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ASSESSMENT OF HYDRAULIC PERFORMANCE AND FLOOD RISK OF STORMWATER DRAINAGE SYSTEM ALONG AGBANI ROAD ENUGU USING COMPUTATIONAL MODELING

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Abstract - Rapid urbanization leads to an increase in impervious surfaces, which results in greater stormwater runoff and subsequent flooding in many municipalities, such as Enugu. Concerns have been raised about whether the existing drainage system can handle the stormwater on major streets and roads in Enugu. To address these concerns, this study focuses on a section of the longest drainage infrastructure, which runs from Portharcourt Express Junction through Agbani Road to Zik Avenue Junction. This study concentrated on Drainage Basin A, which extends from Enugu Motor Market to the Imo Transport Company (ITC) outfall. The study aimed at finding out the current state of existing urban drainage system in Enugu, to provide data for the design of effective urban infrastructural drainage systems in Nigeria, to investigate the existing mitigation measures for flood control and management by government agencies, to evaluate effectiveness of water drainage system using computational model (EPA Stormwater Management Model), and to suggest some remedial measures. Primary data were collected through direct measurements and GIS surveys, while secondary data were obtained from existing literature. The data for Drainage Basin A were applied to the United States Environmental Protection Agency's Stormwater Management Model (EPA SWMM 5.2) to model, evaluate, and analyze the stormwater characteristics of the drainage infrastructure. Field surveys revealed that the drainage sizes from Akwuke Junction to Ebony Junction were insufficient to handle the trash being dumped into them, leading to clogging. The simulation results showed that the drainage from Akwuke Junction to Gariki experienced flooding for 6 hours and 15 minutes, while the drainage from Ebony Junction to the ITC outfall experienced flooding for 1 hour and 5 minutes. These findings indicate that the flooded drainage areas should be redesigned by increasing their depth and width to 1 meter and 0.9 meters, respectively, to ensure an effective drainage system in the study area. The results demonstrate the effectiveness of the EPA SWMM model in evaluating urban drainage infrastructure. Based on these findings, it is recommended that the Enugu state government adopt the EPA SWMM model software to assess and determine necessary refurbishments to the existing drainage systems to mitigate flooding within the city.

Keywords: Drainage, Stormwater, Flooding, Evaluation, and Urban infrastructure.

1. Introduction

The swift rise in global population is significantly impacting various aspects of life and livelihoods around the world. This growth has spurred increased industrialization and urbanization, especially in developing countries, exerting pressure on both natural and man-made resources. As cities expand, so does the construction of buildings, roads, and other infrastructure. This development has reduced the soil's capacity to absorb rainwater, making urban areas more susceptible to flooding during heavy rains (Garcia et al., 2012). Urban settings, with their paved roads and concrete surfaces, prevent water from soaking into the ground, leading to excessive surface runoff and resulting in flooding and drainage problems (Berggren, 2008). Onisarotu (2010) pointed out that rising urban population's worldwide increase the risk of flooding. Umeuduji (2000) found that urbanization enhances the amount of rainfall that becomes surface runoff, which quickly flows from impermeable surfaces like streets and roofs into streams and rivers. This problem is widespread in many urban centers of developing nations (Frimpong, 2014; Aderogba et al., 2012; Satterthwaite et al., 2007; Action Aid, 2006).

Mulualem et al. (2018) observed that inadequate urban stormwater drainage is a frequent issue in Ethiopian towns, worsened by rapid urban expansion. The urgent need for new housing has led to the construction of many estates without sufficient drainage planning (Smith, 2011). Effective drainage infrastructure is crucial for managing surface water runoff from rainfall and soil permeability. Proper stormwater and wastewater management is essential to prevent disease, as stagnant water can become a breeding ground for bacteria and mosquitoes, leading to illnesses like malaria. Poorly designed drainage systems that cannot handle peak rainfall are a major cause of severe flooding, highlighting the need for systems that can efficiently manage overland flow after rain (Anunobi, 2023).

Despite the growing urban population, the development of drainage infrastructure has not kept up, leading to widespread flooding problems in many cities (Offiong et al., 2008). In Ilorin, rapid urbanization and population growth, combined with inadequate drainage infrastructure, have been identified as major contributors to increased flooding, as existing channels cannot manage the water volume (Oluwaseun et al., 2020). Smith (2011) reported that flooding causes displacement, loss of lives and livelihoods, and damage to property and household items. Flooding is especially common in residential areas, floodplains, lowlands, and coastal regions. Coastal cities in Nigeria often experience severe flooding, leading to significant property damage and loss of life (Eze, 2008). The National Emergency Management Agency (NEMA) reported that in 2012, 2.1 million Nigerians were displaced, and there were 363 deaths. In 2016, 15 households were displaced in Enugu, as shown in Figure 1.1

Figure 1.1: Flooding Event in Enugu (PM News, 2016).

The problems of flood and erosion are widespread in Nigeria with the intensity varying from state to state. According to NEMA (2011) flood is the most devastating event affecting all aspects of activities in Nigeria, cutting across all sectors in the nation from economics, social, to educational activities to the extent that most schools were forced to close until the flood had subsided. Statistics from NEMA (2011) confirmed Enugu as one of the thirty states in Nigeria that experienced the worst flood that caused damages estimated at over 2.6 trillion Naira. Despite all these, no study has been carried out to evaluate the effectiveness of drainage infrastructures in Enugu municipality that is seen as the capital of the Southeastern region of Nigeria. This need formed the motivation to undertake this study.

The aim of this study is evaluation of Agbani road Enugu urban drainage infrastructure using computational model. To achieve the above aim, the study pursued the following specific objectives:

- To find out the current state of existing urban drainage system in Enugu.
- To provide data for the simulation of effective urban infrastructural drainage systems in Enugu, Nigeria.
- To evaluate the effectiveness of water drainage system using computational model (EPA Stormwater Management Model).
- To suggest some remedial measures.

2 Materials and Method

Study Area

Enugu urban is the focus of this study, particularly from Enugu motor market to Imo transport company (ITC) outfall of Agbani road Enugu South Local Government Area (LGA) of Enugu state. It has six (6) junctions, namely, Enugu Motor Park, Amagugwu junction, Akwuke junction, Gariki market, Ebony junction, Imo Transport Company (ITC) outfall.

In this study, a thorough field survey of the state of the drainage structures was completed. A car (Toyota Camry 2000 model) driven at a low speed of about 20 kilometer per hour (km/h) on the shoulders along the Enugu urban road was used to perform a visual check of the drainage system with a view to establishing the following:

1. The dimension of the drainage at various locations.
2. To ascertain and note all the drainage junctions at the study area.
3. To identify drainage infrastructural failures or defects.

The dimensions of the drainage system (height and width) were measured using measuring tape rule while the length and catchment areas were measured using GIS surveyor. The topography of the study area was gathered using Goggle digital map. Stops were made frequently close to places where extreme distresses were observed. Pictures of the drainage systems were also taken at various locations using Itel A70 camera. Data regarding the rainfall was obtained through the existing literature while data analysis and simulation were carried out using EPA SWMM Software.

3. Results and Discussions

3.1 Geometry of the Enugu urban drainage system

The result of the measurements, length from junction to junction, area of sub-catchment, drainage width and drainage depth from Enugu motor market to Imo transport company (ITC) outfall junction were shown in table 3.1

Table 3.1: Length, Area, Drainage width and Drainage depth of Junction

S/n	Name of Junction to Junction	Length (meters)	Area (meter)^2	Drainage width (m)	Drainage Depth (m)
1	Portharcurt Express to Enugu motor market	266.24	29559.7	0.9	0.6
2	Enugu motor market to Amagugwu road	366.14	56688.7	0.9	0.6
3	Amagukwu road to Akwuke junction	147.7	25881.7	0.9	0.6
4	Akwuke junction to Gariki market by Apo filling station	340.49	29096.9	0.6	0.6
5	Gariki market by Apo filling station to Ebony paint road	307.17	81956.5	0.6	0.6
6	Ebony paint road to Imo Transport Company (ITC)	619.67	98731.7	0.9	0.6
	Total	**2,047.41**	**321,915.2**		

The result of the visual inspections and dimensional measurement of the system (table 3.1), shows that the width and the depth of the drainage from Enugu motor market junction to Imo transport company (ITC) outfall are the same, measuring 900mm and 600mm respectively. But the drainage size of Akwuke junction to Ebony junction has width of 600mm and depth of 600mm. This size reduction is considered a faulty design as this section of the drainage ordinarily ought to be enlarged as it is expected to be the busiest section given the location of Afor-Awkunanaw market along its breadth. This probably explains the frequent drainage blockages within the section.

3.2 Data for modeling urban drainage systems.

Enugu State monthly rainfall data from 2000 to 2013, shown in Table 3.2, were collected from Nigeria Meteorological Agency (NIMET), Airport, Enugu State. The dimensions of the figures are given in millimeters

The total annual rainfall for the year 2013 is 1,890.3mm, while the monthly average is 157.53mm. Rainfall data of 150mm at 6 hours rainfall duration were, therefore, used to simulate the stormwater runoff characteristics using SWMM.

The topography and calculated slope of the study area were presented in table 3.3.

Table 3.2: Monthly Rainfall Data

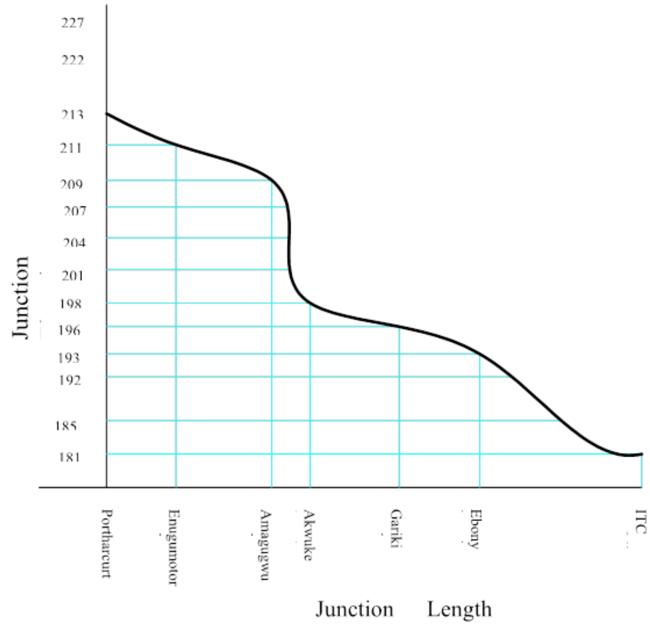
Month/ Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.5	0.5	0	181.5	89.7	279.4	508.3	359.1	317.5	318.8	2.3	25.8
2001	0	37.6	62.4	198.7	346.4	244.8	319.2	264.3	230.5	253.5	2.5	0.7
2002	0	0	111.5	200.9	192.4	354	313	149.3	249.7	105.3	28.8	0
2003	0	5.1	61.7	148.9	109.9	263.7	186.7	390	243.5	72.9	82.9	11.6
2004	38.8	0	9.7	144.5	211.2	140	216	187.2	331.9	181.6	0	0
2005	1.6	0	90.2	194.1	263.7	356.7	340.2	432.1	192.4	261.7	35	0
2006	0	26.7	48.6	160.9	277.2	289.6	368.3	268.4	176.3	303.4	0	0
2007	0	0	111.6	261.3	376.1	344.9	226.8	235	392.3	242.2	68.1	4.1
2008	0	6.1	25.8	161.1	188.7	285.9	259.2	96.2	256.6	217.4	0	0
2009	18.	15.7	30	103.6	223.8	316.8	206.4	100.2	195.1	313.4	24.3	0
2010	32.4	0	32.3	202	357.5	206.1	298.5	331.8	339.7	226.5	0	0
2011	0	28	72.5	305.5	273.8	188.8	152	130.6	407.9	118.1	0	0
2012	0	46.5	10.4	159.1	219.7	296.4	263.3	121.6	270.7	332.5	0	0
2013	0	0	2.9	74	234.3	286.9	400.4	290.2	334.4	227.4	39.8	0

Nigeria Meteorological Agency, Airport, Enugu State. NIMET

Table 3.3: Topography and gradient slope of the study area (Enugu urban)

S/N	Name of Junction	Elevation (meters)	Gradient slope %	Remarks
1	Port Harcourt Express	213	0	Starting point
2	Enugu motor market	211	0.9	
3	Amagugwu road	209	0.9	
4	Akwuke junction	198	5.5	
5	Gariki market	196	1.0	
6	Ebony paint junction	193	1.6	
7	Imo Transport company (ITC)	181	6.6	Outfall

Longitudinal Profile from Portharcurt express to ITC outfall



The results show that the drainage of drainage basin A has descending longitudinal slope, varying between 0.9 percent and 6.6 percent. This range falls above the minimum standard of longitudinal slope range of between 0.3% to 2.0% necessary to facilitate flow of water inside drains with outlets like bridges, culverts, ponds, are provided at interval to restrict the depth of drains. (Indian road congress 2013).

3.4 SWMM simulation result for drainage basin A

The area covered by the drainage under study was used as the sub-catchment area as shown in figure 3.1.

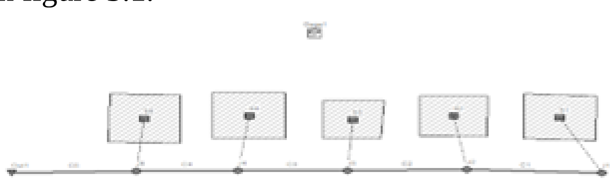


Fig 3.1: Sub-catchment area

Study Area Map

Figures 3.2 and 3.3 are time series TS1 graph and chart of precipitation (mm) against elapsed time (hours), using 150mm for rain gauge data and 6 hours for the elapsed time.

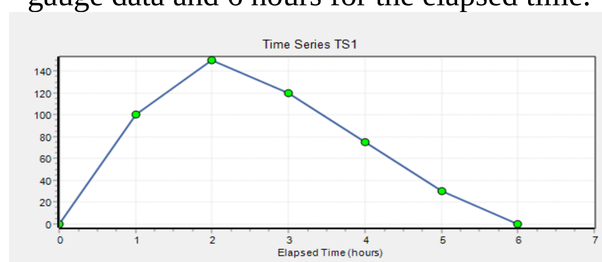


Fig 3.2: Time Series TS1

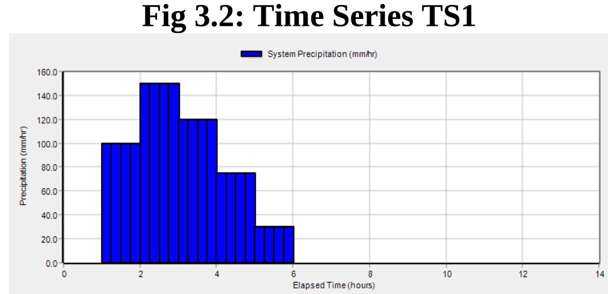


Fig. 3.3: System Precipitation Chart

The chart shows that from 2 to 3 hours of the rainfall is the peak of the rainfall at 150mm and it goes down and stopped at 6 hours storm period. The graph shows clearly the precipitation pattern, rising fast to the peak within 2 hours but decays slowly for 4 hours.

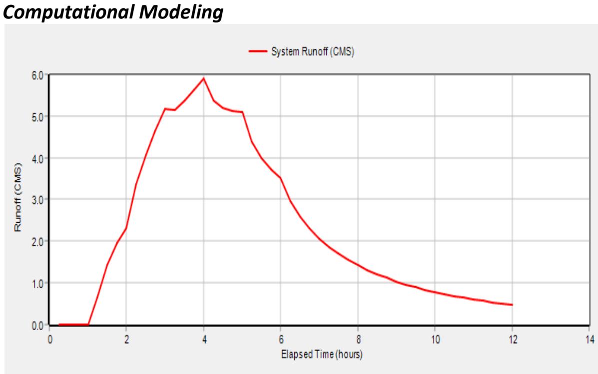


Fig. 3.4: System Runoff

The system runoff graph shows the graph (Fig. 3.4) of runoff in cubic meter per second (CMS) against elapsed time in hours (h) of drainage basin A. As shown in the graph we have maximum runoff of 6.0 cubic meter per seconds (cms) at 4 hours, and the storm water flow subsides and stopped at 12-hour time.

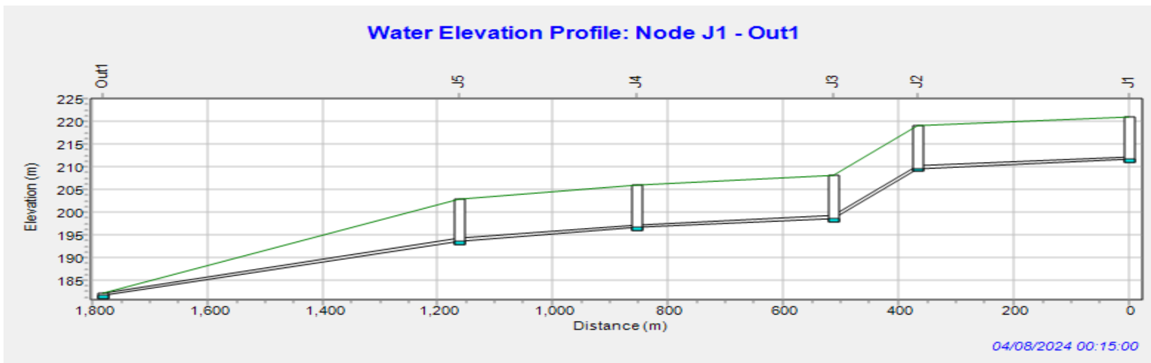


Fig. 3.5: Water Elevation Profile Chart

The water elevation profile as shown in Fig. 3.5 represents the plot of elevation against the distance of the existing drainage of drainage basin A. The graph indicates that Node J1 (Enugu Motor market Junction) has elevation of 211m, Node J2 (Amagugwu Junction), elevation of 209m, Node J3 (Akwuke junction), elevation of 198m, Node J4 (Gariki market), elevation of 196m, and Node J5 (Ebony paint junction), elevation of 193m.

Table 3.3: Simulation Result for Subcatchment Runoff

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10^6ltr	Peak Runoff cms	Runoff Coeff
S1	475.00	0.00	0.00	18.55	118.53	281.43	399.96	20.00	1.18	0.842
S2	475.00	0.00	0.00	18.55	118.53	281.43	399.96	20.00	1.18	0.842
S3	475.00	0.00	0.00	18.55	118.53	281.43	399.96	20.00	1.18	0.842
S4	475.00	0.00	0.00	18.55	118.53	281.43	399.96	20.00	1.18	0.842
S5	475.00	0.00	0.00	18.55	118.53	281.43	399.96	20.00	1.18	0.842

Table 3.8: Simulation Result for Node Flooding

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6ltr	Maximum Ponded Volume 1000 M^3
J3	6.15	2.582	0	04:01	29.971	0.000
J5	1.05	0.256	0	04:01	0.430	0.000

Table 3.9: Simulation Result for Conduit Surcharge

Conduit	Hours both End Full	Hours Upstream	Hours Downstream Full	Hours Above Normal Flow	Hours Capacity Limited
C3	6.15	6.15	6.15	6.15	6.15
C5	1.05	1.05	1.05	1.03	1.05

Table 3.8 shows the node flooding of drainage basin A. Node J3 recorded 6 hours 15 minutes of flood at maximum rate of 2.582 cubic meter per second (CMS) and total flood volume of 29.971x10^6 liters. Node J5 recorded 1 hour and 5 minutes of flood at maximum rate of 0.256 cubic meter per second (CMS) and total flood volume of 0.430x10^6 liters.

Table 3.9 shows that conduit C3 which is drainage from Akwuke junction to Gariki market recorded surcharge of 6 hours 15 minutes end full flood. Conduit C5 which is drainage from Ebony junction to ITC outfall recorded 1 hour and 5 minutes end full flood.

4. Conclusions and Recommendations

4.1 Conclusions

The evaluation of the performances of drainage system from Enugu motor market through Agbani road to ITC outfall were achieved using EPA stormwater management model (SWMM). The simulation of the existing performances of the drainage system of the drainage basin A were carried out successfully. The results of performance of the drainage system showed that at the drainage basin A, the drainage from Akwuke junction to Gariki market was flooded and drainage from Ebony junction to ITC was also flooded.

Generally, these drainages were determined to be insufficient for draining stormwater.

The EPA stormwater management model (SWMM) simulation result shows that increase in the depth of those flooded drainages to 1m and the width to 0.9m or 1m, will take care of the flooded drainage systems. The above drainage sizing is ideal in that it does not take of the activities of some people who are used to throwing regularly wastes of all kinds into surface drains and culverts. These uncivilized acts, if not checked, can keep even properly designed drainages and culverts blocked thereby causing flash flood in the urban drainage system of the study area.

It was discovered that inappropriate drainage design of 0.6mm depth by 0.6mm width at Gariki market, which should be considered as most busy drainage system because of its combine sewer overflow and drainage blockages due to the busy activities going on there, and improper maintenance were the most frequent causes of urban drainage issues.

Inadequate drainage design along Enugu motor market to Imo transport company (ITC) junction has had a variety of far-reaching effects on the Enugu urban municipality.

4.2 Recommendations

EPA SWMM model should be used to evaluate the existing urban drainage infrastructure of Enugu State and for new drainage designs.

The Government agencies like the Federal Road Maintenance Agencies (FERMA) to adopt the use of SWMM for evaluation and designing of new urban drainage system.

Based on the stormwater simulation result, those flooded drainages should be redesigned by increasing the depth and width of those drainages to 1m and 0.95m respectively.

Government should legislate against improper disposal of waste and dumping of wastes into drainages.

Researchers and students should use data gotten from this project for future use.

Institutions of higher learning should have a course on EPA Stormwater Management Model (SWMM), to be able to teach the students new ways of evaluating and designing of effective drainage system using computer.

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