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Hydrological Modelling of Potential Flood Areas from ASTER DEM Using Arc Hydro Tools and HEC-HMS

Anthony Goji Tumba[1]
1.Faculty of Geoinformation and Real Eastate
Universiti Teknologi Malaysia
81310, Johor Bahru, Malaysia
2.Department of Surveying and Geoinformatics
Modibbo Adama University of Technology
P.M.B. 2076, Yola
Adamawa State, Nigeria
anthonytumba13@yahoo.com

Danboyi Joseph Amusuk[2]
1.Faculty of Geoinformation and Real Eastate
Universiti Teknologi Malaysia
81310, Johor Bahru, Malaysia
2.Department of Surveying and Geoinformatics
Waziri Umaru Federal Polytechnic
P.M.B. 1034, Birnin Kebbi
Kebbi State, Nigeria
danboyiamusuk64@gmail.com

***Abstract*—This study used the Arc hydro tools to delineate the drainage characteristics of the study area in order to provide spatial parameters for the identification of potential flood areas. The interest was to simulate the hydrologic behaviour of flow discharge from the upstream areas in order to provide vital hydraulic information for flood mitigation purposes. The Arc hydro tools was used to provide the needed hydrologic flow parameters. Simulation of flow discharges was actualized in the HEC_HMS environment, from already identified sub basins. Information for flood prediction in the study area were identified and derived by the model tool. The result obtained identified the drainage or pour points of steep slope as the first point of potential erosion and flood. Potential flood areas were identified as places of low elevation that have the highest discharge channeled towards them, based on the simulated volume discharge per cubic meter seconds (cms) at their inflow junctions. This information is a useful and vital hydrological data for planning mitigation measures against flood through adequate engineering design and standard.**

Keywords—Hydrological, Modeling, potential flood, Arc hydro, HEC-HMS

I. Introduction

The menace of incessant flooding has become so pronounced that it has become an issue of annual budgets, in many nations, in order to mitigate its effects. It is estimated that, between 1900 and 2016, flooding has caused global loss of about $US 700 billion and have led to millions of deaths (Lai *et al.*, 2016). Studies have also shown that about 22% of natural hazards responsible for shortages in food supply in developing countries is as a result of flood and droughts (FAO, 2015; Neale and Weir, 2015). Flooding occurs when surface water introduced into stream or river channels exceeds its carrying capacity due to increase in water volume passing through its drainage channels. The major issues in flooding are the intensity and duration of rainfall and the steepness of stream gradients and watershed. Although at the global level, flooding has been attributed to climate change (Poussin *et al.*, 2015), the obvious causes of flooding however, still remains inadequate drainages to contain the volume of water flowing from the upstream catchments. The downward flowing water, especially during flash flood (Azmeri *et al.*, 2016) normally lead to substantial damages to human and animal species living within and around the plain of such stream or river channels. Studies by FAO has shown that relatively small hydrologic floods could trigger a brake in the chain of food supplies (FAO, 2015), leading to food disaster situation. While major extreme floods on the other hand could lead to loss of human lives and investments. These damages carry with them not only the losses, but also financial burden to both the affected communities and the governments.

In most advanced economies, flood prediction measures are available as a result of advances in weather prediction models, and mitigation measures are always put in place against emergency cases. However, in developing countries, solutions to the cases of incessant flooding have always been limited to the resettlement ‘scheme’ and distribution of aids, in what is termed, “relief materials”. The idea to provide a lasting model solution to mitigate flooding beyond the relief material, perhaps, have never been thought of. As a tradeoff from previous models; which is always policy and political in nature, this study attempts to employ a GIS model approach from remotely sensed DEM to find the remote causes of flooding using the hydrology of the study area. The aim is to provide spatial hydrological data for planners and engineers so that a lasting solution can be proffered to mitigate potential flood disaster during the design and engineering works stage. This is because events on hydrological services around the world have shown that the hydrological engineers, this days, prefer creation of aesthetic and agricultural wash lands out of potential flood zones (Park *et al.*, 2012) based on knowledge from hydrological models.

II. Hydrological Models

Hydrology encompasses the occurrence, distribution, movement and quality of the waters of the earth and their environmental watershed sustainability (USGS, 2016). The design and construction of any hydrological engineering work requires an up to date adequate knowledge of the catchment's runoffs and watersheds (Oleyiblo and Li, 2010). Hydrological modelling has proven to be an economically viable and ecologically safe method for planning (Haldar and Khosa, 2015; Kauffeldt *et al.*, 2016) in water resources management and development. Hydrological models are a morphology of the flow parts of a Watershed (Mockler *et al.*, 2016), depicting the, flow direction, flow accumulation, stream definition, stream segmentation, catchments, adjoint-catchments, drainage lines, pour points and other general characteristics of river or water channels. Therefore, the understanding of these hydrological parameters gives an insight into what kind of behaviour to expect from downward flowing water from upstream catchments into the lower drainage channels. These models provide enough spatial hydrological evidences to delineate potential flood areas.

A. *Potential Flood Areas*

Potential flood areas, are places that are likely submerged or engulfed by water due to overflow from the channels or drainages. In coastal areas, they are places along the river banks and contributing streams. However, in non-coastal areas, they are areas that gets flooded, especially during heavy down pour, due to their geographic location with respect to slope gradient. These areas are mostly located at down streams of adjoining catchments or watersheds.

III. STUDY AREA, MATERIALS AND METHODS

A. *Study Area*

The study area is Jos North local government area of Plateau state, in central Nigeria (figure 3.1). It is an area of about 291km², located between Latitude 9º 49' 30" and 10º 03' 00", and Longitude 8º 51' 00" and 9º 00' 00". Specifically, this area is an integral part of the plateau from which the state derived its name. It is a metropolitan city and commercial hobnob of central Nigeria. Its population of 429,300 (2006 census) has of recent suffered tremendously from incessant flooding. In 2012, about 35 deaths were recorded and 200 houses destroyed (Vanguard, 2012); rendering many homeless. As a result of this urban flood, property worth millions of Naira were also lost excluding farmlands.

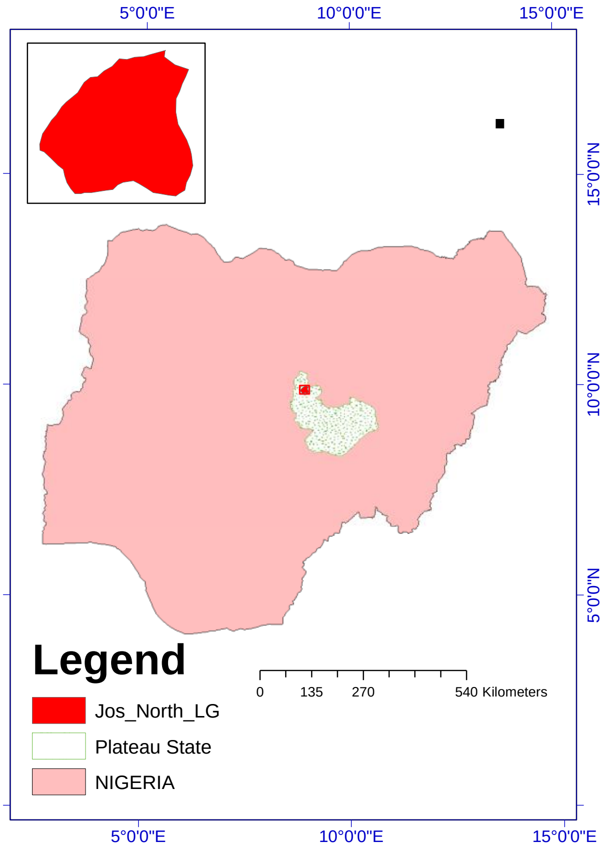

Figure 3.1: Study Area Location

Although government provided relief materials and medical assistance to the affected communities, the menace of this flooding still remains if adequate measures are not taken to curtail future occurrences. To assist in planning during engineering works and design, this study presents the main drainage pattern of Jos North, its hydrology and hydraulics for proper and efficient planning.

B. *Materials*

The materials for the study consist of the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) and the digital elevation model (DEM) of the study area downloaded from *www.usgs.earthexplorer*. The ArcGIS 10.3 software, with Arc hydro extension installed, and the United States' hydrologic engineering center (HEC) hydrologic modelling system (HMS) software were used for the processing of the hydrologic data. The Arc hydro tool is a hydrologic modelling tool used in the ArcGIS extension for modelling drainage morphology or patterns. The HEC-HMS is designed to simulate the complete hydrologic processes of dendritic watershed systems and can make available information about runoff from hypothetical or historical events, with and without water control or other flood-damage mitigation measures in a watershed (HEC, 2008).

C. Methods

The ASTER DEM having a spatial resolution of 30 meters was first filtered (low pass 3x3) in the ArcGIS

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environment, using the spatial analyst neighbourhood tool, to reduce the significance of anomalous cells by smoothening them. This helps to eliminate unwanted elements of the raster pixels. The Arc hydro tool extension of the ArcGIS was then used to fill the sinks in the DEM model, so that artificially created sinks, as a result of the iteration by the sensors are filled. This was followed by determining the flow direction (fdr). The 8D (eight neighbour) flow direction method was employed. The 8D applies the segregation, that for each cell, there are 8 possible neighbouring cells through which water can flow. The flow accumulation (fac) was determined, to give the accumulation of flow as it goes downstream. A stream definition (str) of 5km² threshold was applied to delineate the streams. This means any stretch of water channel having an area of 5km² and above, should be delineated as stream. Stream segmentation was applied (strlnk) to segment streams into classes. Catchment grid delineation (cat) was done, which was polygonised to delineate the sub basins. This vector catchment polygon enabled the determination of other vector data like the main drainage lines, adjoint catchments, drainage points, longest flow part for catchments, longest flow part for adjoint catchments and the slope. These parameters necessitates the determination and prediction of flood prone areas.

In the HEC_HMS, a basin model was created for the entire catchment. Sub basins which form the catchment area were also identified. Stream junctions, reach elements (used to convey stream flow) and outlets were marked, based on the combination of the drainage lines and the sub basin divides or adjoint catchments. Precipitation and curve number (CN) parameters for the simulation were extracted from the Global Temperature and Precipitation maps and the harmonized world soil data (HWSD) web sites respectively. A 24hour ungauged simulation was done for the catchments, to simulate the behaviour of flow from the sub basin channels. This is because the area in question, is an urban flood area. Ungauged simulations, are hydrological simulations from data that are interpolated (Gumindoga *et al.*, 2016). Initial abstractions were set at zero for all the sub basins; that is, water droplets are initiated from zero. The Muskingum routing method which uses knowledge of the cross section and flow properties of the area was used to channel flow through the reaches. This is to enable the predictions of potential flood parameters of the catchments.

IV. RESULTS AND DISCUSSION

A. Watershed and Adjoint Catchments

The delineated watershed in the Arc hydro is shown in figure 4.1. The frame in set shows the entire watershed or catchments; these are areas that serve as temporary basins for water to collect before flowing downstream. However, the main upstream aggregate polygon that collects water in to the mainstream drainage lines is the adjoint catchments. Areas of the watershed that do not form the adjoint polygon are inflow receiving areas. These are also areas that are likely flooded in the event of a heavy down pour.

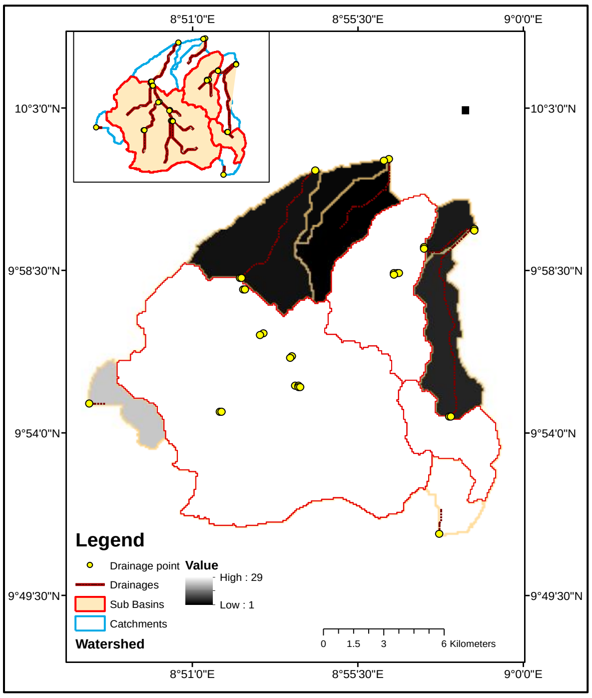

Figure 4.1: Delineated watershed Basins

In the main frame figure, two stream lines (drainage) are visualized. One on the western side, and the other on the eastern side. These stream lines, punctuated by "pour points" are served by eleven sub basins that contribute inflow into the catchments; seven on the western outlet and four on the eastern outlet. This can further be visualized in figure 4.2 below.

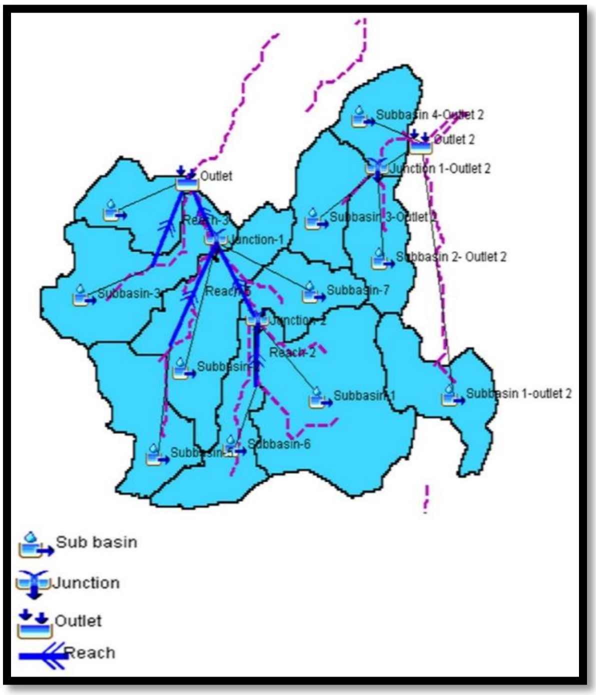

Figure 4.2: HEC_HMS Basin Model

Figure 4.2 shows the HEC_HMS model of the entire basin. It can be seen that the inflow from the upstream catchments through the drainage lines into the outlets continue downstream into the lower portion of the basin from the upstream sub basins. Areas beyond the outlets are therefore potential flood areas, depending on the volume of inflow from the upstream catchments and the elevation of the place above mean sea level. At the junctions, also known as drainage points (pour points), there could be flooding as a result of erosion, because this is where volumes from the sub basins and reaches combine. For instance, in junctions 1-outlet 1 and junction 1-outlet 2; (figures 4.3 and 4.4), about 39cms and 9.7cms flow are respectively channeled into the outlets. In outlet 1, a total volume of 46.6cms was recorded out of which reach 3 and sub basin 4 contributed 8.9 and 4.9 cms respectively.

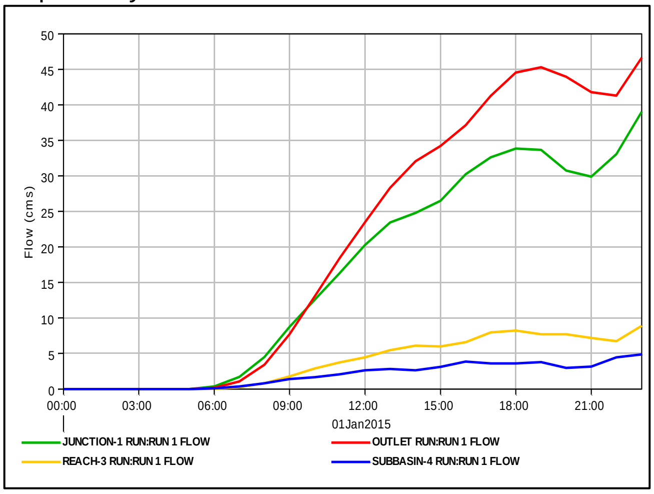

Figure 4.3: Volume Flow at Outlet 1

In outlet_2, aside from the 9.7cms volume from the junction, 5.8cms and 3.8cms comes from sub basins 1 and 4 respectively, via undefined routes. It can also be observed that the initial volume inflow which stated with zero abstraction began to accumulate after 6 hours of simulation; which is essential for flood prediction and early warning.

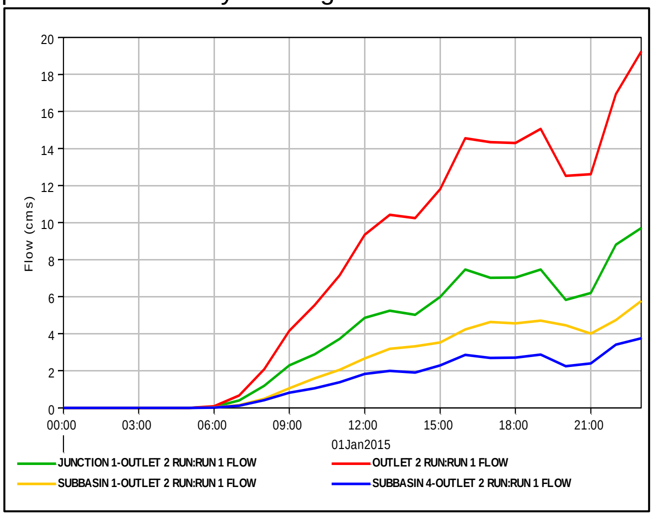

Fig. 4.4: Volume Flow at Outlet 2

A Potential Flood Areas

As earlier stated, potential flood areas are areas close to or around the stream channels that are likely flooded due to overflow of the drainage banks. In this section an analysis of the catchment point junctions is first done. For instance, in figure 4.6, the two junctions each discharge 39cms and 21cms respectively down to the outlet.

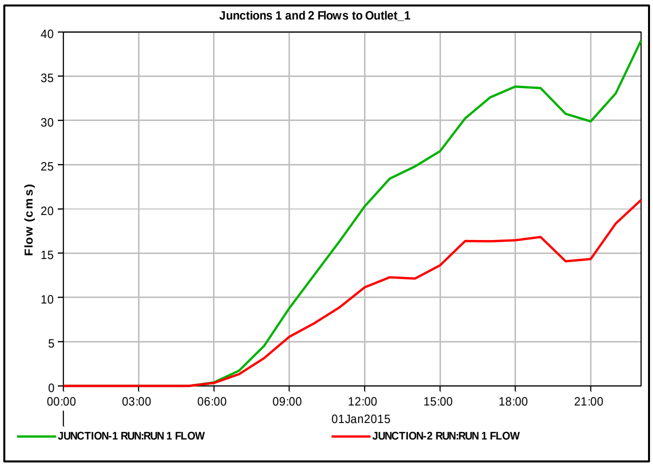

Figure 4.5: Inflow at Junctions 1 and 2

The effect of this is that any area around this discharge points are potentially vulnerable to erosion and flooding; the gravity of which is dependent upon the slope gradient and porosity of the soil type, defined by the soil curve number (CN).

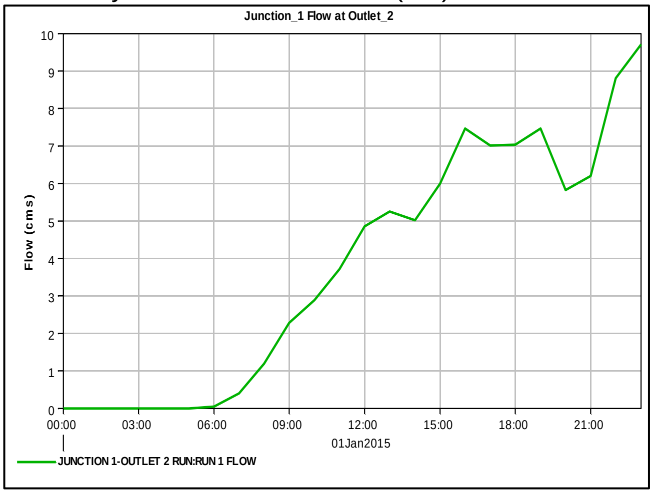

Figure 4.6: Inflow at Junction 1 of Outlet_2

In figure 4.6, it is observed that the eastern side of the basin model contains only one junction which discharges its content into outlet_2. Although it discharges about 9.7cms into the outlet, the flow of discharge from sub basins 1 and 4 direct into the outlet, as previously observed in figure 4.2, is a potential for surprise flooding.

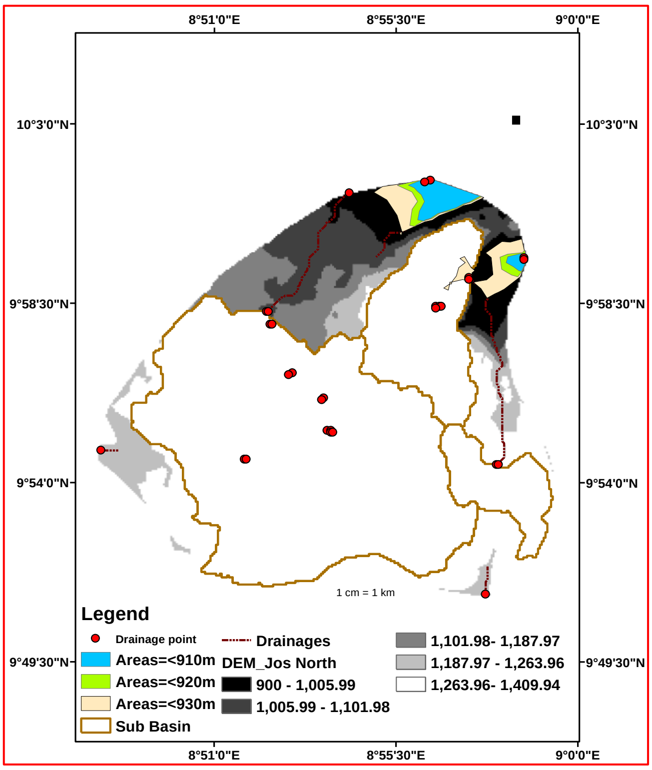

Figure 4.7: Simulated potential Flood Areas

As can be observed from figure 4.7, the lowest elevation in the study area is 900m, and as earlier stated, all areas around clustered pour points are potential flood zones. However, simulation of rise in water or discharge level at certain locations in the study area revealed a total of 3.486km² area will be submerged by flood if the discharge level rises to about 910m. On the other hand, if the discharge level rises to 920m, an area of about 4.856km² is affected. A further rise of about 930m renders an area about 10.072km² susceptible to flooding. It can also be observed that these areas are places of lower elevation and located on steep gradients. However, other structural obstacles on the drainage way may alter the extent of area that may be affected by the flood.

V. CONCLUSION

The study focused on the drainage characteristics of the study area in order to delineate flood potentially vulnerable areas. The interest was to simulate the hydrologic behaviour of flow of discharge from the upstream areas in order to provide vital hydraulic information for flood mitigation purposes. The Arc hydro tools provided the needed hydrologic flow parameters, like the catchment polygons, adjoint catchment, drainage lines and pour points. While the simulation of flow discharges was achieved in the HEC_HMS environment, providing information for flood prediction in the study area. Although urban flood is not easily determined because of complexity in structures and engineering work locations, the study has been able to use the digital elevation characteristics of the study area to come up with locational and dimensional flood data that can be useful in emergency cases. The model presented does not serve as a solution to the problem of flooding, but rather, as a vital hydrological data for planning mitigation measures against flood: through adequate engineering design and standard.

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