inadequate in reducing risk to flood because of changing nature of river flow characteristics, climate change and rapid land cover/use changes [5]. Structural (building dykes, floodwalls and widening river channels) and non-structural (land use planning and flood warning systems) flood control measures are failing [6]. In the Ankobra Basin, numerous measures have been adopted by local and disaster managements to prevent flood and reduce its impact. These measures over the decades have ranged from dredging the Ankobra river bed, creating new drains, retrofitting of buildings. All these measures have succumbed to increasing flood intensity. This problem is not peculiar to the study area, but rather an emerging trend in the world. In 2005, over 80% of New Orleans was submerged in flood waters as dykes and flood walls were unable to flood waters from the Hurricane Katrina [7]. Also, comprehensive land use plan and dykes were unable to shield the Hague-Netherlands in 2012 from inundation [8]. The inadequacy of current flood control techniques calls for newer techniques [9].

Geodesign is a new intervention that can help in the fight of reducing flood events and decrease risk levels. This is mainly because it gives planners and disaster managers the ability to stimulate risk and disaster variables to ascertain which variable when changed can have the optimal effect on reducing flood risk. Also with geodesign, geospatial technicians have the capability to control and manage floods by undertaking numerous flow stimulations to ensure that drains maximise flow of flood waters [10]. Geodesign combines the age-old practice of planning, designing, implementing and evaluating changes to our built and physical environment with modern tools, including digital databases and representational and analysis software tools [11]. Implementing geodesign can ensure a win-win situation for both man and the natural environment by taking into consideration the full spectrum of the earth's life support including everything that lies below, on and above the surface system [12].

The potential of geodesign has been tested by some planners and disaster managers since its inception in 2010. Planners in Asheville and Cap Cod (United States of America), Sabah Al-Salem (Kuwait) and Bodegraven (Netherlands) have been able to redesign their landscapes using geodesign concepts. The results have been a remarkable decrease in flood occurrences and a friendly coexistence of man and nature (flood) [13]. It is based on these success stories that this study seek to assess the ability of geodesign as a flood reduction technique in the Southern Basin of Ankobra.

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2. Literature on geodesign

In reducing flood risk, most measures have centred on storage dams, barriers, land use plans, flood proofing of buildings, land reclamation and flood forecasting and warning [14]. McMillan and Brasington [5] assert that these measures are inadequate considering the constant changes in river dynamics and climate. As such, there is a need for new approaches to solve flood issues [9]. Geodesign is a new approach, which is gaining momentum in the field of geospatial technology with capabilities to solve complex environmental issues by finding the right balance between settlements and nature [11]. The use of the concept of geodesign is within the context that spatiotemporal (geographic) dynamics of events conditions what and how we design to tweak and adapt to our environment [12]. The effectiveness of any form of geodesign is conditioned on having sufficient knowledge of the relevant spatio-temporal characteristics of the area under study.

Geodesign originates from the merging of two words geography (geo) and design [15]. Mathur [16] states that geodesign is the intersection of geography and design. Flaxman [17] defined geodesign as a design and planning method, which combines the creation of design proposals with impact simulations informed by geographic contexts. Impact simulation abilities of geodesign are what most flood reduction measures lack. But geodesign helps in averting these problems by envisioning possible future scenarios with predictive alternatives whose consequence can be evaluated before implementation [18]. Geodesign is an interventionist approach in contrast to the more detached and dispassionate approaches [19].

Geodesign made the world stage in 2010 at the ESRI conferences. As a new field, various practitioners have diverse concepts about what geodesign is or should be. Others have even criticised the concept of being and old age technique of multi-criteria evaluation, as such it is not a new concept. But, Carl Stenitz, a pioneer and advocate of geodesign, developed a framework, which reduces the arguments around the concept. In Stenitz framework, geodesign involves specific actions or activities (**Figure 1**).

According to Steinitz [15], the assessment phase deals with the modelling of the environment, understanding it and the assessing of the elements in the environment, whereas the intervention phase looks at changing the modelled environment, analysing its impact and making a decision. By this, you sketch an idea, find out its implications, make adjustments and try again until a suitable alternative is achieved [20].

2.1. Geodesign as a structural and non-structural measure

Practitioners in the field of geographic information systems have been able to use geodesign to solve diverse environmental problems since it provides an excellent concept for proposing change to the geographical area [11]. Geodesign can be used as structural or non-structural measure in flood risk reduction. This is mainly because some disaster managers concern themselves on modifying only the physical characteristics of a landscape. But others rather introduce new physical elements into a landscape when alteration of already elements is not sufficient to solve flood occurrence.

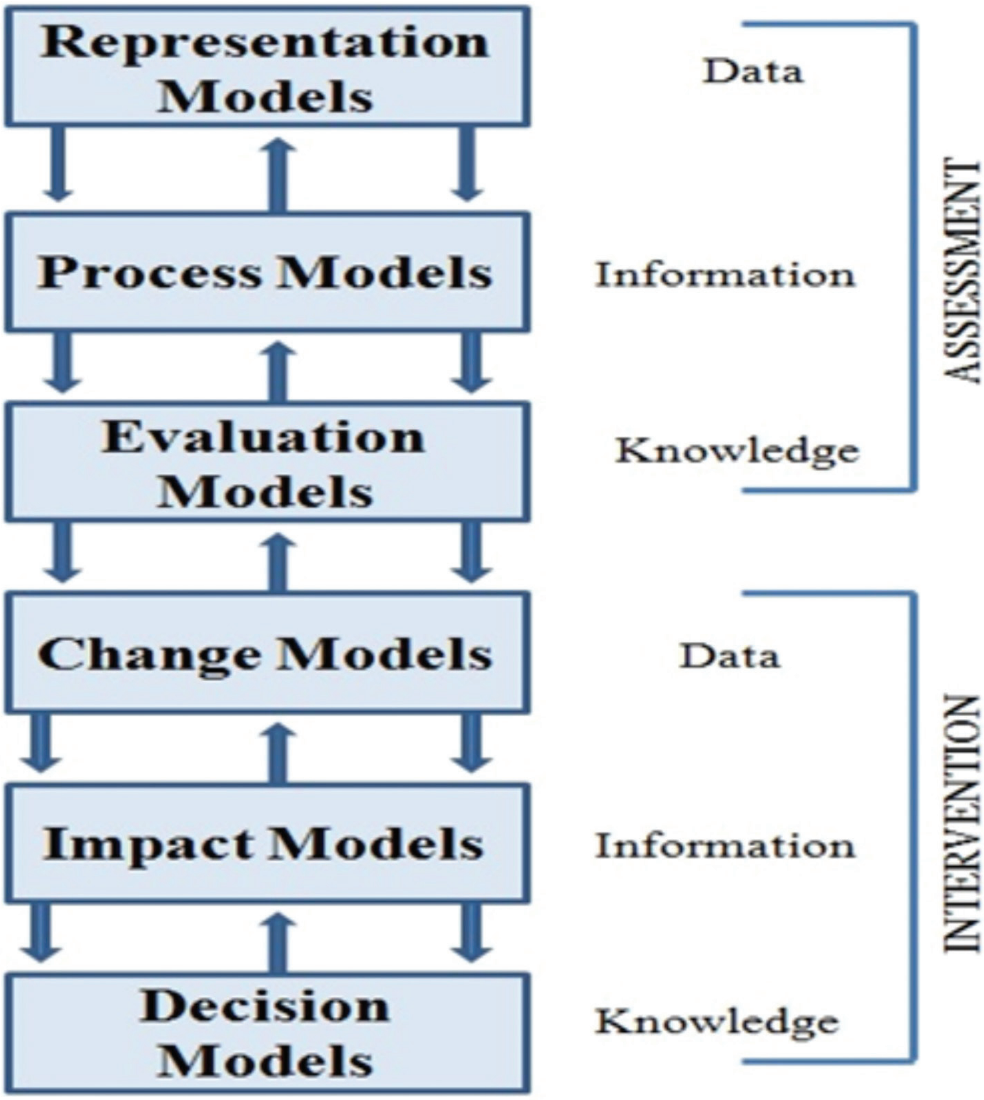

Figure 1. Geodesign framework. Source: Steinitz [15].

In 2008, geodesign was employed by the town Charleville, Queensland in Australia to help reduce flood risk [21]. Geodesigners were able to remodel the town's landscape and the impact of their new model which informed them to construct a 375 m of geodesign pallet barrier serving as a flood defence wall. Since the flood defence wall was constructed in January 28, the town has been safe from spillages coming from Waitaki River. In February 2004, River Severn caused havoc when torrential rain raised its level in Ironbridge town, United Kingdom. In less than 5 hours, a 550 m geodesign steel barrier, which was 1.8 m high, was erected by the United Kingdom Environment Agency along the Wharfage in Ironbridge Gorge. Geodesign barriers have a standard protection height of 0.65, 1.25 and 1.8 m with the ability to interlock, making it easy to superimpose them to increase their height as against flood walls that are static [21]. Also, geodesign barriers were constructed in the River Calder at Hebden Bridge, West Yorkshire, United Kingdom. This diverts water from an old riverside wall reducing and preventing flooding. These examples show the ability of geodesign to aid conventional structural flood reduction approaches.

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As a non-structural measure was employed in Cape Cod, Massachusetts in the United States of America, when the town threatened by sea level rise and coastal flood [22]. Through alternative scenarios modelling, Snyder and Lally [22] were able to find zones fit for human developments free from coastal and sea level rise in the future. China, a country with flood problems costing billions of dollars yearly have resorted to geodesign by remodelling its urban landscape ecologically to help reduce flood. Mainly because the cost to be incurred from geodesign simulations will be lower than normal structural measures [23].

Geodesign flood reduction strategy has challenges like any other intervention. Field experience shows that when geodesign steels are not firmly installed and the plates properly locked high pressure waters can topple over them [24]. On non-structural usage, Ervin [25] argues that there are some ethical issues, which will emerge in the future about geodesign since it does not have a set of ethics.

3. Methodology

The Ankobra coastal estuary lies within 4054'55''N and 2017'44''W to the upper left, 4054'55''N and 2015'58''W to upper right, 4053'41''N and 2015'58''N to lower right and 4053'41''N and 2017'44''W to the lower left. The study area is drained by the Ankobra River, which increases the areas vulnerability to flooding during rainy season (**Figure 2**). Rainfall in the zone is mostly in the ranges of 1500–2000 mm [26]. The area is relatively flat with most part well below 10 m above sea level. There are about 4069 people living within the estuary [27] who are mostly affected during flood.

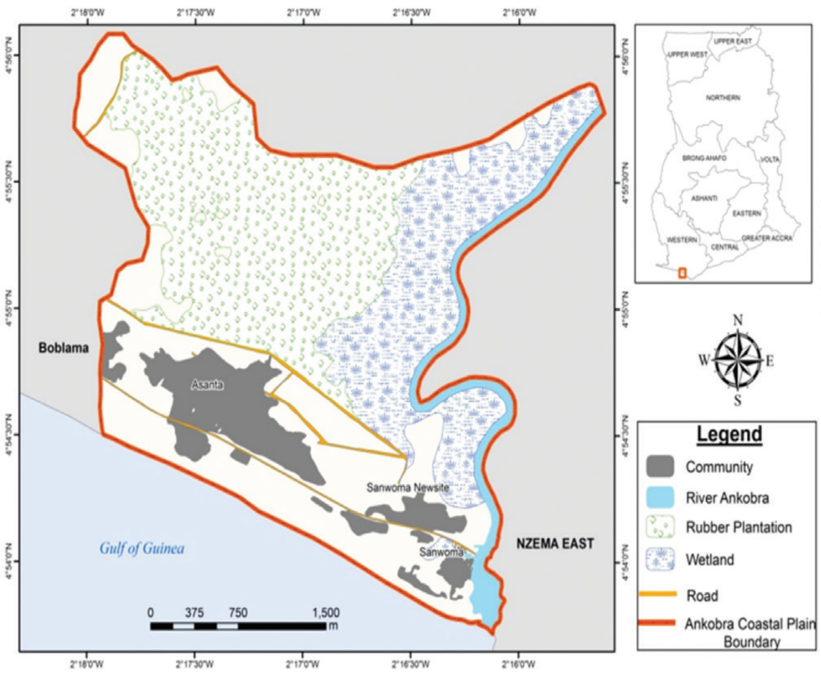

Figure 2. Map of study area.

3.1. Data processing and analysis

The flood risk map was used as the basis for remodelling the landscape to reduce flood risk in the study area. The intervention phase of [15], geodesign framework was adopted. The first part of the intervention phase of geodesign deals with change models. Steinitz [15] explains that change models require remodelling of the landscape. That is, the geodesigner changes some or social features, which have contributed to improper functioning of a zone. In meeting this requirement, some landscape features in the Ankobra estuary had to be changed or remodelled. The first change model of the geodesign undertaken was increasing the foundation heights of buildings in the study area above the worst flood depth experienced in the communities. The second stage of geodesign model was also undertaken by remodeling flow channels (direction, length) of drains. In this regard, a hydrological model was run for the Ankobra estuary from the digital elevation model. The hydrological model tool in ArcMap 10.1 ESRI software was used.

The processes for generating the hydrological model were checking for sinks in the elevation data, filling these sinks and running a flow direction function as well as a flow accumulation function. Finally, the hydrological tool (flow accumulation algorithm) was run to determine where runoffs are likely to move downslope in the Ankobra estuary. This helped in generating a drainage network of the Ankobra estuary. The drainage network of the landscape, the researcher remodelled some part of the land use in Ankobra estuary, channelling away from the communities the excess water, which mostly causes floods. After the remodelling or the change model process, the impact model stage was reached. This stage ascertained whether the landscape model of the estuary designed has the ability to reduce risk.

4. Results and discussions

In an effort to reduce the flood risk in the area, the research adopted the interventionist part of the geodesign concept. Steinitz [15] explains that change model is the first stage of the intervention phase of geodesign, which deals with remodelling the landscape. That is the geodesigner changes or modifies some physical features, which have contributed to improper functioning of an area. In this regard, the drainage and building foundations were remodeled to ascertain their impact on risk levels (**Figure 3**). Risk levels for [28] analysis were extreme: 46,725 m^2, high: 701,525 m^2, moderate: 248,150 m^2 and low: 9,167,758 m^2.

This function of change model is the hallmark of geodesign. The first model element changed for evaluation was the foundation parameters of buildings in the Ankobra estuary. This is because risk is an interplay of a hazard and vulnerable elements together with their coping capacity as indicated by Bollin et al. [29]. The researcher considered a "what if" scenario such as what will be the outcome (risk) if all buildings were above the worst flood risk depth in the estuary, that is 88.39 cm for Sanwoma and 121 cm for Asanta. Because all buildings in the Ankobra estuary were below the flood depth. Nevertheless, if the buildings were constructed above a flood depth, then flood risk levels might differ. Evidence of this is seen in Nzulezu where houses are less risky to floods due to their construction above

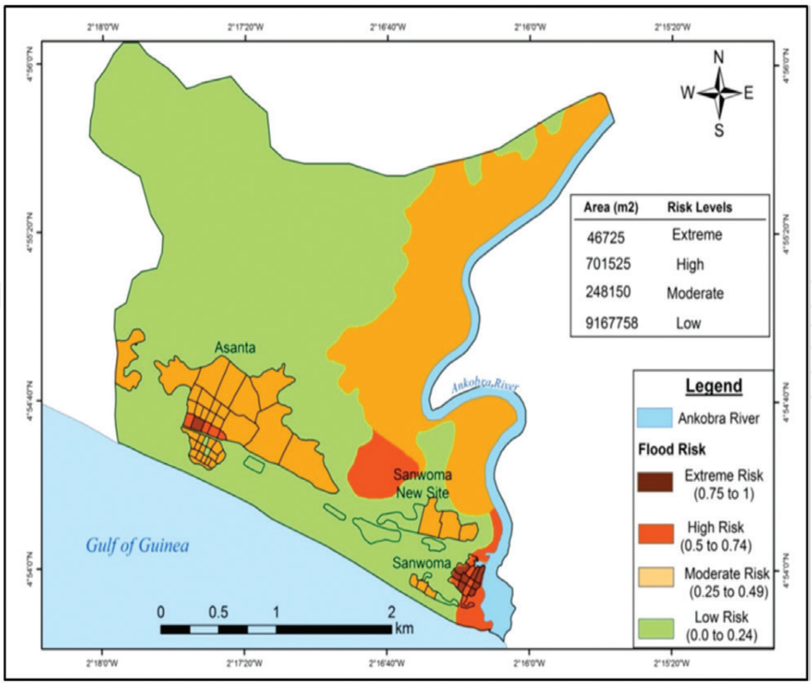

Figure 3. Flood risk of the Ankobra estuary. Source: Osman et al. [28].

the Amansuri water and wetland. Based on this, the researcher held all the variables of risk constant and changed the building foundation height of structures in the area. The second part of the geodesign interventionist phase (impact model) was then considered as it looks at assessing the effect of the change model. The spatial criteria evaluation (processes, problem definition, standardisation, weighting and slicing were considered) was therefore used to run the impact again. The output is depicted in **Figure 4**.

Extreme risk zone completely diminished to zero when compared with the original flood risk map, the high risk zone decreased by 53.27%, moderate risk zone gained by 169.42% and low risk remained the same. The changes in the new flood risk as against the original (flood risk) can be attributed to the fact that a building foundation above flood depth will prevent flood waters causing direct damages to buildings and their contents. This will have an enormous effect on physical vulnerability and therefore reduce flood risk areas.

A second change model undertaken was remodelling of the flow channel in the Ankobra estuary. The flow channels were identified as one of the factors causing floods in the study area. In Asanta community, the main cause of flood is blockage of excess rain water by the Axim-Elubo road, hence no proper drainage to carry excess run-off. In Sanwoma, a stream west of the community mostly causes floods as there are no flow outlets which would divert the water from the community. It was, therefore, important to generate flow channels in the study area (**Figure 5**) to know how they interconnect.

The result showed improper functioning of the water flow system in the Ankobra estuary, the flow in Asanta and Sanwoma. As such, the flow channels were modelled again by adjusting the land use and introducing a water outflow channel to connect the channels which were not

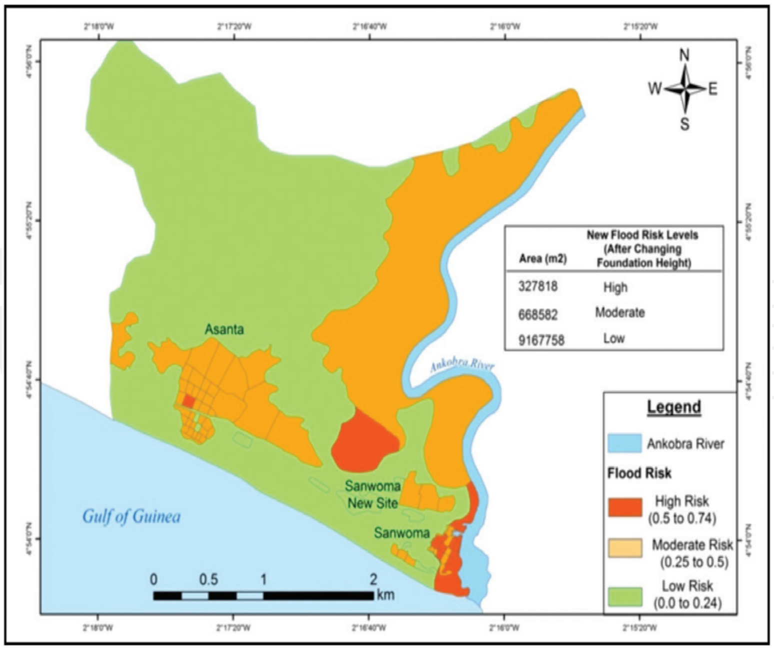

Figure 4. Flood risk reduced map after foundation parameters were increased above the worst flood depths.

linked and also to channel water from the settlements to the sea. In Sanwoma, a channel was constructed to link the Ankobra River to the stream west of the community, which sometimes causes flood during the rainy season. The length of the newly modelled channel was 98.23 m from the stream to the Ankobra River. Also an artificially closed lagoon was constructed to serve as the drain point for the two channels joined at the south west of Sanwoma. This is because a closed lagoon will prevent direct contact between the sea (waves and surges) and the channel water which can lead to flooding. The area of the closed lagoon modelled was

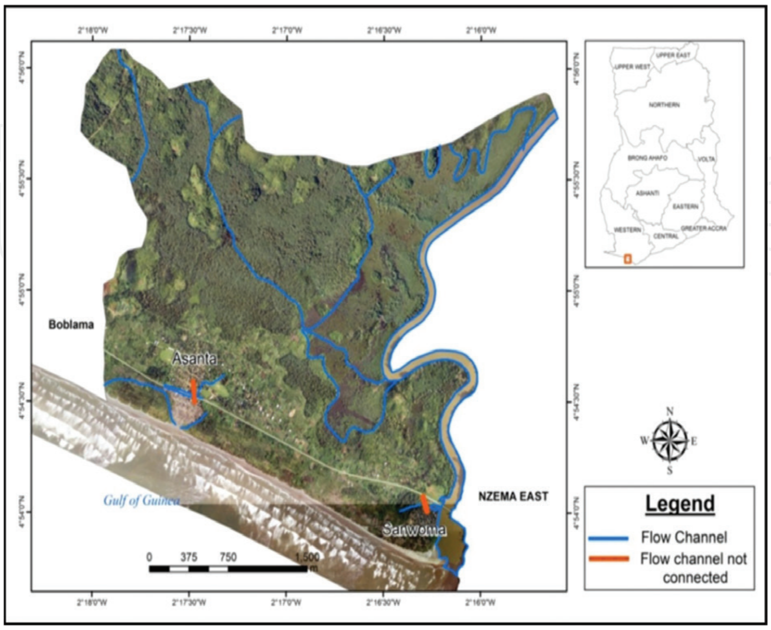

Figure 5. Flow channel of Ankobra estuary generated from DEM.

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1347.85 m^2 with a depth of 242 twice the depth of the worst flood in Asanta. **Figure 5** shows the new modelled landscape with the channel. In Asanta, the main cause of flood is blockage of rain water by the Axim-Elubo road. In order to solve the problem, the researcher created a new channel within the community (**Figure 6**) from the northern part of the community to the southern part of the community. The length of the new channel in Asanta is 103.24 m.

The second stage of the intervention phase of geodesign was again employed where the new landscape was fed into the spatial multi-criteria evaluation to ascertain its impact. The impact assessment of the newly modelled landscape shows a new flood risk map with flood levels reduced (**Figure 7**).

The new flood risk zones from the remodelled landscape and drainage were high, moderate and low risk zones without extreme risk zones. Also, the area covered by these flood risk levels changed, the low risk zone remained the same in area size and moderate risk zone increased while high and extreme risk zones decreased. **Table 1** shows differences in area sizes of the risk levels before and after the geodesign application. The extreme flood risk area diminished from 46,725 m^2 to zero (0), whereas the high risk zone decreased by 72.23%. The moderate risk zone also gained 223.03%, whereas the low risk zone remained the same. In the outputs of the first change model (foundation) and this new change model (remodelled landscape and drainage system), the low risk zones remained the same because the researcher did not apply the interventions in these areas as they were already safe from flood risk.

It can be concluded that the impact assessment of the change models (foundations parameters and remodelled landscape and drainage) reduced flood risk levels in all the various risk levels. But as Fisher [18] remarks, after the last part of geodesign is the decision making stage where whether the impact was desirable and should be accepted or rejected by the geodesigner

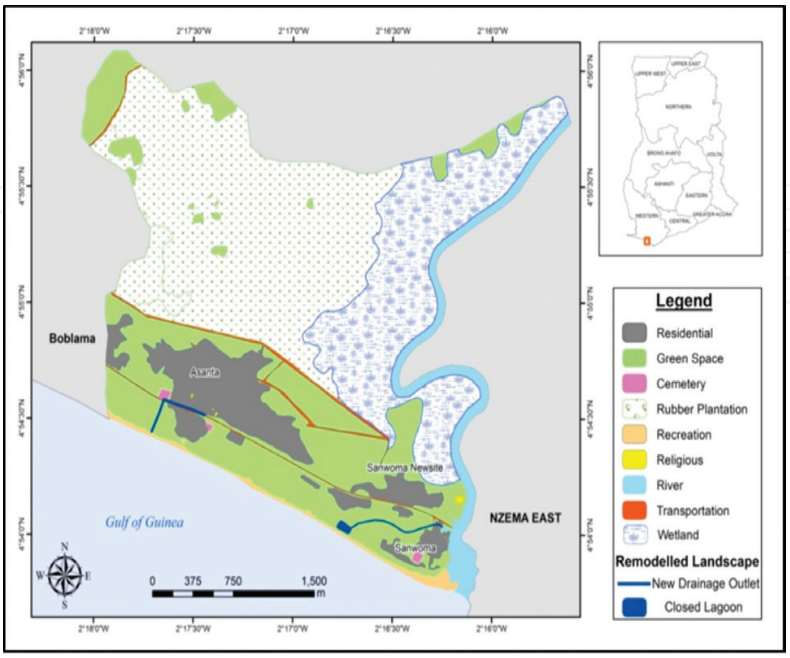

Figure 6. Remodelled landscape and the new channels.

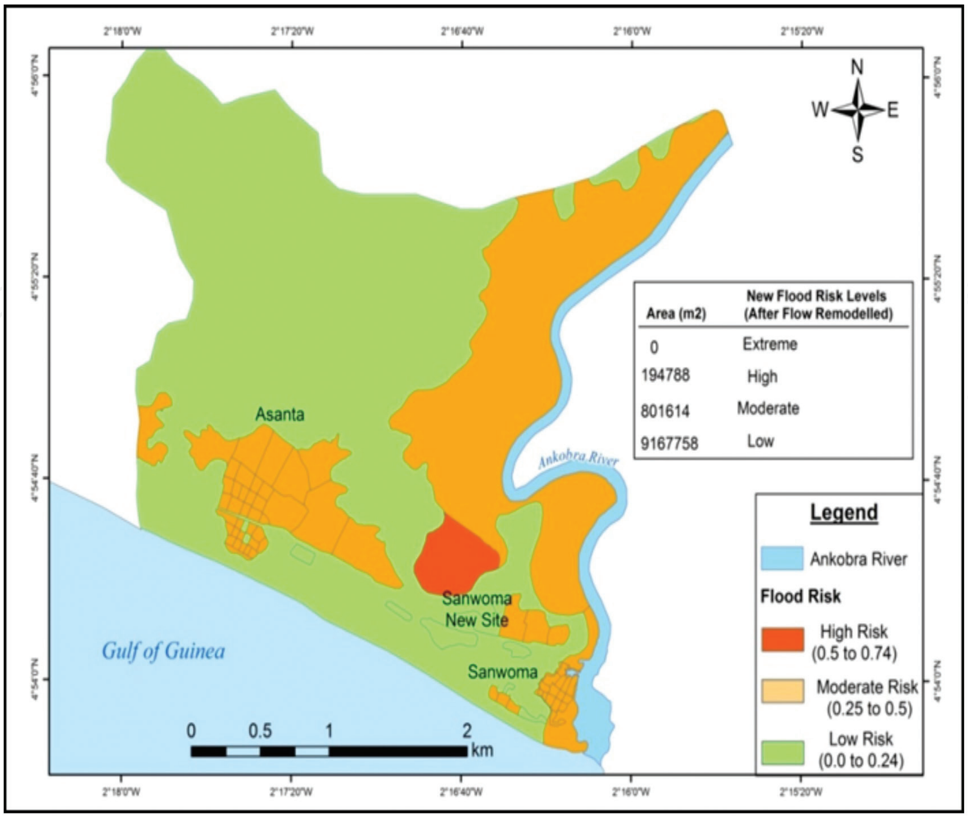

Figure 7. Flood risk reduced map after remodelled landscape and drainage.

is determined. Taking into account the two results (statistics of flood risk reduced map) in **Tables 1** and **2**, the researcher decided to adopt the results (flood reduced map) of the remodelled landscape and drainage system as the best intervention compared with remodelled foundation of buildings for the estuary since the flood risk reduction map from the change of building heights still had some wards in high-risk zones. Another reason for this decision is that it would be easier to create channels in the estuary since those areas where the channels to be created are not developed. Also, unlike the first change model (change of building

Flood risk levels	Area of flood risk levels before geodesign (m^2)	Area of flood risk levels after changed foundation parameter (m^2)	Differences (m^2)	Percentage change
Extreme	46,725	-	−46,725	−100
High	701,525	327,818	−373,707	−53.27
Moderate	248,150	668,582	+420,432	169.42
Low	9,167,758	9,167,758	-	-
Total	10,164,158	10,164,158		

Source: Osman et al. [28].

Table 1. Flood risk levels after change in foundation parameters.

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Flood risk levels	Area of flood risk level before geodesign (m²)	Area of flood risk level after geodesign (m²)	Differences (m²)	Percentage change
Extreme	46,725	-	−46,725	−100.00
High	701,525	194,788	−506,739	−72.30
Moderate	248,150	801,614	+2,927,044	223.03
Low	9,167,758	9,167,758	-	-
Total	10,164,158	10,164,158		

Table 2. Flood risk levels after change in drainage channels.

parameters), physically changing the building foundations laterally will mean demolishing buildings for new buildings with higher foundations to be put up. Most of the buildings had their foundations in the ground. Furthermore, this activity (physically changing the building foundations) will put much financial burden on inhabitants in the Ankobra estuary considering the fact that their socio-economic vulnerability is high. Analysis and results from the geodesign confirm Fisher's [18] assertion about geodesign capabilities and Dangermond [11] believe that geodesign can help men live in harmony with nature.

5. Conclusion and Recommendations

Geodesign is an innovative way of solving modern environmental problems in the face of climate change. This study adopted geodesign approach in testing its effectiveness as a flood risk reduction measure. Data employed were drainage channels, digital elevation model, land use, building parameters. Analysis was based on changing parameters of building foundation and drainage channels. Results showed, all change models generated better results and were effective in reducing flood risk levels. The downside of geodesign is where physical developments have fully taken place as implementing results might be difficult. In this research, changing building foundations provided the best option to reducing flood risk. However, buildings are structural entities which will be difficult to change in the shortest time to get the results of the model. The study recommends that planners should be made to adopt geodesign frameworks and models before developing physical plans. This is to give them a better understanding of the likely effects of their plans. It will also help in integrating disaster management into their physical plans to make our communities less risky to flood and other hazards.

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