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*Full length Research **Paper***

Flood Inundation Simulation using HEC-RAS Hydrologic Model: A Case Study of Oyun River, Nigeria.

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Abstract
Flood inundation simulation account for one aspect of hydrologic processes which is characterized by a continuous movement of water leaving the earth's surface and eventually returning in the form of rainfall. Floods are the most long-lasting and costly natural hazard around the world thereby causing serious financial impacts. The flood inundation simulation plays an important role in providing appropriate information of possible impending floods in the study area which requires urgent attention on whether to issue flood warning. Oyun River Basin, the study area, is located about 20 km to Ilorin, capital of Kwara State. In recent decades, Hydrologic Engineering Centre's River Analysis System (HEC-RAS) has become a popular tool in floodplain mapping. The aim of this study was to develop a flood inundation simulation of Oyun River Basin using HEC-RAS. A development research design was adopted in this study. RAS Layers, stream layers centerlines, flow path center lines, main channel banks and cross-section cut-lines were generated using a Digital Elevation (DEM) of Oyun River Basin in Hec-GeoRAS and exported into HEC-RAS. The HEC-RAS model using the RAS Layers generated solved the hydraulic equations of open channel flow in a downstream direction and maps the flood inundation area. Hydro-meteorological data used in this study include rainfall, temperature, river discharge, river cross sections, Digital Elevation Model (DEM). The modelled results obtained were compared with the flood inundated areas of Oyun River basin measure at different periods. The results showed R^2 value of 0.857.

Keywords: *Flood Inundation, HEC-RAS model, Hydrologic modeling, Inundation Mapping, Simulation.*

Introduction

Flood can be defined as an unusual high stage in a river, normally the level at which the river overflows its banks and inundates the adjoining areas (Nelson, 2009). Therefore, floods may occur as an overflow of water from river channel, resulting in some of the water escaping its usual boundaries, or it may occur due to an accumulation of rainwater on saturated ground in a floodplain area. Risk associated with flooding rises up due to a combination of climate change, population growth, urbanization and economic development. Climate change tends to be the major factor that increases the likelihood of floods due to changes in precipitation, river flow regime, wave climate and sea level (Mbajiorgu, 2015). Though the water level in a river vary with seasonal changes in precipitation, these changes in water levels are unlikely to be considered significant unless it flood properties, drown domestic animals or destroy agricultural farms (Williams, 2006).

In Nigeria climatic change and poor urban planning is one of the major causes of flooding. The influences of flooding in Nigeria have been severe through destruction of agricultural farmlands, social and infrastructural development. Every part of Nigeria's life stream is affected in one way or the other with floods. The effect is most particularly in the Niger Delta region of Nigeria causing traffic congestions, disruption in telecommunication and power supply (Ogunbodede and Sunmola, 2014). In 2012, Nigeria experienced the worst flooding resulting from heavy storms that lasted many days and release of water from the Lagdo Dam in Cameroon. NEMA (2013) reported that over 32 states in Nigeria were affected with 24 considered severely affected. The floods also affected about 7.7 million people with more than 2 million people reckoned as internally displaced persons (Nkwunonwo *et al.*, 2014). In 2017, Nigeria is witnessing again flooding in several states similar to that of 2012.

Historically, coastal and fluvial floods were the two types of floods that are common in Nigeria. These floods affected mostly coastal environments where there is seasonal interruption of major rivers with water overtopping their natural and artificial banks. Fluvial floods accounts for the majority of the flood threats experienced in many states in Nigeria such as Kwara, Adamawa, Kano, Niger, Jigawa, Kaduna, Cross River and Kebbi (Iloje, 2005). The 2006 Kano State fluvial flood disaster was the worst in the north-western region of Nigeria which affected hundreds of thousands of lives with economic loss worth over millions of US dollars (Adebayo and Oruonye, 2013). The effects of these costal and fluvial floods have been too hazardous on agricultural farmlands, properties and life's exposed to them due to the attractions of coastal areas for good soil fertility and socio-economic activities. Nigeria ranked amongst the top 20 countries that are exposed to flooding based on present population and future scenarios of climate change and socio-economic factors (Nkwunonwo, 2016). Similarly, pluvial flooding due to events of annual rainy seasons, which always occur between July and October, is not only ravaging many cities within Nigeria but also the most frequently experienced. From food security point of view, the effects of flooding in Nigeria continues to generate concern in the areas of agricultural production, land and water management, humanitarian needs and services, primary health delivery, environmental management, solid waste management, urban development, professionalism in engineering practice and the dynamism of Nigerian democracy and political system (Clement, 2013). However, the challenges of floods is a global phenomenon, hence, its effects cannot be over emphasized. In recent years, Hydrologic Engineering Centre's River Analysis System (HEC-RAS) has proven to be a good floodplain mapping model (USACE, 2005).

The knowledge regarding to climate change is constantly changing, thereby, making flood inundation simulation difficult. Since the beginning of the existence of mankind, floods and drought have affected human activities greatly throughout the world. An upsurge in the risk of a flood hazard can be influence by natural and human factor. Demographic pressures also cause the encroachment of informal settlements on hazardous locations in the floodplains, as it is in the case of great number of over 5,200 people living and farming along the Oyun River floodplain. By living there, they are exposed to weather-related natural disaster such as floods and their effects. Consequently, majority of these people who are settling in this floodplain areas have been severely affected by flood disasters in recent decades especially in 2012, 2014, 2017, etc. The main objective of this study was to model the flood inundation simulation of Oyun River using HEC-RAS hydrologic model.

HEC-RAS Modelling

Flood inundation mapping is an important tool for engineers, planners, and governmental agencies who uses it for municipal and urban growth planning, emergency action plans, flood insurance rates, ecological studies, etc. By understanding the extent of flooding and flood water inundation, decision makers would be able to make choices about how best to allocate resources to prepare for emergencies and to generally improve the quality of life in the floodplain. In view of the above, U.S. Army corps of Hydrologic Engineering Center's (HEC) began development of model known as HEC-2 that soon became the water surface profile program. Nearly in the mid 1960's, HEC-2 was the most widely used and accepted program worldwide for determination of water surface elevations. In 1993, the HEC introduced HEC-RAS (River Analysis System), the first version of their Windows based software for water surface profile calculation. Hydrologic Engineering Center's River Analysis System (HEC-RAS) became a software package that models the hydraulics of water flow through natural rivers and is well-suited for developing flood inundation maps for a variety of applications especially for flood forecasting by solving hydraulic equations.

With its companion utility, Hec-GeoRas and ArcView GIS, seamless integration with GIS program ArcView with 3-D analyst and Spatial Analyst extensions makes both the construction of the model geometry and the post-processing of the output very easy. Geo-RAS can be used to create cross sections and other geometric data for use in Hec-Ras and can be used to export water surface data from HEC-RAS back into ArcView to create flood maps. Hec-Ras model supports water surface profile calculations for steady and unsteady flows, including subcritical, supercritical, or mixed flows. The energy losses between two neighboring cross sections are computed by the use of Manning's equation in the case of friction losses and derived from a coefficient multiplied by the change in velocity head for contraction/expansion losses (U.S. Army Corps of Engineers, 2001). The basic computational procedure of Hec-Ras for steady/unsteady flow is based on the solution of the 1-dimensional energy equation and Saint Venant equation using an implicit, finite difference method.

Literature review has shown that HEC-RAS is one of the most commonly used programs for flood inundation mapping. Gonzalez (1999) used Hec-Ras to determine the maximum capacity of a floodway channel of a river. He noted that HEC-RAS required few input data, but presented a simplified view of the flow pattern with complex channel geometry. Cook (2008) also used HEC-RAS in floodplain mapping and hydraulic modelling of two river reaches. It was found that the simulation in HEC-RAS was easy and quick. More so, Safari (2001) zoned flood risk in Neka River in the Mazandaran Province and concluded that this model has high efficiency in planning and determining floodplain management optimal model. Jalali-Rad (2002) simulated flood risk in urban areas of Darabad, Tehran by using Hec-Ras model. His study demonstrated the ability of the Hec-Ras model to process the water surface in different elevation. The HEC-RAS model is free and simple to use in modelling flood patterns and other hydraulic features within the river basin. The outputs of this software is widely accepted by most government and private agencies and extensively supported by USACE. The add-on packages are available which makes it possible to work with or to be integrated with other hydrological programmes. The above mentioned featured, advantages and its high accuracy for floodplain mapping necessitated the selection of this model.

Materials and methods

Oyun River basin was the study area selected for the flood inundation simulation using HEC-RAS hydrologic model. Oyun River Basin is about 20 km to Ilorin the Kwara State capital. It has an estimated average terrain elevation of 370 m above mean sea level and lies on Longitudes 4°30'East and Latitude 8°26'N (Awu *et al*., 2016). A river has a specific length and direction, hence, its latitudes and longitudes will not be a single value as mentioned above? Please check it again. Rain normally starts in April and stops in late October with June and September recording the highest rainfall values. The dry season lasts from November to March. Flooding is expected in the month of September while drought may be expected in the months of December through February. The mean annual rainfall value of the study area is about 1700 mm. The mean monthly maximum and minimum temperature values in the study area are 31°C and 29°C, respectively, with the highest temperature values recorded in the months of February through April. The potential evapo-transpiration of the area is between 1500 mm to 1700 mm per annum (Manta *et al*., 2010).

Oyun River flows from south east to south west for about 30 km before joining Asa River. The vegetation of Oyun River falls under Southern Guinea Savannah Zone of Nigeria which is categorized with undulating land scape, grassland and remnants of tropical forest. Oyun River is the main source of water to Offa town and its neighbouring town as well as the University of Ilorin water supply scheme (Mustafa and Yusuf, 2012). Figure 1 shows the catchment area of Oyun river basin enclosed within the thick black.

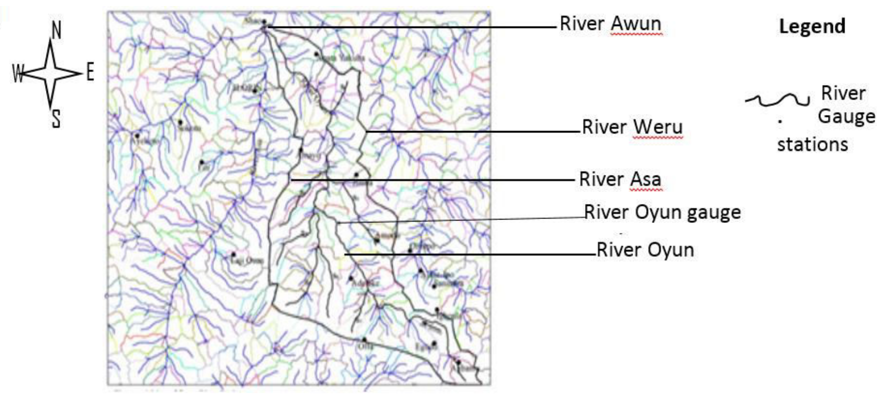

Figure 1: Catchment Area of Oyun River (Awu *et al*., 2016)

Oyun River catchment is relatively a small catchment with elongated narrow shape and non-steep slope. The basin area of the river is approximately 830 km^2 along with 0.57%, 0.46 and 0.35 for slope, elongation and circulatory ratio, respectively. These attributes have contributed to the slower draining of water into the river (Awu *et al*., 2016).

The application of HEC-RAS models for flood inundation mapping was based on the hydrologic data collected from the Land and Water Engineering Department of the National Centre for Agricultural Mechanization (NCAM), Ilorin. NCAM is located at km 20 Ilorin-Lokoja Highway, Ilorin, Kwara State, Nigeria. The hydrologic data collected include the river cross sections, water discharge, Digital Elevation Model (DEM) and the topographical map.
The results obtained from this study will provide large-scale information on flood inundation mapping as well as for integrated land and water resources modelling.

Flood inundation simulation of Oyun River using hydrologic engineering center's river analysis system (HEC-RAS)

HEC-RAS is a hydraulic model that computes water surface profile by solving hydraulic equations of open channel flow in a downstream direction. Oyun River surface water flows were calculated utilizing a series of developed channel cross-sections from a schematic representation of the river channel and floodplain. With the companion GIS utility, HEC-GeoRAS, those water surface profiles were converted to flood inundation map. Developmental research design was adopted in this study.

RAS Layers were created for stream centerline, flow path center lines, main channel banks, and cross-section cut-lines using Digital elevation (DEM) of Oyun. The RAS layers created was used to extract additional geometric data for import into HEC-RAS. These additional geometric data include land use, ineffective flow areas, and storage areas. The stream centerline generated was used to establish the river reach network and also to digitize the river network in the direction of flow. This was followed by assigning a unique river and reach name to the river network using the river reach ID tool. Each river length and reach from starting station to end station was as well calculated. The bank lines layer which was used to identify the main channel conveyance area from that of the overbank floodplain areas. Main river channel identification will also provide greater insight into the terrain, movement of water in the floodplain, and in identifying non-conveyance areas. The flow path lines layer was generated to determine the downstream reach lengths between cross section in the channel and overbank areas. A flow path line was created in the center-of-mass of flow in the main channel, left overbank, and right overbank for the water surface profile of interest. Flow path lines were digitized in the downstream direction, following the movement of water. The flow path line were labeled and assigned using flow path tool as left line, main channel and right line. Cross-section cut lines were created to identify the locations where cross-sectional data were extracted from the Digital Elevation Model (DEM). The intersection of the cut lines with the other RAS Layers determines the bank station locations, downstream reach lengths, Manning's 'n' values, ineffective areas, blocked obstructions and levee positions. The cut lines were perpendicular to the direction of flow and oriented from the left to right bank. The entire extent area of the floodplain was covered with Cut lines. River reach name and river station to each cross section was assigned based on the intersection with the stream centerline. Bank station locations to each cross section were also assigned. Finally, the reach length was assigned based on the flow path lines using downstream reach length menu.

The elevation for each cross-section was extracted from the Digital Elevation Model (DEM) and validated at Oyun River location. The elevation extraction process was converted from 2-D features to 3-D features. This resulted in the generation of a new feature class.
The final task was executed before exporting the GIS data from Hec-GeoRas utility to HEC-RAS geometry file by assigning Manning's 'n' value to individual cross-sections. In Hec-GeoRas, this was accomplished by using a land use feature class with Manning's 'n' stored for different land use types. The land use layer was a polygon data set used to establish roughness coefficients for each cut line. The land use data set have a field that holds descriptive information about each polygon. Depending on the intersection of cross-sections with land use polygons, Manning's 'n' were extracted for each cross-section, and reported in the XS Manning Table. Prior to writing the results to the RAS GIS import file, the layers which were to be exported from GeoRas are field with appropriate format. All the RAS layers verified as required in the surface terrain type, the layers verified are stream centerline, cross-section cut lines, cross-section cut lines profiles, optional layers bank lines, flow path centerlines, land use and Manning table, etc. After verifying the GeoRAS data, the GIS data was exported to an XML file and then into the SDF format.

HEC-RAS hydraulic analysis was used to perform one-dimensional steady flow and unsteady-flow analysis of Oyun river systems. RAS GIS import file was used in HEC-RAS which contains geometric data of the Oyun River. In order to map the inundation area, the ArcMap SDF file was converted back into an XML file using Import RAS SDF file button. Mapping was achieved using RAS GIS export file, terrain type, output directory. After the analysis extent was defined, the water surface profile was generated using profile with highest river flow. This process creates a surface with water surface elevation for every selected profile. The TIN that was created in this step were used to define a zone that connects the outer points of the bounding polygon. The water surface profiles were computed from one cross section to the next by solving the energy equation with an iterative procedure called the standard step method giving by equation 1.

$$WSE_2 = y_2 + Z_2 = y_1 + \ Z_1 \ \frac{\alpha V_2^{-2}}{2g} - \ \frac{\alpha V_1^{-2}}{2g} + h_1 \qquad (1)$$

where α_1 is the kinetic energy coefficient at downstream cross section; α_2 is the kinetic energy coefficient at upstream cross section; g is the acceleration of gravity (m/s^2); h_t is the total energy loss between adjacent cross sections (m); v_1 is the average velocity at downstream cross section (m); v_2 is the average velocity at upstream cross section (m/s); WSE_2 is the water-surface elevation at the upstream cross section (m); y_1 is the flow depth at downstream cross section (m); y_2 is the flow depth at upstream cross section (m); z_1 is the bed elevation at downstream cross section (m); and z_2 is the bed elevation at upstream cross section (m).

Results and Discussion
The results of this research study will be discussed under flood inundation simulation of Oyun River Basin, Kwara State. The parameters of the HEC-RAS model generated were calibrated and used to determine the flood inundation map of Oyun River basin. A USGS 30 arc-second Digital Elevation Model for Oyun River basin was downloaded and converted into Triangulated Irregular Network (TIN) format using 3-D Analyst tool in ArcGIS 9.3 for further analysis as shown in Figures 2 and 3.

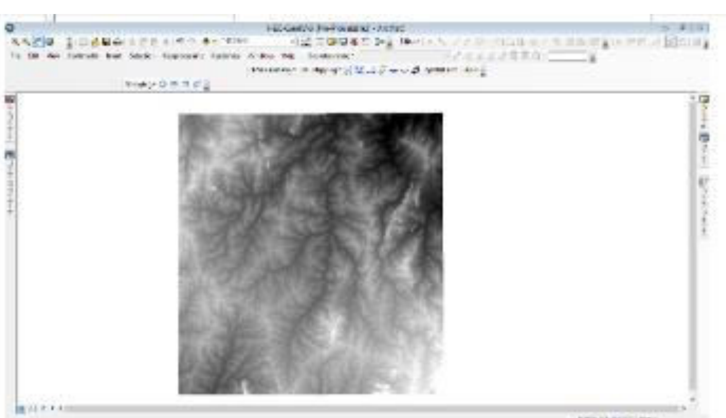
Figure 2: A USGS 30arc-sec Digital Elevation model for Oyun River basin

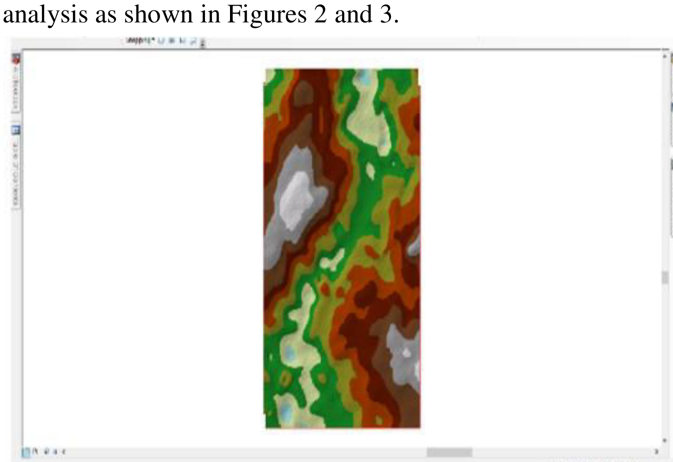
Figure 3: Oyun River basin TIN converted from the Digital Elevation Model

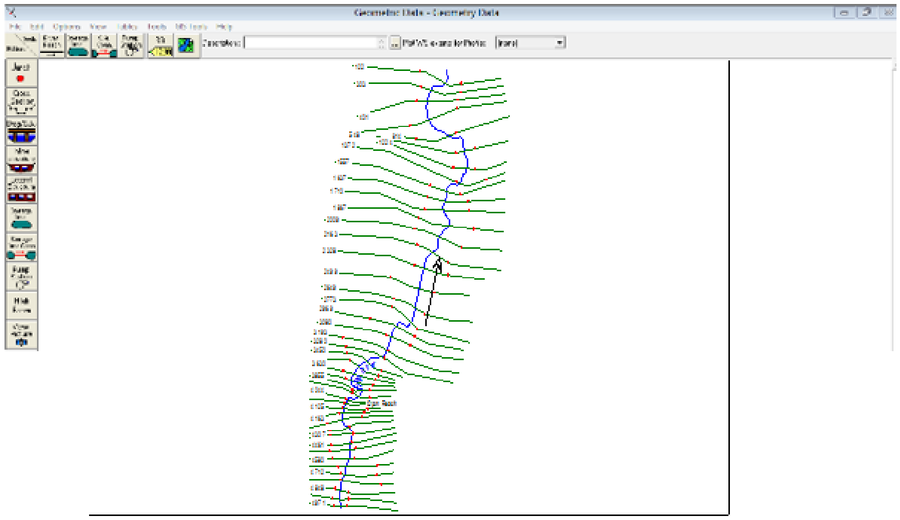

Figure 4: Oyun River Geometric Data

Using the RAS Geometry function; stream centre-line, river bank, flow path lines, cross-sections was created as shapes files for preprocessing. The land use map was used to generate the Manning's 'n' values for Oyun River basin. After all layers were created and digitized, the GIS data were exported to Hec-Ras. Figure 4.13 shows the geometric data of Oyun River basin. River discharge data was used as the upstream boundary condition while normal depth was used as the downstream boundary condition for the analysis. These boundary conditions require the input of the Energy Grade Line (EGL) slope at the downstream boundary. River cross-sections were used at 100 meters distance each. The profile plot is shown in Figure 4 while Figure 5 shows the Oyun River water surface profile.

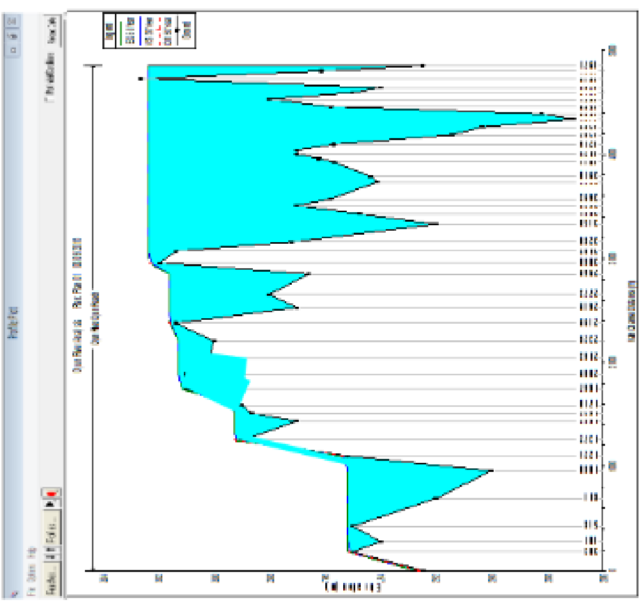

Figure 5: Oyun River Water surface Profile Plot

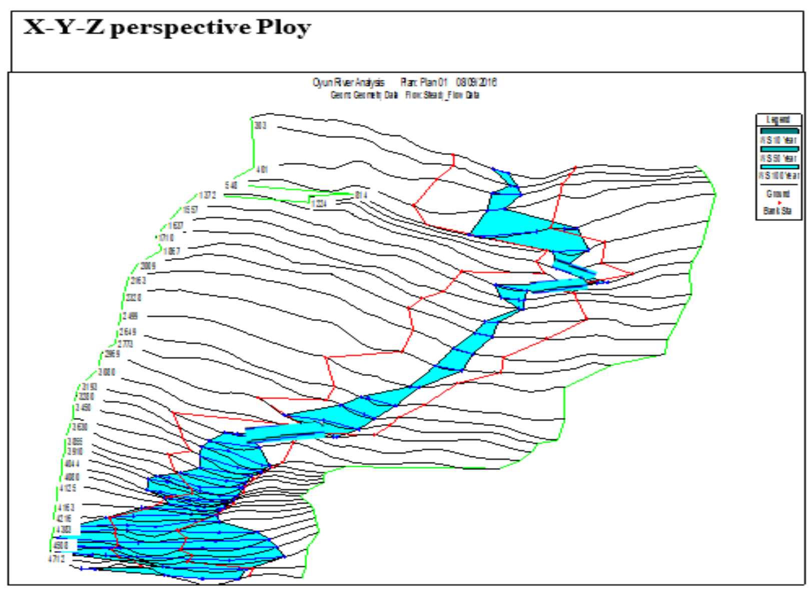

Figure 6: Oyun River 3-D Water Surface Profile

Results obtained from the analysis of Hec-Ras were used to generate the water surface profile which indicated that flood inundation area were at low lying areas within the Oyun River reach covering total area of 11.217 m^2 while the depth of the inundation area varied from 0.6 m to 2.8 m, respectively as shown from Figures 7 to 9. The HEC-Ras modelled results obtained were compared with the flood inundated areas of Oyun River basin measure at different periods. The results showed R^2 value of 0.857 as the flood inundated area is more on outside Oyun River reach due to various factors including excess rainfall, seepage, waterlogging, soil moisture, topography and land use. Most of these factors were not considered in the analysis. It would be better if these factors are analyzed briefly to supplement the results.

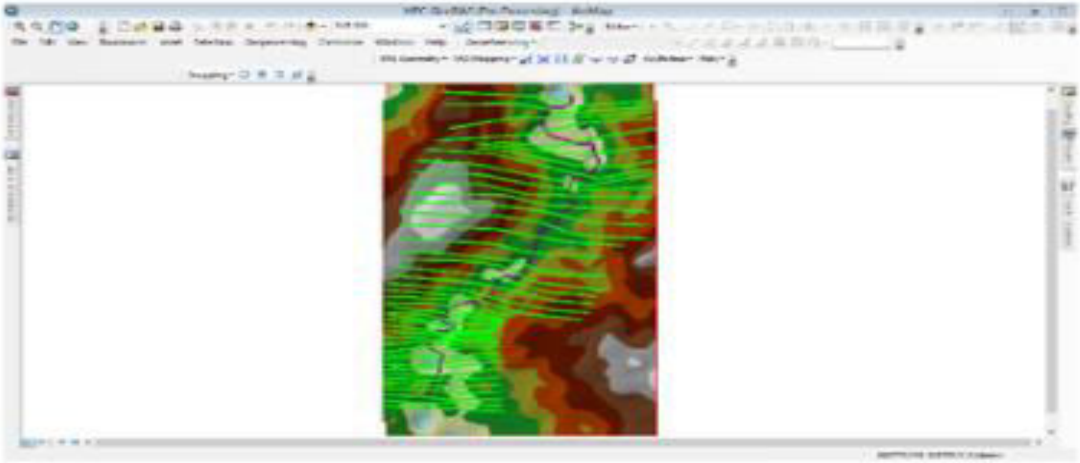

Figure 7: Oyun River basin TIN shown Oyun River cross-section lines

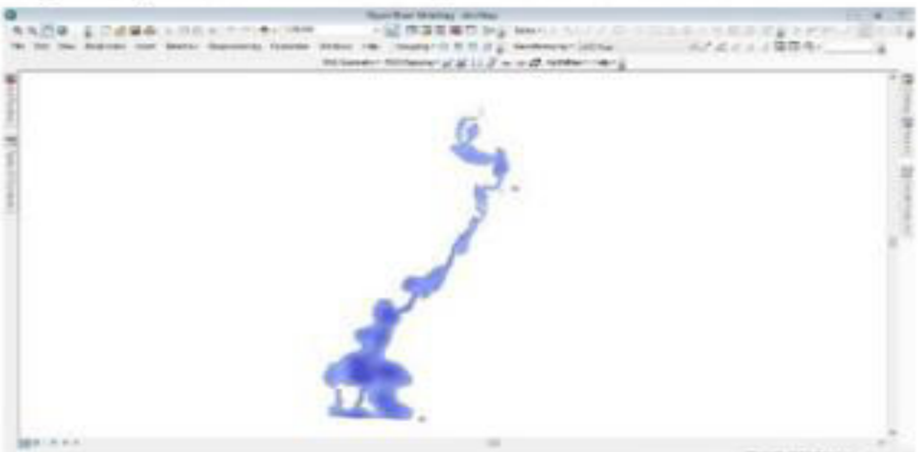

Figure 8: Flood Inundation map of Oyun River Overlaid on ArcGIS Hec-GeoRas

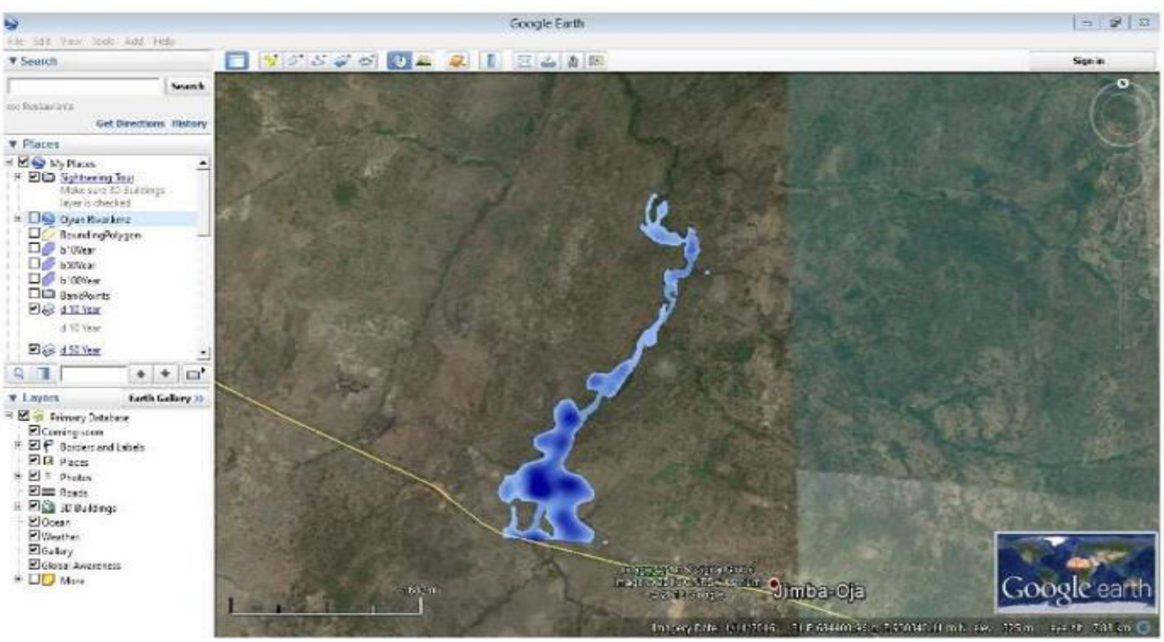

Fig 9: Flood Inundation Map of Oyun River Overlaid on Google Map

Conclusion and Recommendation

Flood inundation simulation is an important aspect of hydrologic processes for flood risk management that enables us to take decision on whether to issue flood warning or not. Developmental research design was used in this study to map the floodplain of Oyun River basin. However, the simulation of the flood inundated area using Hec-Ras model was successful for the Oyun channel reach and the flood inundated area beyond the river reach. The floodplain map which was overlaid on the Google map of Oyun River basin shows the area of flood inundation.

It was also believed that the results obtained from this study will provide large-scale information to governments and agencies for better policy and decision making for flood control and integrated water resources management. The need to investigate the flood risk management using HEC-RAS hydrologic model is highly recommended.

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