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EFFECTIVENESS OF GIS-BASED APPROACH FOR FLOOD HAZARD ASSESSMENT OF ONA RIVER, IBADAN, NIGERIA

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Abstract: Flooding is one of the most reoccurrence natural disasters globally and the plan to mitigate the effects of flood cannot be over emphasized. This study assessed the flood stage and flood extent of Ona River, Ibadan, Nigeria using Geographic Information System (GIS) in concert with Hydrologic Engineering Center-Geographic River Analysis System (HEC-GeoRAS). The results of the study revealed that the highest flood stage was predicted at 4.73 m, and 33% of the flood prone areas has a flood stage above 2 m based on the developed inundation map which implies that human and urban infrastructure are not safe. In the case of flood extent, the smallest flood extent was estimated at 694 m^2 (Mount Zion Baptist church at Oke-Ayo and its environs) while the largest flood extent was estimated at 115,329 m^2. It is recommended that an emergency rescue plan should be formulated to mitigate the effect of flooding in the affected areas such as Sweeco Foods, Tedaz Organic Home, Rehoboth Cathedral, a section of Oluyole Estate Road, Zartech Limited, 7-Up Bottling Company, Obasanjo Farm, and a section of Arapaja estate which are most prone to floods.
Keywords: Floods, Inundation Map, GIS, HEC-RAS, Ona River

INTRODUCTION

Flood has become an annual event globally particularly in Nigeria during the rainy seasons as a result of by increased precipitation due to climate change and variability (Adaku, 2020) or dam break phenomenon which may cause substantial loss of life and property damage downstream of the dams (Balogun and Ganiyu, 2017). Flood occurs in the form of coastal flood, river flood, flash flood and urban flood. In the past decades, many cities have experienced unusual and devastating flood disasters which are beyond the government's capability to prevent (Komolafe et al., 2015). In view of this, modeling of floodplain is very important because it focuses on many areas of civil and environmental engineering such as preparation of comprehensive floodplain studies, design of transportation features (such as roads, bridges and other facilities), floodwave development, and structural and non-structural solutions to flood problems (Mohammad and Parviz, 2013). Floodplain modeling predicts water surface profiles and generates floodplain maps to identify flood prone areas (Moramacro et al., 2005). The inundation/floodplain maps as explained in Ayemu et al. (2015) study can be classified as low, medium and high flood hazards.

Charles and Hamisi (2018) assessed the floodplain mapping of Bunga-Soya, Uganda. The return periods were estimated using Gringorten method, while the simulated inundated areas were mapped by incorporating HEC-RAS and HEC-GeoRAS extension of ArcMap. The result indicated that discharges of 618 m^3/s, 709 m^3/s, 850 m^3/s, 974 m^3/s, 1126 m^3/s, 1350 m^3/s and 1435 m^3/s were estimated for the return periods of 1, 2, 5, 10, 20, 50 and 60 years respectively. The 60-years return period produced maximum flood depth of 1.25 m and it was observed that HEC-RAS is an effective tool for flood inundation mapping. In the study carried out by Olasunkanmi and Dan'azumi (2018), flood inundation and hazard mapping of River Zungur Watershed, Bauchi, Nigeria was assessed using GIS and HEC-RAS models at return periods of 2 to 100 years. Area inundated by 2, 5, 10, 25, 50 and 100-year floods were 186.71 m^3/s, 189.15 m^3/s, 193.59 m^3/s, 197.63 m^3/s, 200.09 m^3/s and 205.32 km^2 flood extent respectively with maximum inundation depths ranging from 5.37 m to 7.37 m for 2 to 100 years. Flood inundation mapping showed the areas likely to be affected by the100-year flood included agricultural land, and it can be deduced from the study that hydraulic simulation and GIS are effective tools for floodplain mapping and management.

Tolera and Fayera (2019) modeled the floodplain of Awetu River Sub-Basin, Jimma, Oromia, Ethiopia. The magnitude of the flood was determined using Log-Normal distribution function for different return periods. The 1000-year return period predicted a discharge of 783.1m^3/s. HEC-RAS was used for the simulation, and the flood extent and stage for 1000-year return period was estimated at 1.852 km^2 and 21.2 m respectively. Bikram (2010) conducted a study on flood plain analysis and risk assessment of LotharKhola watershed, Nepal using HEC-RAS and GIS. Gumbel, Log Pearson Type III, and Log Normal method were used to analyze the flood frequency. The results of flood frequency analyzed by Log Pearson Type III method showed the discharges of 286 m^3/s, 647 m^3/s, 990 m^3/s, 1347 m^3/s, and 1284 m^3/s for 2, 10, 50, 100 and 200-years return period of floods respectively. The flood extent of inundated areas by return periods of 2, 10, 50, 100 and 200-years were estimated as 230 km^2, 239 km^2, 246 km^2, 249 km^2 and 252 km^2 respectively. The flood depth showed that most of the flooding areas had water depth greater than 3m.

Nigerian cities have a history of flood disasters particularly Ibadan city in Southwestern part of the country. Floods are common occurrence in the city and have been officially recorded since 1951 but records on urban floods in Ibadan are patchy and characterized by incomplete information. The heaviest rain on record that caused flood in the city occurred in 1980 when the city recorded 274 mm of rainfall during a single flood episode. The second heaviest recorded rainfall was 258 mm in 1963. The amount of rain that fell on 26th of August, 2011 was 187.5 mm which was the third heaviest recorded (Agboola et al., 2012). Many studies have been carried out on flood in Ibadan city with major focus on River Ogunpa which is the popular river that spread over Ibadan but with the flood of August 2011, it is apparent that other rivers in Ibadan require immediate attention. River Ona was among the water bodies that were flooded in 2011 causing several loss of lives and properties at the downstream (Jonah, 2011). This study presents the development of a comprehensive flood inundation map for River Ona which predicted the flood stage and flood extent of the identified flood prone areas. The map is a very useful tool which may be used to plan land use features in the floodplains and also, to formulate an emergency rescue plan to mitigate the effect of flooding in the affected areas.

METHODOLOGY

— Description of the Study Area

The River Ona is situated upstream of Eleyele River and continues at the downstream of the river in the city of Ibadan, Nigeria. River Ona lies within geographical coordinates of Latitude 7°20'- 7°25'N and Longitude 3°51'- 3°56'E and spans within the Ido and Ibadan North-West Local Government of Oyo State. Eleyele reservoir was formed from confluence of River Ona and River Alapata. An earth dam was constructed along the confluence at Eleyele community in 1942 for the supply of raw water for treatment at the Eleyele waterworks to provide potable water for the city of Ibadan. The dam also acts as flood control during high flow periods through its reservoir holding capacity. The River was further dammed at Nigeria Horticulture Research Institute (NIHORT) Idi-Isin and traverses many locations within Ibadan Metropolis such as Odo-Ona Apata, Oluyole Estate, Odo-Ona Elewe and New Garage Challenge (Elufioye, 2016). Figure 1 shows the map of the study area.

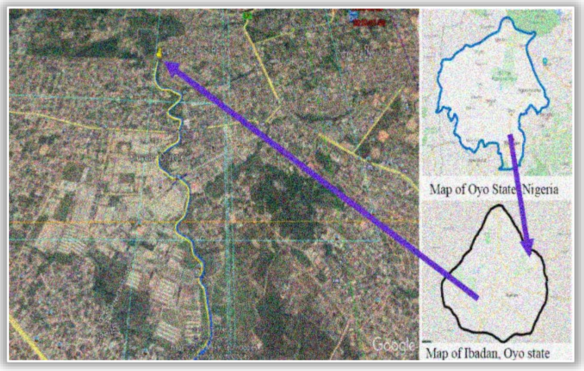

Figure 1: Map of the study area

— Model Development

The flood model for this study was developed from the combination hydrologic and hydraulic models where the spatial (DEM, Land use map and Soil map) and temporal (meteorological) data served as the model input data. The hydraulic model used for this study was Hydrologic Engineering Center's – River Analysis System (HEC-RAS) model. HEC-RAS requires two main input data which are geometric data and steady flow data. The flowchart of the modeling processes is shown in Figure 2.

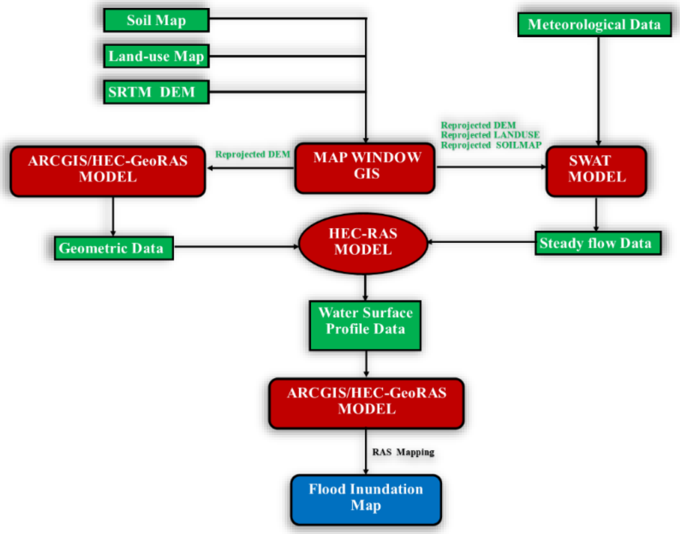

Figure 2: Flowchart of flood inundation mapping processes

In order to predict the steady flow data of the river, the spatial data (DEM, land use map and soil map) for the study area were delineated and processed in Map Window GIS. The processed spatial data were used in conjunction with temporal data which consist of 30-year daily meteorological data (precipitation, humidity, maximum and minimum temperature, solar radiation and wind speed).

Weather data from January, 2012 to December 2020 were obtained from the Nigerian Meteorological Agency (NIMET). Temporal data from January 2021 to December 2041 were forecast using Markov model. Markov model is a basic idea and concept of stochastic process or time series. It is used in modeling streamflow, rainfall, temperature, and other phenomena whose values changes with time *(Loucks and Van Beek, 2005)*. Both the spatial and temporal data were used as model inputs for the SWAT model. The model was run, and the predicted flow of 30-year return period was used as steady flow data in HEC-RAS model. Figure 3 shows the SWAT model run interface as used in the research.

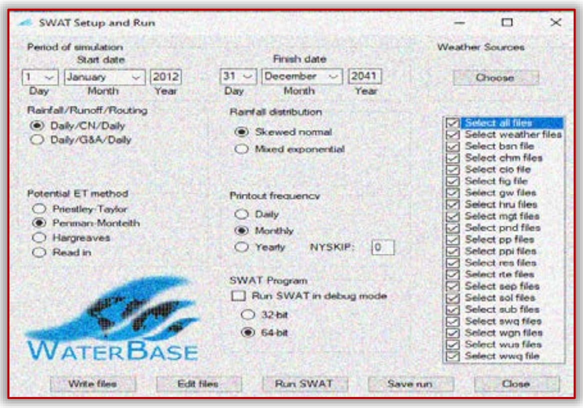

Figure 3: SWAT setup and run interface

The geometric data for this study was generated in HEC-GeoRAS (an extension of ArcMap version 10.1), where 90 m resolution Digital Elevation Model (DEM) was used as the main input data for the model. The DEM which gives a description of elevation of the area was extracted from the Shuttle Radar Topography Mission (SRTM) as shown in Fig. 4.

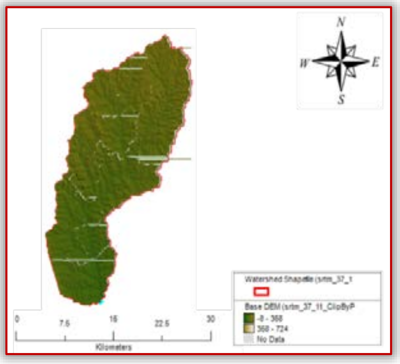

Figure 4: DEM of the study area

The DEM which was converted to Triangular Irregular Network (TIN) was used in order to set up 2D models for generating geometric data and processing the results of flood inundation. After creating all the required geometric data for hydrologic modeling, the created River Analysis System (RAS) layers containing stream centerline, main channel bank, flow path centerline, cross-sectional cut lines and bridges were exported into HEC-RAS model as presented in Figure 5. The geometric data was then imported in HEC-RAS model as presented in Figure 6. Manning's value was also inputted into the model. The characteristics of the channel and banks of the river were compared with Chow (1959) Manning's Table and the values of 0.04 and 0.045 were assigned to the channel and banks of the river respectively. Boundary conditions are also required to perform the calculations. In this study, the normal depth was used as a boundary condition. The flood model was run to compute the water surface profiles of the study area. The model result was then exported and visualized in GIS incorporated with HEC-GeoRAS.

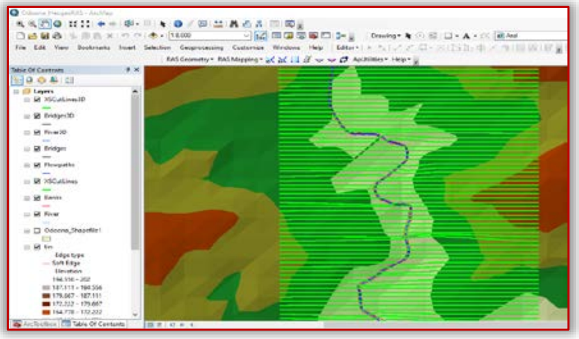

Figure 5: Graphical interface of River Analysis System (RAS) layers

In the flood mapping phase, the model results from HEC-RAS model were analyzed with HEC-GeoRAS, an extension of ArcMap 10.1 to produce the flood extent polygons (inundation map) of the study area. The inundation map was then overlaid on Google earth image to identify the affected areas.

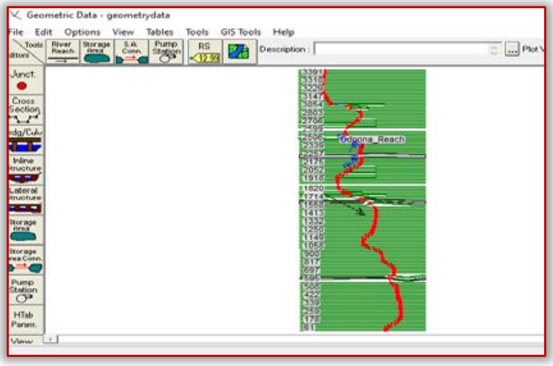

Figure 6: Graphical interface of geometric data in HEC-RAS model

RESULTS AND DISCUSSION

— Prediction of Steady Flow

The watershed of the study area was delineated and discretized into 10 sub-basins and 30 Hydrological Response Units (HRU). The predicted flow for all the sub-basins was represented with map as shown in Figure 7.

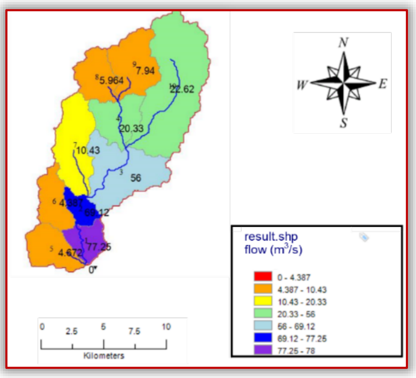

Figure 7: Spatial map of flow of the study area

It was observed from the map that sub-basin 6 has the lowest predicted flow of 4.39 m^3/s whereas, sub-basin 1 which was represented with purple colour has the highest predicted flow of 75.25 m^3/s and considered for the worst flood condition. The value was used as steady flow data in HEC-RAS model.

— Prediction of Flood Stage

It was reported in Srinivasa et al. (2019) that flood stage is classified into five hazard levels according to Japan Ministry of Land Infrastructure and Transport (Table1).

Table 1: Flood hazard classification according to MLIT

Flood hazard	Depth (m)	Hazard	Implications
H1	<0.5	Very low	Easy evacuation for human and animals
H2	0.5-1	Low	Difficult evacuation for adults, infants and animals
H3	1-2	Medium	People can get drowned but safe in their homes having plinth level to be 0.6 to 1 meter
H4	2-5	High	Not safe in their homes but may safe on their roofs
H5	>5	Extreme	Not safe even on their roofs

Source: Srinivasa et al. (2019)

The flood hazard classification was used to classify the flood stage of the study areas into various hazard levels. Figure 8 shows the flood stage of the study area. From the result, it was observed that an estimated 33% of the flood prone areas has a flood stage above 2 m (H4 classification) with the highest flood stage predicted at 4.73 m. Some landmark infrastructures (Zartech Limited, E99 Events Centre, Alaafin Avenue road, Sweeco Foods and Rehoboth Cathedral) were identified to be prone to flooding. This implies that human and urban infrastructure are not safe.

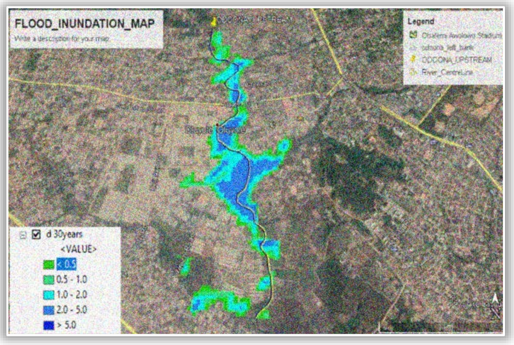

Figure 8: Inundation map showing the flood stage of the study area

— Prediction of Flood Extent

The inundation map produced shows the flood extent at peak flow as shown in Figure 9. The model revealed that the river has overflown its banks invariably causing flood to the downstream parts of the river.

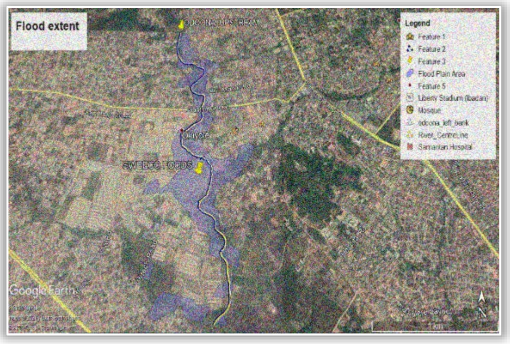

Figure 9: Inundation map showing the flood extent of the study area

The total flood extent of the study area was estimated at 0.585 km^2. The smallest flood extent was estimated at 694 m^2 (Mount Zion Babtist church, Oke-Ayo and its environs) while the largest flood extent was estimated at 115,329 m^2. Some of the identified flood prone areas are Sweeco Foods, a section of Oluyole Estate Road, Tedaz Organic Home, Rehoboth Cathedral, Zartech Limited, 7-Up Bottling Company, Obasanjo Farm, and a section of Arapaja estate.

CONCLUSION

This study presents a systematic approach to the process of flood inundation mapping. SWAT model was used to predict a 30-year simulation steady flow data. The estimated steady flow (75.25 m^3/s) served as the data for the HEC-RAS model along with geometric data which was generated using GIS in concert with HEC-GeoRAS and DEM. The HEC-RAS model was used to simulate the floods for a 30-year return period, and the flood inundation map was produced in GIS environment where the flood stage and flood extent were predicted. The model revealed that 33% of the flood prone areas had a flood stage above 2 m with the highest flood stage predicted at 4.73 m. In the case of flood extent, the smallest and largest flood extent were estimated at 694 m^2 and 115,329 m^2 respectively. It can be deduced from the study that HEC-RAS and GIS models are effective tools for floodplain mapping and the map is a very useful tool to formulate an emergency response plan of the affected areas.

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