Flood Risk Mapping and its Effects on livelihood in Ghana using Sentinel-1 data. A case study of Accra

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Abstract: **Flooding has been a major issue in Ghana, and several driving factors have been attributed to flooding in Accra. Among the factors outlined throughout the literature are climatic influences such as rainfall which results in a change in the natural hydrology of the area. Other causes include building in waterways and dumping of refuse in the drainage area. This paper seeks to develop an operational methodology using Synthetic Aperture Radar images to support the response agencies by providing timely information on flood risk areas over a period to prioritize response activities within the Greater Accra Metropolitan Area (GAMA) area. The method used was a change detection algorithm where the after-flood mosaic was divided by the before-flood mosaic, resulting in a raster layer showing the degree of change per pixel. Additional Dataset to refine the flood layers were adopted such as Digital Elevation Model (DEM) and Global Surface-water dataset. One of the major findings of this study is that the Ga south district is the district with the highest average flooding extent compared to the other districts within GAMA and the main reason was because of the Weija Dam being situated close to the district. When the Dam is full and being spilled over, it causes surrounding environments to experience flooding. The implication is that much attention should be given to the Ga south district to curb the menace of flooding in GAMA.**

Keywords: **Digital Elevation Model, Ground Range Detection, Interferometric Wide Swat, Multicriteria Decision Approach, Synthetic Aperture Radar.**

I. INTRODUCTION

Over the past decades, flooding has become a global issue, which affects economic and social development. This global issue has in most cases led to the loss of lives and damages in most countries including Ghana. Aside from demographic growth, urbanization trends, and climate change, the causes of floods are shifting, and their impacts are being felt. Most flooding happens in urban areas when there is prolonged rainfall and water drainage facilities can no longer contain the surface running water. Flooding is triggered by a lot of factors. Floods which have serious environmental and social implications have been mostly caused by a climate-related factor such as severe rainfall and in some cases severe snowmelt as well (CRED, 2015).

Flooding has been a major issue in Ghana, especially the capital city, Accra since the early 1930s [4] with significant floods recorded in 1955, 1960, 1963, 1973, 1986, 1995, 1999, 2001, 2002, 2010, 2011, and 2015 (IFRC, 2016). Flooding in Ghana has caused massive destruction since 1995 when the first devastating floods even occurred (Twumasi & Asomani 2002). The July 2015 floods affected 46,370 people, 187 houses were partially destroyed, and 300 people died (IFRC, 2016). The estimated cost of property destroyed was about $55 million [7].

[9] have determined the possible role of climate change in Accra's flooding. This they say is because of changes in rainfall and temperature coupled with changes in climatic conditions that result in a change in the natural hydrology of the area through heavy precipitation and increasing peak run-off discharge [19].

To prevent the occurrence of natural hazards such as floods, Remote Sensing and Geographic Information System technologies are being used as effective tools for risk assessment and hazard management. This technology provides effective and faster analysis than conventional survey methods. Remote Sensing systems are often used for flood risk mapping and has offered different levels of accuracy [15]. However, since optical observations are limited in their validity by clouds, which are most common during floods, microwave SAR systems are preferred because they provide more efficient analysis due to their capabilities of penetrating the atmosphere [15].

Most research into flood risk mapping has been based on a Multi-criteria decision approach using several parameters such as DEM, Slope, Aspect, soil, etc.

In a study conducted by [17], a special MCDA (Multi-criteria Decision Approach) was developed, implemented, and executed to identify the potentially flood-prone areas through creating maps of five classes of flood vulnerability from very low to very high flood-prone zones.

Other studies have also demonstrated flood risk monitoring by generating inundation maps from hydrological models which requires DEM as well as computing infrastructure to model the effects of obstacles on the flow of floodwater in flood plains [14].

The contribution of this research is seen in a way that the use of satellites for monitoring flood risk overcomes the challenges provided by the hydrologically based model. Most approaches in mapping flooding in Ghana have relied on multi-criteria analysis using GIS-based models. This has not been able to provide a spatial-based analysis of the situation. Optical images provide a more accurate way of mapping flood risk zones.

Although optical images have great potential for mapping during good weather conditions with image analysis capacity and accuracy, their use is limited in Accra due to high cloud coverage during the rainy season. Since clouds always occur during the rainy season, the utilization of satellite optical data is infeasible in providing flood risk maps during the disaster.

The main objective of this research was to use sentinel-1 data to map flooding risk areas and their effects on livelihood in the GAMA of Ghana. Damage assessments on livelihoods such as urban areas and population were made. Specific objectives include (1) Mapping the extent of Flooding within the Greater Accra Metropolitan Area from 2015-2019; (2) Quantify the estimated number of urban environments affected by flooding in the Greater Accra Metropolitan Area; (3) identify the districts within the GAMA that experienced high risk of flooding over the study period.

II. MATERIALS AND METHODS

2.1 Study Area

The Greater Accra Metropolitan area is located between 505′27″ to 5028′2″north latitude and 0045′8″east longitude to 0037′3″ west longitude along the Atlantic coast of Ghana (Figure 2). The size of the study area is approximately 1585km2. The region is made up of 12 administrative divisions. The area also has a population of about 4,000,000 (World Population Review, 2019).

The topography of the study area varies from flat to gently undulating slopes that rise to 75m at the foothills with a few isolated hills and rocks. In terms of climate, the region lies in the dry equatorial climatic zones and it has two rainy seasons. The first starts in March and ends in July, while the second starts in September and ends in November. The rains are most intensive and normally cause floods in most parts of the region. Mean monthly temperature ranges from 24.7^{0}C in August to 33^{0}C in March, with an annual average of 26.8^{0}C. Coastal savannah shrubs interspersed with thickets mainly covers the area. Grasses are short and grow barely beyond one meter with the trees growing to an average height of five meters (Farvacque-Vitkovic et al., 2008).

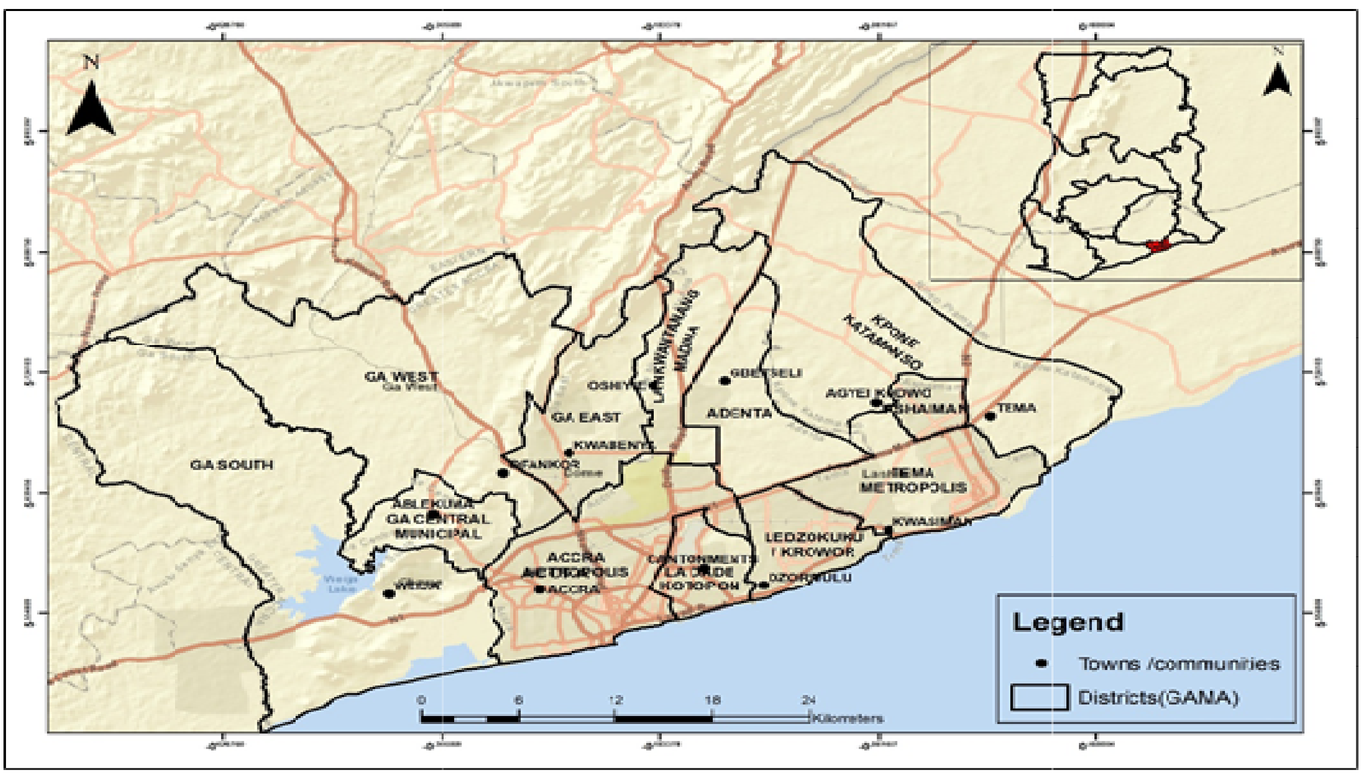

Figure 1: Study area showing districts.

2.2 Software/hardware/materials used

All image processing from data acquisition, pre-processing, and analysis was performed within the Google Earth Engine cloud-based platform (GEE). GEE is very efficient for the analysis of large datasets like satellite images because all the processing is done within the cloud infrastructure provided by Google. Other map creation and visualizations were executed in the ArcGIS desktop version. Also, the ArcGIS online version was used to create a time slider where the flood extent layers for the various years were animated.

2.3Methods/procedures followed.

A detailed overview identifying each major research phase with their required inputs and expected results is shown in the diagram below.

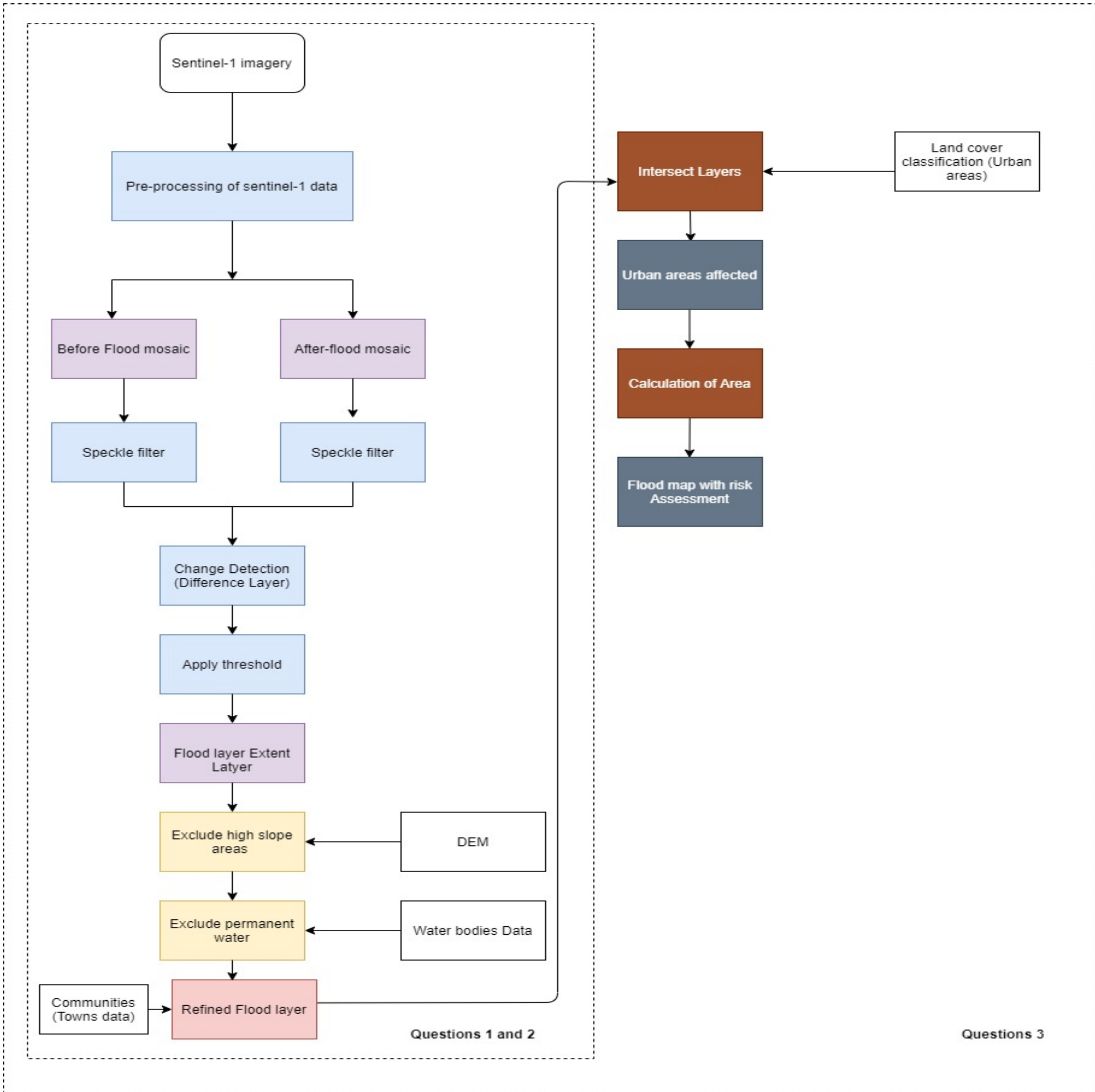

Figure 2 Workflow of methodology

2.4 Major Flood periods and Dates

Major Flood periods within the Greater Accra Metropolitan area were identified based on literature studies. According to the Poverty & Equity Global Practice paper 156 of the World Bank, some major flooding occurred in 2015 where about

53,000 people were affected in the Greater Accra Metropolitan Area. Other flood events occurred in 2016, 2017, 2018, and 2019, respectively. For the flood event analysis, the 2018 flood event was used for demonstrating flood risk assessment in the Greater Accra Metropolitan Area. The 2018 floods were also considered a major flooding event due to the heavy rains and thunderstorms that occurred on the 18th and 28th of June 2018 and resulted in 14 deaths, displacement of 34,076 others, and damaged properties according to the National Disaster Management Organization (NADMO) (Ansah et al., 2020).

2.5 Datasets used, pre-processing and Analysis.

Sentinel-1 dataset based according to the flooding periods defined for this project; before and after flooding were downloaded for the pre-processing and analysis of flood risk mapping. This was done in Google Earth Engine. The data as provided within GEE (Sentinel-1 Level-1) is a Ground Range Detected (GRD) and therefore has a resolution of 10m. The instrument mode is Interferometric Wide Swath (IW). For this project, the image used was acquired in ascending mode pass direction due to the coverage of the study area which is located within the Ascending mode. The images were then clipped to the study area boundary.

Information from the Sentinel-1 Level-1 Ground Range Detected (GRD) imagery in Google Earth Engine has already undergone some pre-processing steps including the application of orbits, border noise removal which removes low-intensity noise and invalid data on the scene edges, thermal noise removal, radiometric calibration which computes backscatter intensity using sensor calibration parameters, terrain correction and conversion of backscatter coefficient into decibels, among others. The only pre-processing steps applied was the smoothing filter to reduce the speckle-effects of radar imagery.

2.5.1 Change Detection

The change detection approach was applied in the analysis of flood extent, where the after-flood mosaic is divided by the before-flood mosaic, resulting in a raster layer showing the degree of change per pixel. This approach was adopted from the United Nations Office for Outer Space Affairs Knowledge Portal on Space-based information for Disaster Management and Emergency Response (2020).

In this regard, high values represent bright pixels and indicate high change, while low values represent dark pixels and show little change. A predefined threshold was then applied in this case, assigning 1 to values greater than the threshold and 0 to values less than the threshold value. The raster layer created by this layer shows the potential flood extent. The thresholds used were considered and adjusted due to either high rates of false positives or false negatives.

2.5.2 Refining the flood layer

Additional datasets were used to refine the flood layer extent where false positives were eliminated in flood layer extent. The Global Surface Water dataset was used to mask out all areas covered by permanent water. This dataset has a resolution of 30m. Also, to remove high slope areas over 5% in the study area, a digital elevation model, DEM data was used. This operation helps to reduce the noise to the extent of flooding.

2.5.3 Area calculation and exposed urban population

For the computation of the area of the flood extent, the flood layers as generated in the google earth engine were then exported as raster layers and opened in the ArcGIS Desktop. These layers were then converted into polygons for the various years and a calculation of the entire polygon area for the specific years was done using the Geometry tool in ArcGIS. To know the affected urban population, a landcover classification of the study area was made where the urban areas from the landcover were extracted to assess potentially affected urban areas.

2.5.4 Time Animation of Flood events

Processing of the vector layers of flooding extent for the years 2015, 2016, 2017, 2018, and 2019 was done where an addition field was created to handle the date of flooding (year of flooding). These layers were then published on the ArcGIS online platform where the time animation widget was added to show in animation, the extent of flooding in the study area between 2015 and 2019.

III. RESULTS

The result as presented in this section gives an overview of the flood extent layers from 2015 to 2019 within the GAMA area. The statistics in terms of which year as well as which district has the highest flood records are also provided in the results. And in terms of the risk assessment, the extent of the urban environment affected by flooding, using the main flooding event (2018) as the basis for that calculation is also provided. Results from this research show that the year 2018 experience the highest flood extent of 54.57% within the area, followed by 2016, experiencing about 13.22% of the total flood extent by year, followed by the year 2017 (11.72%), followed by the year 2015 (11.07%) and finally the year with the lowest flood extent is 2019 (9.43%).

Other results showed that on average, the Ga South district experienced the highest flooding extent over the period (2015-2019), followed by Ga west district, then the Kpone Katamanso district, Accra Metropolis, Tema Metropolis, etc. the district that recorded the lowest rainfall extent was the Amasaman district. In terms of the urban areas affected, a classification of the study area shows that 45.7% are urban whiles 54.4 are non-urban areas (water, vegetation, wetlands among other landcover types). Out of the 45.7% urban areas, about 25% urban areas were affected by flooding, using the year 2018 as the base flood layer, since it recorded the highest rainfall extent.

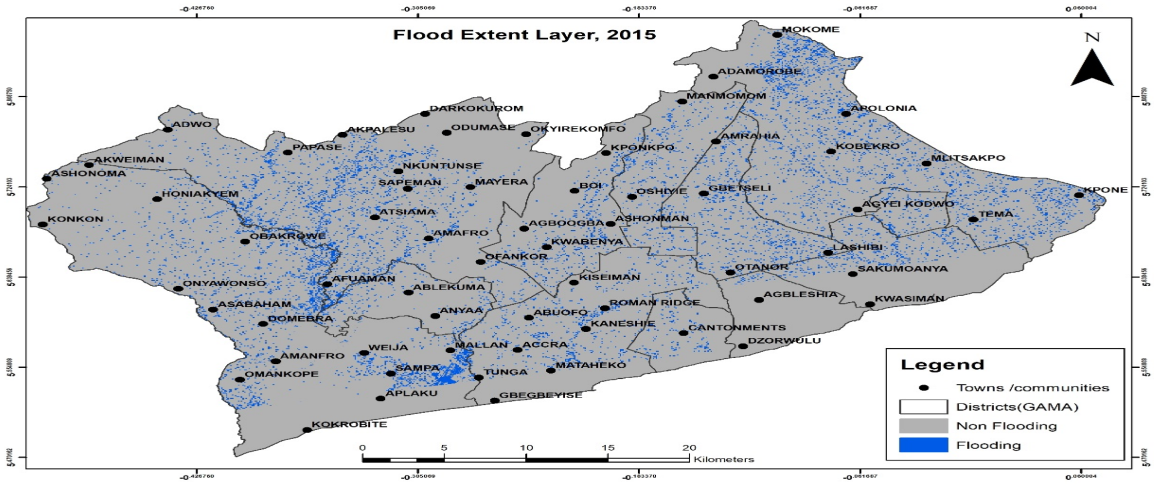

Figure 3: Flood extent, 2015

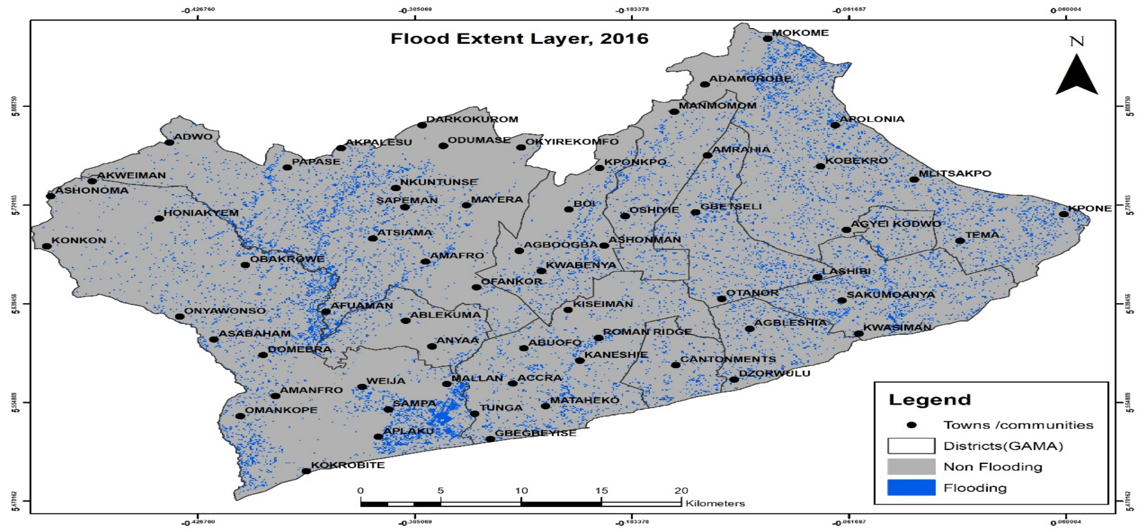

Figure 4: Flood extent, 2016

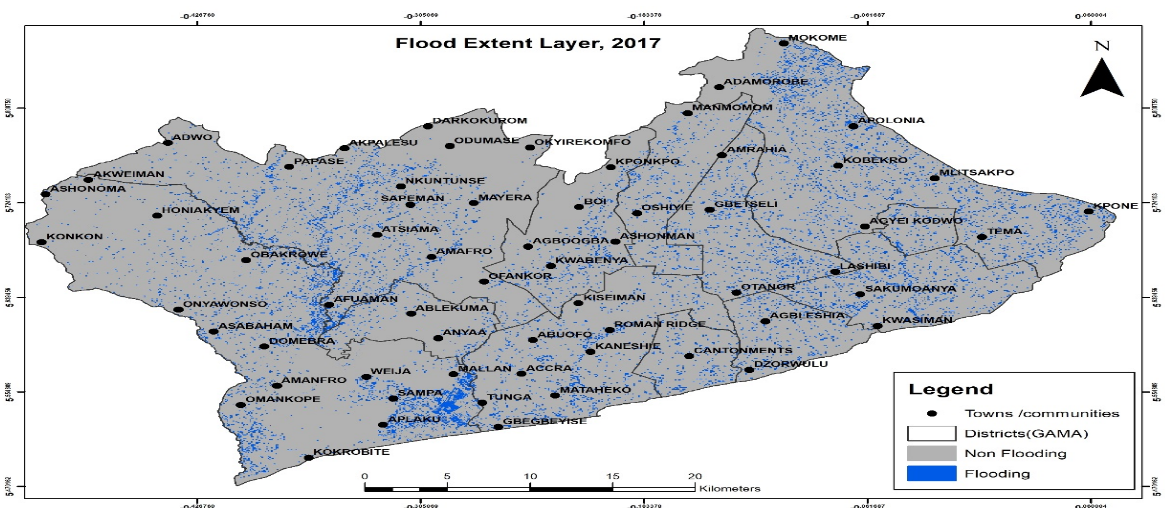

Figure 5: Flood extent, 2017

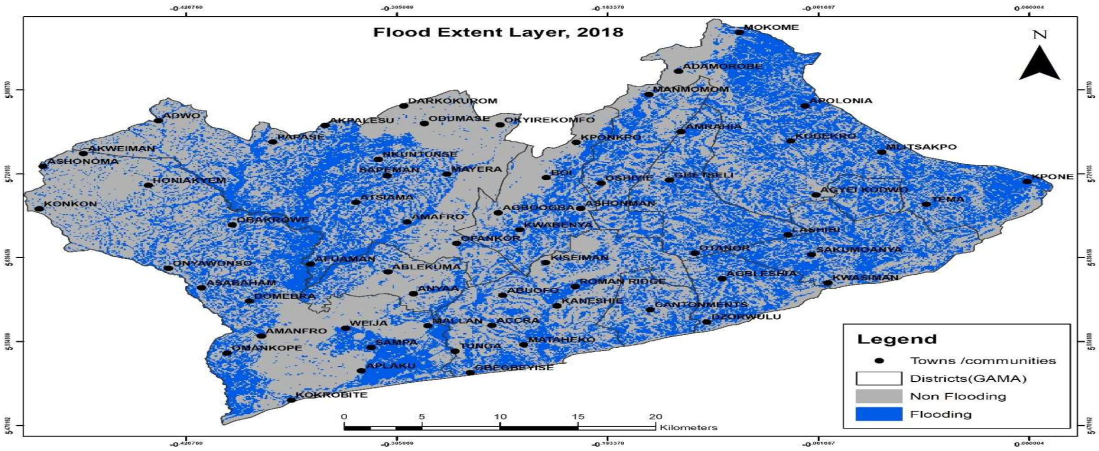

Figure 6: Flood extent, 2018

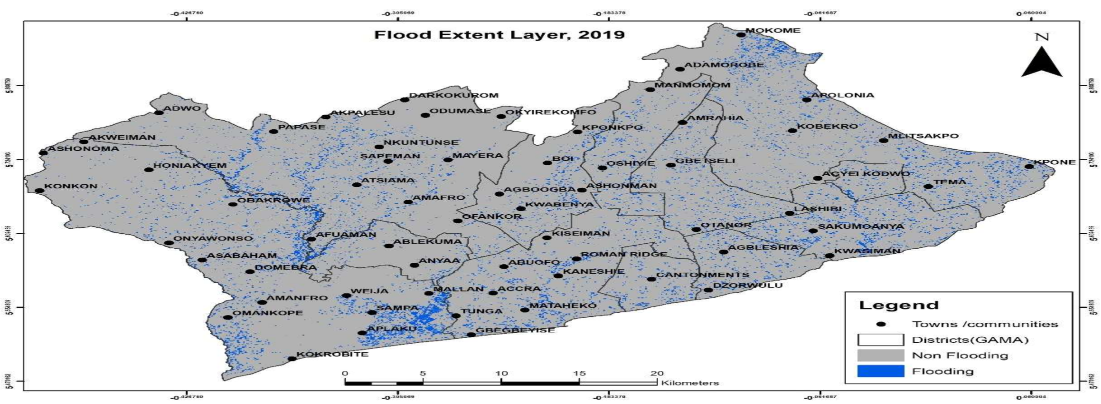

Figure 7: Flood extent, 2019

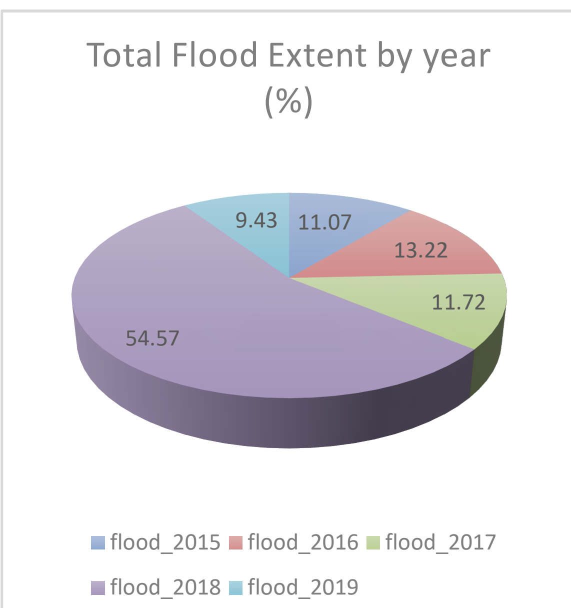

Figure 8: Flood extent by year

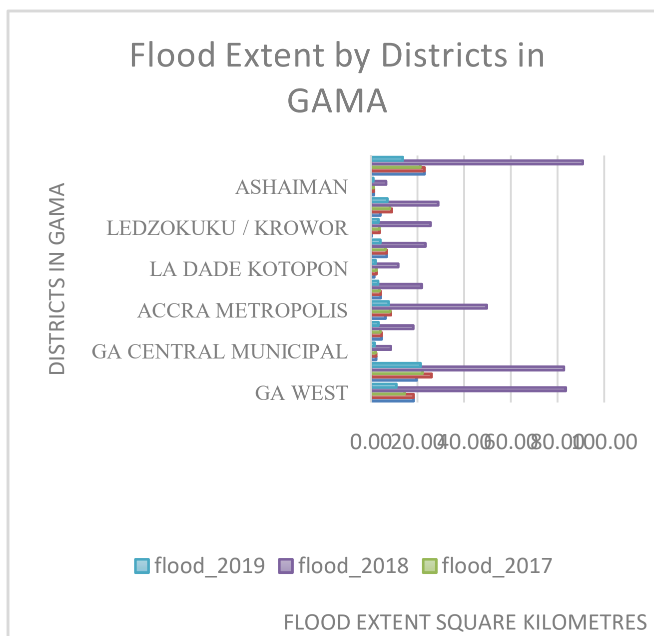

Figure 9: Flood extent by districts in GAMA

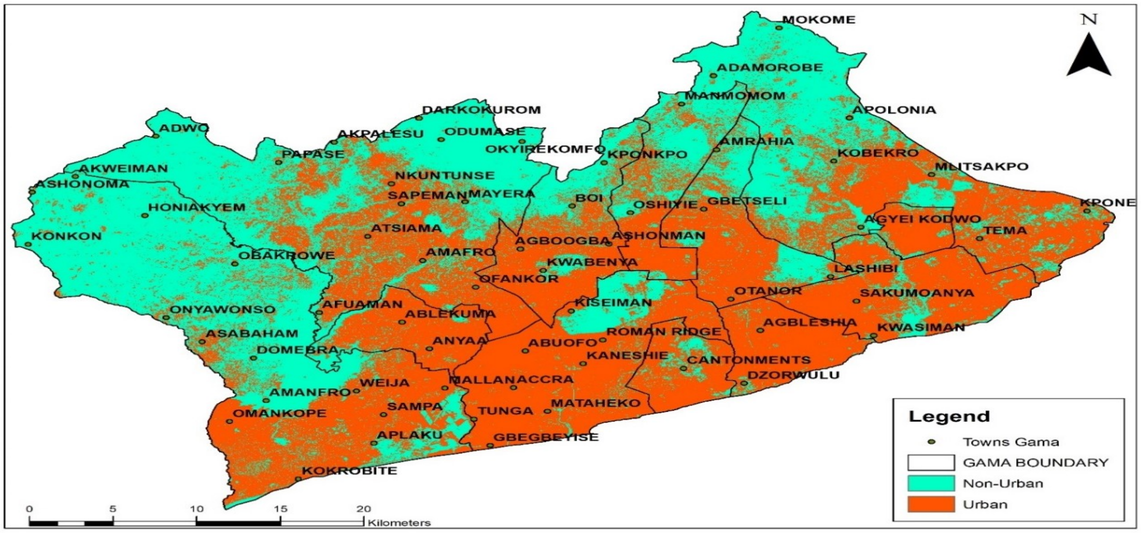

Figure 10: Classification of GAMA into urban and non-urban

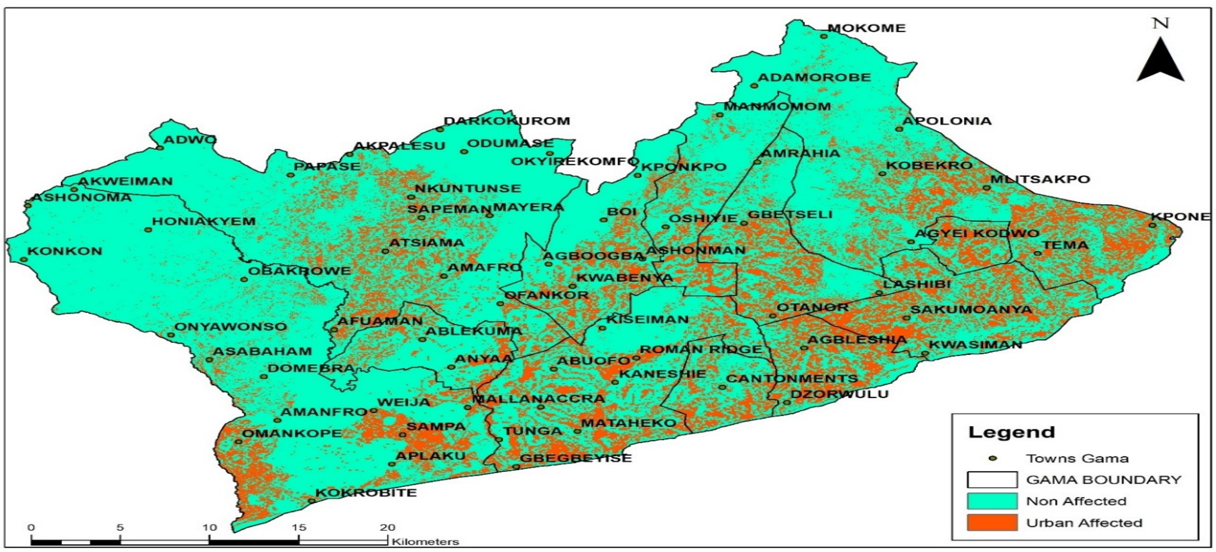

Figure 11: Affected urban areas, 2018.

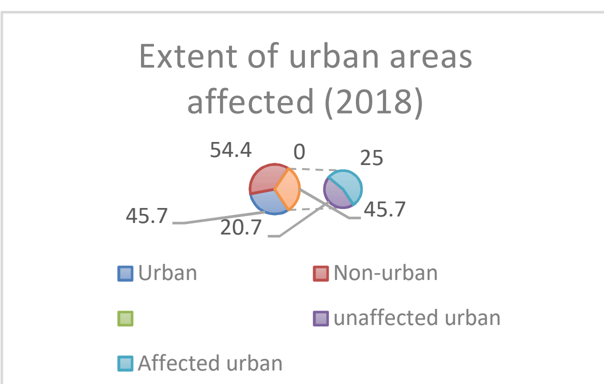

Figure: 12 Extent of affected urban areas, 2018

IV. DISCUSSION

The flood extent for the period between 2015 and 2019 shows that flooding in 2018 was very intense as compared to the other years. This shows that there was a heavy downpour of rains in 2018 in comparison to the other years. The year with the lowest flooding extent was 2019, which could be due to a smaller number of rains experience within that period or due to the changing climate.

A careful study of flooding by the districts within GAMA was analyzed and it showed that the GA South district experienced the highest flooding extent over the period (2015-2019), followed by Ga west district, then the Kpone Katamanso district, Accra Metropolis, Tema Metropolis, etc. The district that recorded the lowest rainfall extent was the Amasaman district.

In terms of the urban areas affected, a classification of the study area shows that 45.7% are urban whiles 54.4 are non-urban areas (water, vegetation, wetlands among other landcover types). Out of the 45.7% urban areas, about 25% urban areas were affected by flooding, using the year 2018 as the base flood layer, since it recorded the highest rainfall extent.

The Ga south district is more flood-prone as compared to the other districts. This can be attributed to the closeness to the Weija Dam [2]. The Weija Dam which was constructed in 1978 has always served as the primary source of water in the Greater Accra Region, supplying up to 80% of the water in Accra, unfortunately, due to human activities such as the dumping of waste, its banks keep closing [11]. Whenever the Ga south district experiences severe rainfall, the Weija Dam is filled with excess water beyond its capacity, and therefore the Ghana Water Company Limited (GWCL) begins spillage of the Dam to prevent the collapse of the dam [6]. This action however leads to severe flooding in the district especially surrounding communities, particularly Tetegu, Oblogo, and Weija Dam catchment area.

On 10th July 2017, about four regions including Greater Accra, East, West, and Central Regions were declared to have flood emergencies with the potential to cause devastation. According to the assessment conducted in Greater Accra, households located in the low-lying areas in Weija and Tetegu in the Ga South district had been inundated with water because of spillage from the Weija Dam (IFRC, 2019).

Another factor for high flooding occurrence is the low-lying nature of the Greater Accra Region in general. Accra is generally a low-lying area, though it rises to 100m above sea level in some locations. Several catchment areas lie between the two ridges in the east and west party of the city [5]. According to (Okyere, 2015), topography provides insight into the direction of moving waters and areas which are potential receptacles of run-offs. The Greater Accra District is of importance when it comes to flooding because it is the capital city of Ghana and the hub of urban infrastructure as well. According to [18], flooding problems can be attributed to the weak planning systems that the country faces. Accra has a massive development, most of which are residential development. The problem now is that most of these developments take place ahead of planning and thus proper layout and infrastructure which should accompany residential development in developing areas have been decidedly absent and this goes a long way to cause flooding during high amounts of downpours.

The year 2018 from the analysis happens to have experienced the highest amount of flooding within the GAMA area. This could be attributed to climatic factors such as high amounts of rainfall experienced within the year in question. Research according to [2], suggests that climatic variability especially rainfall contributes immensely to the issue of flooding. Hence the unavailability of rainfall data for the study period to make a comparison between the flood extent years and the amount of rainfall experience for the corresponding years makes it quite difficult to attribute the cause of high flooding extent in 2018 to high amounts of rainfall received.

According to results from this study, about half of the urban areas within the study area gets flooded during heavy rains within GAMA. Per the land cover classification performed with the 2018 satellite data, about 45% of GAMA is urban and the city is currently experiencing rapid growth and spatial sprawl. Most of this growth is occurring in the peri-urban areas particularly in the GA south, Ga west, and GA east districts which initially were rural areas. The increase in urban areas has a significant hydrological implication. It reduces the flood regularity of the city according to [18]. This is because the infiltration rate is reduced by increase urban environments and thus increase susceptibility to flooding. This explains why the majority of urban areas experience flooding.

The results provide a general overview of flooding within the GAMA zone from 2015 to 2019. This flood extent shows the total amount of flood experience as well as showing which district has the highest flooding in comparison to other cities. This is very critical for the government and the national response agencies to help in their response and rescue missions during flood outbreaks. Flooding in Ghana, especially in Accra always leads to the loss of lives and properties which in most cases needs responses from government agencies. Being aware of districts that experience the highest flooding is going to better inform the response team as to the allocation of resources to the affected districts of flooding.

Having an overview of the current flooding extent helps in forecasting the extent of flooding in the coming years which will eventually help the government in planning the cities in response to flooding.

The results give a general picture of districts and communities within the GAMA area that is mostly affected by flooding. What is lacking here in terms of the damage and response assessment of the flood events was to quantify in terms of the exposed population to flooding. This was missing because of the unavailability of population data which to perform such analysis. The district-by-district analysis of flood extent generalizes the situation in the district. There however could be local situations that will probably be different from what the entire district portrays. Hence the analysis could have taken into consideration smaller communities for the analysis instead of looking at entire districts within GAMA.

The derived flood maps provide spatial and temporal dynamics of the flooding area across the study area. The utilization of the GEE for the image processing facility in this study helped to develop an operational land cover map for damage assessment. The method can be used to monitor land cover regularly as the analysis can easily be re-run while new satellite data is ingested in GEE. The derived maps and charts provide crucial information for local disaster management agencies, which help to prioritize relief and rescue operations. The use of SAR images provides significant advantages, as their cloud-free and all-weather capabilities enable the production of regularly sampled flood extent information in a real-time delivery manner.

4.1Remaining gaps/needs for further research.

The study produced a flood map with some level of accuracy, however, there were also some uncertainties due to the change detection method used, where some changes could not be because of flooding and hence classifying all changes because of flooding might not be entirely accurate. To overcome those uncertainties, local knowledge is crucial. Alternatively, unmanned aerial vehicles (UAVs) are emerging tools for monitoring real-time floods in disaster management. This could be applied to accurately map real-time flooding events (Uddin et al., 2019). Further research should consider a comparison of rainfall amounts experienced for the various years with the flood extent for the years of study to accurately justify that rainfall or climatic conditions are the result of high flooding in a particular year compared to the other years.

V. CONCLUSIONS AND RECOMMENDATIONS

The whole study area is vulnerable and has experienced flooding throughout the study (2015 – 2019). The Ga South district is the district that has the highest extent of flooding averagely over the study period due to the spillage of the Weija Dam within the district. Most communities such as Tetegu, Kaneshie, Odorkor, Accra, Weija, and Mallam among others are considered flood-prone areas or areas liable to flooding. Other conclusions were made that due to the topography of Accra which happens to be a low-lying area, the majority of such communities are therefore liable to flooding. Other causes of flooding are the rapid urbanization in the study area which leads to the construction of buildings in waterways.

Recommendations

Based on the findings arising from this study, several recommendations are hereby put forward for policy considerations. The government should intervene in displaying the political will to prevent further development of buildings in the area very close to the Weija Dam. These are legally acquired buffer zones that some developers have encroached upon, therefore authorities should invoke the relevant legislation to prevent further loss of lives and property in the areas. Again, structures identified to cause a flood or in waterways need to be demo0lished. And there should be no political interference in exercising such authority.

Efforts should be made to construct drainage facilities and complete all projects aimed at reducing flood risk in the study area. This requires increased funding for such projects to be performed.

There should be sustained funding for NADMO activities so that they can provide more relief items to affected victims, as well as embarking on sensitization programs to build communities real residence to floods.

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