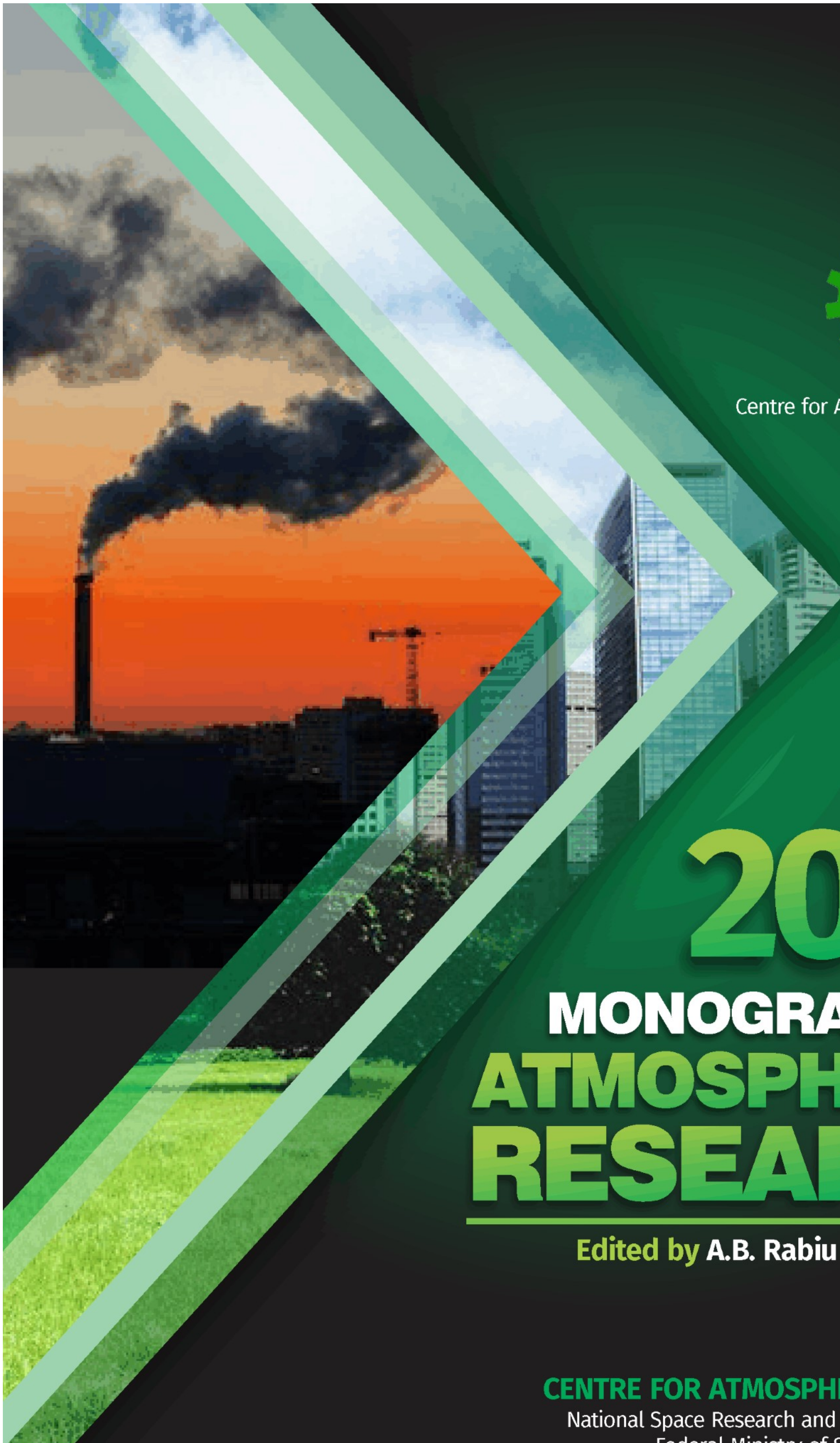

Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by A.B. Rabiu and O. E. Abiye

A Publication of
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PREFACE

The Centre for Atmospheric Research was established in January 2013 with a compelling mission to improve our understanding of the behaviour of the entire spectrum of the Earth's atmosphere; promote capacity development in relevant atmospheric sciences as a way of facilitating international competitiveness in research being conducted by atmospheric scientists; and disseminate atmospheric data/products to users towards socio-economic development of the Nation. CAR's extant core research focus includes: space weather, tropospheric studies, atmospheric research software and instrumentation development, microgravity and human space technology, and atmospheric chemistry and environmental research.

Pursuant to the above, The *Monograph of Atmospheric Research* published by the Centre for Atmospheric Research (CAR), is a collection of peer-reviewed manuscripts in Atmospheric Sciences and closely related fields. This maiden edition comprises articles presented during two separate workshops; *1st National Workshop on Microgravity and Environmental Research* (26 - 29 November, 2017) and *1st National Workshop on Air Quality* (13 - 16 March, 2018). Such workshops are integral part of CAR's capacity building program and they were primarily aimed at advancing the course of atmospheric research in Nigeria towards sustainable development. The Microgravity workshop was geared towards introducing new research opportunities in space life science by simulating microgravity conditions here at the earth's surface as a means of investigation space biological environment. The Air Quality workshop was organized in collaboration with Ministry of Environment and Nigerian Meteorological Agency (NIMET). The workshop analysed current Air Quality scenario in Nigeria, explored new opportunities for collaborative research and offered novel means of improving the present quality of life of the populace without jeopardizing the chance of the future generation. Cumulatively 196 participants participated in these two workshops and about 52 articles were eventually submitted for publication consideration in this monograph. The twenty-one articles in this very monograph are the articles that eventually made it through the rigorous peer-review process. We remain grateful to the reviewers for doing thorough work on the articles.

Thus, we are very pleased to present the *2018 Monograph of Atmospheric Research* which contains twenty-one articles, including some review papers, to readers in all spheres of interest across Nigeria and beyond. It is our hope that this effort will continue and will serve as a reference to atmospheric researchers in Nigeria.

Prof. A. B. Rabiu and Dr. O. E. Abiye,
Editors

Centre for Atmospheric Research

Urban flood risk modelling and assessment of a part of Eti-Osa L.G.A in Lagos State

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ABSTRACT

Urban floods are mostly due to heavy rainfall, irresponsible anthropogenic activities, and climate change and variability. This is a major concern affecting development of coastal cities all over the world with the most pronounced in developing nations. In this research, answers are given as to the area at risk of flood disaster and its spatial extent in Eti-Osa LGA of Lagos State, Nigeria.For the methodology, LIDAR data, rainfall data, land use maps and GPS points are input data layers. Input data were processed by creating a geodatabase for GPS points collected, LIDAR data mosaicking on Surfer software, generation of 5-meter resolution DEM, and land use map of the study area. Three-dimensional views and flood maps of the modelling results are provided. Flood modelling validation was done with the GPS coordinates collected, and photographic images of the locations during and after heavy rainfall at various times. Coordinates were plotted on the flood map produced. Additional analysis on the spatial relationships between existing land structures, land cover types and predicted flood risk maps was carried out using the ArcGIS software. Buildings at risk were assessed and suggestions on how the flood plain can better be managed are also provided. The results showed that 65.45% of the buildings at risk serve residential and commercial purposes with an average flood depth of 3-meters. From the flood modelling and validation process carried out, the areas that are at the highest risk are within Ikoyi. Included in this research, are recommendations for disaster risk reduction strategies in the areas which are at a severe risk of devastation in the event of extreme weather conditions.

Keywords: Environmental GIS, 3D-Modelling, Spatial Analysis, Flood Assessment, Flooding

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INTRODUCTION

The concepts of hazard, vulnerability and risk have been extensively used in various disciplines with a different meaning, impeding cross-disciplinary cooperation for facing hazardous events(*Aimilia P and George T, 2007*). Concentrating on the flood hazard, it can be supported that the capture of the natural phenomenon requires the frequency of the flood events as well as their magnitudes (and thus their anticipated flood damages) (*Alexander, 1991*). With climate change, urban areas flood more frequently. Short peak rainfall intensities usually exceed the storm water drainage capacity and this causes flooding of streets and possibly buildings and homes (*Kluck et al, 2010*). Urban floods are known to lead to erosion of soil, pollution of the area and significant economic damage. With the increase in flooding frequency, urban flood models have been gaining interest as they are a tool to understand and mitigating floods (*Ilia, 2015*).

Asides economic and social damage, floods can have severe consequences, where cultural sites of significant archaeological value are inundated or where protected wetland areas are destroyed. Regarding floods in Europe, two trends point to an increased flood risk and to greater economic damage from floods. First, the scale and frequency of floods are likely to increase in the future as a result of climate change, inappropriate river management and infrastructure development in flood risk areas. Second, an increase in vulnerability has been noted due to the number of people and economic assets located in flood risk zones. Therefore the coming decades are likely to see a higher flood risk and greater economic damage (*Aimilia P and George T, 2007*). This is the similar case in Nigeria – especially in urban-coastal cities like Lagos, which is a low-lying area yet the commercial and economic hub of the country. In Nigeria, flood accounts for the highest occurring natural hazards, with great consequences on the life and property (*Aderogba, 2012*).

In the past, flood modelling and analysis have been carried out for flood vulnerability maps production using different technologies. Areas vulnerable to floods have also been assessed by researchers using varying criteria. In most cases, methodologies employed have largely been influenced on data availability, objectives of the study, as well as the desired outputs. However, with the advent of technologies like Global Positioning Systems (GPS), Light Detection and Ranging (LIDAR) technology and Geographic Information Systems (GIS), data extraction, processing and presentation have since improved.

According to *Akinola et al (2015*), mapping and prediction of flood hazards are important aspect of flood risk assessment. Flood nature, intensity and frequency of occurrence are better understood through mapping and simulating of both the already occurred and potential flood hazards. They are essentially useful for assessment of the level of risk (knowing the affected people and properties), providing early warning in case of future reoccurrence and hydraulic design, especially for potential flood management and disaster risk reduction. Although little researches have been conducted in this area based on the existing literatures, some Nigerian scholars have however conducted researches on the flood mapping in Nigeria, with most of them using remote sensing data aided by the Geographic Information Systems (GIS).

Ojigi et al., (2013) delineated and mapped 2012 flood in some parts of Central Nigeria (Niger-Benue-Kogi). The flood extent of the event was mapped using a combination of RADARSAT, Infoterra SAR, SPOT-5 imageries, Shuttle Radar Topography Mission (SRTM) with field information provided during the flood. Spatial analysis such as buffer was used to categorize the flood hazard extent using GIS and GPS data. In another study (*Haruna et al., 2013*), made use of hydrological model by simulating the effects of climate change on a Kaduna river. An open source model called Hydrognomon was used for the hydrological data processing with future climatic data. The results displayed the expected river discharge for each climate change scenarios. Still on Kaduna River, (*Jeb and Aggarwal 2008*) utilized remote sensing and GIS, Digital Elevation Model (DEM) integrated with flood stage data results from Gumbel's Extreme distribution model to estimate the extent of flood inundations in different flood return periods in Kaduna Metropolis. With this model, flood area extent was delineated and classified to different classes of risk.

The usefulness of remote sensing and GIS in the assessment of flood hazards as reflected in the study undertaken by *Rose et al. (2014)*. They employed Remote Sensing (RS) and Geographic Information System (GIS) techniques to carry out flood hazard assessment for the flood prone areas within the low-lying flat river valley of the River Dep watershed for 2-year to 1000-year using flood inundation maps previously obtained by *Daffi (2013)*. The map was overlaid on the settlement map of the study area to view those that will be affected by flood of these return periods. It was also overlaid on the Landsat land use classified map to view and analyse the land uses that would be inundated by the floods. In the same vein, *Abah (2013)* also applies Geographic Information Systems (GIS) in mapping flood risk zones in Makurdi Town. In the study, he draws its relevance from the importance of a GIS database in tackling flood related problems and creates a map of flood risk zones in Makurdi town. The ArcView GIS package was used to digitize a topographic map and other relevant themes of the study area. Through GIS overlay and manipulative functions, a Digital Elevation Model of the study area; and a classification map of flood risk zones in Makurdi town were created. The map of flood risk zones generated shows that Makurdi town is generally susceptible to flooding and very little has been done in steering away development from 'highly susceptible' areas.

Figure 1: Location of the study areas with adjacent water body.

Mayomi et al. (2013) work have demonstrated the capability of geo-information techniques in assessing the 2012 floods incidence that swept the communities along the coastal areas of Nigeria as well as those along the valleys of the major rivers in the country. In the study, vulnerability was classified into four: Highly vulnerable, vulnerable, marginally vulnerable and not vulnerable. The study found that all the 120 communities in the area were described as vulnerable to flood, that is, they were either highly vulnerable, vulnerable or marginally vulnerable.

In this research, flood mapping, modelling and vulnerability assessment is performed to delineate risk areas and suggesting ways to mitigate this hazard. The study used state of the art flood models which integrates all hydrological processes for more accurate prediction and mapping of flood risks.

The aim of this project is to analyse and model flood risk in an urban environment, Eti-Osa Local Government Area, in order to identify and mitigate the menace. It involved modelling adjoining areas of the study area which extends to the area in which the drainage network data covers – a key modelling component acquired for this research. The HEC-HMS and HEC-RAS models are used for the flood modelling processes with inputs such as: land use data, a LIDAR (DEM), precipitation data and building infrastructure information. A two-dimensional representation and three dimensional representation of the flood modelling results of the study area is produced.

The study area

For this study, Lagos Island local government areas and its environment which are generally considered to be low-lying areas in Lagos State is considered. The area is characterized as a mixed land use. This study area shares boundaries with Lagos Lagoon to the North, the largest coastal lagoon in western Africa, and the Atlantic Ocean to the South. With a land area of approximately 180Km2 and an average population of about 500,000 people, this area is fast-developing with an average population growth rate of 3.2%. It is located within Latitude 6o 26' 34" N and Longitude 3o 24' 30" E on the left and Latitude 6o 29' 04" N and Longitude 3o 39' 09' E on the right. Figure 1 shows the location of the study area. It clearly depicts the study area surrounded by water, with Eti-Osa directly adjoining the Atlantic Ocean.

MATERIALS AND METHODS

In the determination and delineating of flood inundated areas for this research, HEC (Hydrologic Engineering Centre) tools developed by the United States Army Corps of Engineers were used. These tools are HEC-HMS (Hydrologic Modelling System) and HEC-RAS (River Analysis System). The early work of this project culminated with the development of the Spatial Analysis Methodology (HEC-SAM), which included a grid-cell data bank and analysis software for hydrologic and flood damage calculations. However, the HEC-HMS and HEC-RAS were developed as a geospatial hydrology toolkit for Engineers and Hydrologists with little GIS experience.

HEC-HMS

This tool simulates precipitation-runoff processes of dendritic water systems (*Arpita, 2012*). HEC-HMS is a physically based, semi-distributed hydrologic model developed by the US Army Corps of Engineers to simulate the hydrologic response of a watershed subject to a given hydro-meteorological input (*Scharffenber et al., 2010*). The model uses underlying DEM information to partition the basin into sub-watersheds. The size of the sub-watershed is determined a priori by the modeller, and few or no guidelines are available for sub-watershed selection. In most cases, the balance between the resolution of the distributed information and the computation time required for simulation is the main factor considered for this selection.

The model can simulate individual storm events as well as continuous precipitation input at minute, hourly, or daily time steps (Zhang et al., 2013). A particularly important parameter is the infiltration rate as it has the highest effect in determining runoff loss. Feldman, (2000) gave a detailed explanation on computations necessary to achieve the modelling.

Excess precipitation is computed using:

$$G_e = \frac{(G - F_a)^2}{G - F_a + S} \quad (1)$$

Substituting the empirical relationship of Fa and S, given as , as developed by the SCS, the equation is given as follows:

$$G_e = \frac{(G - 0.2\,H)^2}{G + 0.8\,G} \quad (2)$$

The maximum retention S and the watershed characteristics are related through an intermediate parameter, the curve number (CN). Equation 3 gives measurement in foot – pound (imperial units) system while Equation 4 is given in SI units.

$$H = \frac{1000 - 10\,CN}{CN} \quad (3)$$

$$H = \frac{25400 - 254\,CN}{CN} \quad (4)$$

Where,
H = potential maximum retention;
Fa = Initial abstraction (loss);
Ge = Runoff (mm); and
G = accumulated precipitation depth (mm);

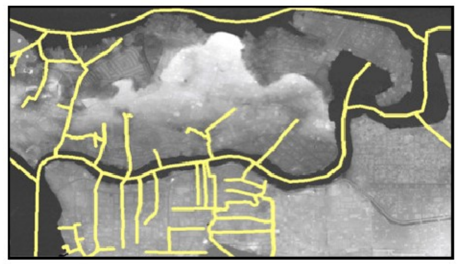

Figure 2: Drainage network

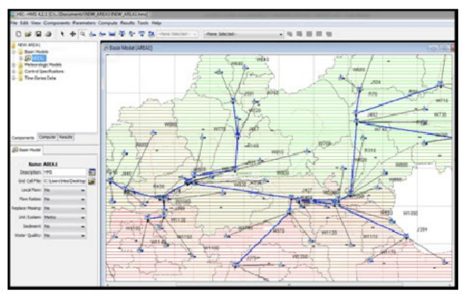

Figure 3: HEC-HMS modelling with watershed

HEC-RAS hydraulic Analysis System

HEC-RAS was designed to perform one-dimensional, two-dimensional, or combined 1D and 2D hydraulic calculations for a full network of natural and constructed channels. The system consists of four one-dimensional river analysis components for: (1) Steady flow water surface profile computations; (2) unsteady flow simulation (one- and two-dimensional hydrodynamics); (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 design features that can be invoked once the basic water surface profiles are computed. Steady flow computation is based on the energy equation expressed (Manual, 2016):

$$Z_2 + Y_2 \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 \frac{a_1 V_1^2}{2g} + h_e \quad (5)$$

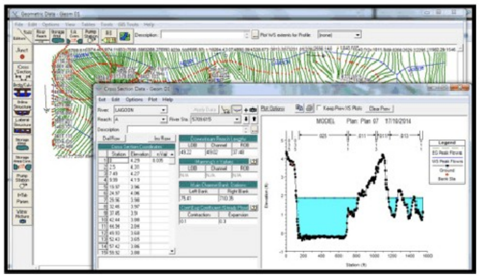

Figure 4: Geometric data and Run off volume computation of the hydraulic model in HEC-RAS

$$h_e = LS_f + \left| C\,\frac{a_2 V_2^2}{2g} - \frac{a_1 V_1^2}{2g} \right| \qquad \text{Eqn. 6}$$

$$h_e = LS_f + \left| C\,\frac{a_2 V_2^2}{2g} - \frac{a_1 V_1^2}{2g} \right| \qquad \text{Eqn. 7}$$

L_{lob}, L_{ch}, L_{rob} = cross section for flow in the left overbank (lob), main channel (ch) and right over bank (rob), respectively;

$Q_{lob} + Q_{ch} + Q_{rob}$ = arithmetic average of the flows between section for the left overbank (lob), main channel (ch) and right over bank (rob), respectively;

Where,

V_1, V_2 = average velocities (overall discharge/total flow area);

Y_1, Y_2 = water depth at cross sections;

Z_1, Z_2 = elevation of channel bottom;

a_1, a_2 = gravitational acceleration;

he = energy head loss;

Sf = representative friction slope between two sections;

C = expansion or contraction loss coefficient; and

L = discharge weighted reach length;

Data Acquisition

All data used, its sources and the processing steps taken is covered here. The following is a list showing the data used and their sources:

i. Drainage network for 2012 of the study area was derived from the Lagos State Drainage network manual.

ii. 2002 and 2011 land use map covering the study area was acquired from the Ministry of Physical Planning, Lagos State.

iii. 2008 LIDAR data (DEM) covering the study area was obtained from Office of the Surveyor General of Lagos State.

iv. Infrastructure location data in vector format covering most part of the study area for the year 2009 was also obtained from the Office of the Surveyor General of Lagos State.

v. 6 months of daily rainfall data of 1ST July – 31st December 2013 from TRMM Online Visualization and Analysis System (TOVAS).

Subsequent sub-sections highlights how the above data were processed. With the need to attain high accuracy in analyses, authoritative data as opposed to crowd sourced from the Lagos State ministry were used to delineate land usage for study area. Additionally, in order to identify true flood inundated areas at peak periods, datasets for a period within 2012 where Lagos State experienced its worst flood

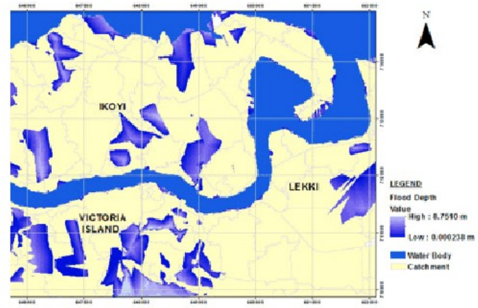

Figure 5: Flood Inundation map with catchment and adjoining waterbody

Table 1: Percentage coverage of buildings at risk

BUILDING TYPE	PERCENTAGE COVERAGE AT RISK
Residential	32.240%
Commercial/Business	33.210%
Institutional	13.164%
Other uses	9.097%
Recreational	12.289%

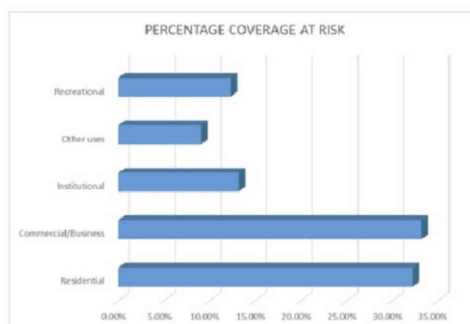

Figure 6: Chart showing Percentage Buildings at risk

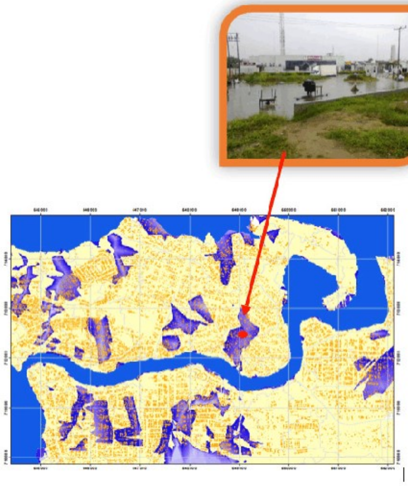

Figure 7: Relating site picture of flooded location with its GPS position on the map

scenario in more than two decades was preferred for this research. Overall, data availability and its accuracy are factors that influenced the choice of dataset.

Hydrological model development

Rainfall and runoff water volume were analyzed using the HEC-HMS Hydrological Model. A basin model, meteorological model and control specification components were used in order to develop the hydrological model in HEC-HMS three components are required - a. The basin model was created using the ArcGIS extension of HEC-HMS, HEC-GeoHMS. The LIDAR DEM served as the foundation for this process. A terrain preprocessing was carried out on the DEM. A DEM reconditioning process and a final production of the hydrologically corrected DEM was carried out. Further operations to prepare the DEM for use in HEC-HMS were carried out. All hydrologic parameters and basin characteristics were provided. A final basin processing was carried out in HEC-HMS after a project generation in the same modeling package. Figure 2 shows the LIDAR DEM with the embedded drainage network.

Using the HEC-HMS modelling package and precipitation data collected over a daily six-month period, a meteorological model was created. This made provision for rainfall information to be used in the model computation. Figure 3 shows the HEC-HMS model generation procedure.

Hydraulic model development

To predict the movement of runoff water over the surface, hydraulic model, HEC-RAS was used. Previously derived output from the hydrological modelling, volume of rainfall groundwater runoff, was used to simulate where water cumulates, and on the long run, creating inundation problems. A hydraulic model developed in HEC-RAS for floodplain inundation analysis, is constituted by two groups of datasets: the geometrical data (shown in Figure 4) and the runoff water flow data.

The geometrical data needed for the development of the hydraulic model was extracted from the LIDAR DEM using the HEC-GeoRAS extension in the ArcGIS environment. All geometric data such as the stream centrelines, bank lines, flow paths as well as cross sections were imported into the HEC-RAS modelling environment. Manning's N values were assigned to the cross sections for the flow analyses and subsequent run off computations.

RESULTS AND DISCUSSIONS

The flood inundation map showing the flood depth and extent was prepared in ArcGIS environment and this is shown in Figure 5. While in the cause 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 5.356 sq. kilometres. This value excludes the area covered by the water body present in the project.

Assessing Buildings at Risk

Within the inundated areas are buildings at the greatest risk in the event of flooding – heavy downpour. To ascertain the extent of potential damage, a count on the buildings were taken. Below is the table summarizing the percentage count of land feature at risk.

Model Validation

Because it is important to validate the results of any research carried out, photographs of the locations within the study area were collected in-situ, before, during and after heavy rainfall at defined intervals. GPS locations and place names of these locations were also acquired and plotted on the flood map. The locations were geo-tagged and hyperlinked with the image files. Field observations were taken at places where the model showed to be vulnerable to flood as well as locations with little or no flood risks. This is so as to test for precision in prediction.

DISCUSSION

The flood modelling system used in this study has provided results that can support decision making to mitigate the effects and plan for emergencies, where necessary. The flood model result showed a range of flood depths and its extent in the study area considered. From the results provided in Table 1 above, and the chart in Figure 6, business/commercial infrastructures have the highest risk with a total percentage coverage of 33.210% are residential. This is followed closely by buildings that are residential with a percentage coverage of 32.240%. These results show that the lives and livelihood of the residents which are at the risk of devastation would have a grave effect on the socio-economic well-being of the local government area, state and country at large.

There is therefore a need for the local authorities to devise a temporary solution while planning a long-term solution. Some of these short-term strategies may include: expansion of drainage systems and weekly maintenance of same. The long-term could be to construct large underground channels to take excess groundwater into the adjacent Atlantic Ocean.

Based on the analysis, a large number of the vulnerable areas include Binuyo and Dolphin Estate. This was further confirmed through site visitation. Major road linkages like Adeniji road which conveys both residents and businesses alike. Noticeably, these portions are very low in elevation and has most of the drainage outlets redirected here.

CONCLUSION AND RECOMMENDATIONS

This research showed the effectiveness in using LIDAR and remote sensing data, flood modelling tools and geospatial analyses in delineating flood vulnerable areas and their vulnerability levels – from least to worst – as well as in making valuable predictions.

The importance of the accuracy of data used for such research cannot be over emphasized, as it does affect the accuracy of decision making. In addition, it is recommended that:

i. This project should be integrated into policy making decisions by leaders of Eti-Osa LGA for adequate planning and management.

ii. Results from this research are incredibly useful start points upon which the community understudy could build resilience against this annual menace.

iii. Further research is encouraged with the availability of recent data in different temporal scales for more predictive analysis.

iv. Provisions should be made for adequate flood warning systems to monitoring ground water levels.

v. An online visualization system should be considered as a means of engaging the public and increasing their participation.

vi. In future research efforts, socio-economic and human-insurance information should be incorporated in modelling flood risks.

vii. Exhibition, workshop and seminar organisers should consider displaying the results of this project, as a way of encouraging more awareness as well as public participation.

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REFERENCES

Abah, R.C., (2013). An application of geographic information system in mapping flood risk zones in a north central city in Nigeria. Int. J. Water Resources Environ. Eng., 7: 365-377.

Aderogba, K.A., (2012). Qualitative studies of recent floods and sustainable growth and development of cities and towns in Nigeria. Int. J. Basic Applied Sci., 1: 200-216.

Aimilia P, George T (2007). Flood Risk Assessment: A Methodological Framework. Centre for the Assessment of Natural Hazards & Proactive Planning, National Technical University of Athens, Greece.

Akinola A. K, Suleiman A., and Francis O. A (2015). A Review of Flood Risk Analysis in Nigeria. Department of Remote Sensing and GIS, Federal University of Technology, Akure, Ondo-State, Nigeria. American Journal of Environmental Sciences 2015, 11 (3): 156 – 160.

Alexander, D. (1991). Natural disasters: a framework for research and teaching. Disasters 15 (3), pp. 209–226.

Arpita Mandal (2012). Flooding, An Impact Of Climate Change In Jamaica Hydrological Models For Rainfall – Runoff Relationships. Department of Geography and Geology, University of the West Indies Mona Campus, Jamaica.

Daffi, R.E., (2013). Flood hazard assessment for river DEP catchment using remote sensing and geographic information system techniques. PhD Thesis, Ahmadu Bello University Zaria, pp. 1-5.

Feldman, A. D. (2000). Hydrologic Modelling System HEC-HMS: Technical Reference Manual, US Army Corps of Engineers, Hydrologic Engineering Centre.

Haruna, G., I. Abubakar, I. A, A. S and F. B (2013). Hydrological modeling of the impact of climate change on a tropical perennial river flooding. Int. J. Eng. Sci., 3: 30-35.

Ilia A. (2015). Urban Flood Modelling. Recommendations for Ciudad Del Plata. Bachelor Thesis, Faculty of Engineering Technology (CEM).

Jeb, D.N. and S.P. Aggarwal (2008). Flood inundation hazard modelling of the river Kaduna Using remote sensing and geographic information systems. J. Applied Sci. Res., 4: 1822-1833.

Kluck J., Claessen E.G, Blok G.M., Boogaard F.C (2010). Modelling and mapping of urban storm water flooding - Communication and prioritizing actions through mapping urban flood resilience. NOVATECH 2010, 2.

Mayomi, I., A. Dami and U.M. Maryah (2013). GIS based assessment of flood risk and vulnerability of communities in the Benue floodplains, Adamawa State, Nigeria. J. Geography Geol., 5: 148-160. DOI: 10.5539/jgg.v5n4p148

Ojigi, M.L., F.I. Abdulkadir and M.O. Aderoju (2013). Geospatial mapping and analysis of the 2012 flood disaster in central parts of Nigeria. Proceedings of the 8th National GIS Symposium, Apr. 15-17, Dammam, Saudi Arabia.

Rose, E.D., A.O. Johnson and I. Abubakar (2014). Flood hazard assessment of river DEP floodplains in North-Central Nigeria. Int. J. Water Resources Environ. Eng., 6: 67-72. DOI: 10.5897/IJWREE2013.0457

Scharffenber W., Ely P., Daly S., Fleming M., Pak J. (2010). Hydrologic modeling system (HEC-HMS): Physically-based simulation components [online]. 2nd Joint Federal Interagency Conference, Las Vegas, NV, June 27–July 1, 2010.

Zhang H.L., Wang Y.J., Wang Y.Q., Li D.X., Wang X.K. (2013). The effect of watershed scale on HEC-HMS calibrated parameters: A case study in the Clear Creek watershed in Iowa, US. Hydrology and Earth System Sciences. Vol. 17. Iss. 7 p. 2735–2745.

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Our Mandates

The Center for Atmospheric Research, CAR, is a research and development center of NASRDA committed to research and capacity building in the atmospheric and related sciences. CAR shall be dedicated to understanding the atmosphere—the air around us—and the interconnected processes that make up the Earth system, from the ocean floor through the ionosphere to the Sun's core. The Center for Atmospheric Research provides research facilities, and services for the atmospheric and Earth sciences community.

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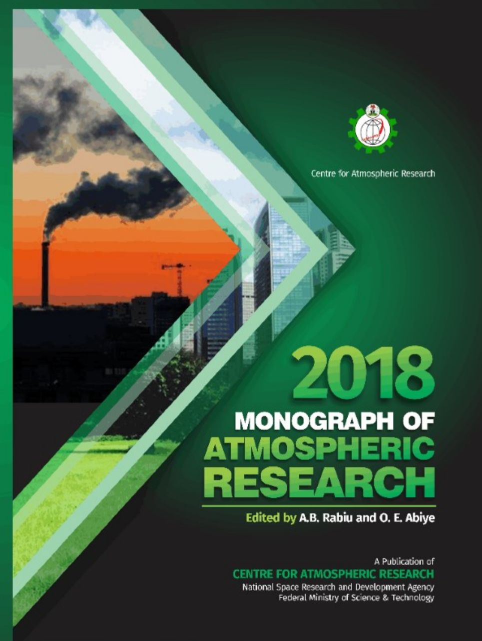

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