Journal of Remote Sensing & GIS

Kwang and Osei, J Remote Sensing & GIS 2017, 6:1
DOI: 10.4172/2469-4134.1000191

Research Article Open Access

# Accra Flood Modelling through Application of Geographic Information Systems (GIS), Remote Sensing Techniques and Analytical Hierarchy Process

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**Rec date:** February 08, 2017; **Acc date:** February 23, 2017; **Pub date:** February 25, 2017



**Abstract**

Urban Flooding is one of world's problems in recent times because of its frequent occurrence which results in loss of lives and properties. The first step in flood management is the development of hazard maps. Flood hazard mapping forms the foundation of the decision-making process by providing information which is essential to the understanding of nature and characteristics of flooding to risk community or city. Flood modelling is a complex problem and therefore a lot of factors should be considered before the final map showing flood prone areas are produced. The degree at which each of these factors contributes to flooding must be weighted by using multi decision process before incorporating them in an integrating environment such as GIS to produce the final prediction map. In this study, this approach was employed by using GIS and Analytical Hierarchy Process (AHP). The layers that were used in the flooding included; Slope, Drainage basin, Rainfall, Soil, Land Use and Digital Terrain Model (DEM). The result obtained was more accurate as compared to the previous works done on Accra flooding. This is because more than one contributing factors were considered and at the same time, weights were assigned to these contributing factors before overlaying them to produce the final map. The previously occurred flood places were all found in the high possibilities flooding zones. The flood prone map indicates that almost the whole area of Accra and Greater Accra Region has a possibility of flooding. However, the riskiest areas are Accra Metropolitan, Ledzokuku Krowor, Ga West and Ga South.

**Keywords:** Accra flood; Flood hazard mapping; GIS; Remote sensing; Urban flooding; AHP

## Introduction

Urban flooding is one of world's problems in recent times because of its frequent occurrence which results in loss of lives and property. The first step in flood management is the development of hazard maps. Flood hazard mapping forms the foundation of the decision-making process by providing information which is essential to the understanding of the nature, risk and characteristics of flooding to the community or city that could be affected by the flood. Flood hazard map can serve as an important source of information by assisting decision makers, engineers and planners in making the right decisions and in taking the appropriate steps in dealing with flood related issues and controlling. Flood hazard mapping also plays an importance role when it comes to land use management and planning. Flood studies are important because of its effect on human health, living conditions, property and on the economy as a whole. A flood hazard map is a map which shows flood scenario with high, medium and low flood event probabilities. There are many contributing factors that lead to flooding and among these are as follows; indicated that "long-term changes of land-use, changes of land cover structure, land drainage, historical shortening of the river network and the modifications of streams and floodplains" as some of the factor that contribute to flooding. In general, flooding in urban areas can be caused by one or more of the following type and these are flash floods, coastal floods or river floods and urban flooding [1]. A flash flood is a type that normally occurs in a low land area and is caused as a result of heavy or excessive rainfall [2]. The intensity and the occurrence of flash flooding can be determined by the intensity and the distribution of the rainfall, the nature of the topography and land use and soil type [3]. Coastal flood is a type of flood that occurs at the coast of sea or low land areas near the sea. Ref. [4] indicated the coastal flood is mainly caused by the storm action which in terms results in rise of the level of sea above normal level. Dawson et al. [5] highlighted the main factors for costal flood risks as "Rising sea levels, Local and broad-scale natural and anthropogenically driven morphological change, that may lower or raise beach levels and Changes in exposure to flooding and erosion due to socio-economic changes". Urban flooding mainly happens in the urban area when there is a heavy or prolonged rainfall and the water drainage facilities can no more contain the volume of the running water. The effects of urban flood are more severe than all the other types of flooding and is the most frequent occurring flood type. Urban flooding is triggered by a lot of factors which most of these factors are human induced.

Remote Sensing has made substantial contribution in flood monitoring and damage assessment that leads the disaster management authorities to contribute significantly. A major contribution to flood mapping and planning is derived from the information made available by the use of remote sensing technologies and its integration with geographical information systems, GIS.

It is sad that almost once every two/three years, Accra has seen floods that keep on killing Ghanaians [6]. For instance, in June 3, 2015, Accra experienced the ever-worst flooding which claimed the lives of about 150 people and enormous loss of property [7]. From literature, Accra normally experiences flood in almost every June and July. The frequent flooding of the city is becoming worse year by year and therefore, there is the need to use the right and advanced technology and methodology to solve this issue of flooding. The management of this flood issues in Accra start by producing an accurate and precise map predicting the areas that are prone to flooding. Most scholars such as Twumasi [8] have produced some maps indicating areas prone to flooding in Accra but this paper seeks to use GIS and Remote Sensing technique in addition to Multi Decision Criteria tool such as Analytic Hierarchy Process (AHP) to predict these flood prone areas.

### Study area

The capital city of Ghana, Accra is one of the most populated urban city in Ghana but most often the city is faced with flooding issues. Accra and its surrounding communities are in low land topographic areas with average mean level of around 61 meters [9]. Geographically, Accra can be located with latitude 5°30′ N and longitude 0° 13′ W [10]. Accra has two main rainy season patterns, with the major rainy season starting from April to mid-July and minor rainy season also starting from September to November, averagely the annual rainfall is around 730 mm [9]. The flooding of Accra normally occurs between June and July and the history of Accra flood is illustrated in Table 1.

| The History of Accra Flood | |
|---|---|
| **Year of Flood** | **Impacts** |
| June 1959 | The flood led early closure of shops, offices and business in the city [11]. |
| July 1991 | Floodwaters affected two million people inhabiting the great area of Accra |
| July 5, 1995 | The flood had an impact on 700000 people and killed 145 in flash flood. The flood resulted in the breakdown of communication networks in country because of the power cut by the food and also billions of Cedis wealth of properties were damaged [12] |
| June 13, 1997 | Some of the major roads in the metropolis were affected by the flood which made movement of vehicle difficult for motorists and the Odaw and Onyasia were full to their banks which forced some near residents to flow to higher and safer grounds [11]. |
| 2001 | Report by the National Disaster Management Organisation (NADMO) confirmed that the flood in some parts of Ashaiman and Tema resulted in loss of about 11 lives [13]. |
| June 28, 2001 | This flood was so far, the worst flood since July 4, 1995 and some of the affected communities were Madina, Achimota, Dzorwulu, Avenor, Santa- Maria and Adabraka Official Town [11]. |
| June 16, 2002 | There were no casualties this year, but bridges and culverts were once again swept away. The rain soaked personal property and industrial material. |
| June 3, 2007 | At least five persons were confirmed dead and hundreds of residents were forced out of their houses |
| February 24, 2011 | The flood damaged million of cedis wealth of property of residents in communities such as Adabraka, Kisseman, Alajo Junction, A-Lang at SantaMaria, Oyarifa, Haatso, Adenta and the Tema Timber Market [11] |
| November 1, 2011 | Report indicated that 43,000 people displaced and 14 deaths recorded by the flood. |
| May 31, 2013 | Properties washed away. People became homeless and the affected areas were Kwame Nkrumah Circle, Darkuman Kokompe, the Obetsebi Lamptey Circle and portions of the Graphic Road, Santa Maria and the Dansoman Roundabout [11] |
| June 6, 2014 | Properties washed away. People became homeless. The most affected areas were in Anyaa, Taifa, Dome, NiiBoi Town, Dansoman, some parts of Kaneshie, Adabraka, Awoshie, the Kwame Nkrumah Circle, Mallam, Abeka, Dansoman and Odorkor [11]. |
| July 4, 2014 | Properties washed away and people were left homeless. The affected areas included Anyaa, Taifa, Dome, Nii Boi Town, Dansoman, some parts of Kaneshie, Adabraka, Awoshie, the Kwame Nkrumah Circle, Mallam, Abeka, Dansoman and Odorkor [11]. |
| June 3, 2015 | The flood resulted in the loss of about 154 Ghanaians and various level burns and injuries were sustained by people, properties wealth of about over $428,000 are destructed as a result of the flood and fuel station explosive [14]. The most affected communities were LedzokukuKrowor Municipal Assembly, Accra Metropolitan, LaNkwantanang-Madina Municipal, Labadi Municipal, Shai Osudoku, Kpone-Katamanso, Ningo-Prampram, Ada West and Ada East [15]. |
| June 6, 2016. | Flooded areas were Kwame Nkrumah Circle, parts of Teshie, Airport Residential, Dzorwulu, Achimota and Tse Addo. One person got missing [16]. |

**Table 1:** The history of Accra flood.

## Materials and Methods

When it comes to the production of map depicting flood prone areas, a lot of methods could be applied and among such methods are; (1) by the use mathematical modelling technique, (2) the use of Remote Sensing and GIS, and (3) method based on morphologic parameters such as land levels and slopes, distance from the river and so on. Flood modelling is a complex problem and therefore a lot of factors should be considered before the final map showing flood prone areas are produced. The degree at which each of these factors contributes to flooding must be weighted by using multi decision process before integrating them in an integrating environment such as

GIS to produce the final prediction map. In this study, this approach was employed by using GIS and Analytical Hierarchy Process.

The land use layer was produced from Landsat 8 image by using the Normalized Difference Vegetation Index (NDVI). The layer was further reclassified by using Reclass tool in ArcGIS to produce the flood prone suitability layer. The soil layer and the digital terrain elevation layer were also reclassified in order to produce flood prone suitability layers. The slope layer, the drainage networks and the drainage basin layer were produced from the digital terrain elevation. The slope layer and drainage basin layer were reclassified as well to produce the flood prone suitability layers. The rainfall data was first of all converted into a continuous surface layer by using the Inverse Distance Weighing (IDW) interpolation tool. After the interpolation of the rainfall point data, the interpolated layer was reclassified into flood prone suitability layer. The flood prone suitability for each layer were classified on the scale of 1 to 5. The scale of 1 represent no possibility of flooding, 2 represent low possibility of flooding, 3 represent medium, 4 represent high possibility of flooding and finally 5 represent very high possibility of flooding. Before performing the weighted overlay analysis, the flooding contributing factors were assigned weights by using the Analytical Hierarchy Process tool. The assigning of weights was necessary as each of the flooding contributing factors has different influence on flooding. The materials used and their source of origin for this research are summary in Table 2 below.

| Data Used | Source |
|---|---|
| Digital Terrain Model (DEM) | http://131.220.109.2/geonetwork/srv/en/resources.get?id=2733&fname=GVP_dem-90x90m-hillshade_volta-basin_ras.sld&access=private |
| Landsat 8 Image | https://earthexplorer.usgs.gov/ |
| Soil Type Data | http://131.220.109.2/geonetwork/srv/en/resources.get?id=2525&fname=GVP_-soil-classification-ghana.zip&access=private |
| Rainfall Data | Ghana Meteorological Service |
| Administrative Boundary Layer | http://biogeo.ucdavis.edu/data/diva/adm/GHA_adm.zip |
| Flood Occurred Towns | Ghana Web, Graphic Online |
| Towns and Villages Layer | http://131.220.109.2/geonetwork/srv/en/resources.get?id=2509&fname=GVP_regional-capitals_small-towns_ghana-west-africa.zip&access=private |

**Table 2:** Data used and their source of origin.

## Results and Discussion

### Land use

Land use and other human activities are one of the contributing factors of the Accra flooding and therefore was considered when modelling the flood prone areas in Accra. Various land use types play a role in flooding modellings. For example, in undeveloped areas, there are a lot of vegetation covers which serve as a media for absorbing the running water resulting from rains but urban areas, where the land surface is covered by roads, pavement and buildings, there is less or no absorption of rainwater. The development of urban normally involve the removal vegetation cover and most often replacing permeable soil with impermeable surfaces such as pavement. Urbanization and its associated increase in population has resulted in making people putting up buildings and structures on floodplains and flood risk areas. The NDVI in Figure 1 was prepared in order to determine the land use type within the study areas. Areas with high NDVI values were the undeveloped areas with vegetation cover whiles the developed urban areas and water bodies were with negative or low NDVI values. The high possibilities of flooding areas are those with negative or low NDVI values whiles those with low and no possibilities of flooding are with high NDVI values.

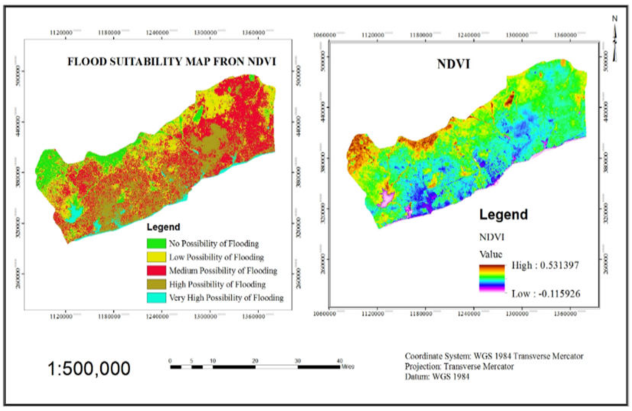


**Figure 1:** The land use type.

### Soil

Soil permeability was considered in the flood modelling because of its important plays in flooding and flood recovery. Soil permeability is one of the parameters used to determine absorption of water by the soil. Soils with higher permeability such as sandy soil are not easily flooded by water because water could easily penetrate through these soils with the least resistance. However, Soils with lower permeability such as clayey soil are easily flooded with water because the higher resistance to free flow of water through these soil types. The soil type distribution and the flood suitability map produced from the soil types are illustrated in Figure 2. The low permeable soils are those with high possibilities of flooding whiles those with low and no possibilities of flooding are soil types with high permeability.

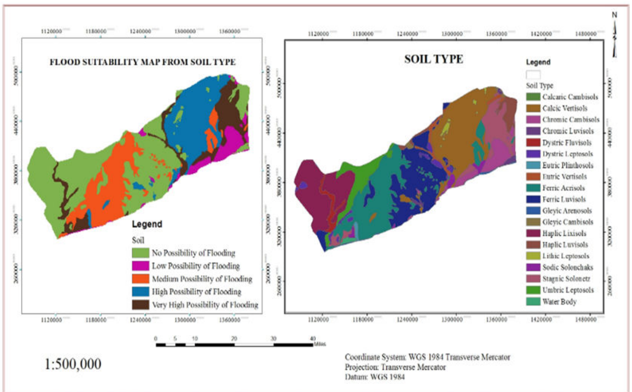


**Figure 2:** The soil suitability map and soil type.

## Rainfall

With flash flooding, the rainfall is the most important factor that causes flooding because flooding usually occurs after there is a heavy and intensive rainfall. Understanding and modelling the rainfall pattern and subsequently using them in flood risk modelling mapping is of critical important. Flooding usually occurs when there are more rains than what the drainage system can take. This may happen either when there is heavy rain for a very short period or there may be light rain for many days and weeks. The main factor leading to the flooding Accra cities is the rainfall. Brief periods of intense rainfall can lead to flash flooding in Accra. The rainfall distribution map and its associated flood suitability map are show in Figure 3. The high rainfall areas are the most flood prone areas.

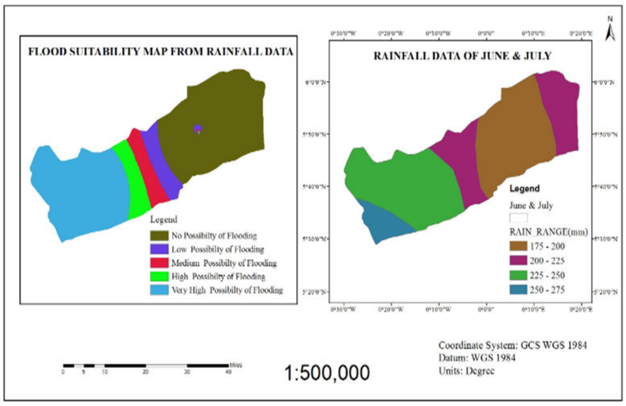


**Figure 3:** The rainfall distribution map and its associated flood suitability map.

## Topography and slope

The topographic nature and the slope of the land can be a contributing factor of flooding as they are principal variables that affect the movement of the flood wave and is, therefore, critical to the prediction of inundation extent. Running water move very quickly on steep slopes thereby reducing the amount of water be penetrated or absorbed into the ground. Topography on the hand other also defines drainage pattern and the flow accumulation. Water accumulated at the gentle slope areas become difficult to flow quickly and if the permeability of the soil is weak and the intensity of the rainfall is high as well, then this can result in flooding. Figure 4 illustrates the Digital Terrain Model and its associated flood suitability map. The areas with high elevations are the less flood prone areas whiles the lowland areas are those with high possibilities of flooding.

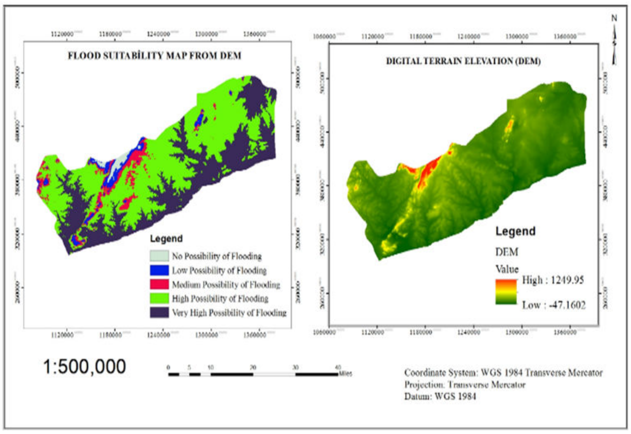


**Figure 4:** Digital Terrain Model and its associated flood suitability map.

## Drainage network

Drainage networks from raster DEMs is needed in determining surface water flow direction, flow accumulation and watershed within raster DEM. Drainage basin or catchment basin is an important factor when modelling flood prone areas because it shows the extent or an area of land where all surface water from rain converges. Normally the converged areas are of lower elevation. Water usually flow and accumulate at lower elevation. The flow direction and the accumulation points of the water constitute drainage network and should be considered when modelling flood risk map. Figure 5 shows the flood suitability map produced from the drainage basin, the drainage basin and the drainage networks. The areas with high drainage basin values are more prone to flooding whiles the areas with low drainage basin values are the low or no flood possibilities areas.

**Citation:** Kwang C, Osei EM (2017) Accra Flood Modelling through Application of Geographic Information Systems (GIS), Remote Sensing Techniques and Analytical Hierarchy Process. J Remote Sensing & GIS 6: 191. doi:10.4172/2469-4134.1000191



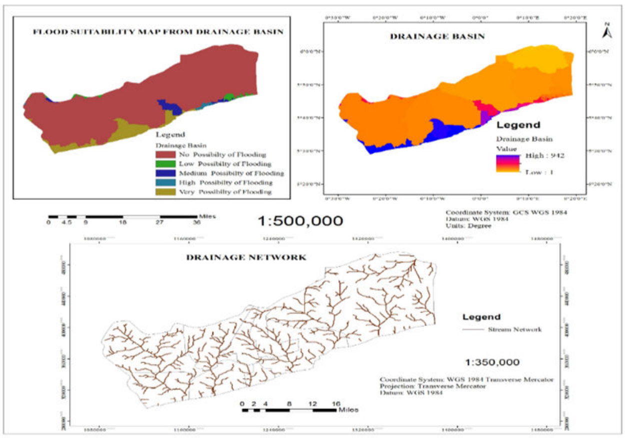


**Figure 5:** Flood suitability map produced from the drainage basin, the drainage basin and the drainage networks.

## The weights of the contributing factors

| | | NDVI | DEM | Soil | Drainage Basin | Slope | Rainfall | Weight |
|---|---|---|---|---|---|---|---|---|
| 1 | NDVI | 0.09 | 0.13 | 0.02 | 0.28 | 0.03 | 0.04 | 9.9% |
| 2 | DEM | 0.28 | 0.39 | 0.29 | 0.28 | 0.31 | 0.59 | 35.7% |
| 3 | Soil Type | 0.28 | 0.08 | 0.06 | 0.03 | 0.03 | 0.04 | 8.7% |
| 4 | Drainage Basin | 0.03 | 0.13 | 0.17 | 0.09 | 0.21 | 0.07 | 11.7% |
| 5 | Slope | 0.28 | 0.13 | 0.17 | 0.05 | 0.10 | 0.07 | 13.4% |
| 6 | Rainfall | 0.03 | 0.13 | 0.29 | 0.28 | 0.31 | 0.20 | 20.6% |

**Table 3:** Data used and their source of origin.

The Analytic Hierarchy Process (AHP) is one of decision making tools which help in setting priorities and making best decision. The Analytic Hierarchy Process makes evaluation of attribute by making a pair-wise comparison which is based on absolute judgement that indicate how much one attribute dominates another attribute [17]. The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion. In this research work the AHP tool was used in setting the priorities for the flood modelling in a form of weights as indicated in Table 3. DEM was set as the highest priority with a weight of 35.7%. This means that the topographic nature of the study area was considered as the most influential factor that contributes to flooding. Rainfall with a weight of 20.6% was the seconded most contributing factor of flooding. All most, the flood which has occurred in Accra were the result of heavy rainfall or continuous period of rains. The least contributing factors were soil type and the land use which was produced by using the NDVI. Urbanization, for instance, can contribute to flooding but if proper drainage systems are placed in and maintained, the impact of urbanization on flooding would be minimized. And with drainage systems placed in, the water from the rains can flow into a big water bodies without necessary accumulating on the land surface. In case, the permeability of the soil might not have much influence on flooding.

Consistency Ratio (CR) measures the consistency between the variable be compared and for pairwise comparison of the variable used in the flood modelling, a value of 0.092 was obtained which is within the acceptable range of 0.1 or less than 0.1. This means the judgments or the pairwise comparison were trustworthy and not subjective.

## The flood prone map

Flood prone maps have played important roles in flood management and control. The frequent flooding of Accra in recent years has become one of Ghana's problems during the rainfall season especially in June and July. The occurrences of the flooding could not be prevented but the impacts of the flooding can be minimized. With this flood-prone map, areas that are most likely to the occurrence of flooding can be identified and other preventive measures can be taken before even the flooding happens. The flood prone map in Figure 6 shows the areas within Accra and the Greater Accra region and their possibilities of flood occurrences. According the flood prone map, almost the whole areas within Accra and Greater Accra have some possibility of flood occurring even though there are some variations within these possibilities of the flooding. In terms of percentage areas, only 0.04% of the total area is not subjected to flood occurrence, 2.42% of the total area is having low possibility of flood occurrence, 60.9% of the total area having medium possibility of flood occurrence, 34% of the total area having high possibility of flood occurrence and finally 2.6% of the total area having very high possibility of flood occurrence. The areas with the high and very high possibility of flooding occurrence include Accra Metropolitan and Ledzokuku Krowor and Ga West and Ga South but most part of Ga West and some of part of Ga East and Adenta are with high possibilities of flood occurrence. Most of the flooding have occurred within Accra Metropolitan, then followed by Ga East. The reasons for the frequent flooding in Accra Metropolitan might be due to the high urbanization and the poor management of drainage system. The Odaw river which is one of the causing factors flooding in Accra is also located within the Accra Metropolitan. The accuracy of this flood prone map was tested by overlaying the flood occurred town layer. All the places where flood has occurred coincided with the high possibility flood zones.

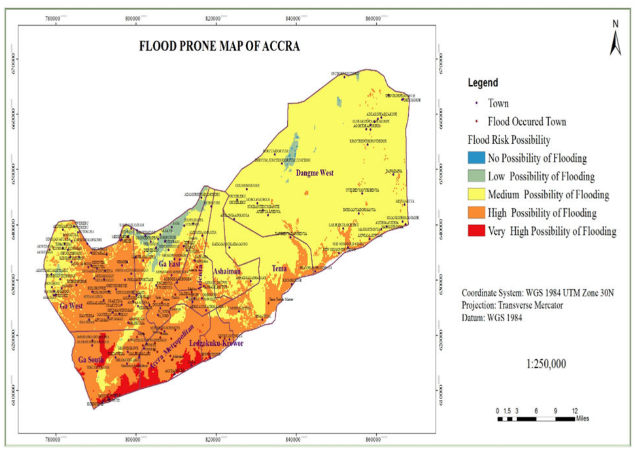


**Figure 6:** Flood prone map of Accra.

## Conclusion

Geographic Information Systems and Remote Sensing techniques are one of the techniques used recently in solving problems concerning the environment. They have also proven to be useful in making decisions. Geographic Information Systems can be combined with multi decision making tool such AHP to produce the best result. In this research work, these capabilities of Geographic Information Systems and AHP were illustrated through the production of the flood prone map of Accra. The result obtained was more accurate as compared to the previous works done on Accra flooding. This is because more than one contributing factors were considered and at the same time weights were assigned to these contributing factors before overlaying them to produce the final map. The previously occurred flood places were all found in the high possibilities flooding zones. The flood prone map indicates that almost the whole area of Accra and Greater Accra Region has a possibility of flooding. However, the most risk areas are Accra Metropolitan, Ledzokuku Krowor, Ga West and Ga South.

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