Flood Inundation Mapping of Gbaganu Area Minna, Niger State

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Abstract

Flooding in recent times has become a critically problematic phenomenon of spatio-temporal order and considerably high frequency of occurrence all over the world. Gbeganu area of Minna covering an area of 16.389hectares within Niger state, Nigeria has witnessed and is still witnessing multivariate cases of flooding which attains its peak in the rainy seasons (April-October) of every year, sometimes resulting to loss of life and economic valuables/properties. In order to curb this menace, an integrated solution of drainage morphometric parameters with remote sensing and geographical information system capacity is thus herein presented using the downloaded Shuttle Radar Topography Mission (SRTM) of 1-arc second (30m resolution) which covers nearly the entire Niger State and the DEM of the study area was extracted and digital elevation model (DEM) generated from topographical point data (position and elevation of points within the area) taken with Differential Global Positioning System receivers and the satellite image of the study area to delineate watershed, contributing area, flow direction and flow path/channel. The Height Above the Nearest Drainage (HAND) tool was used on ArcGIS software for analyses. The study was able to produce a map depicting within the study area; regions that are highly susceptible to flood. The morphometric analysis of flood inundation hazard in the area watershed shows that the risk to building will be more serious in the nearest future meanwhile the implementation of flood countermeasures and the identification of priority areas for flood risk reduction using flood inundation map will also help to reduce the flood impacts within the study area.

Keywords: *Flood inundation mapping, digital elevation model, remote sensing, geographical information system and height above the nearest drainage*

INTRODUCTION

Floods can be explained as excess flows exceeding the transporting capacity of river channel, lakes, ponds, reservoirs, drainage system, dam and any other water bodies, whereby water inundates outside water bodies areas (Getahun and Gebre, 2015). In many parts of the world, flood is one of the most expensive and devastating natural hazards especially in urban areas (Emmanuel, *et al.*, 2016). Nigeria is one of the luckiest countries on earth in respect to water resources. But we must acknowledge that flooding and water stress in Nigeria, Africa and across the world, are environmental challenges that need intervention to ensure sustainability (Magami, *et al.*, 2014). Periodic floods occur on many rivers; these rivers overflow for reasons like excess rainfall, water ways blockage, etc. (Magami, *et al.*, 2014). Flooding in recent times has become a critically problematic phenomenon of spatio-temporal order and considerably high frequency of occurrence especially in coastal nations / states (Odumosu, *et al.*, 2014). It therefore, becomes necessary to effectively estimate and forecast flooding so as to prevent its ill-effects. On a small area basis, fully empirical solutions could suffice, however as extent coverage increases and consequently drain network becomes more complex, deterministic and reservoir runoff models with graphical capability becomes the best approach. This makes the use of GIS for flood monitoring and control a very efficient tool (Odumosu, *et al.*, 2014). The availability of digital elevation data has made it easy to compute topographic characteristics such as slope, specific catchment area and the wetness index. Often, topographic characteristics are computed from regularly spaced grids of elevation values called digital elevation models (DEMs). River hydraulic geometry is an important input to hydraulic and hydrologic models that route flow along streams, determine the relationship between stage and discharge, and map the potential for flood inundation give the flow in a stream reach. Traditional approaches to quantify river geometry have involved river cross-sections, such as are required for input to the HEC-RAS model (David, *et al.*, 2017). Extending such cross-section based models to large scales has proven complex, and an alternative approach, the Height Above Nearest Drainage (HAND) uses multi-directional flow directions derived from a Digital Elevation Model (DEM) using the D-Infinity method in TauDEM software (http://hydrology.usu.edu/taudem) to determine the height of each grid cell above the nearest stream along the flow path from that cell to the stream (David, *et al.*, 2017). With this information, the depth of flow in the stream, the potential and depth of flood inundation can be determined (David, *et al.*, 2017). The aim of this study is to model flood inundation of Gbaganu area Minna, Niger State using Height Above Nearest Drainage (HAND) tool with a view of predicting, controlling and managing flood effect by acquiring satellite image of the study area from google Earth, determining the river network and boundary of the study area, downloading and generating the Digital Elevation Models (DEMs) of the study area using remote sensing and conventional ground surveying method, modelling the flow direction of the study area using Height Above the Nearest Drainage (HAND) tool, generating the flood inundation map of the area and validating the map by overlaying the flood inundation map on the DEMs.

2.0 STUDY AREA

As measured on Google Earth Imagery, (2019), Gbeganu is an area covering 16.389hectares located within Minna, Niger state. Situated along Mina-Bida expressway. Gbeganu area has a stream called "Shanu River" within it running through the south-western part of the area. This area lies within 227546.056mE, 1061858.331mN and 228471.065mE, 1061331.973mN.

Study shows that flood occurrences in the Gbaganu Area Minna, Niger State has always caught many in surprise in terms of its magnitude, extent as well as the huge resultant damages of public facilities and lives claimed. This area was one of the worst hit areas, being affected by three (3) major floods within a short period of five (5) years. However, looking at the situation of the environment in Gbeganu Area of Minna, Niger state, there has been a lot of abuse and disturbance on the ecological system in the area like buildings in the water ways, closing up of drainages, improper waste disport, etc. which has been causing a lot of damage to the residents, hence generating a flood inundation map of the area using Height Above Nearest Drainage (HAND) will help depict the regions prone to much effect of flood considering the stream running through the middle of the area. Figure 1.1 is the map of Nigeria shows the location of Niger state, Figure 1.2 is the map of Niger state shows local government areas boundary and depicting the location of Minna in red colour while Figure 2.1 is the map of Gbeganu area of Minna (map of study area)

Figure 2.1: Map of the study area

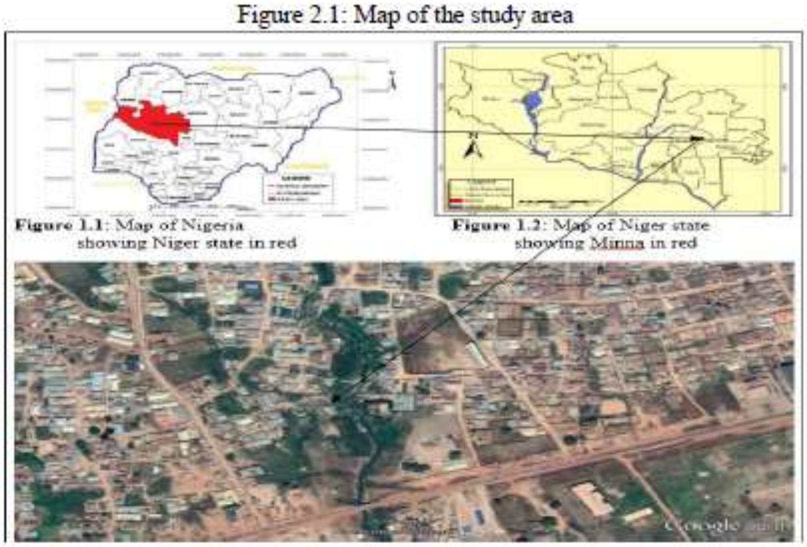

Figure 1.1: Map of Nigeria showing Niger state in red

Figure 1.2: Map of Niger state showing Minna in red

3.0 LITERATURE REVIEW

3.1 Flood

Flood is a natural hazard that resulted from combination of hydrological and meteorological factors. It occurs when a normally dry land areas are temporary inundated due to overflowing of water at the natural or artificial confines of a river, including groundwater caused by prolonged or heavy rainfall. (Martini and Loat, 2007; Klijn, 2009; Anuar, 2018). Hydrologists define flood as a sudden increase in water discharge that caused a sudden peak in the water level. Once flood is over, the water level will drop back to near-constant base flow or no flow. As summarized by Anuar, (2018), flooding is when water and/or sediments exist at unwanted areas other than the water body. Thus, flood can be categorized into different types based on location of occurrence and what cause them. The major ones are the river flood, coastal flood, urban flood and flash flood.

3.2 Flood prone areas

The areas adjacent to a river prone to flooding can be defined as floodplain and floodway. A flood area that is deep with high flow velocities with presence of debris flow that can cause possible erosion is identified as floodway. There should be no development allowed to take place within the floodway area except for critically necessary infrastructure such as bridges (Anuar, 2018). A floodplain on the other hand represents the areas surrounding the river channel (including floodway) that can be inundated during the occurrence of a flood (Anuar, 2018). The boundary of a floodplain cannot be defined as the magnitude of a flood is limitless. The higher a point in the floodplain is, the lesser the probability of inundation. A flood line however can be drawn up to define a floodplain area based on the water level of a flood with specified annual exceedance probability. No development should take place within this flood line. In the field of flood risk management, the confusion is not only arising in use of risk related definition, but also in the naming of different flood maps (Anuar, 2018). For instance, Anuar (2018), proposed four type of flood map namely as flood danger map, flood hazard map, flood vulnerability map and flood damage risk map. In general, flood map can be defined as a map presenting the area prone to flooding at one or more floods with given return periods. Flood maps are created by various institutions and used by many stakeholders. The main producers of flood map either at local scale or basin scale are governmental institution and private company particularly to insurance company or cooperation between the government and private company. Anuar (2018) highlighted that the use of flood maps serves at least one of the three purposes of flood risk management which are: Preventing the build-up of new risks (planning and construction), reducing existing risks, and adapting to changes in risks factors.

3.3 Drainage morphometric analysis using Height Above the Nearest Drainage (HAND) Tool

The most widely recognized methodology for routing flow over a terrain surface represented by a grid DEM is the eight-direction method (D8) where the bearing of steepest plummet towards one of the eight (side and diagonal) neighbouring grid cells is used to represent the flow field (Odumosu, *et al*. 2014). Other methods include the D-infinity multiple flow direction (D∞) (Odumosu, *et al*. 2014) and Rho 8.

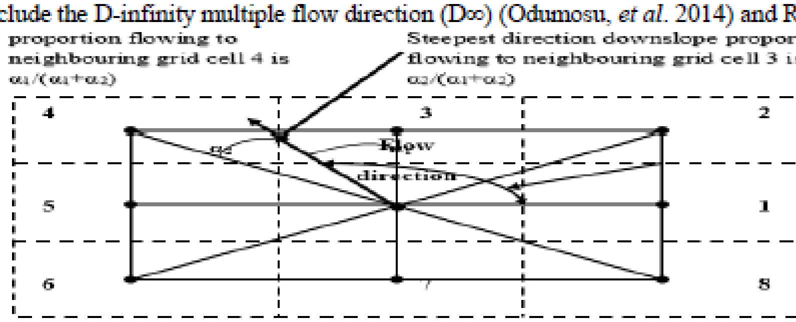

Figure 3.1: D-8 multiple flow direction model (Odumosu, *et al*. 2014)

Flow direction defined as steepest downwards slope on planar triangular facets on a block cantered grid. All flow field methods assign flow from each grid cell to one or more of its adjacent neighbours. In grid DEMs the basic model element is a grid cell, but the same concepts can be applied to any set of topologically connected model elements.

The flow proportions assigned to each downslope element are positive and should satisfy the conservation constraint viz:

$$\sum_j P_{ij} = 1 \quad (3.1)$$

where, P_{ij} denotes the flow proportions assigned to each cell.

Thus, the general accumulation function for each grid is defined as the integration of a loading field over a contributing area as:

$$A = \int_{CA} w.da \quad (3.2)$$

where, A is the general accumulation function, CA denotes the contributing area and integration of loading field is given as w.

Recursive algorithm for evaluation of accumulation in the D8 case that was extended to multiple flow direction methods (Odumosu, *et al.*, 2014). Numerically, flow accumulation is evaluated recursively for each element as:

$$A_i = w_i\Delta + \sum_{(k:\,P_{ki}>0)} P_{ki}\, A_k \quad (3.3)$$

where, i is a location in the field, represented numerically by a model element such as grid cell in a DEM and A_i represents the accumulation at that element. The model element area is Δ and the $(k{:}\, P_{ki} > 0)$ notation denotes that summation is over the set of k values such that $P > 0$ (i.e., summing the contribution from neighbouring elements k to element i).

Height Above the Nearest Drainage (HAND) metric which was formalized by Renn´o, *et al.*, (2008) is based on the principle of D8 multi-flow direction algorithm. This metric may be more adequate to identify Drainage morphometric different landscape units than the traditionally used elevation above mean sea level. HAND calculates the elevation of each point in the catchment above the nearest stream it drains to, following the flow direction. It thus extracts from the relatively uninformative topographic elevation the far more informative "hydrologic" elevation, thereby increasing the hydrologic information content of elevation data (Nobre *et al.*, 2011).

Input data for HAND were stream raster and Digital Elevation Model (DEM), the process was supervised and the flow chart was re-organised and the output given were; watershed, flow direction and fill (flow accumulation area) and basins.

4.0 RESEARCH METHODOLOGY

4.1 Conceptual design

For successful completion of this study an algorithm or work flow that consist the step by step process or procedure to the study was developed. Figure 4.1 shows the work process which begin from the acquisition of the required data which are the satellite imagery, topographical point data samples, and the digital elevation model of Gbaganu area.

The next step is to begin the data processing, which are further classified or divided into image registration, vectorization, boundary and stream network rasterization, drainage morphometric analysis and mapping flood inundation of the area. *Image registration process* make use of the satellite image and the topographical point data samples which produced a geo-referenced satellite image of Gbaganu area, *Vectorization process* make use of the registered satellite imagery, *boundary and stream network rasterization* make use of the vectorised boundary and stream network of the area, the *Drainage morphometric analysis* make use of the Digital Elevation Models (DEMs) data and the stream network raster. The drainage morphometric analysis also involves the fill analysis, the flow accumulation analysis. the flow direction analysis and the basin analysis. These analyses help in the determination of the areas that are very vulnerable to flood and the areas that are not vulnerable to flood and the process of *mapping flood* *inundation* of the area involve the usage of Digital Elevation Models, Satellite image, boundary, stream network and the flow accumulation from morphometric analysis.

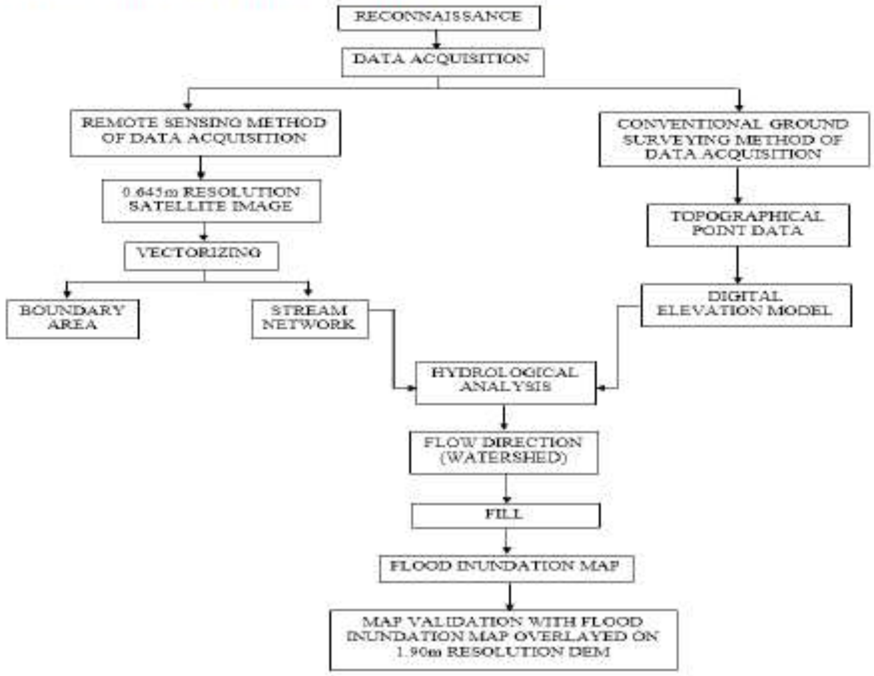

Figure 4.1: Methodology work flow

4.2 Data acquisition

Some of the method of collecting data include point data samples, aerial photogrammetry, remote sensing etc. but for the purpose of this study the method employed were point data sample from ground surveying method and remote sensing method of surveying. The data required for the completion of this study are: (i) Satellite image of the study area, (ii) Point data samples of the study area and (iii) Digital Elevation Models of the study area.

4.2.1 Satellite image

The satellite image of Gbeganu was downloaded from Google Earth which is an open software. After launching the google Earth program, Gbeganu area was searched and zoomed into. Once it got zoomed to the desired resolution (0.645metres), the page was saved.

4.2.2 Point data samples from ground surveying method

A Differential Global Positioning System (DGPS) receivers with model V30 pro was used to acquire the Northing, Easting and Height coordinates of points over the study area. The DGPS base receiver (with serial no.: 10000203 and pin: 0201010131) was setup on station PBBM 7605 with coordinate 228080.1984mE, 1061440.1193mN and 227.6545mH, the rover receiver (with serial no.: 10000346 and pin: 0201010131) was connected to the base receiver. The selected reference geoid was EGM2008 for geoidal height realization. The DGPS was operated on Hi-RTK (High-target Real Time Kinematics) mode after which scattered points were picked all around the study area.

4.2.3 Digital Elevation Models (DEMs)

4.2.3.1Downloaded SRTM DEM

The Shuttle Radar Topography Mission (SRTM) is an international research effort that obtained Digital Elevation Models (DEMs) on a near-global scale ranging from 56^0 S to 60^0 N, so as to generate the most complete high resolution digital topographic database of the Earth. The downloaded SRTM DEM is of 1-arc second (30m resolution) which covers nearly the entire Niger State. Figure 5.5 shows the DEM of the study area extracted from the downloaded SRTM DEM. The DEM is arranged in tiles each one covering one degree of longitude and one degree of latitude and are named according to their south-western corners.

4.2.3.2 Generated Digital Elevation Model (DEM)

Northing, Easting and Height (N, E and Z) coordinates of points observed on the site were extracted from the entire result given by the Differential Global Positioning System (DGPS). These extracted coordinates were imported into ArcGIS software on which kriging tool was used to generate a 1.90m resolution Digital Elevation Model (DEM) of the study area.

4.3 Image registration

Image registration which also mean image geo-referencing refers to the process of converting photo coordinate or image coordinate to a ground coordinates or geographical coordinates. For the purpose of this study, the downloaded satellite image of the study area was imported into the ArcGIS software and was geo-referenced using coordinates of corner points gotten from the topographic point data samples observed on the site.

4.4 Vectorization

For the course of this study, ArcGIS 10.3.1 software was used for the vectorization of boundary and stream network and also used to extract the Digital Elevation Model (DEM) of the study area. ArcGIS is a geographic information system (GIS) software package developed by Environmental Systems Research Institute (ESRI) that runs on Microsoft windows operating systems, it handles raster, vector and elevation data and also provides viewing, conversion, coordinate projection and other general GIS functions, it has an active user community with a mailing list and online forums.

4.5 Boundary and stream raster depiction

For clear evaluation of this process, a 0.645m resolution satellite image of the area gotten from google Earth program, from where the boundary and stream network were vectorised after the satellite has imported to the ArcMap environment. The vectorised boundary and Stream network were then converted to raster. The converted boundary was then used to mask the DEM to the exact shape of the area.

4.6 Drainage morphometric analysis

4.6.1 Watershed

Watershed is the upslope area contributing flow to a given location. Such an area is also referred to as a basin, catchment, sub-watershed, or contributing area. A sub-watershed is simply part of a hierarchy, implying that a given watershed is part of a larger watershed. Watersheds can be delineated from a DEM by computing the flow direction and using it in the watershed function. The watershed function uses a raster of flow direction to determine contributing area.

4.6.2 Flow direction

Flow direction or drainage network shows the path or the direction the water will follow in the process of flowing. It determines which direction water will flow in a given cell. Based on the direction of the steepest descent in each cell, in addition, the z-value difference and slope are calculated between neighbouring cells. Slope is the ultimate factor of how water flows in any model. Hydrologists use flow direction model to model surface runoff contributes to flooding; flow direction calculates the direction water will flow using slope from neighbouring cells. When water flows in the east direction, it has a value of 1, when it flows west, it has a value of 16. All 8 adjacent directions at a given can be described using the eight-direction pour point model as given in Figure 3.1.

4.6.3 Flow accumulation (FILL)

The flow accumulation (FILL) function calculates accumulated flow as the accumulated weight of all cells flowing to each downslope cell in the output raster. If no weight raster is provided, a weight of one is applied to each cell, and the values of cells in the output raster will be the number of cells that flow into each cell.

4.7 Mapping flood inundation of the area

The outputs were then used along with the boundary and the 0.645m resolution downloaded satellite image to map regions prone to flood in the area. This map was then overlaid on the DEM for analysis.

5.0 RESULTS AND DISCUSSION OF THE RESULTS

5.1 Results presentation

The downloaded map of the study area from where the boundary and the stream network were vectorised is shown in figure 5.1, the topographical point data (i.e. spot height) of the study area observed with Differential Global Positioning System (DGPS) were shown in figure 5.2, figure 5.3 shows the distribution of the point data over the study area, a 1.90m resolution Digital Elevation Model (DEM) shown in figure 5.4 was generated using the topographical point data while the 30m resolution DEM shown in figure 5.5 was downloaded from Shuttle Radar Topography Mission (SRTM) website, figure 5.6 and 5.7 shows the flow direction (watershed) and the flow accumulation respectively which were the result of the analyses performed using Height Above the Nearest Drainage (HAND) tool on ArcGIS. These results were then further analysed to generate the flood inundation map of Gbaganu area as shown in figure 5.8 which was validated by its correspondence with the wet index of the 1.90m resolution DEM as shown in figure 5.9 and its correlation with the present situation in the area.

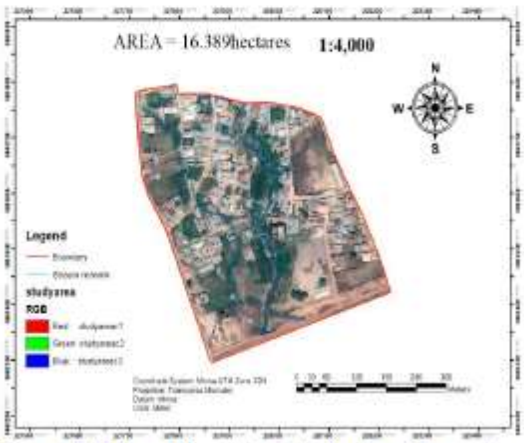

Figure 5.1: Map of the study including boundary and stream network

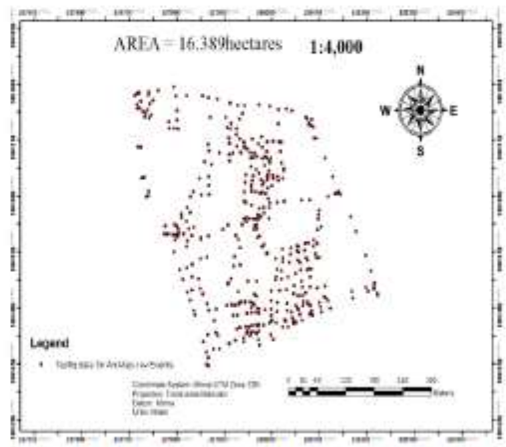

Figure 5.2: Point data gotten from Differential GPS

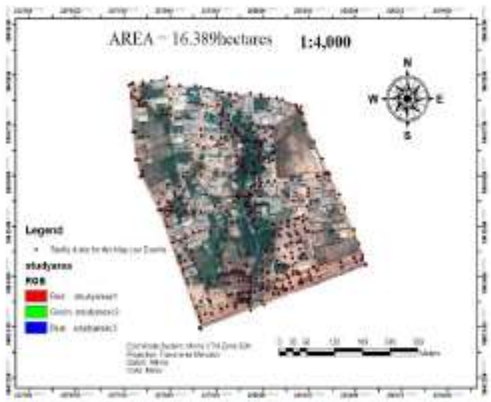

Figure 5.3: Point data distribution over study area

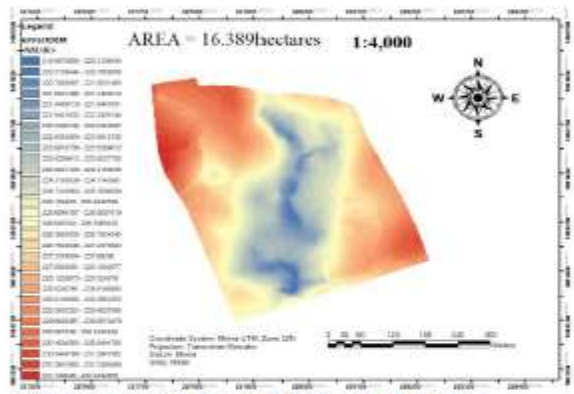

Figure 5.4: DEM generated from point data (using conventional ground survey method)

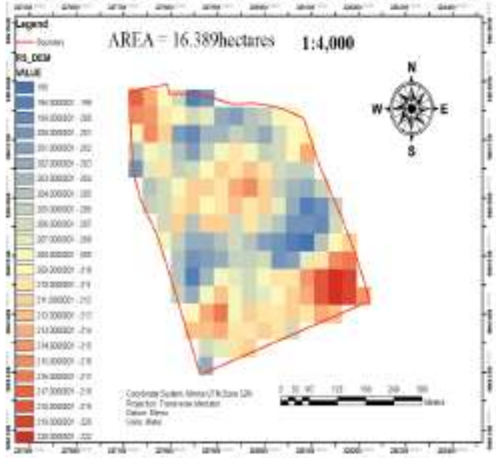

Figure 5.5: DEM downloaded from SRTM (using remote sensing method)

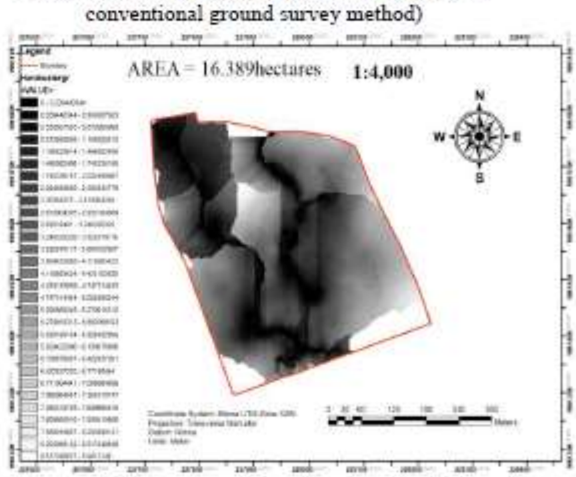

Figure 5.6: Direction of flow of water from High regions to lower regions (watershed)

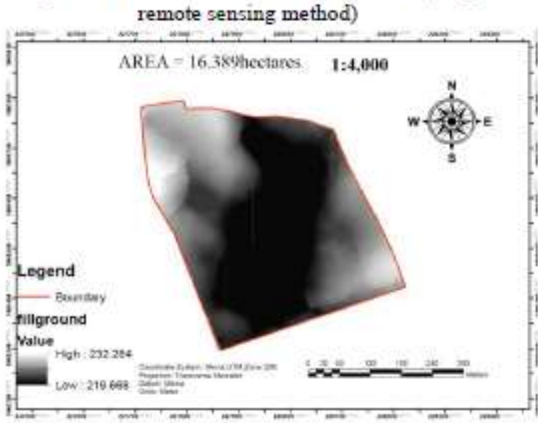

Figure 5.7: Region within the area that could be dammed

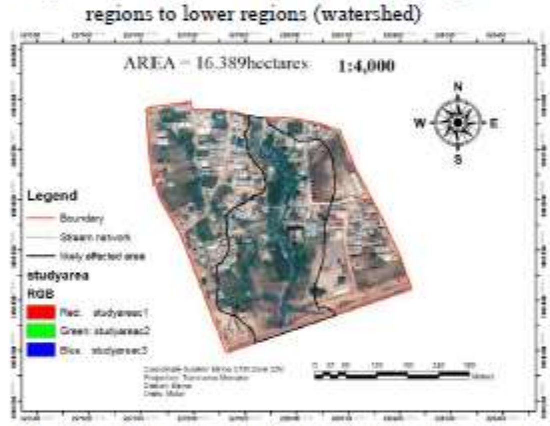

Figure 5.8: Prediction of flood effect within the area

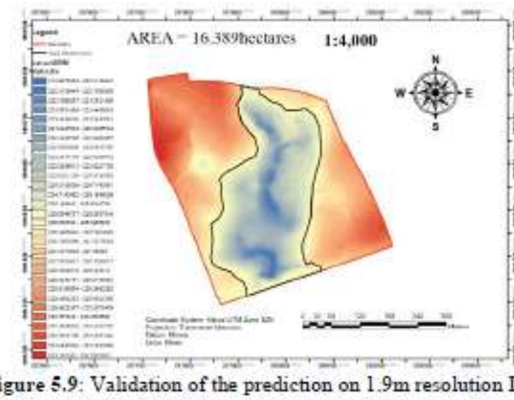

Figure 5.9: Validation of the prediction on 1.9m resolution DEM

5.2 DISCUSSION OF RESULTS

Study area boundary and stream network were vectorised from the 0.645m resolution satellite image downloaded from google earth software as shown in Figure 5.1 both of which were used along with the 1.90m resolution DEM on Height above the Nearest Drainage (HAND) tool for drainage morphometric analyses. Figures 5.2 and 5.3 show the topographical point data observed using Differential Global Positioning System (DGPS) receivers and the distribution over study area which was processed to generate the 1.90m resolution Digital Elevation Model of the study area shown in Figure 5.4.

Figure 5.5 shows the 30m resolution DEM of Gbeganu area about 16.389hectares, extracted from the downloaded SRTM DEM. The output of the drainage morphometric analyses although this was limited by the small area size, gives Figure 5.6 which depicts watershed i.e. direction of flow of water from higher ground to lower surface and Figure 5.7 shows the fill i.e. the regions with high tendency of water concentration (regions water could be dammed) in case of flood occurrence which made it clear that water passing through a region does not guarantee that the area could get flooded in as much as there is enough slope for the water to escape to a lower surface. This was further analysed and overlaid on the study area satellite image to map flood inundation within the area as shown in Figure 5.8. Regions highly susceptible to flood were encapsulated and about 77 buildings were most likely to be affected. Figure 5.9 further shows the correlation of the flood inundation map with the wet index of the 1.90m resolution DEM.

From the flood inundation map produced, development along the water course violates the rules guiding them, this in turn disturbs the ecological cycle, a case is Shanu river running through the area. This might cause continuous flooding of the area, since the river have to find a new course. This might have adverse effect on Gbeganu as a rapid developing area. Also, from the basin analysis and the satellite image, it is discovered that the region prone to flood has be developed with about 77 living edifies and can be inhabited by Gbeganu residence. Conclusively, the wet index part of the DEM were the regions identified by HAND as regions that are highly susceptible to flood.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

This paper has investigated the drainage morphometry and flood dynamics of Gbeganu via morphometric simulation using Height Above the Nearest Drainage (HAND) tool on ArcGIS software. Flood inundation hazard is very destructive and it's a common phenomenon in Gbeganu, it causes heavy damage to lives, property and economy well-being of the affected area. The morphometric analysis of flood inundation hazard in the area watershed shows that the risk to buildings will be more serious in the nearest future. The implementation of flood countermeasures will contribute to reduced flood impacts, the identification of priority areas for flood risk reduction using flood inundation map will be helpful to decision makers as they adopt strategies at local and regional scales. Flood inundation mapping considering uncertainties in flood modelling can be most useful for land-use planning in flood risk areas and can help urban planners prioritize their response measures. The prediction of flood situations will be useful for planning and designing structural and non-structural measures. Moreover, a flood inundation map might be used for early warning systems.

RECOMMENDATIONS

1. Development along water body should be monitored by appropriate authority
2. Awareness about the danger of building along flood prone areas should be given to the public by both private and governmental organisations.
3. Measures should be taken against building that fails the vulnerability test along waterways
4. Futuristic measure must be considered when planning for any development to reduce or mitigate unforeseen circumstances.
5. Conventional ground survey method should be used to generate DEM to improve resolution

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