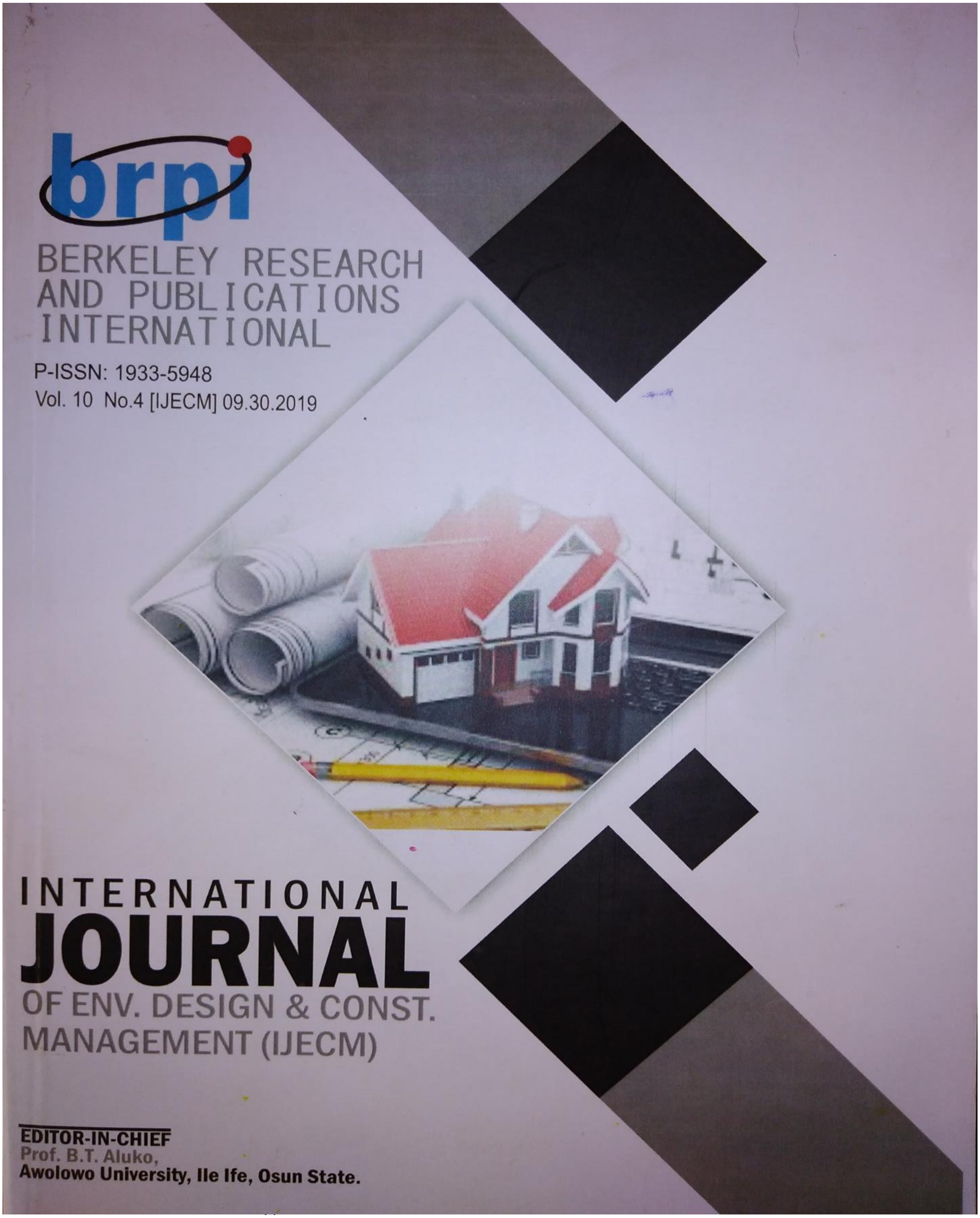
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Flood Inundation Mapping of Lagos Island Local Government Area of Lagos State

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ABSTRACT

Lagos Island is characterized by flooding on a yearly basis. This flooding leads to loss and damage of millions of properties. One of the most extreme flooding that occurred in this location was in July 2012 and July 2017, causing serious damage to both public and private properties. Hence this present study applied the HEC (Hydrological Engineering Centre) modelling packages such as HEC-HMS and HEC-RAS software packages as well as ARCGIS software to simulate flood occurrence in Lagos Island using LIDAR data, rainfall data, land use maps and GPS points as input data. Findings in this study showed that the average flow depths within the study area is 3.2m and over 60% of the Residential and Commercial buildings are at risk. The areas within the city with high risk of flooding were identified from the flood hazard maps that were generated. Three-dimensional model of the location with embedded flood inundation map is also generated for a better understanding of the severity of flooding in the location.

Keywords: Flood Inundation, GIS, HEC-HMS-RAS, Modelling, Risk Assessment

INTRODUCTION

Flood is a naturally occurring disaster that makes no distinction in the status of any society in the world. Or the flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area (The University Corporation for Atmospheric Research, 2010)

The event of the rains, the monsoon wind that usually brings heavy rain in the West African coast, and the rising sea levels due to the melting of glacier in the polar region has contributed to the floods in states like Rivers, Cross River especially Lagos, among others.

But with the city's drainage system mostly poorly planned and, in some places, non-existent, flooding has become a costly annual experience. The floods have been mainly seen on Lagos Island, the major business district, with paved roads and streets flooded no thanks to overflowing street gutters. Some of the worst hit areas are also the country's most expensive residential and commercial real estate in neighborhoods like Victoria Island and Lekki. But the aftermath is also likely to reveal some lower-income slum neighborhoods with poor structures will be also badly affected. Residents across the city spent most of the weekend stuck indoors sharing videos and photos of flood scenes on WhatsApp as well as other public social media platforms like Twitter and Facebook.

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The government has often blamed the repeated floods on illegal houses and office structures built without city permits and without adequate planned drainage systems. Residents' poor waste disposal habits have also been cited, with most of the city's streets littered with waste which often ends up blocking street gutters and causing them to overflow.

Given its low-lying position next to the Atlantic Ocean, Lagos is also susceptible to severe climate change floods. One factor is a rise in mean sea levels, which will be around 50 centimeters by 2070 as warmer temperatures cause oceans to expand (Channel News Asia, 2012). For its part, the state government has urged residents living in flood prone areas to relocate.

In the long-term, Lagos' floods could yet get worse as a result of an ambitious 5-mile new city which is currently under construction. Eko Atlantic, funded by private investors, is planned as a modern economic hub which, once completed, will be home to a new financial district, luxurious apartments and sky scraper office complexes. Built by dredging up and filling more than six miles worth of land in the Atlantic sea, the new city is protected by "The Great Wall of Lagos," a sea wall built around it to protect it from the surrounding Atlantic and its "worst storms."

But, according to some experts, the sea wall, while protecting Eko Atlantic, will leave much of Lagos even more susceptible to flood.

Several efforts have been employed in solving flood related issues; both from industrial and academic points off view. Most of these efforts seemed to be based on the availability of flood data sets; a major problem in analyzing flood risks.
A cursory observation of the LIDAR data for the last four years (2014 -2017) revealed that flood, storms, temperature and droughts account for about 30% of total economic losses in the country out of which flood events had caused 5% of all the total losses.
Of the naturally occurring hazards in Nigeria, Flood is the highest with resulting effects on humans and properties. Basically while its natural causes are due to heavy rainstorm and ocean storms along the coast, its human causes are as a result of burst water main pipes, lack of effective drainage systems, dam failure and spills.
The growing number of flood victims and the constrained sustainable development caused by flooding within the country suggest that much of what is known regarding flooding in the country is deficient on remedies. More critical is the subject-matter of Nigeria being one of the most populated countries of the world with population size estimated at over 170 million people (World Bank, 2013).

The study Area
Lagos Island is located on the South–Western part of Nigeria, on the narrow plain of the Bight of Benin. Lying approximately on longitude 30 24' 30"E and 30 22' 42"E respectively, and between latitude 60 26' 34"N and 60 27' 08"N.

The dominant vegetation of the area is the swamp forest of the fresh water and mangrove swamp forests, both of which are influenced by the double rainfall pattern of the state, which makes the environment a wetland region. Generally, the area has two climatic seasons: Dry [November-March] and Wet [April-October]. The drainage system of the State is characterized by a maze of lagoons and waterways.

Figure 1: The study area dominated by water

Lagos Island can be described as a place with a variety of land uses. It is notably a commercial area with a mixture of residential and institutional land uses. Figure 1 shows the location of the study area. The Figure vividly describes the water surrounding nature of the study area.

The Philosophy of Flood Modelling

The need to provide Information for varieties of activities for water resource studies such as preparing for and responding to floods and regulating flood plain activities, among others require record of historical flow, stage or precipitation which are not readily available because the change has not yet taken place. Waiting to observe changes in these water resource activities could be uneconomical and cause more damages. An alternative is to develop a model to provide the needed information.

The term model therefore means the equations that represent the behavior of hydrologic systems components. For example, the combination of the continuity and momentum equations together form a model of open channel flow for routing (Feldman, 2000).

Hence, a model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components (Hydrologic Engineering Center, 1998).

The Flood Model Systems

Flood model systems are mathematical equations that are too numerous or too complex to solve with pencil, paper, and calculator, they are translated into computer code and an appropriate equation solver (an algorithm) is used. The result is a computer program. Thus, HEC-HMS, HEC-FDA, HEC-FIA, HEC-SSP, HEC-ResSim are computer programs that include a variety of models.
The Hydrologic and Hydraulic Model systems are the two Flood inundation models employed in this study. The Hydrologic Models are one of the platforms provided by the United States Hydrologic Engineering Centre (HEC). The models are conducted over two systems provided by HEC viz: the Hydrologic Modelling System (HMS) and River Analysis System (RAS). Since availability of data is an integral part of model selection, the HEC modelling packages (HMS and RAS) which has been tested and trusted by several hydrologic and hydraulic scientists in the past is employed in this research because of the ease of the parameterization of spatial data available for the study area. The resulting models have compatibility with GIS applications as the platforms maintains a perfectly consistent interaction during the modelling process.

The modelling softwares have demonstrated to be of good practical use in the previous modelling of urban areas in same locality using elevation and land cover data sets, hence suitable for this present work.

HEC-HMS Model

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the complete hydrologic processes (physical properties of river basins, the meteorology) of dendritic watershed systems.

The software features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the software. Simulation results are stored in HEC-DSS (Data Storage System) and can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

SCS Curve Number Loss Model

The SCS curve number method is a simple, widely used and efficient method for determining the approxient amount of runoff from a rainfall even in a particular area. The stat requirements for this method are very low, rainfall amount and curve number. The curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

The Soil Conservation Service (SCS) Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:

$$Pe = \frac{(P-I_a)^2}{P-I_a+S} \qquad (1)\ \text{(Feldman, 2000)}$$

Where P_e= accumulated precipitation excess at time t;
P= accumulated rainfall depth at time t;
I_a= the initial abstraction (initial loss);
S= potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation.

Until the accumulated rainfall exceeds the initial abstraction, the precipitation excess, and hence the runoff, will be zero.

An empirical relationship of I_a and S is developed by SCS from analysis of results from many small experimental watersheds**:**

$$Ia = 0.2S \qquad (2)$$

Thus, substituting Ia and S into (2), equation (1) becomes

$$Pe = \frac{(P - 0.2\,S)^2}{P + 0.8S} \qquad (3)$$

The maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number (CN) as:

$$S = \begin{cases} \dfrac{1000 - 10\,CN}{CN} & \text{(foot – pound system)} \\ \dfrac{25400 - 254\,CN}{CN} & \text{(SI)} \end{cases} \qquad (4)$$

The basic definition of CN according to SCS method is CN = 1000/ (10 + S) (Muhammad, Hyung, & Seung, 2017).

HEC-RAS model

HEC-RAS allows the hydrologic engineers to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling.

The HEC-RAS system contains several river analysis components for: (1) steady flow water surface profile computations; (2) one- and two-dimensional unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is, that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to these river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

The HEC RAS solves open-channel flow problems and is generally used to compute stage, velocity, and water surface profiles. Computes steady-flow stage profiles, given steady flow rate, channel geometry, and energy-loss model parameters. Computes unsteady flow,

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given upstream hydrograph, channel geometry, and energy-loss model parameters. HEC-RAS assumes a steady, gradually varied flow scenario and uses iterative computational procedure of the energy equation which states that the total energy at any given location along the stream is the sum of potential energy and kinetic energy.
The energy equation is given by (Eric, 1999):

$$H = Z + Y + \frac{\alpha V^2}{2g}$$

Total energy = H
Potential energy = (Z + Y)
Kinetic energy = ($aV^2/2g$)
The Change in energy between two cross-sections (head loss) is called the head loss, h_L
The energy equation parameters are illustrated in the following graphic (Eric, 1999):

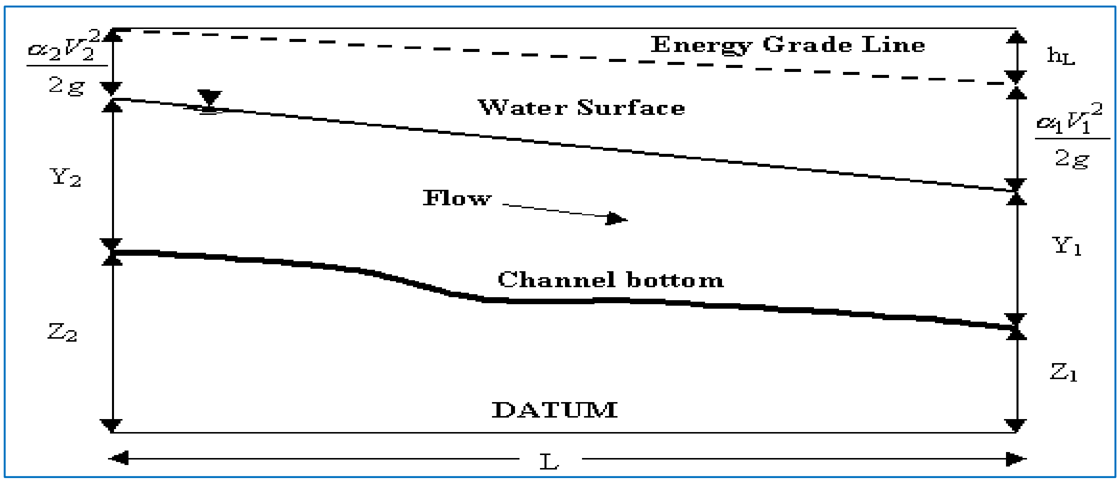

Figure 3: Illustration of energy equation parameters

HEC-GeoRAS
HEC-GeoRAS (Hydrological Engineering Centre – Geospatial River Analysis System) is a GIS tool developed by Hydrologic Engineering Centre for support of HEC-RAS using ArcGIS.
The extension allows users with limited GIS experience to create an HEC-RAS import file containing geometric data from an existing digital terrain model (DTM) and complimentary data sets.
The current version of HEC-GeoRAS creates an import file, refered to as RAS GIS import file, containing river, reach and station identifiers; cross sectonal cut lines, cross sectonal surface lines, cross sectional bank stations, downstream reach length foir the left and right over banks and main channels and cross sectional roughness coefficients (Ackerman, 2011).

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HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI) that allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. (http://www.hec.usace.army.mil/software/hec-georas/).

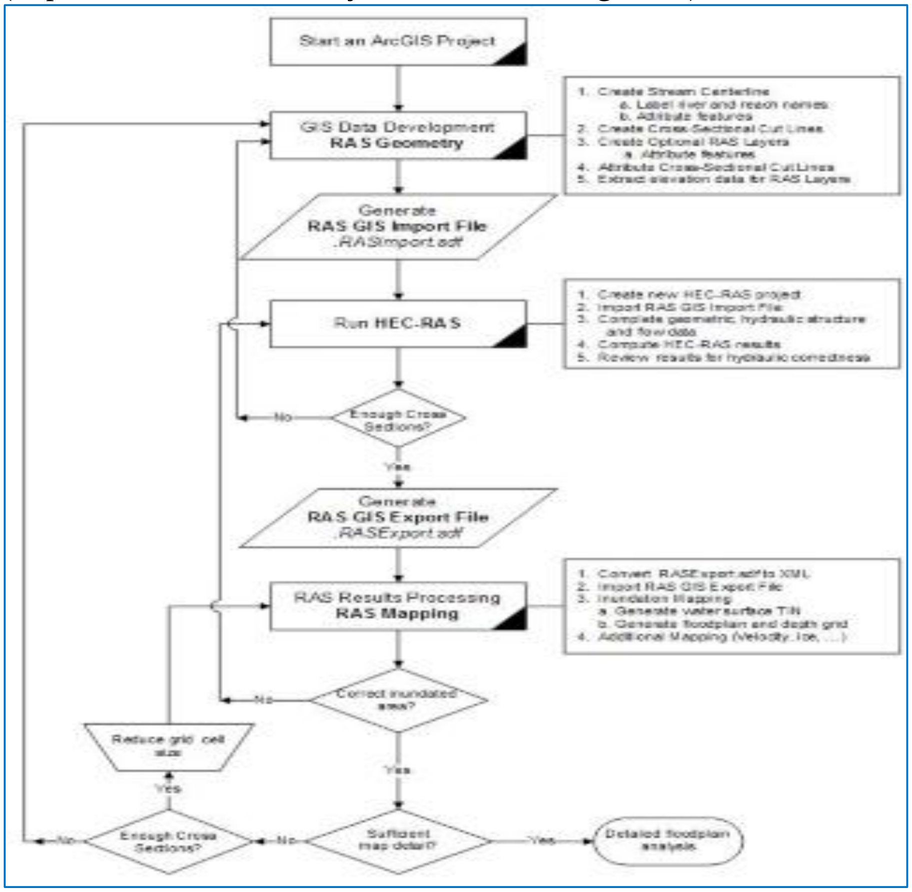

Figure 4: Process flow diagram for using Hec-GEoRAS (Ackerman, 2011)

METHODOLOGY

The integration of spatial data sets in the hydrological model (HEC-HMS) and the hydraulic model (HEC-RAS into Hec-GeoRAS was the adopted method in this study.

Data Used

Various Required data have been collected from different sources viz;

- Land use map of study area collected from Ministry of Physical Planning, Lagos State.
- Daily rainfall data for six months (1st July – 31st December, 2012) was collected from Tropical Rainfall Measuring Mission (TRMM)
- 2008 LIDAR DEM, in classified text file format, covering *the* study area was obtained from the Office of the Surveyor General of Lagos State. A 5m resolution DEM was created from the text files.

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- ESRI vector shapefiles of buildings covering the study area for the year 2009 was obtained from the Office of the Surveyor General of Lagos State.
- Drainage network details of the study area (2012 Drainage network manual).

The development of Hydrological Model (HEC-HMS modelling)

HEC-HMS simulates hydrologic processes through the development of a basin and meteorological model (figure 5a &5b). Through user input, the basin characteristics including soil loss, hydrograph transformation, base flow, and river reach routing provide a hydrologic representation of the modeled basin. The meteorological model specifies how precipitation, rainfall or snow, is applied to the basin model and also dictates evapotranspiration processes within the watershed. The basin and meteorological model work together to define the rainfall-runoff processes within the watershed.

Excess precipitation is routed to the subbasin outlet as overland flow using a unit hydrograph transform (Clark Unit Hydrograph) method. Precipitation infiltrating into the soil is routed to the subbasin outlet using the recession base flow method. Overland flow and base flow are combined at each subbasin outlet before entering the reach network. As the combined flow is routed down through the river reach network of the basin, flow is aggregated from additional subbasins and routing reaches in hydrologic order.

A meteorological model was developed in which meteorological data (such as observed discharge, evapotranspiration, wind speed, humidity and sunshine hour) and daily precipitation data were spatially and temporally distributed over the river basin within six months period (1st July – 31st December, 2012) were added to the HEC-HMS project generated. The daily precipitation data was to provide the model with adequate amount of rainfall data to be used in the model calculation process.The meteorological model provides precipitation in the form of rain as input to the basin model, while the basin model uses input loss parameters to calculate precipitation lost to storage in the watershed, precipitation infiltrating into the soils, and the subsequent amount of excess runoff precipitation.

Since daily precipitation data was acquired for the study, a time interval of 24 hours was created by the control specification manager to control time interval of simulation window for which the model calculates discharges.

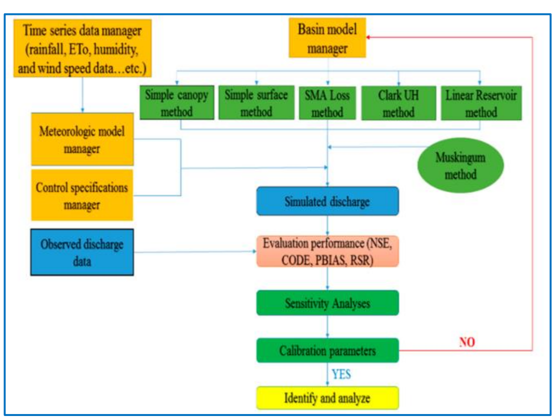

Figure 5a: HEC-HMS model flow chart

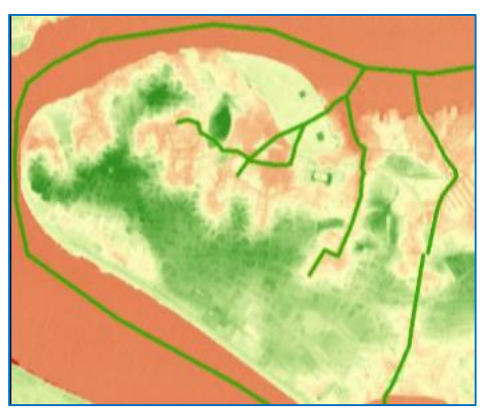

Figure 5b: Drainage network overlaid on

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DEM

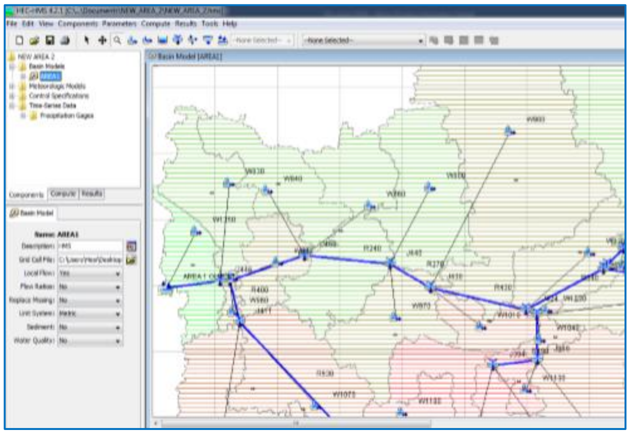

Figure 5c: HEC-HMS modeling Process

The development of Hydraulic Model (HEC-RAS Modelling)

When we study a segment of a specific river to see where the water would flow if reached a certain value, different questions arise such as what will be the height reached by the water profile? Will surrounding areas be flooded? To what extent? The rainfall runoff volume (hydrological model) created from HEC-HMS was used as input in HEC-RAS to analyze the way the water moves on the study area and the places where it concentrates, thereby creating inundation problems.

The next step was creating RAS layers that was used for developing geometric data and extraction that were used in the hydraulic modelling. The geometric layers that were created are the river center lines, cross section bank stations, flow path centerlines and cross sections cut lines and surface lines, downstream reach lengths for the left over bank main channel and right over bank. These layers were extracted from the LIDAR DEM by use of the Hec-GEoRAS extension in the ArcGIS 10.2.

This HEC-GeoRAS file gathers geometric data of the study area including the riverbed**,** cross sections, water flow lines**,** etc. When this file is imported to HEC-RAS, we can obtain velocity and depth results through hydraulic calculations. Finally, these results can be exported to ArcGIS to be processed and therefore obtain flood and risk maps**.**

Having created the geometric layers, proper preprocessing (preparation and entering the necessary inputs to the model, importing GIS data and defining the model output) was carried out using Hec-GEoRAS. Once the hydraulic computations are performed, exported water surface and velocity results from HEC-RAS are imported back to GIS using Hec-GEoRAS for spatial analysis.

A polygon layer (with a field to reference for N values) is created from the land cover data and was used to estimate roughness coefficient (Manning's N values) along each cross sectional cut line in HEC-RAS. The intersection of the cut lines with other RAS layers will determine bank station locations, downstream reach lengths, manning's values, ineffective areas, blocked obstructions and levee positions (Ackerman, 2011).

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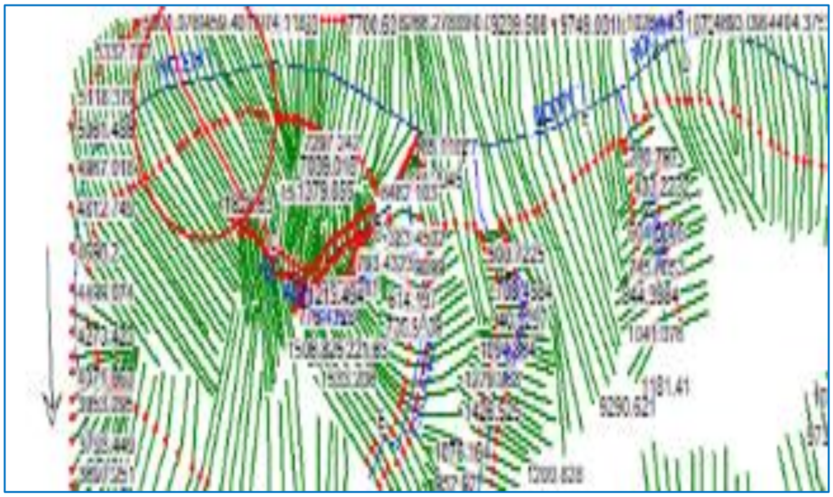

Figure 6: Cut lines spanning the entire floodplain

We imported all geometric data into the HEC-RAS modelling environment. The steady flow data was added with analysis applying a time series of discharge rates at each river reach in the computation of cross sectional hydraulic flow. The discharge rates are fed into columns (profiles) in the steady flow data workspace.
A DSS (data store) connection was made to the location of the data store of results from the HMS model run so that profiles can read information from the HMS discharge model results at specified time steps.

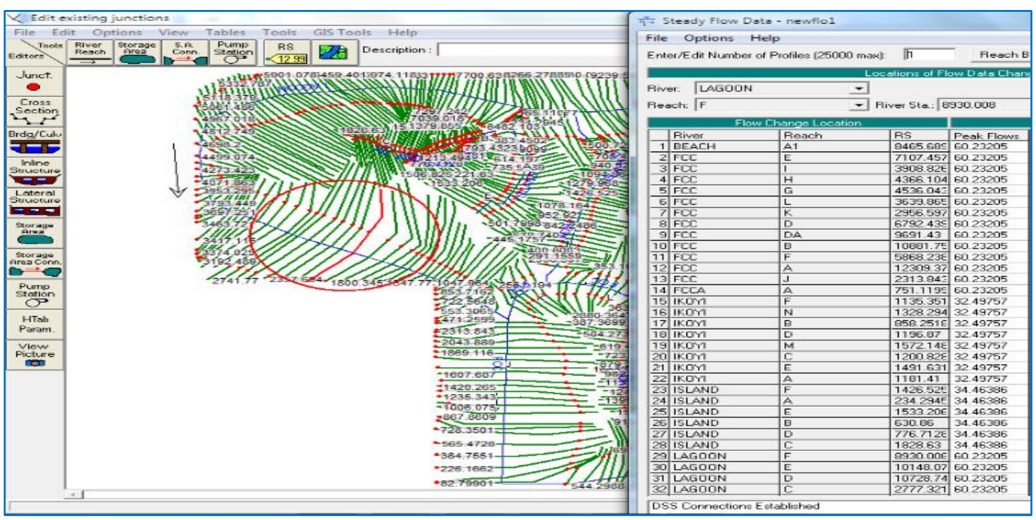

Figure 7: Database table showing flow data and conditions for all input reaches

The RAS export file generated from model run in HEC-RAS was imported into the GIS using Hec-GEoRAS for the further processing and flood mapping of the model results. The post process results such as the water surface generation, flood plain delineation grids are saved into output directory and the subsequent flood inundation map was produced, while the vector data generated in post processing are saved into the dataset within the specified

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geodatabase. The cross sectional cut lines and bounding polygon that were created are used for building flood plain data sets.

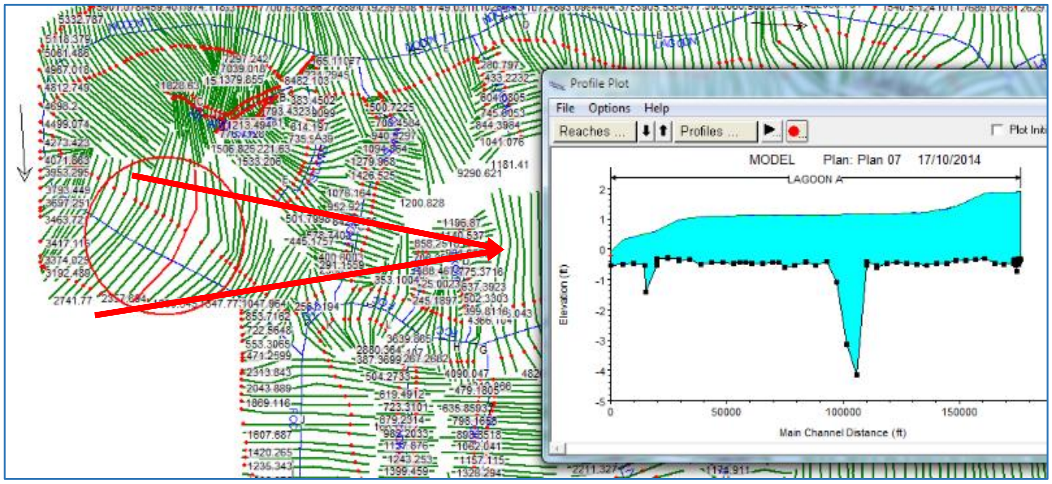

Figure 8: Cross-sectional profile check and display (for peak flows).

RESULTS AND DISCUSSION

The goal of water hydraulics may not be complete when we cannot ascertain specifically where the water would flow if reached a certain value, or will surrounding areas be flooded and to what extent will be the flood?

The flood inundation map showing the flood depth and extent was prepared in ArcGIS 10.6 (Figure 9). In the course of delineating the flood extent, a bounding polygon for the inundation extent was created and the area for this polygon was calculated. The total area covered by this polygon was 2.006sq.kilometres). This value excludes the area covered by the water body present in the study area.

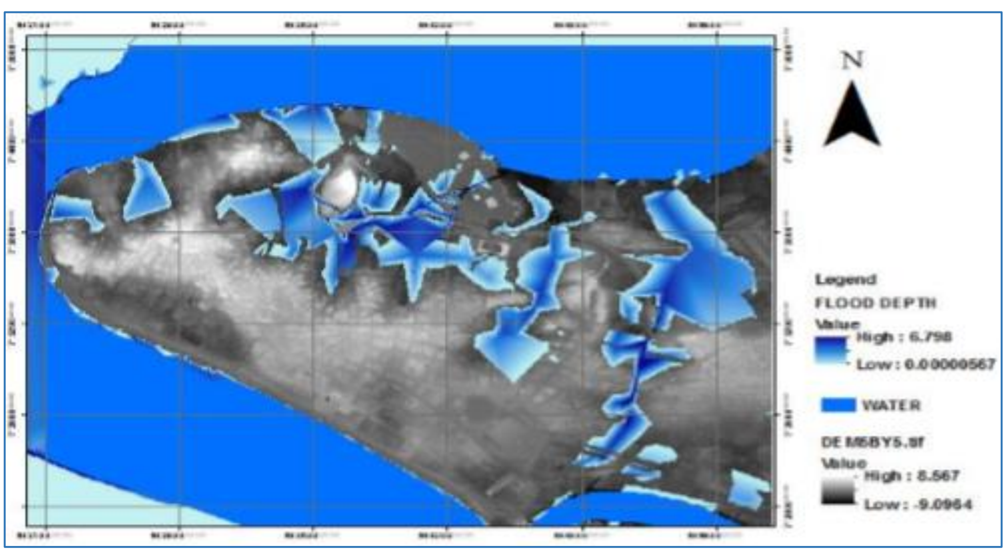

Figure 9: Flood inundation map showing flood depth and extent (see map legend)

The Risks Involved

The Environment Agency and Local Planning Authorities require a professional Flood Risk Assessment (FRA) to be submitted alongside planning applications in areas that are known to be at risk of flooding within flood zones. A Flood Risk Assessment (FRA) identifies the level of flood risk to buildings or land parcels. This will enable identification of measures (if any) that are necessary to make buildings or land parcel safer.

In this study, Lands and buildings that fall within the inundation zones are at the greatest risk during flooding. The severity of the flood will tell the level of destruction on the lives and properties in each parcel. It is against this backdrop that it becomes imperative to make a count of the building types that lie within these areas so as to know the structures that are at risk and the threat this poses on the lives of people and even the environment at large. The buildings in the study area are shown in table 1 and Figures 10 and 11.

Table 1: Percentage Number of Building Categories at Risk

Building Category	**% Coverage at Risk**
Commercial	36.56
Institutional	16.56
Residential	25.45
Recreational	14.56
Others	6.87

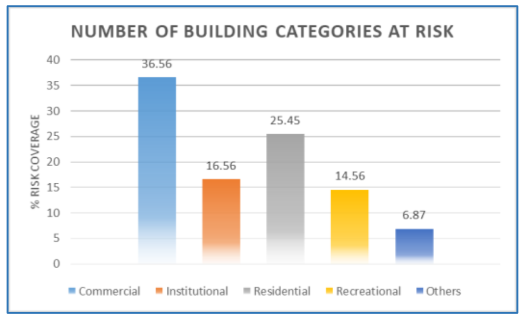

Figure 10: Percentage Number of Building Categories at Risk in the study area

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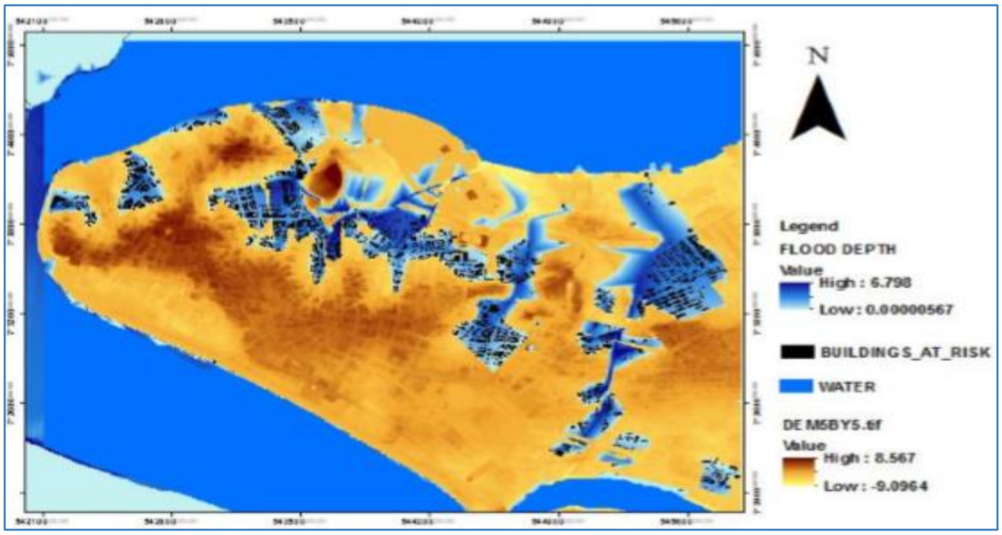

Figure 11: Land parcels and Buildings at Risk in the study area

Model Validation

Model validation is a key topic in flood risk analysis, as flood risk assessments are characterized by significant levels of uncertainty (Handmer, 2003; Jongman, et al., 2012; Merz, et al., 2010); unfortunately, only a few researches on flood carryout validation of flood risk assessments.

In this study the results of the flood model was compared to the actual flood occurrence so as to check the ability of the model to accurately predict flooding at the selected locations in the study area.

Pictorial representations of flood events after rainfall at the selected locations with their corresponding GPS locations as well as names of the selected locations in the study area were collected in the field. These GPS locations and place names were overlaid on the flood map and the photographic images of the flood events after the rainfall at each selected locations where hyperlinked to the map.

Field verification was performed at locations were the model returned considerable amount of flood and also those locations that had little or no flood returns. This is to test for locations that were over-predicted, under-predicted or where there was no prediction for flood inundation (figure 12). An inspection of the modelled inundation against the pictorial representations was then conducted at each location and a comparison between the modelled inundation and actual inundation illustrates a close agreement between the simulated and observed inundation.

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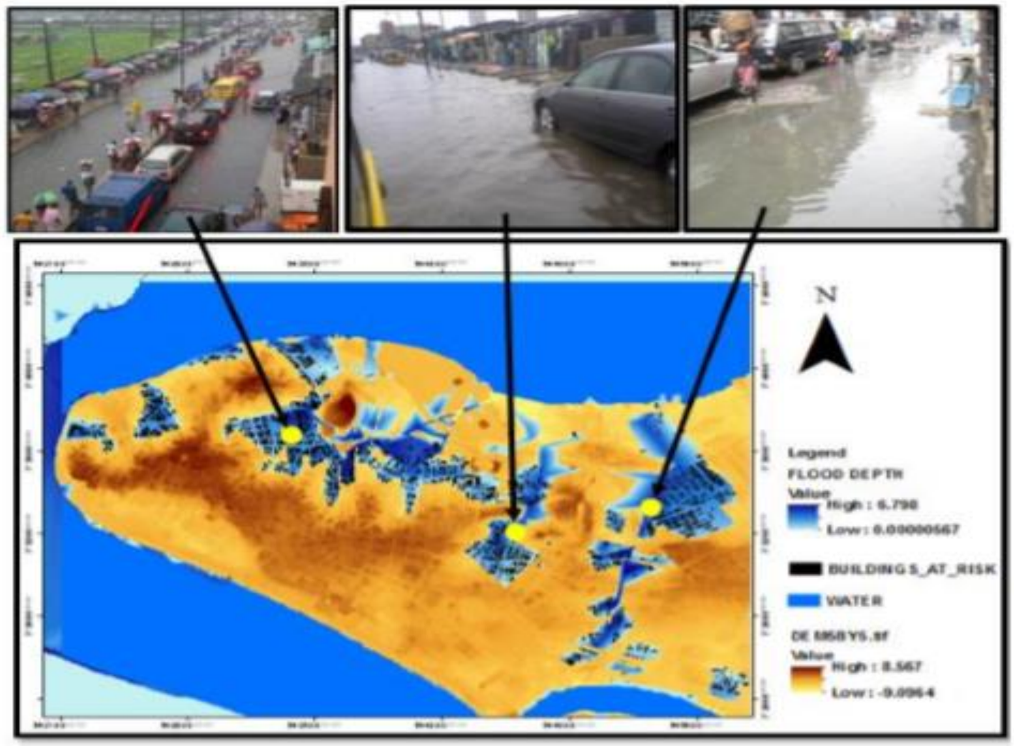

Figure 12: Geo-location of GPS coordinates of selected locations in the study area

3D Model of Result

Three Dimensional Model is used in various industries like films, animation and gaming, interior designing and architecture. They are also used in flood hydrology for the interactive representations of relationship between structures and facilities in flood zones. The three-dimensional floodplain view (figure 12) of the area is very useful for flood mapping and inundation extent visualization. Three dimensional representation of the terrain, the flood inundation extent and the building features that are within the flood extents was rendered in ArcScene.

Figure 13: 3D Representation of features in the study area that are highly at risk and within the flood extents

SUMMARY AND CONCLUSION

Review of research literatures in flooding has shown that the capabilities of GIS and Remote sensing alone are not enough to adequately measure the intensity and the extent of flood and its effects. Its high time our local flood experts embraced the application of the state of the art flood models available, some of which are open source are necessary to improve the flood risk analysis in the country. A typical example of such is the use of HEC (Hydrological Engineering Centre) modelling packages such as HEC-HMS and HECRAS software packages as well as ARCGIS software. The hydrological model (HEC-HMS) was used to analyze the rainfall water volume and the amount of runoff water volume that was generated. This was used as input in HEC-RAS to analyze the characteristic movement of water on the study area and the places where it concentrates, thereby creating inundation problems.

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