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Assessment of Road Vulnerability to Flood: A Case Study

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ABSTRACT: *A flood-free institution and the wellbeing of students as well as the staffs of the institution are significant goals towards quality education for all.The study area is the University Road inUniversity of Lagos. Flood along this busy roadis caused byprolonged rainfallwhich happens during the rain and poor drainage system.This work assesses the vulnerability of the road to flood and uses Geographic Information Systems (GIS) tools. The vulnerability of the road to flood was determined by understudying the drain architectural system, water discharge from adjoining roads and longitudinal and cross sectional profile of the road.Data from longitudinal and cross sectional profile survey of the road were used as input in ArcGIS to determine the flow direction, flow accumulation and flow length. Findings show that there is always traffic along the road during rainfall which is as a result of flooding caused by stagnation of the rain water, lack of water outlets along the road to discharge excess rainwater into the drain, the topography of the road, sediments and refuse deposits in the drains. The need for flood flow analysis in flood management and the importance of GIS as a spatial tool for flood study has been demonstrated in this study.*
Keyword: *Flood,Flow direction, Flow accumulation, Flow length, GIS, Vulnerability*

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I. INTRODUCTION

Road development is closely inter-related with economic growth. The reverse causality is also true as roads facilitate economic development. The availability of roads is very often seen as a means to develop regions and provide people access to markets, schools and work places etc.

The past 30 years have witnessed natural disasters that have resulted in the death of not less than 4 million people and at the same time adversely affecting about 850 million people.

In July 2012, Lagos state witnessed one of the worst cases of extreme rainfall events which led to severe flooding that caused serious damage to both public and private properties.

Since time immemorial, the study area have been plagued with floods and due to the importance of the study and its peculiarity to its affected community, it is crucial to assess the vulnerability of the road to flood using tools, such as imageries and digital elevation data collections in geographic information system throughout the region.

Roads can be damaged by floods and also can enhance hazardous flood conditions. The flooding of a road induces two levels of consequences: on the one hand, people may be injured and vehicles may be destroyed; on the other hand, the disruption of traffic may have severe indirect consequences (Rogelis, 2015). Flooding in a road network can occur if there is insufficient capacity in the drainage system, water on the surface collects in depressions in low-lying areas. The contributing drainage areas can be the surrounding areas as well as direct drainage on the road (Rogelis, 2015).

While the natural causes of flood in the study area are due to heavy rainstorm, its human causes are as a result of burst water main pipes and faulty drainage systems, sedimentations and indiscriminate waste disposal in the drains and the topography of the road.

Due to the importance of roads to emergency services, the majority of the currently available approaches do not properly analyze road network connections and dependencies within systems, and as such a loss of roads could cause significant damages and problems to emergency services in cases of flooding (Albano, Sole, Adamowski, & Mancusi, 2014). Thus, it is very important to identify sections of the road that are potentially vulnerable to flooding in order to prevent and/or be adequately prepared for flooding. However, recent studies have shown that interpretations of flood-related statistical variables basically depend on the accuracy of the initial data (Koutsoyiannis, 2013).

Various people and researchers in various ways have carried out flood vulnerability assessments. Their methods are tied to the data availability, objectives of the flood vulnerability study as well as the desired results to be obtained (Olayinka & Irivbogbe, 2017).

The Description of the Project Site.

Lagos, being a coastal state, water is its most significant topographical feature. Water and wetlands cover over 40% of the total land area within the state and an additional 12% is subject to seasonal flooding (Iwugo, D'Arcy , & Andoh, 2003)

The project site(University of Lagos, Akoka) is within the Metropolis of Lagos state which constitutes about 33% of Lagos State with 455sq.km of the metropolis being water bodies, wetlands and mangrove swamps. Akoka is known to be the hub of most schools in Yaba and two major tertiary institutions in Lagos; these are the prestigiousUniversity of Lagos (popularly known as UNILAG) and the Federal College of Education (Technical), Akoka. The Akoka Community experiences unrest due to flood activities.

There exists two main seasons in the area; the rainy season and dry season, which usually lastfrom April to October and October to March respectively. The area is located in the equatorial climate region with mean annual rainfall above 1800mm and an average temperature of 27^{0}C.

The project route is the University road from UNILAG Senate junction and terminated at UNILAG first gate. The road comprises of two segments and four lanes.

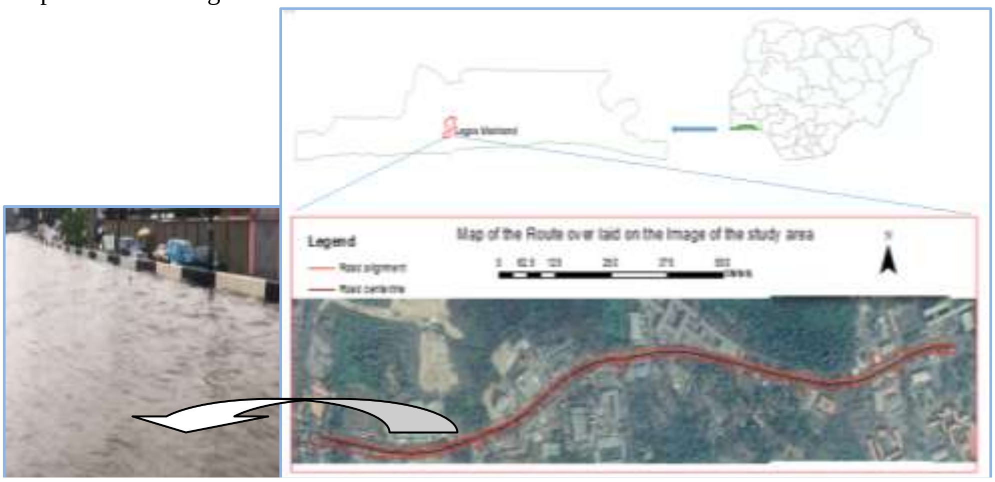

Figure 1: The Vector map of the Route overlaid on imagery of the Study Area

The length of road covers about 1.481km.Various means of transportation ranging from motor circle (Okada), Tricycle (Keke-Napep) and motor vehicles such cars, lorry, truck etc. plight this road. The road is such a busy one especially during peak and off peak periods and most often there is usually traffic congestion during this periods.The situation on this road is usually very much critical whenever there is rainfall, which results to flooding along this route. As the number of users and vehicles plighting this road keep increasing every now and then especially during rain, there is the need for mitigating the unrest created by the flood. This calls for a flood vulnerability study of the road.

II. MATERIALS AND METHOD

Data Needs.

The data requirements for the study are coordinates of control beacons to coordinate the project with its geographic location, location of structures along the road corridor and elevation (longitudinal and cross section) datasets along the road (Table I).

Table I – Data Needs

Data	Data Type	Data Source	Data Format
X,Y,Z Coordinates of points on the road	Spatial	Filed measurements	Digital
Coordinates of Control Beacons	Non-spatial	Archive of the Department of Surveying & Geoinformatics, UNILAG	Analogue

Instrumentation

The equipment used were calibrated and checked for errors before being used for data collection.

Table II – Equipment used

Equipment used	Quantity	Purpose
Total Station (Leica)& its accessories	1	Road alignment measurements and detailing of features
Level Instrument& its accessories	1	Determination of spot elevations

Geospatial Data Acquisition

All equipment used for data collection were checked and calibrated where necessary to ascertain a high level of quality data. The results of the checks confirmed that the instruments are in good order for data capture exercise.

Traverses were carried out using the total station equipment to fix all noticeable structures such a drains, culverts etc. that are along the road corridor. The level instrument was used to carryout spot height levels at 25m for longitudinal profile and 2m for cross sectional profile. Filed data collected from the total station equipment were downloaded, processed and stored as script files to be run in AutoCAD Civil 3D software, while the longitudinal and cross sectional spot height data downloaded from the level instrument were computed using the rise and fall method. This gives the nature of the undulation of points along the center line of the road. The completed AutoCAD drawings of the details (road alignment, buildings along the corridor, trees etc.) were migrated to ArcMap 10.6. These drawings were imported as shapefiles in ArcMap.

Triangulated Irregular Network (TIN)

The spot heights obtained from field measurements were added in ArcMap and converted to raster (TIN) by krigging, using the spatial analyst tool in the Arc toolbox.This is in other to show regions with height differences along the road.The extent of the road was clipped out from the TIN for better analysis.

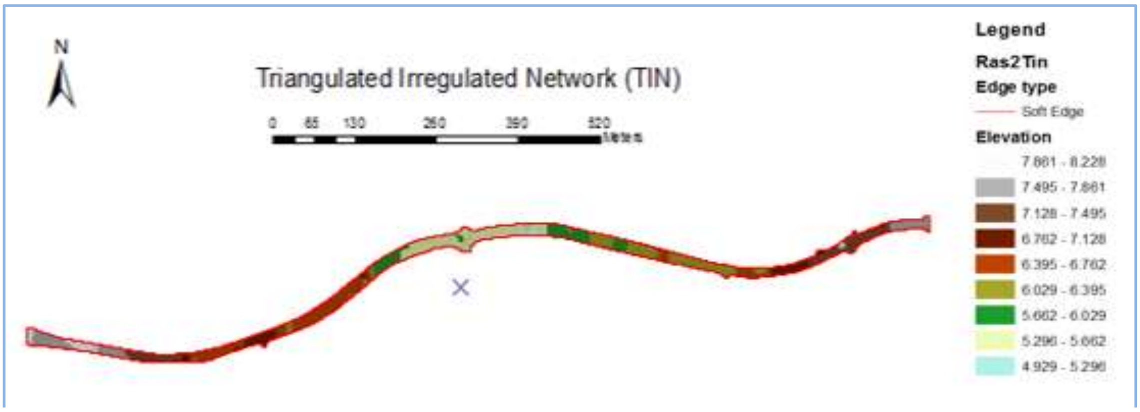

Figure 2: Triangulated Irregular Network of the study area.

Flow Direction

Flow direction is the direction which water flows in a flood area. Flow direction determines which direction water will flow in a given cell. This spatial analysis creates a raster of flow direction from each cell to its steepest downslope neighbor. This is calculated as follows:

maximum_drop = change_in_z-value / distance * 100

This tool takes the kriging surface as input and outputs a raster showing the direction of flow out of each cell. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model.For example, when water flows in the east direction, it has a value of 1. When water flows west, it has a value of 16. All 8 adjacent directions at a given point can be described using the eight-direction pour point model.

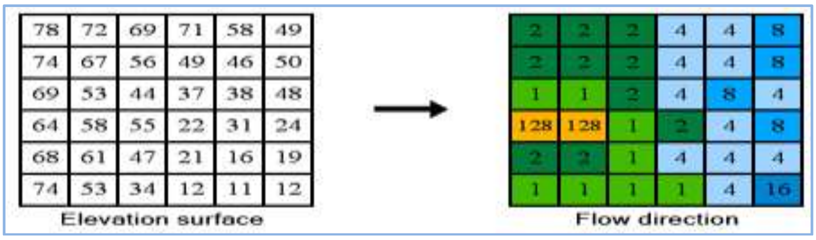

Figure 3: Direction Coding; Jenson and Dominque (1988).

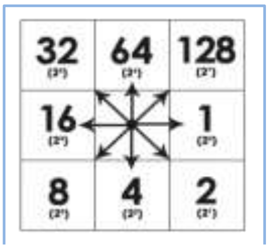

Figure 4: Flow Direction: Eight Direction Pour-Point Model

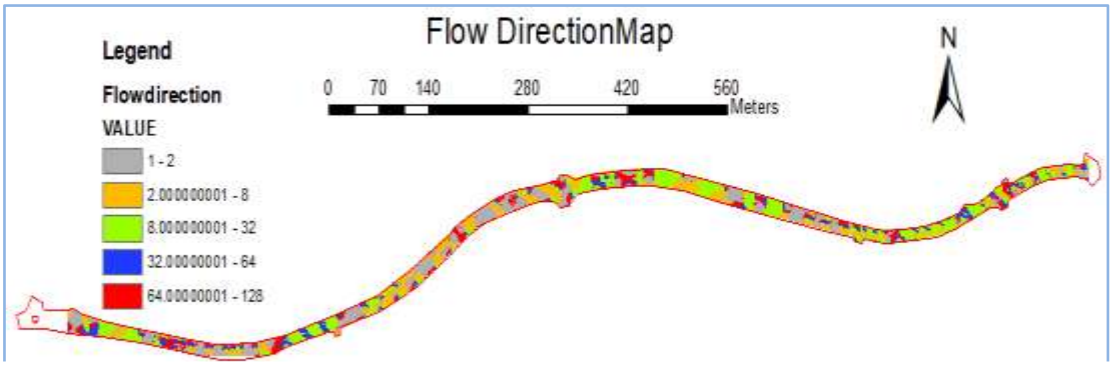

Figure 5: Flow Direction map of the study area

Flow Accumulation

Flow accumulation map contains cumulative hydrologic flow values that represent the number of input pixels which contribute any water to the outlets (or sinks if these have not been removed).

In its simplest form it is the number of upslope cells that flow into each cell (ESRI, 2013). Flow accumulation is used to find the drainage pattern of a terrain. Accumulated flows are calculated as the accumulated weight of all cells flowing into each downslope cell in the output raster. If no weight raster is provided, a weight of 1 is applied to each cell, and the value of cells in the output raster is the number of cells that flow into each cell. In the graphic below, the top left image shows the direction of travel from each cell and the top right the number of cells that flow intoeach cell(ESRI, 2013).

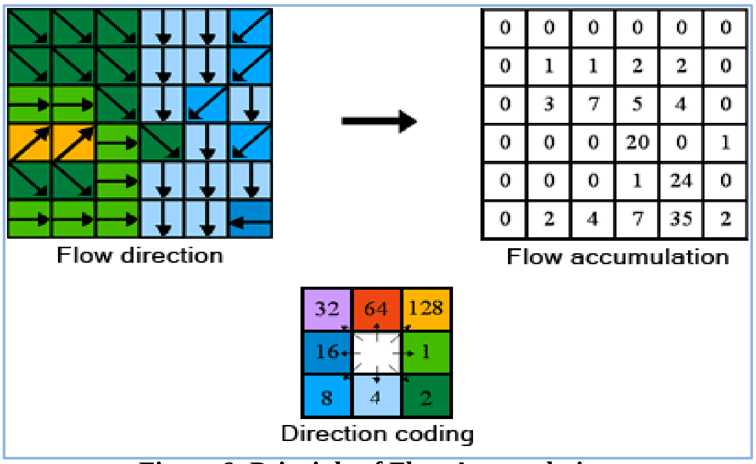

Figure 6: Principle of Flow Accumulation

Cells with a high flow accumulation are areas of concentrated flow and may be used to identify flood paths.

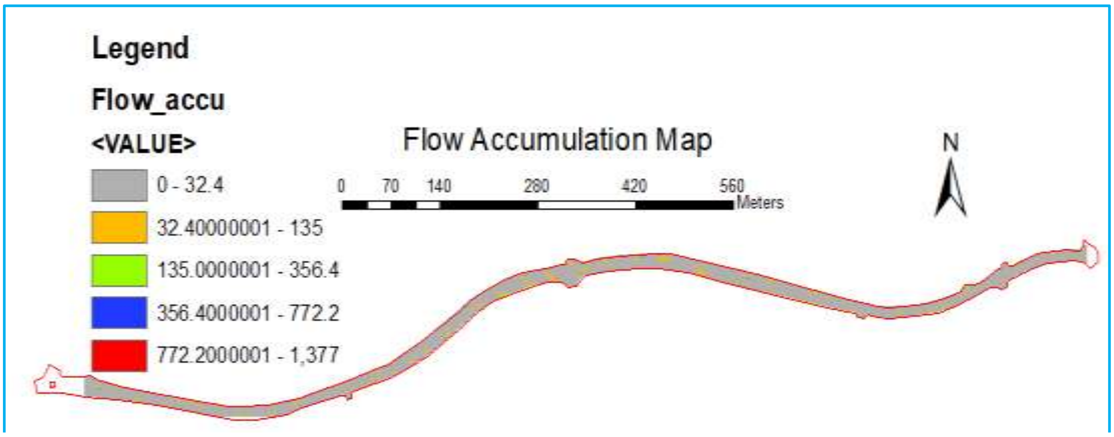

Figure 7: Flow Accumulation map of the study area

Flow Length

Finally, the flood flow pattern and analysis was done using the flow length tool in Arc toolbox. The flow length displays regions with low and high flood flow and also regions liable to flood.

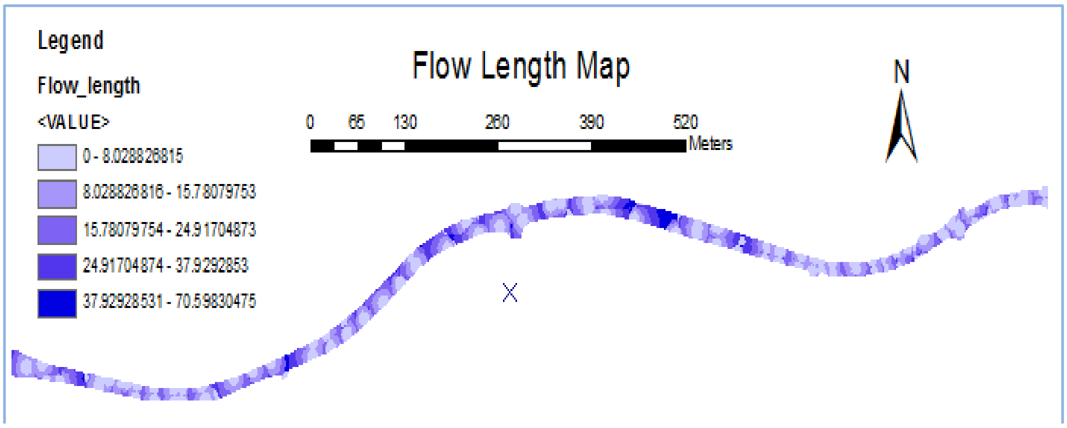

Figure 8: Flow Length map of the study area

Flood Vulnerability Map

A flood flow map is finally produced showing areas along the route that are flood prone. The flood prone areas are built and executed by a single Map Algebra expression in raster calculator that uses Python syntax in a calculator-like interface. It is a multiplication of the overlays of the flow length, flow accumulation and flow direction rasters.

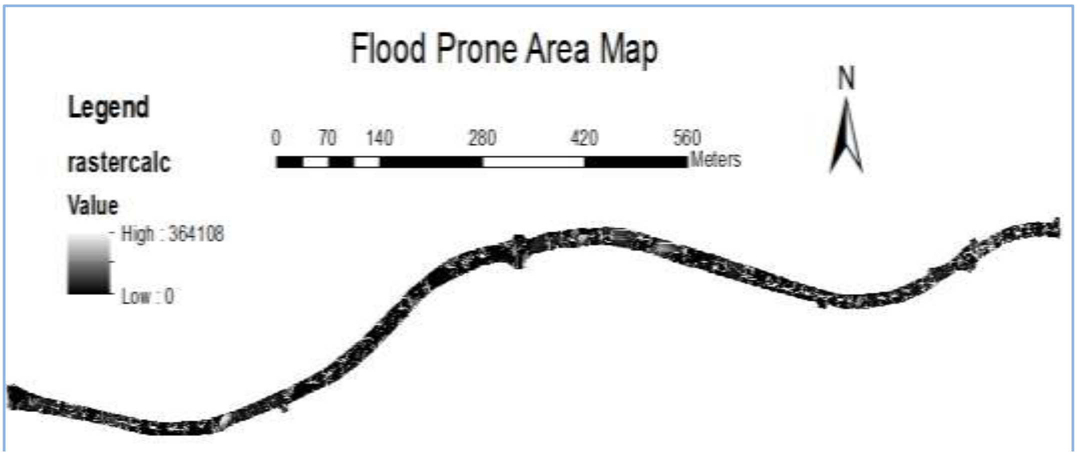

Figure 9: Flood prone areas along the route

III. RESULTS AND DISCUSSION

The flood flow patterns (Flow direction, flow accumulation and flow length) indicated that areas with high elevation tend to have low flood. Thus, all water tend to flow to places that have least elevations.

At some portions of the road, the heights of the top of the road is found to be at the same level with the drain invert. This means that there is no flow of water into the drain at such portions of the road. This is as a result of deposits of sand sediments at the bottom of the drain. The implication of this is that rainfall water stagnates on the roads thereby resulting in flooding.There are also no outlets at some portions along the road to channel rain water to the drains. Drains around the canal do not support flow of water because they have low elevation, thus hindering the free flow of water into the canal during rainfall.

A model (Flow direction) of how surface runoff contributes to flooding in the study area is shown (figure 5). This is important in hydrologic modeling because in order to determine where a flood water drains, it is necessary to determine the direction of flow for each cell in the landscape. By using hydrology tools like flow accumulation and direction,GIS has helped in understanding the flow of water during floods in the study area.

The next step in hydrologic modeling after flow direction is the flow accumulation. Flood paths are defined spatially by the geomorphological property of drainage. In order to generate a drainage network, it is necessary to determine the ultimate flow path of every cell on the landscape grid. The principle of flow accumulation (Figure 6) was used to generate a drainage network, based on the direction of flow of each cell. By selecting cells with the greatest accumulated flow, we are able to create a network of high-flow cells (Figure 7). The flood flow pattern was validated by confirming that the analyzed flood matched with the actual flood event at the different flood locations. A flood map (Figure 9) showing the overall flood prone regions on the route is finally produced. This is the result of the geoprocessing of the flood flow length, flow accumulation and flow direction.

IV. CONCLUSION AND RECOMMENDATIONS

Flooded roadways are the second leading cause of weather related fatalities. The vulnerability assessment showed that flooding in the area is caused by a combination of topography of the road, sand sediments at drain bottom and blockage of the drains by wastes.

The need to evacuate the sand deposits and refuse in the drains is envisaged to avoid continuous flooding in the future. The flood flow analysis from this present study can be used as a base for subsequent flood research and developing an alert system for related flood areas. This study advocates the inclusion of the use of GIS as a spatial tool to carry out flood flow analysis in the management of road floods.

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