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Mapping and analysis of urban drainage system in Asaba metropolis delta state using remote sensing and geographic information system

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Abstract

This study focuses on mapping and analyzing the urban drainage system in Asaba Metropolis, Delta State using Remote Sensing and Geographic Information System (GIS) techniques to improve storm water channeling. The objective is to map the existing system, determine the best routes considering natural storm water runoff, delineate drainage routes and sub catchments, and design the drainage network. The method used involves using existing topographical maps to create Digital Elevation Models (DEM), drainage route and drainage sub catchment maps. The results include digitized contour, digitized Spot Height, Triangular Irregular Network (TIN), Contour DEM, Drainage Map, Flow Accumulation, Stream Delineation Grid, Catchment Polygon, Drainage Line Map, and drainage data from the Storm Water Management Module. The study identified vital information for future development and growth of the as-built environment in the study area. The conclusion is that proper drainage design is needed, waste management boards should conduct frequent sensitization on waste dumping, and more drainage construction is needed to evacuate waste water.

Keywords: DEM; Drainage; Runoff; Geographic information system

1. Introduction

Drainage systems are essential for maintaining a clean environment by transporting waste water and sewage neatly to disposal points. They include components like closed ditches with pipe drains, drainage pipes, channels, and conduits. Sustainable drainage systems aim to manage water quantity, water quality, and amenity issues in the environment, considering long-term environmental and social factors. They regulate surface water runoff and simulate natural drainage as closely as possible, reducing flooding causes and impacts, removing pollutants from urban runoff, and combining water management with recreation and wildlife.

Subsurface tile drain systems, which have increased the ratio of subsurface to surface drainage, are the focus of this study due to their limited locational information and complex layouts. Detecting these systems is valuable for assessing field hydrology and understanding water flow in agricultural areas. Remote sensing has been established as a key strategy due to its ability to reduce human intervention and constraints in large areas.

In Nigeria, there is a significant need for properly managed sustainable drainage systems to manage surface water runoff. Neighborhoods are often unplanned, leading to clogged gutters and a lack of proper planning for drainage and waste disposal. Proper planning is crucial for reducing the impact of waste on the environment and promoting sustainable development.

Drainage systems are crucial in maintaining a clean environment and preventing overflowing gutters. They ensure the transportation of waste water and sewage to disposal points, preventing unsanitary conditions and environmental

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degradation. Sustainable drainage systems, which consider long-term environmental and social factors, aim to manage water quantity, quality, and amenity issues. These systems regulate surface water runoff close to its source, simulate natural drainage, and reduce flooding impacts. They also remove pollutants from urban runoff, enhance water quality, and protect natural flow regimes in watercourses. By combining water management with recreation and wildlife, sustainable drainage systems help protect natural flow regimes and improve water quality.

The research aims to address issues such as blockage in major drainage systems, proper waste water collection, adequate drainage design, and proper channeling of waste water. Flood control is crucial in areas like Asaba ShopRite through Okpanam Road, as proper drainage prevents water logging and mosquito breeding. Improper drainage can compromise structural integrity, affecting motorable paths and pedestrian walk paths. Studies are needed to provide efficient drainage systems for handling storm water runoff. The study focuses on the position, distribution, and alignment of drainages in urban areas, as assessed by Gumbo et al (2002) at the University of Zimbabwe. The study combines a Digital Elevation Model (DEM) with a rainfall-runoff model based on the Soil Conservation Service South African Manual (SCS-SA). Storm drainage coverage in Zimbabwe is closely linked to road networks, and the problem persists due to nonchalant attitude of road users and contractors.

This study aims to map and analyze the urban drainage network in Asaba Metropolis using remote sensing and GIS to provide information on natural and artificial factors, aiming to improve storm water channeling. The objectives of the study are as follow:

- Map the existing urban drainage system in Asaba Metropolis.
- Determine the best routes considering the natural flow routes of storm water runoff of Asaba metropolis.
- Delineate drainage route and subcatchment of the corresponding drainage routes in the study Area.
- Design the drainage network of the study Area.

1.1. Description of the Area of Study

Asaba Metropolis is the capital city of Delta State, Nigeria, located at the western bank of the Niger River. With a population of over half a million people, Asaba is known for its social activities and amenities, such as hotels, clubs, cinemas, malls, and event centers. The city is known for its high crime rate, including pickpocketing and robbery.

Asaba's location on the Onitsha bridge separates it from Delta and Anambra state. Founded in 1884, Asaba was once the colonial capital of the Southern Nigeria Protectorate. Between 1886 and 1900, it hosted the Royal Niger Company, which has since grown into UAC Nigeria PLC. Scottish explorer William B. Balkie remarked on Asaba's importance in trade and education during a trade treaty with Igbo chief Ezebogo. Asaba is known as the regional capital of the Anioma area due to its influential history, geography, and strategic political and economic influence in Nigeria. The city is situated on a terrace of the lower Niger River, overlooking the point where the Anambra River flows into it. The historic Niger River forms a connector between western, eastern, and northern Nigeria through the Niger River and via the Asaba Niger Bridge. Given its location, Greater Asaba occupies an area of about 300 square kilometers and maintains an average tropical temperature of 32 °C during the dry season and an average fertile rainfall of 2,700 millimeters during the rainy season.

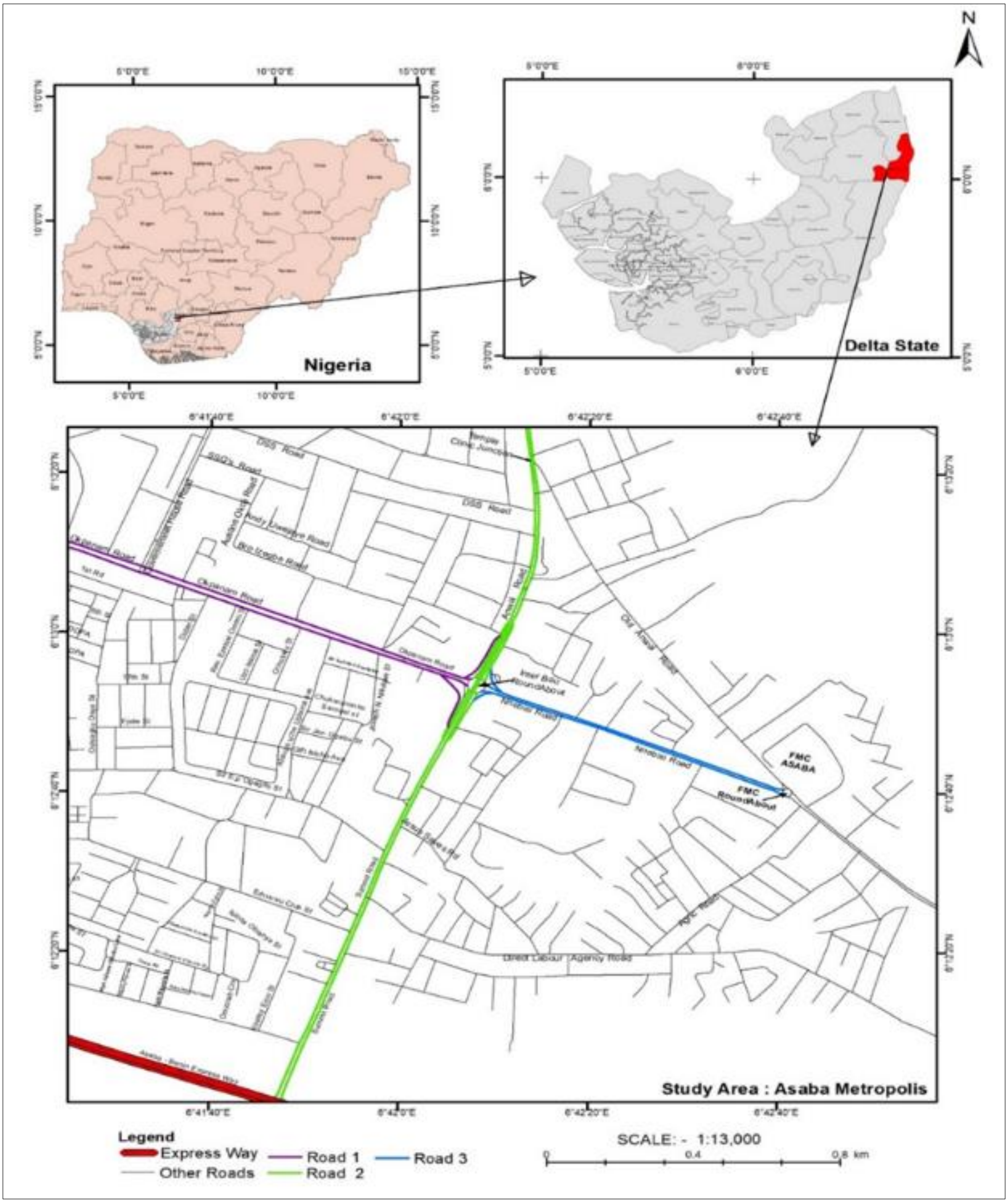
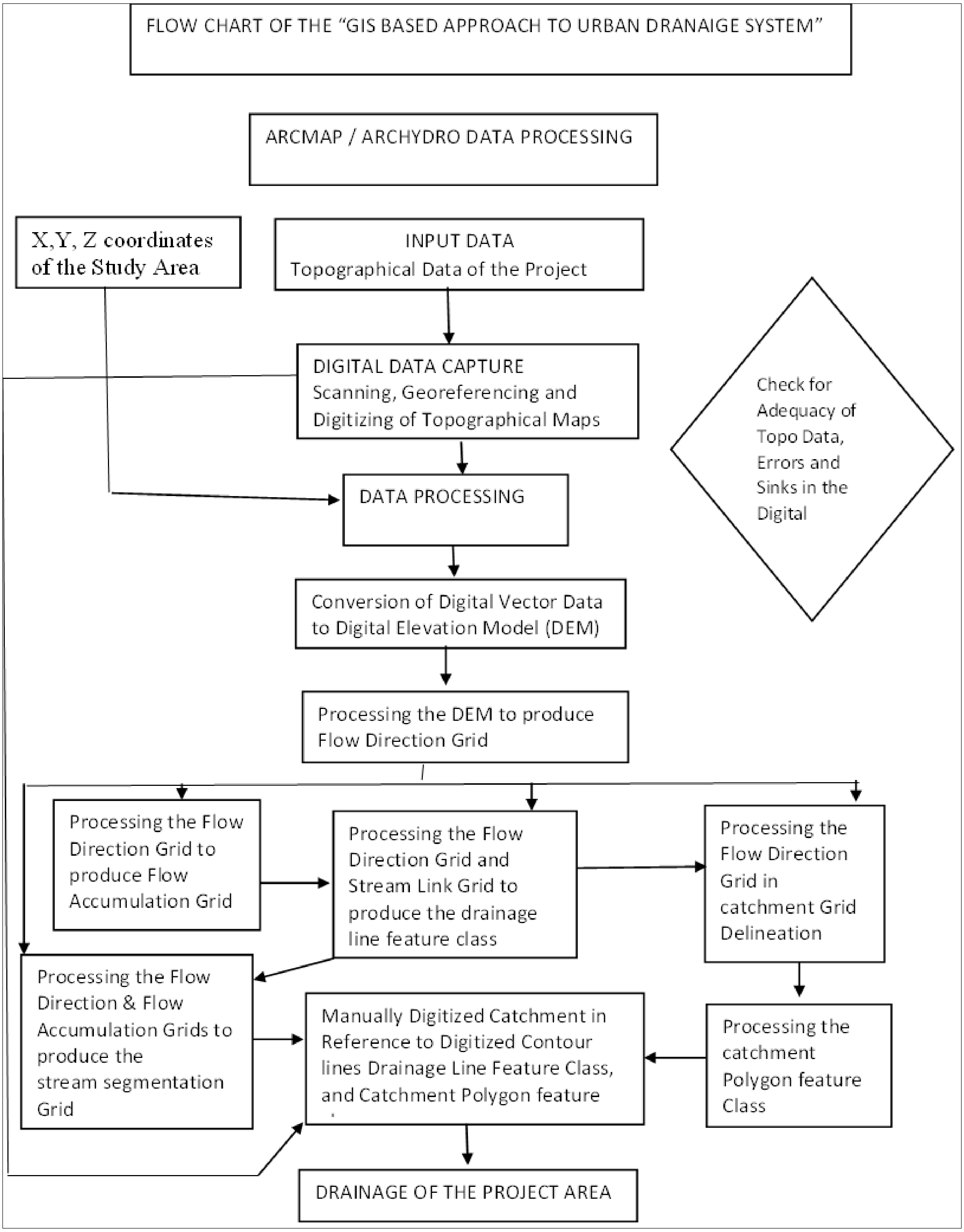


Figure 1 Descriptive Map of the area of Study

2. Materials and Methods

The study utilized existing topographical maps to create Digital Elevation Models (DEM) on a GIS platform, which were then processed to create drainage route and subcatchment maps, enabling effective urban area runoff management. The flowchart of the methodology is presented in the figure below.


FLOW CHART OF THE "GIS BASED APPROACH TO URBAN DRANAIGE SYSTEM"
ARCMAP / ARCHYDRO DATA PROCESSING
X,Y, Z coordinates of the Study Area
INPUT DATA
Topographical Data of the Project
DIGITAL DATA CAPTURE
Scanning, Georeferencing and Digitizing of Topographical Maps
Check for Adequacy of Topo Data, Errors and Sinks in the Digital
DATA PROCESSING
Conversion of Digital Vector Data to Digital Elevation Model (DEM)
Processing the DEM to produce Flow Direction Grid
Processing the Flow Direction Grid to produce Flow Accumulation Grid
Processing the Flow Direction Grid and Stream Link Grid to produce the drainage line feature class
Processing the Flow Direction Grid in catchment Grid Delineation
Processing the Flow Direction & Flow Accumulation Grids to produce the stream segmentation Grid
Manually Digitized Catchment in Reference to Digitized Contour lines Drainage Line Feature Class, and Catchment Polygon feature
Processing the catchment Polygon feature Class
DRAINAGE OF THE PROJECT AREA

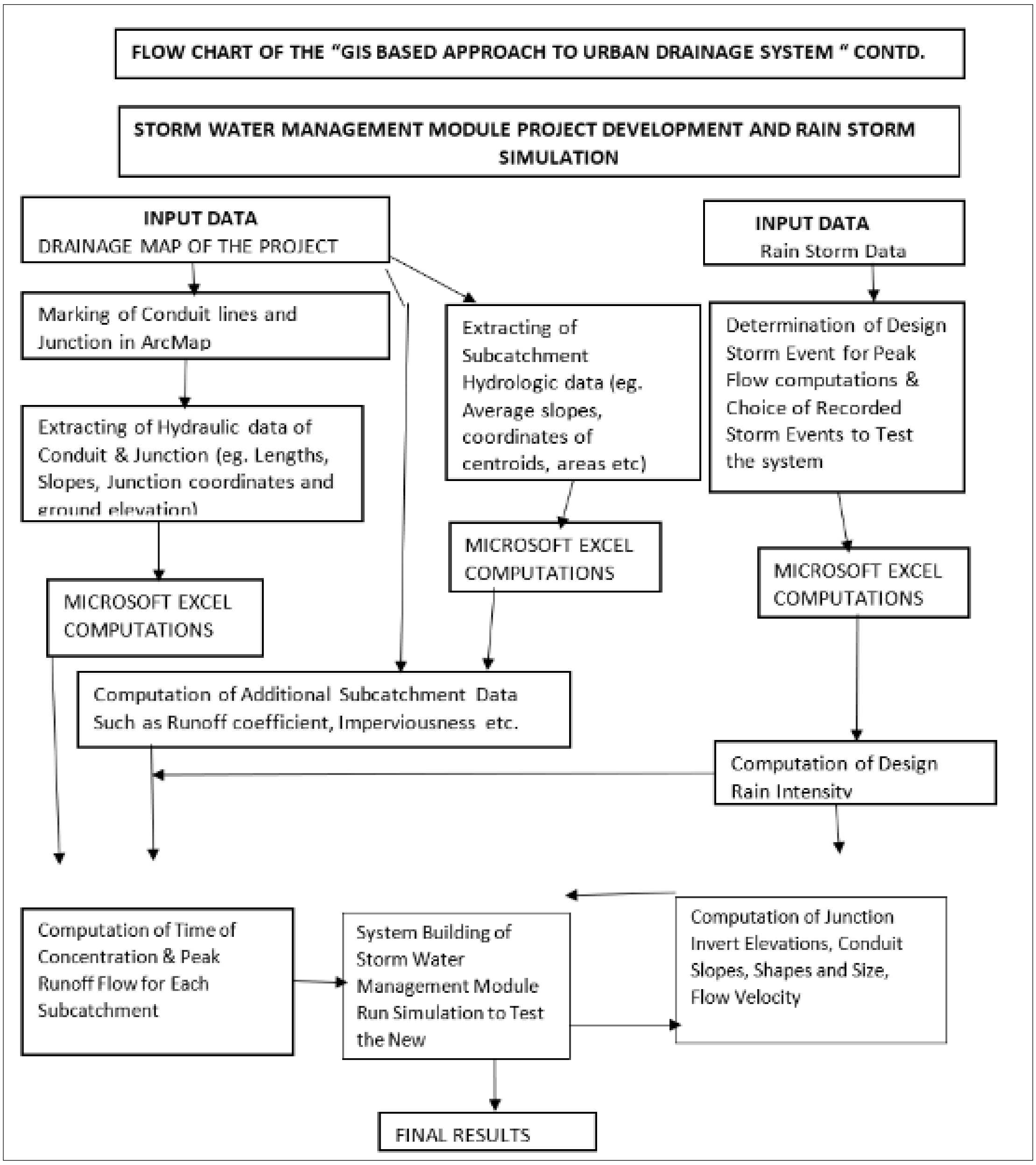


Figure 2 Flow Chart of the methodology modified from Chukwuocha (2012)

The topographic map of the Study Area was scanned, georeferenced in WGS84 datum and digitized. The X,Y,Z coordinates were obtained on the ground using DGPS and integrated with the digitized topographic map of the Study Area. Differential Global Positioning System measurements was carried out using the E600 – H Multi Frequency RTK DGPS over 2 points spread out fairly at the central area of the study area. The details are presented in Table 3.1. blow. The DGPS observed orthometric heights differed from those of their corresponding points extracted from the Digital Elevation Model (DEM) of the project within a range of -0.653m to 0.524m and the average being -0.062m.

Table 1 Comparison of DGPS determined Orthometric height with the corresponding DEM values

S/n	Observation point	Place name	Northing (m)	Easting (m)	Dgps elevation	Dem value	Dgps minus dem
1	DGPS 1	Interbau	687484.3964	245704.1231	63.8073	64.0670	-0.2597
2	DGPS 2	FMC Round About	687087.5099	246762.5967	63.6301	64.2300	-0.5999

It is also noted that the general characteristics of the pixels is a generalization of the elevations possible to occur in the DEM cell. Each cell being of the size of 4.576m x 5,650m, with a diagonal of 7.654m. Since the DEM was derived from the contour of a topo map, the consistency of the DEM values with the field observed values is dependent on how closely the contours are packed together. In other words, it is a function of the density of data from which the DEM is derived. This DEM created from the topographic map of Asaba was accepted as good enough for the research. Compared to the reliability of other sources of topo data such as Shuttle Radar Topographic Mission (STRM) DEM and The Advance Spaceborne Themal Emission and Reflection Radiometer (ASTER) DEM. A standard deviation of the heights based on SPOT for flat terrain of 2.64m for open and 2.99m for forest areas, for SRTM X – band 3.97m for open and 4.49m for forest areas, for SRTM C – band 4.25m for open and 6.14m for forest areas and for ASTER 7.29m for open and 8.08m for forest areas has been achieved" (Sefercik, U., Jacobsen, K., Oruc, M., Marangoz, A., Zonguldak, undated).

The digitized vector data was converted to raster DEM. The DEM was used to produce the flow direction grid. The flow direction grid was processed to generate the flow Accumulation grid. The flow Accumulation grid was used to produce the drainage line features and the catchment Area. The catchment Area was vectorized and integrated with the drainage line feature to generate the drainage map of the Study Area. The SWMM 5.0 was used to simulate the drainage pattern using the drainage map of the Study Area. The hydraulic data (height, slopes, junction coordinate and ground elevation) were extracted and exported to Microsoft excel. Also, the subcatchment hydrologic data (e.g Average Slopes, Coordinates of Centroid, areas etc) were extracted and exported to Microsoft excel to compute additional subcatchment data such as runoff coefficient, imperviousness etc. this was further used to compute the time of concentration and peak runoff flow for each Subcatchment. Rain storm data was acquired and used to determine the design storm event for peak flow computations. This was used to compute the design rain intensity and for computation of junction invert elevations, conduit slopes, shapes and size, flow velocity. The result were integrated with the result of computation of time of concentration and peak runoff flow for each subcatchment to produce the final result.

3. Discussion of Results

3.1. Existing Drainage System in Asaba Metropolis

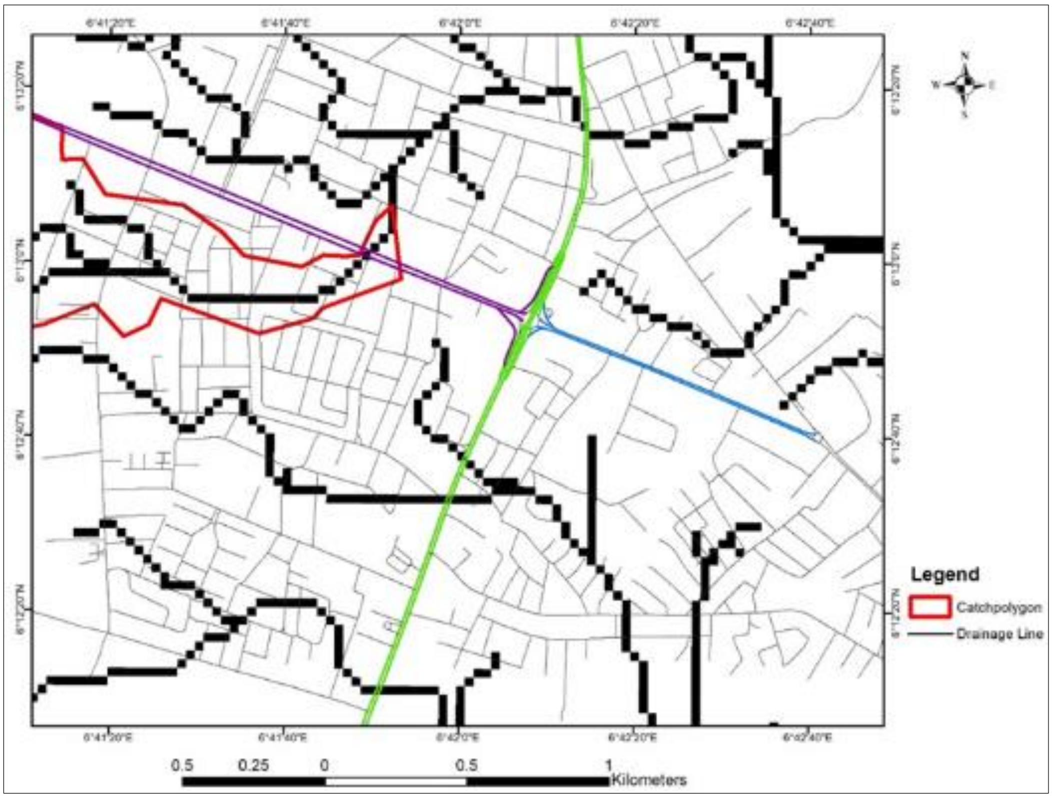


Figure 3 Map of the automatically generated catchment polygon of the Study Area

Fig. 3 shows catchment polygons with drainage lines, which are impractical for designing drainage systems due to their short links and lack of outpouring points. Instead, a polygon representing subcatchments that flow runoff into a route and output points is needed. The existing drainage system around Asaba Metropolis has an inlet that allows storm water to enter, but this design often leads to floods due to inadequate drainage to collect storm water.

3.2. Best Routes of Storm Water Runoff in Asaba Metropolis

The best route for storm water flow from Asaba Metropolis is shown in Figs. 4 to 8. Storm water flows freely along Inter Bua, leading to Federal Medical Center and the Niger River. Water from Summit Road and Okpanam Road joins at Asaba Mall's collection center.

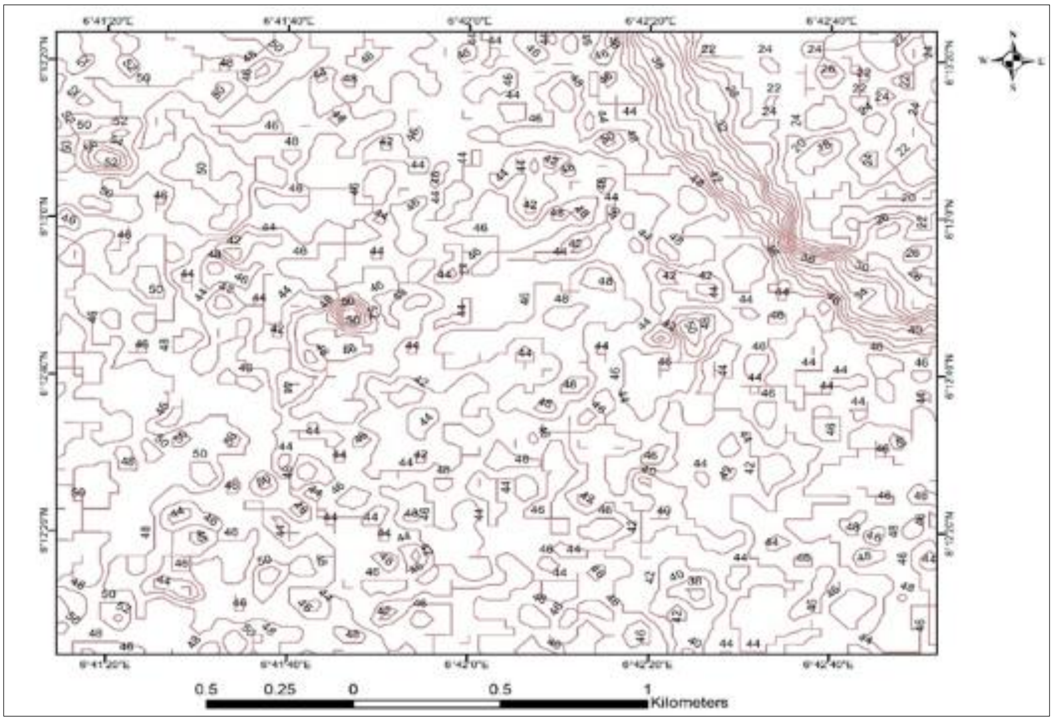


Figure 4 Digitized Contour Coverage of the Project Area

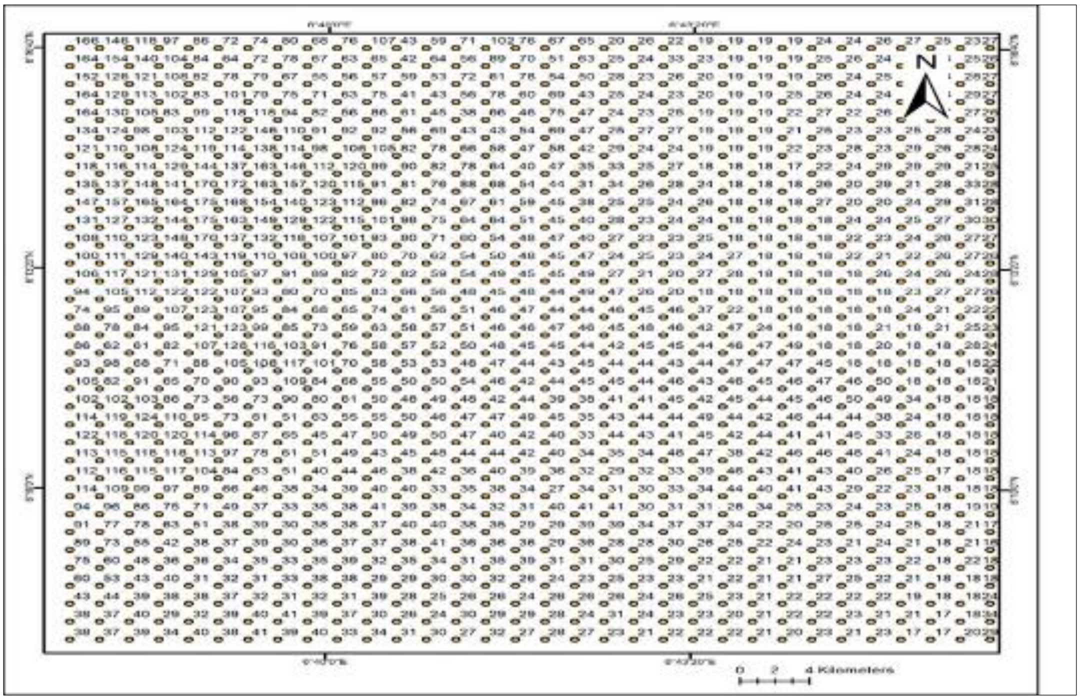


Figure 5 Digitized Spot Height Coverage of the Project Area

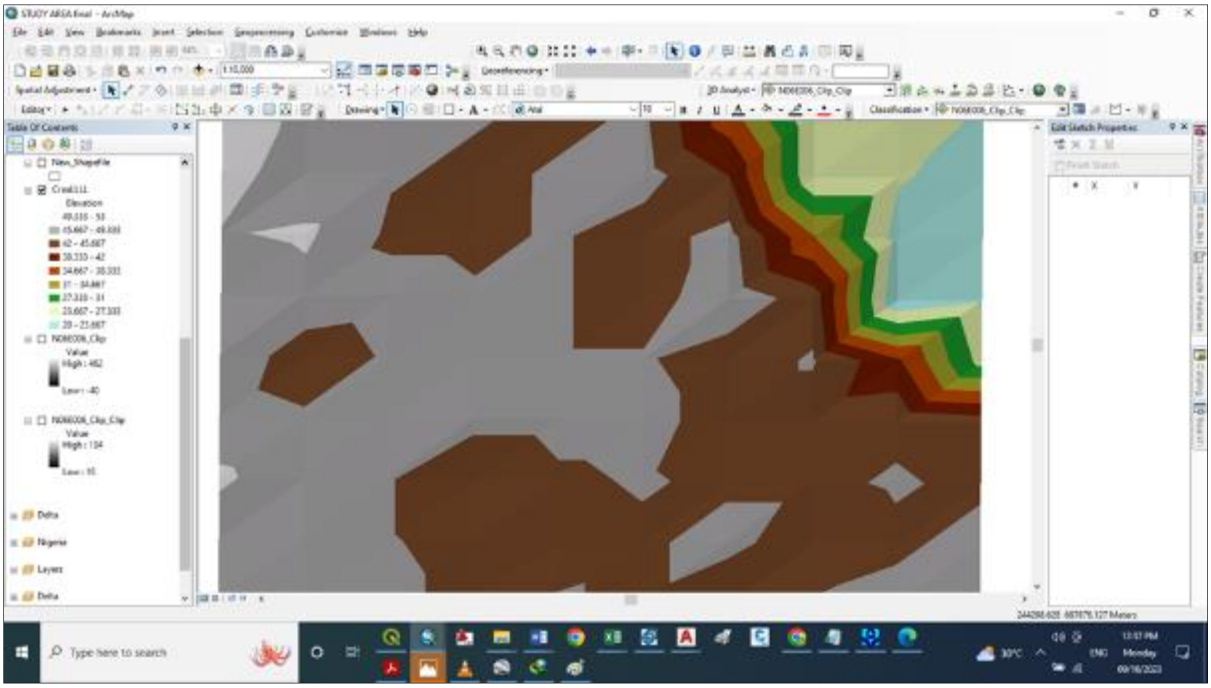


Figure 6 Screen print of the Triangular Irregular Network (TIN) of the Project Area

The Digital Elevation Model (DEM) was created using contour and spot height data, but it was found that the spot height DEM contained sinks, erroneous depressions caused by the interaction between the DEM creation algorithms and the data itself. The problem was observed in the contour DEM, not the spot height DEM, indicating that sinks were present in the spot height DEM.

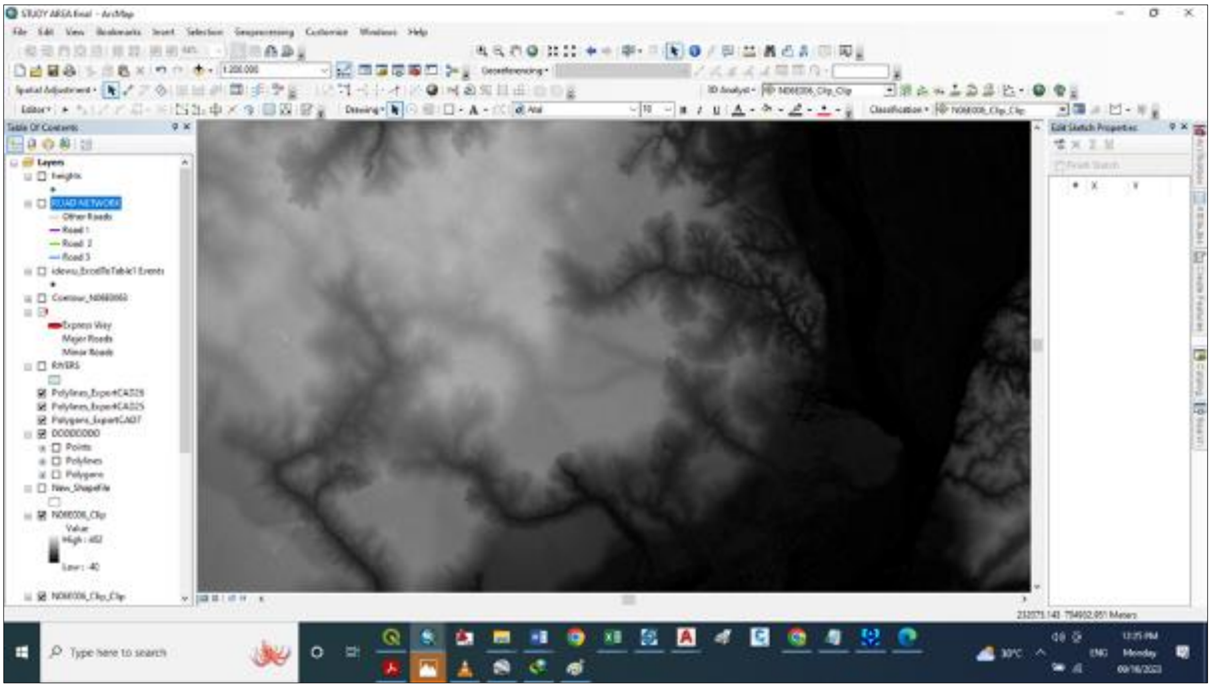


Figure 7 Screen print of Digital Elevation Model (DEM) of the Area. The blue arrows point to the sink.

The elevation values of shapefiles were checked for errors in sinks, and if no errors were found, the problem could be corrected through GIS filling sinks in the DEM. Natural field data is preferred, and the contour DEM was chosen for further processing to create necessary maps. All DEM undergo GIS sink filling to ensure visibility of sinks.

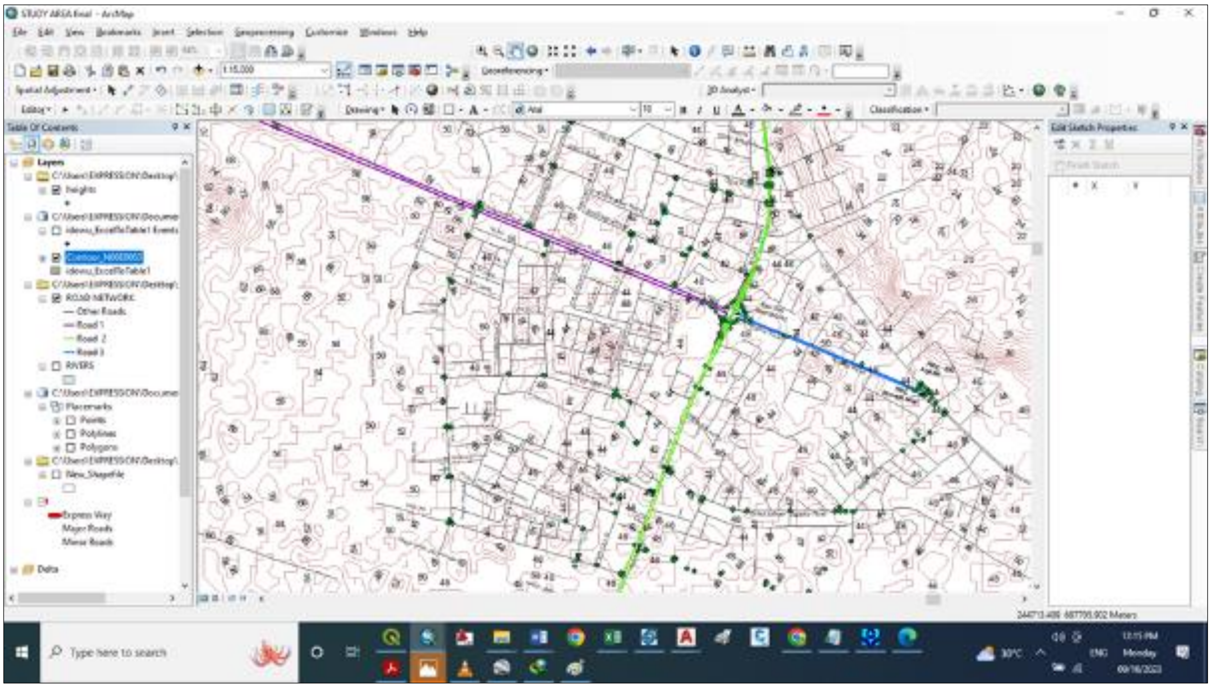


Figure 8 Screen Print of Contour DEM

The Asaba DEM, created using ArcMAP 3-D Analyst tool, is a grid of elevation cells with each cell representing the elevation value of the space. It is adaptable for various elevation analyses. The DEM's size depends on the sampling distance and interpolation options, with linear interpolation being chosen. The project area has a longer side of 2,651.81m and a 200-sample distance, resulting in 201 columns and 120 rows with cell sizes of 2.380m × 3.621m.

3.3. Delineation of Drainage Route and Subcatchment in Asaba Metropolis

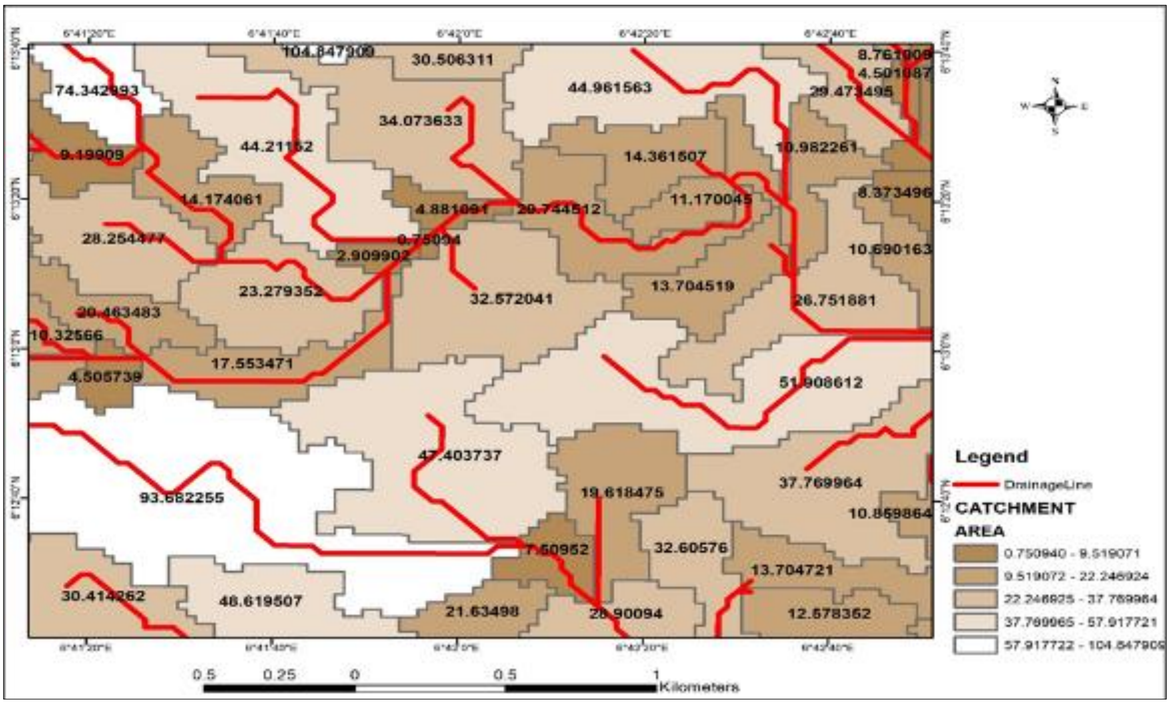


Figure 9 Map of the manually generated Project area Subcatchments with the drainage line

The catchment polygon was simplified relative to clearly defined drainage routes, and the drainage line map was overlaid with the project area's contour. Contour ridges were traced around a given route, typically on the two sides of the drainage and upstream side of the line. These drainage subsheds were created by digitizing polygons marked by contour ridges around each drainage line. The manual Drainage Area Delineation result is shown in Figure 9.

Figure 9 displays manually generated subcatchments with drainage lines highlighted, displaying their sizes in square meters. Figure 3.14 displays the complete Drainage Map of the project area, showing subcatchments, drainage lines, and relief data as contours. Most drainage decisions were based on this map, providing a comprehensive view of the project area.

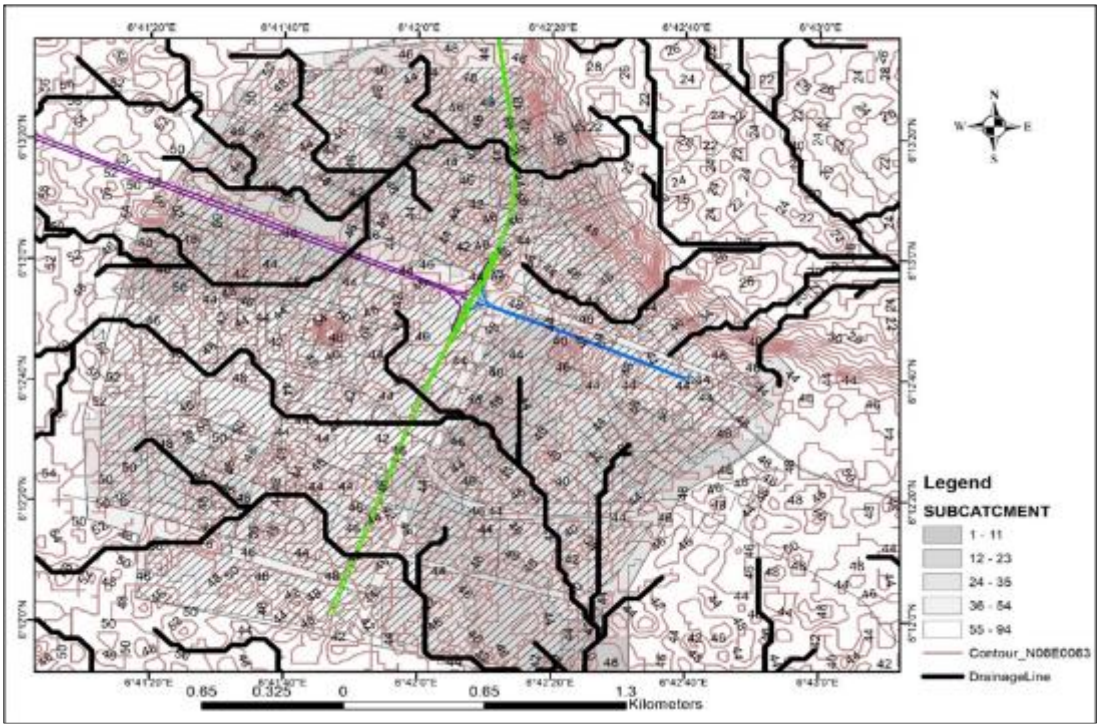


Figure 10 Drainage Map of the Project Area

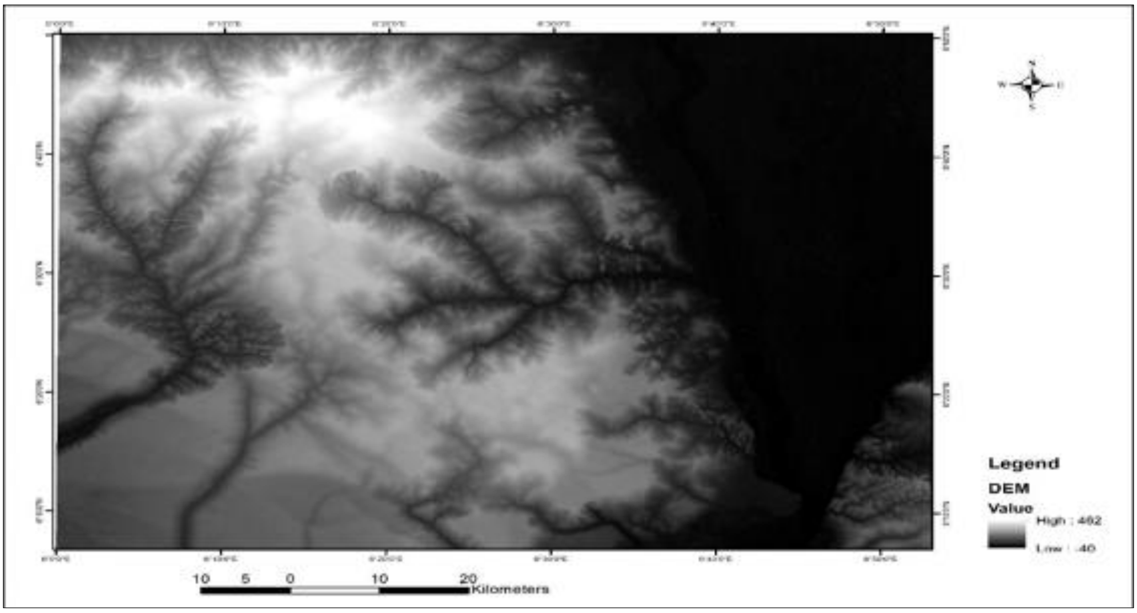


Figure 11 A display of the DEM with its value coded in Pink shed. The DEM value stretch in discrete values from 42 to 424, the lowest and highest value of the project area

3.4. Design of the Drainage Network of Asaba Metropolis

Effective drainage plans aim to capture runoff and reduce overland flow. Each subcatchment's drainage lines link up with other lines, indicating the flood flow route. Polylines marking drainage pipes were drawn in ArcMap as shapefiles to drain water in the slope direction of the flow route. The drainage map of the integrated project area was exported to USEPA SWMM 5.0 for flow simulation. The attribute table of drainage pipe polylines contains data needed for the design of actual conduits, such as upstream and downstream elevations, conduit length, subcatchment area, and identity. The attributes determined from ArcMap for each subcatchment include the area, centroid coordinates, longest overland flow distance, upstream and downstream elevations, and average slope. The USEPA SWMM terminologies were used for proper adaptation in the drainage flow simulation stage.

3.4.1. Flow Accumulation Grid

The Flow Direction Grid is used to calculate the accumulation of each cell in the grid. The Flow Accumulation tool calculates the accumulated flow by calculating the 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 flowing into each cell.

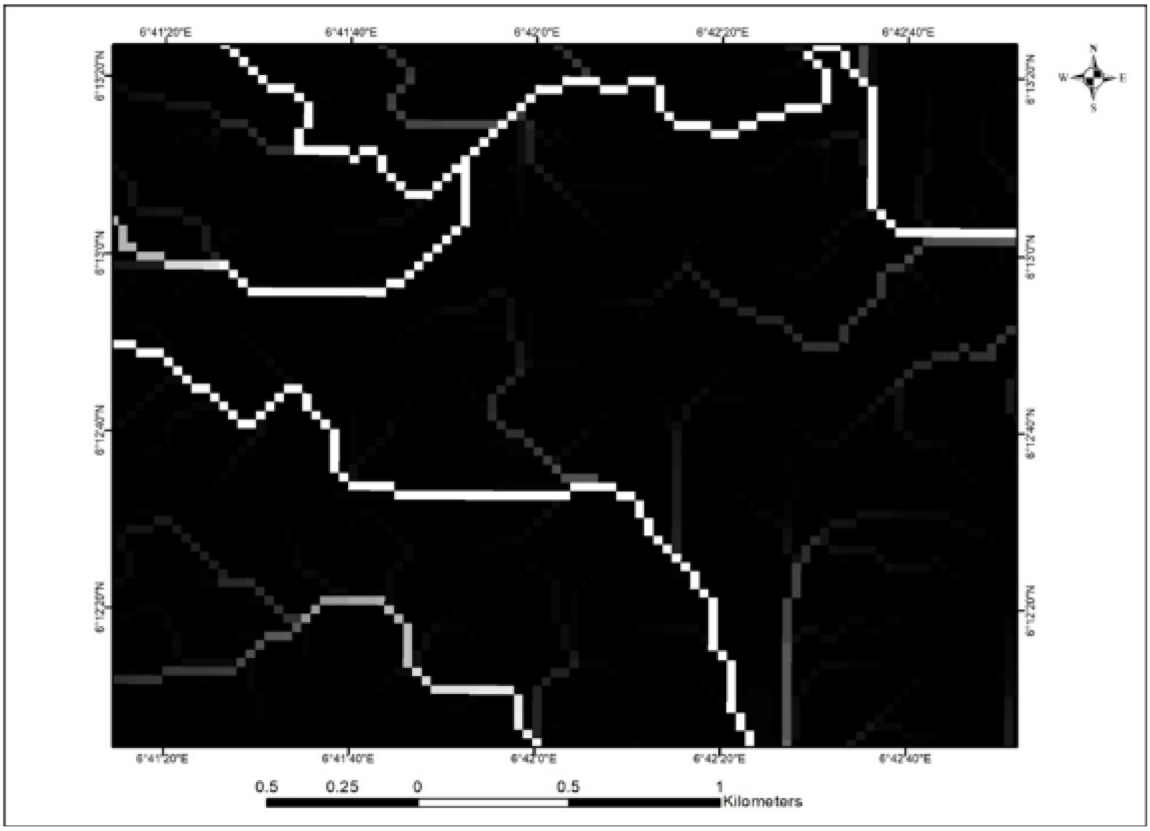


Figure 12 Flow Accumulation of the project area: the accumulation here ranges from 0 pitch black to brilliant whit color

3.4.2. Stream Definition Grid

The Stream Definition Grid generates a unique grid of stream segments, either head segments or between two junctions. Each segment has a specific grid code. The output is in link grid format. The Drainage Line Processing function converts the input Stream Link grid into a Drainage Line, with each line containing the catchment's identifier.

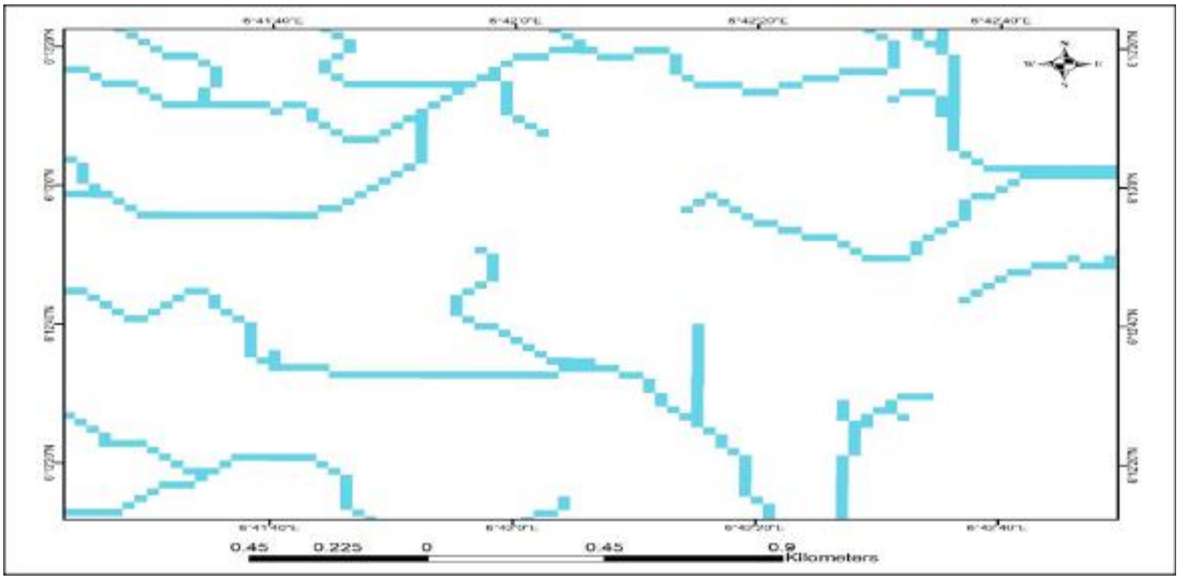


Figure 13 Stream Definition Grid of the project area using 20 cell accumulation threshold

3.4.3. Stream Segmentation

Stream segmentation is a method of designing a unique grid of stream segments, either head segments or segments between junctions of other segments. Each segment has a specific grid code, and it uses the Flow direction grid and stream Grid as input to create the stream link grid.

3.4.4. Catchment Grid Delineation

The process of stream segmentation involves delineating a catchment grid, where each cell has a grid code indicating its catchment. The input grids are the Flow Direction Grid and the Stream Link Grid, which are used to create the catchment grid. The result is displayed in Fig. 14, illustrating the catchment grid for the project area.

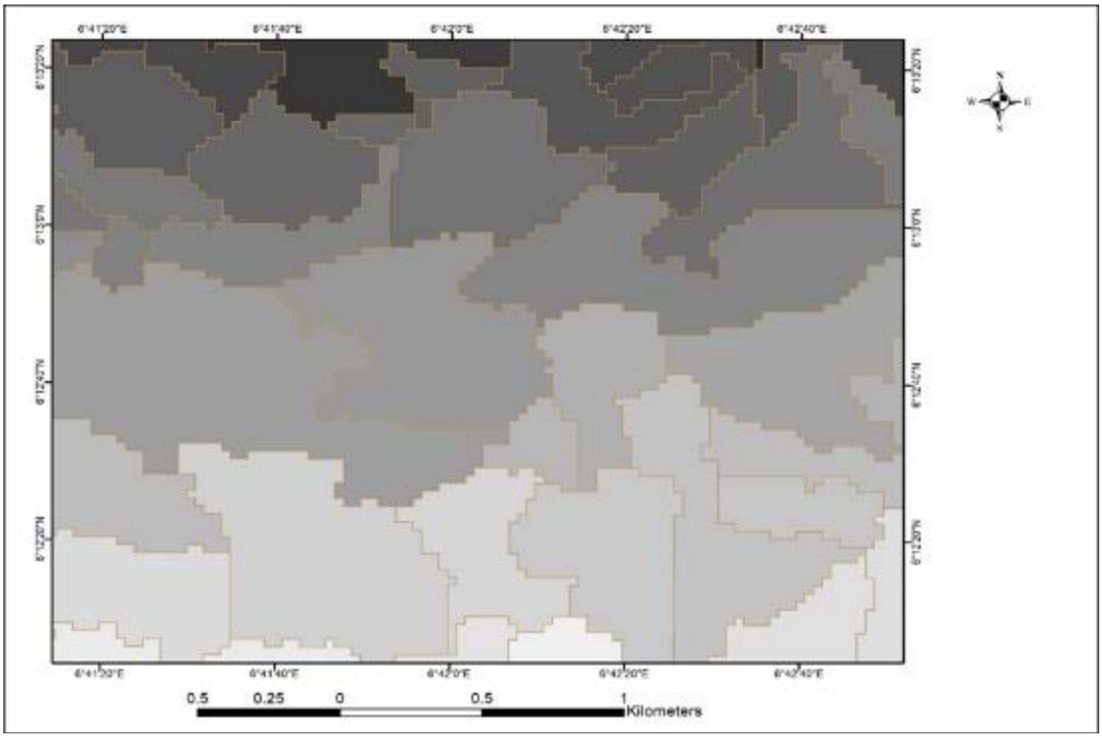


Figure 14 Catchment delineation Grid

3.4.5. Catchment Polygon Delineation

The Catchment Grid Processing function converts the Catchment grid into a catchment polygon feature class, separating adjacent cells with the same code into a single area. This process vectorizes the boundary, identifying the boundary of a watershed, such as a catchment, drainage basin, or river basin. Delineation is crucial in environmental science, engineering, and management for studying flooding, aquatic habitat, or water pollution. The Catchment Polygon of the project area is shown in Fig 15.

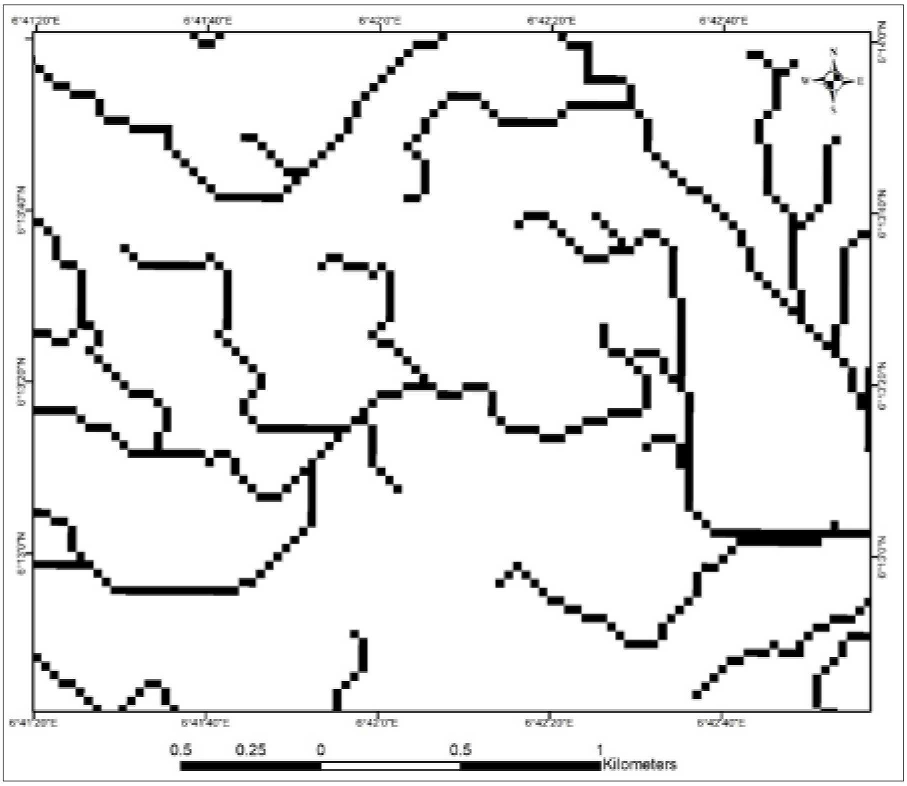


Figure 15 Catchment Polygon of the project area

3.4.6. Processing of Drainage Line

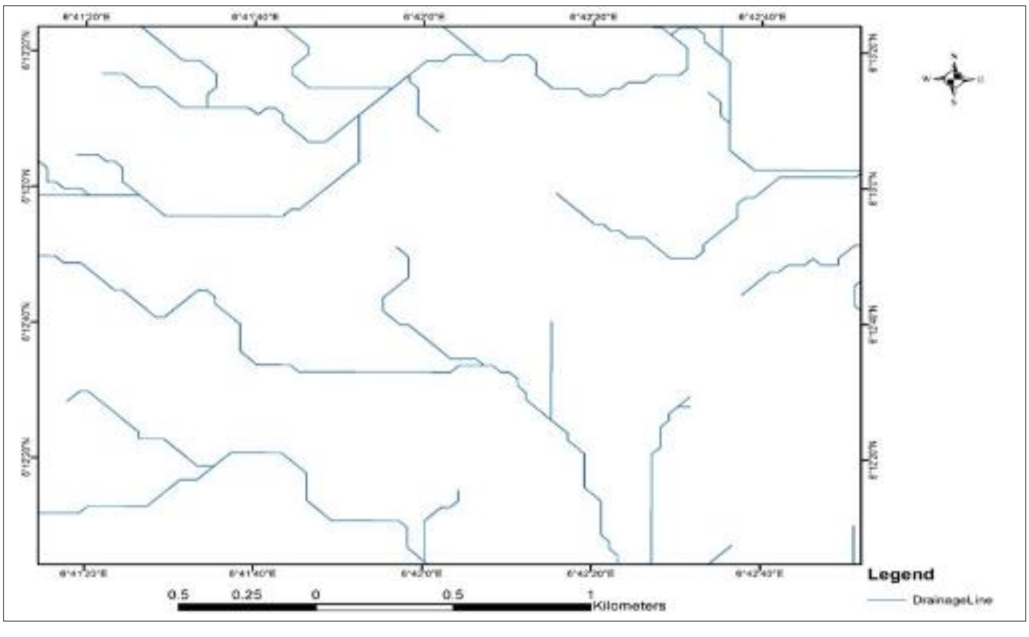


Figure 16 Drainage Line Map of the Project Area

The Drainage Line Processing function converts the input stream link grid into a Drainage Line feature class, each line containing the catchment identifier. The attribute table in this feature class identifies each line with its location identifier, marking out drainage routes under a specific drainage threshold. These lines are then used to convey runoff.

3.4.7. The Drainage Mapping

Drain mapping is a crucial process that involves creating a detailed map of all drains and sewer lines in a specific area, including their location, size, type, manholes, catch basins, and other features. This map is essential for planning and managing sewer systems, as it helps in assessing the condition of existing infrastructure and identifying potential problems. It is crucial for decision-makers when planning new developments or making changes to existing infrastructure, as an inaccurate map would make it difficult to design and construct new sewer lines. Drain mapping also helps assess the condition of existing sewer lines, identifying potential issues like high corrosion or cracking, allowing for repairs before major damage occurs. It can also identify blockages or other issues causing system problems. Overall, drain mapping is an essential tool for managing and maintaining sewer systems, providing vital information for planning new developments, assessing existing infrastructure, and ensuring proper design, construction, and maintenance.

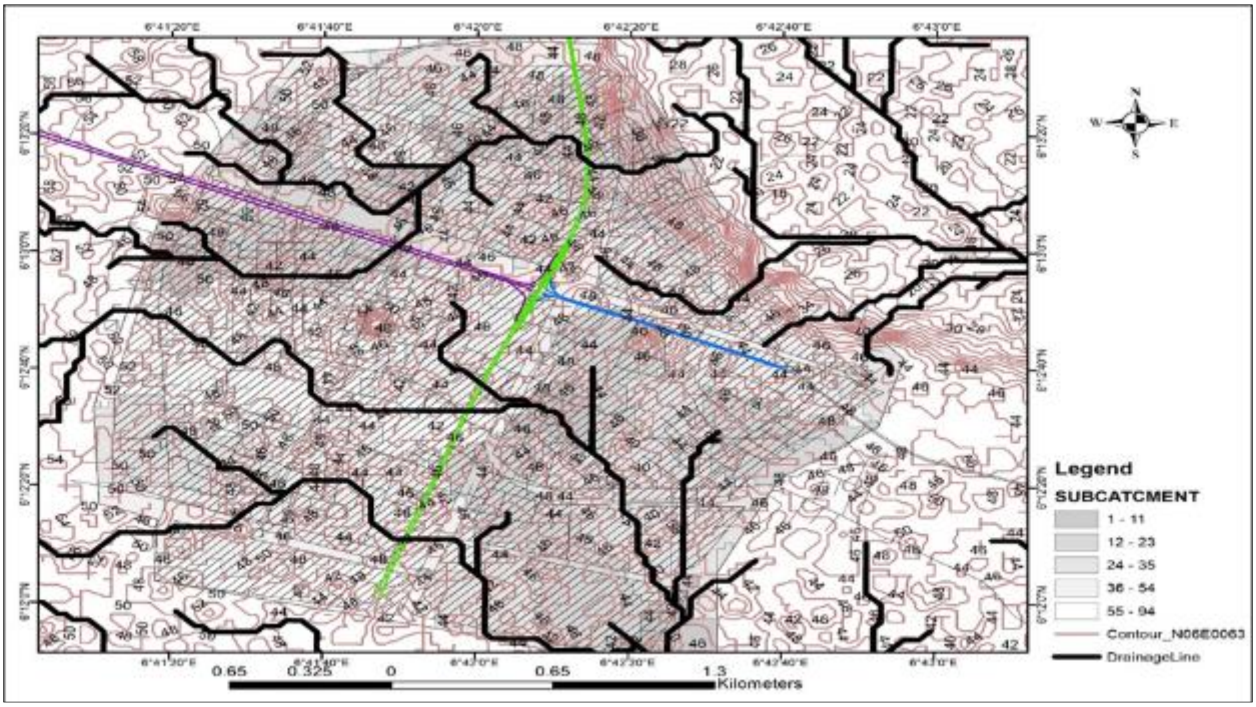


Figure 17 Drainage map of the project area showing the subcatchments numbered and the drainage line

Urban drainage is crucial for mitigating erosion, which can lead to soil nutrient wastage, waterborne diseases, and flooding. To reduce runoff flow volume and rate, especially at steep river banks, urban areas should be drained using suitable drainage pipes. The drainage map offers the option to design more effective urban drainage networks considering the natural drainage line, ensuring lower costs and a more accountable system.

In flat areas where runoff does not accumulate heavily, options include reducing the stream definition threshold until the drainage line is visible or choosing the drainage line at the central transverse of the area considering the point at which the drainage would empty. The drainage map also introduces the concept of the best drainage routes, which is useful for designing the main network of a virgin area for urban development or responding to drainage needs of an existing urban area.

The drainage map concept is useful for more accurate drainage designs, as it provides accurate area of each subshed and average slope. Overlapping the drainage map with satellite imagery can help determine terrain information, such as land use and land cover, accurately, and enter it in feature properties. This is particularly useful for the design of drainage systems.

4. Conclusion

This study reveals that the main causes of flooding in the Asaba metropolis are poor drainage channeling, blockage of major waste discharge, inadequate construction of drainage linkages, insufficient collection centers, and inability of waste water to transport properly. The topography has a free slope for waste water, but contractors did not consider the area's runoff, leading to flooding. The drainage systems are not properly constructed, causing flooding around the metropolis. The waste water from Okpanam Road lacks a proper inlet, causing flooding around Asaba Mall, Delta State. Therefore, long-term solutions are needed to address these issues.

Recommendations

In consideration of the studies carried out, the following recommendation should be made;

- During the course of the study, we noticed that not all the drainage are fully built and not all the basic amenities have drainage and the very few that do not have a discharge route or a link to the drainages that do have, Some don't even have any drainage at all so it should be taken into consideration.
- More studies on Drainage systems should be carried out outside the study area so as to help expose student to the practical and vitality of the issue (Drainage) plus, the application of Surveying and Geoinformatics in solving Drainage issues.
- There is need for more enlightenment as regard solving the major challenges facing natural and artificial drainage network, so that when problems such as blockage and refuse dump in the drain occur, such problem can be manage efficiently.
- The Environmental Management Board should provide proper waste disposal point around major junctions to enable road users dispose their waste properly. Also the agency should enforce taskforce bodies to monitor public pollutant around the city capital.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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