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Flood Mitigation and Pollution Abatement in Kaduna Metropolis Through Engineering Assessment and Analytical Hierarchy Process Design

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ABSTRACT

Pollution abatement and flood control activities require effective water resource planning, engineering assessment, sophisticated technology, and appropriate hydraulic structure designs. This paper x-rays flood mitigation and pollution abatement strategies that can be adopted in the Kaduna metropolis in Nigeria. Analytical hierarchy process of design, questionnaires, engineering assessment approach, and standard method for estimation of the runoff discharge was adopted for this research. Estimating water balance components and QSWAT Hydrological Model can be used with the QGIS interface for a greener environment. Suitable hydraulic systems were designed for long-term flood control in the River Kaduna catchment area through an analytic hierarchy Process. Statistical analysis, manning equations, and rational methods were utilized for adequate assessment and planning. The hydraulic discharge capacity of culverts, open channels, and other hydraulic structures was carefully checked. Flooding greatly impacts infrastructural development, and inadequate drainage systems contribute to it. Mitigation strategies, adequate water resource planning, and management will greatly benefit from addressing flood-related issues in the study area. This research provides information on the flood vulnerability of infrastructures and mitigation strategies that can be adopted in the study area. Viable policies and management strategies can be utilized to avert losses traceable to floods in developing and developed countries.

INTRODUCTION

Environmental pollution and flooding-related issues must be avoided in developing and developing nations. Since rivers provided a consistent, even though not always reliable, flow of water for household, agricultural, industrial, and nautical purposes, numerous cities grew independently along many river valleys around the world. These cities include New York along the Hudson River, Cairo along the Nile River, and Kaduna, the capital of Kaduna State in Nigeria, which is situated along the River Kaduna. It is vital to reduce shortages caused by the water demands of irrigation systems in a variety of climatic and environmental settings. Even though the ideal scenario would satisfy all water needs, the best results would indicate otherwise. To preserve the effectiveness, maintenance, and sustainability of the aquifer, the groundwater level drawdown can be decreased (Rezaei & Safavi 2022). Governments, the general public, and all other participants in the water sector are all impacted by the serious issue of water stress. Groundwater must be utilized for industrial purposes, effective irrigation systems, and the production of drinking water in the majority of countries globally (Felisa et al. 2022). Flood control, efficient use of water resources, and catastrophe mitigation must all be prioritized by those in charge of managing river basins and water projects. By acting quickly and correctly forecasting floods, flood damages can be decreased (Oyebode et al. 2022). Pollution abatement refers to technology applied, or measures taken to reduce pollution and its environmental impacts. The most commonly used technologies are scrubbers, noise mufflers, filters, incinerators, wastewater treatment facilities, and composting of wastes. It promotes more efficient use of raw materials, staff resources, equipment, energy, and water. It improves worker health and safety through improved air quality, decreased use of toxic substances, and fewer personnel protective equipment requirements. Groundwater contamination is an international issue affecting both ecological services and human health. The water sector will benefit from strategic management, which will also address issues relating to human health threats (Oyebode & Otoko 2022, Oyebode 2022, Ogarekpe et al. 2023). Natural disasters are unavoidable, necessitating careful observation and implementing mitigation strategies to

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lower vulnerability and risk. The main goal of vulnerability index creation, a crucial instrument in flood management, is pinpointing the region most susceptible to floods. Flood risk is examined and divided into three categories: exposure, susceptibility, and flood hazard. Malaysia's average annual flood damage costs around $100 million (Chan 2015, Bahar et al. 2022). Overuse of environmental resources degrades the watershed's ecosystem, and poor agricultural households are blamed for this degeneration (Sunaedi et al. 2022). Watershed improvements have been made due to the implementation of the Payment for Environmental Services (PES) program, particularly regarding water services (Redondo-Brenes & Welsh 2006, Pissarra et al. 2021).

On several occasions, these rivers overflow their banks and flood the adjoining properties on their floodplains. There are cases of flooding, such as River Kaduna in 2003, Elbe River in 2003, 2005, and 2007, River Sokoto in 2006, River Ogun in 2007, and many others. Consequently, flooding, an associated natural hazard with floodplain developments, is a major problem these cities had to contend with and develop policy, legislative and technical measures to control (Proverbs & Lamond 2017). Flooding is when a lot of water covers a normally dry area. It could be brought on by prolonged periods of heavy rain or a river overflow. Flooding is a catastrophe that needs to be reduced to prevent endangering lives (Oyebode 2018). Around the world, natural disasters frequently result in physical (such as injuries, casualties, and property damages) and non-physical (psychological and mental) disruptions. The most common natural hazard, flooding, is not an exception. Over the past few decades, it has significantly harmed the environment and caused social harm in various parts of the world (Adjei-Darko 2017, Parsian et al. 2021).

Several unresolved problems and environmental dangers in rural areas and important settlements in Nigeria can be linked to floods and erosion (Oyebode 2021). Environmental damage was caused by migration and industrial development (Oyebode 2022a). The best materials and most recent structural engineering developments must ensure that water-retaining structures are adequately protected from sliding, earth pressures, hydrostatic forces, and overturning moments (Oyebode 2022b). There is a need for adequate policy, maintenance of road networks, and weather station for effective planning, construction, and management of floods in developed nations of the world (Oyebode 2021). In Nigeria, the flooding of urban settlements has become an annual occurrence. This usually becomes obvious at the peak of the rainy season. The resultant damage caused by the flooding calls for a more pragmatic approach to flood management and control. There are a lot of bridges and collapse of buildings and flooding scenarios. Marketplaces and farmlands have also been submerged for weeks and sometimes washed away. As a result, flooding in Kaduna must be assessed.

Innovative stormwater management techniques, which depart from traditional "end of pipe" strategies, have attracted increasing attention over the past ten years (based on conveying water offsite to centralized detention facilities). By evacuating people and property from danger zones, nonstructural techniques lessen the damage. Elevated structures, property buyouts, long-term moves, zoning, subdivision, and building codes are some of them. New approaches that promote managing runoff as close to its source as possible, such as sustainable urban drainage systems, low-impact construction, or green infrastructures, have thus become quite popular among practitioners and public authorities (Sage 2015).

Measures performed to reduce, halt, and eradicate pollution from the environment are referred to as pollution abatement. Using catalytic converters in cars to reduce air pollution is an example of a technological solution. Equipment upgrading and installation of more effective equipment to cut waste production and raw material usage are very important. The decrease in environmental degradation and economic growth are mutually beneficial objectives. As the effort to reduce pollution increases, its effectiveness may rise as well. Even if environmental policies remain unchanged, pollution can be reduced because efficiency improvements make abatement less expensive (Managi 2006).

AREA OF THE STUDY

River Kaduna can be found upstream of the Shiroro Reservoir. Geographically, River Kaduna is located between latitudes 9°52′38″N and 10°39′07″N and between longitudes 6°52′33″E and 8°28′50″E (Fig. 1). Air masses, atmospheric pressure, and other climatic conditions control rainfall in the study area. (Butu et al. 2020). Fig. 2 presented flood-prone areas and hazard assessment of some Areas in Kaduna State.

PAST STUDIES

There were records of flood incidences in Kaduna state in Nigeria, according to George & Abdulkadir (2019), floods affect human activities, lives, and properties (Adelekan & Asiyanbi 2016, Ibrahim & Abdullahi 2016). The technology used, or actions performed to reduce pollution and its environmental effects are referred to as pollution reduction. Scrubbers, noise mufflers, filters, incinerators, wastewater treatment facilities, and waste composting are the most frequently utilized technologies. Table 1 presented

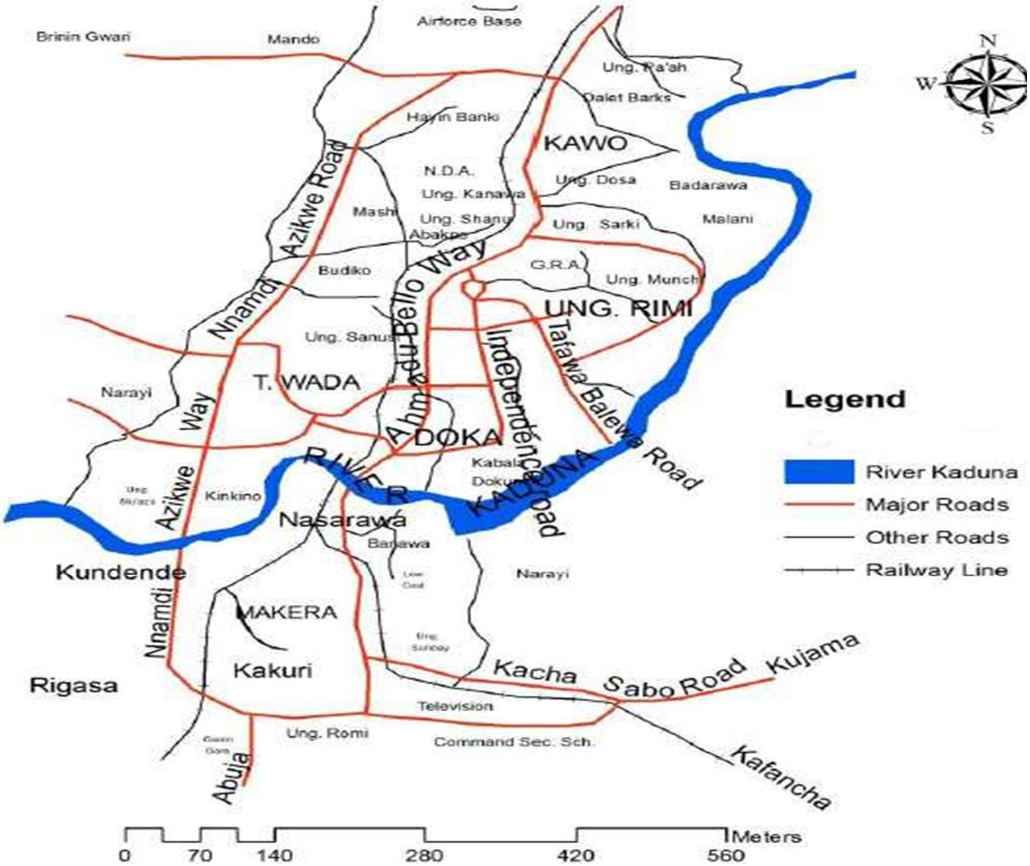
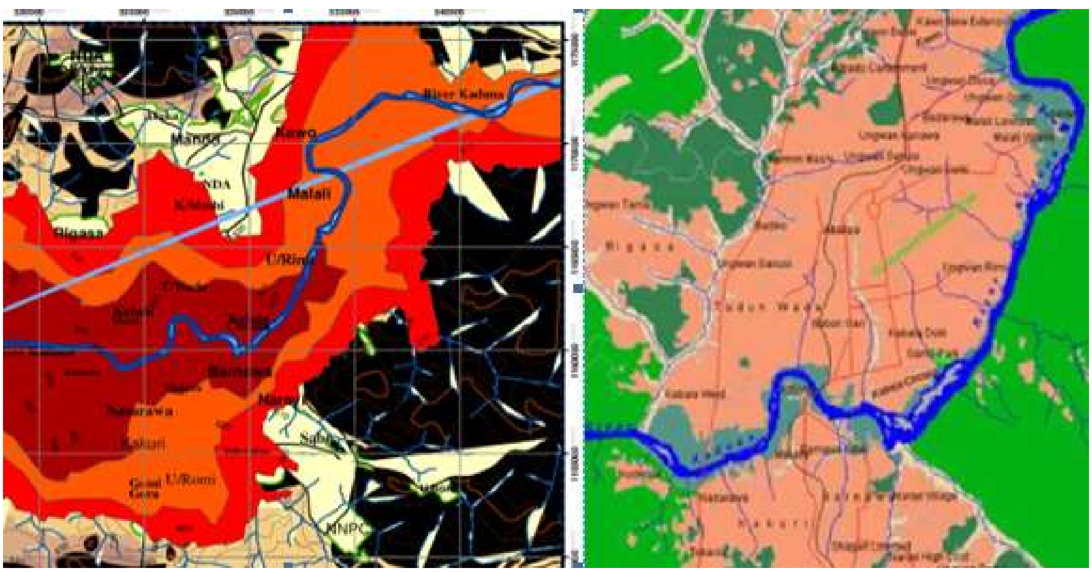


Fig. 1: Map of Kaduna Metropolis indicating major roads and the river.



Source: (Sule et al. 2016).

Fig. 2: Flood hazard assessment of some areas in Kaduna State.

Table 1: Continuous Occupation Floodable areas of Kaduna metropolis.

Consequence	Respondents (n=196)	Respond-ents [%]
Houses affected by flooding	127	64.29
Collapse Structure through floods	50	25.51
People restricted from movement	81	41.32
Polluted water origin	44	22.44
Heath Hazards traceable to floods	49	25

percentages of the flooded areas from a questionnaire survey. Table 2 presented flooding in 65% of the houses occupied by the respondents. There are cases of collapse for 26% of houses due to flooding. Besides harming personal belongings, every respondent stated how flooding impacted public infrastructures. These included flooded highways, downed telephone and electric lines, flooded marketplaces, flooded schools, and blocked drainage systems.

MAJOR CAUSES OF FLOODING IN KADUNA METROPOLIS

Table 2 gives a summary of the scenario. Most tropical flood events, which are partly or entirely climatologically in nature, are thought to be primarily caused by rainfall intensity, duration, and amount (Johnson et al. 2016, Ibrahim & Abdullahi 2016).

EFFECTS OF FLOODS

Flood risks and disasters can be traced to blocked drainages, uncoordinated human activities, erratic electricity, and poor communication networks. Many farmlands, surface water, and accommodation were affected (Wahab & Falola 2018, Wamugi 2016).

Table 2: Main reasons for floods in Kaduna State.

Major reasons	Strongly agree	Agree	Neutral	Disagree	Strongly agree
Heavy rainfall	127(64.79%)	44(22.44%)	19(9.69%)	6(3.06%)	0(0%)
Overflowing of River Kaduna bank	105(53.57%)	60(30.61%)	6(3.06%)	22(11.22%)	3(1.58%)
Topography	114(58.16%)	61(31.12%)	0%	10(5.10%)	11(5.61%)
Infiltration	84(42.85%)	73(37.24%)	12(6.12%)	11(5.61%)	16(8.16%)
Lack of drainage network	160(81.63%)	31(15.82%)	0%	3(1.53%)	1(0.51%)
Poor drainage network	147(75%)	39(19.90%)	0%	4(2.04%)	6(3.06%)
Building on the water channel	96(48.90%)	52(26.53)	2(1.02%)	22(11.22%)	24(12.24%)
Dumping of waste on channels	122(62.24)	34(17.34%)	2(1.02%)	10(5.10%)	28(14.28%)
Climate change	27(13.77%)	73(37.24%)	1(0.51%)	34(17.34%)	61(31.12%)

Source: (Fieldwork 2015)

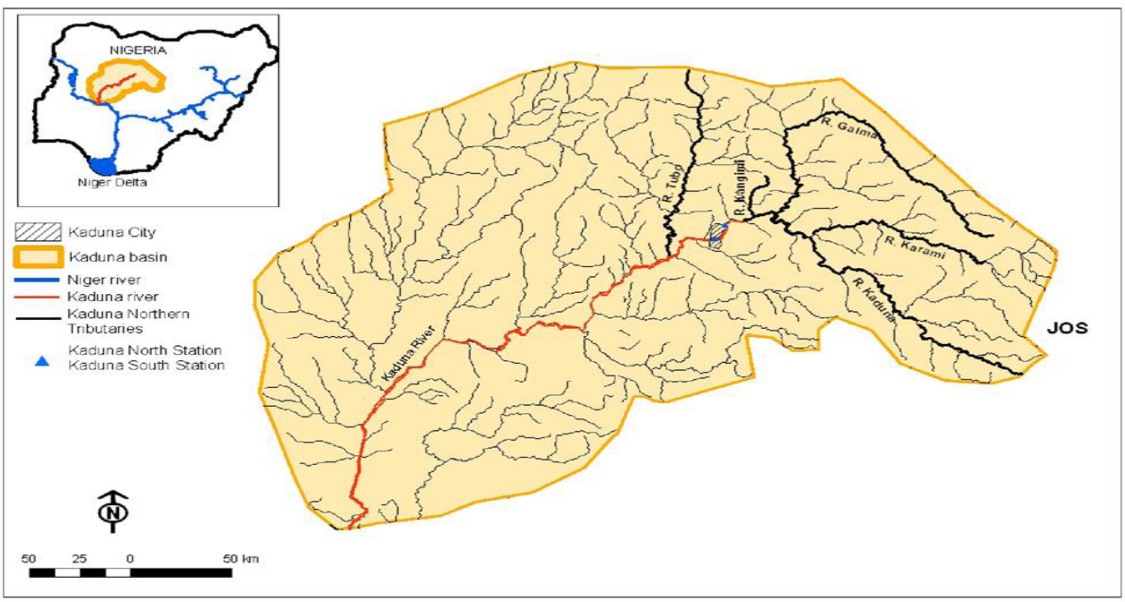


Fig. 3: Kaduna River basin.

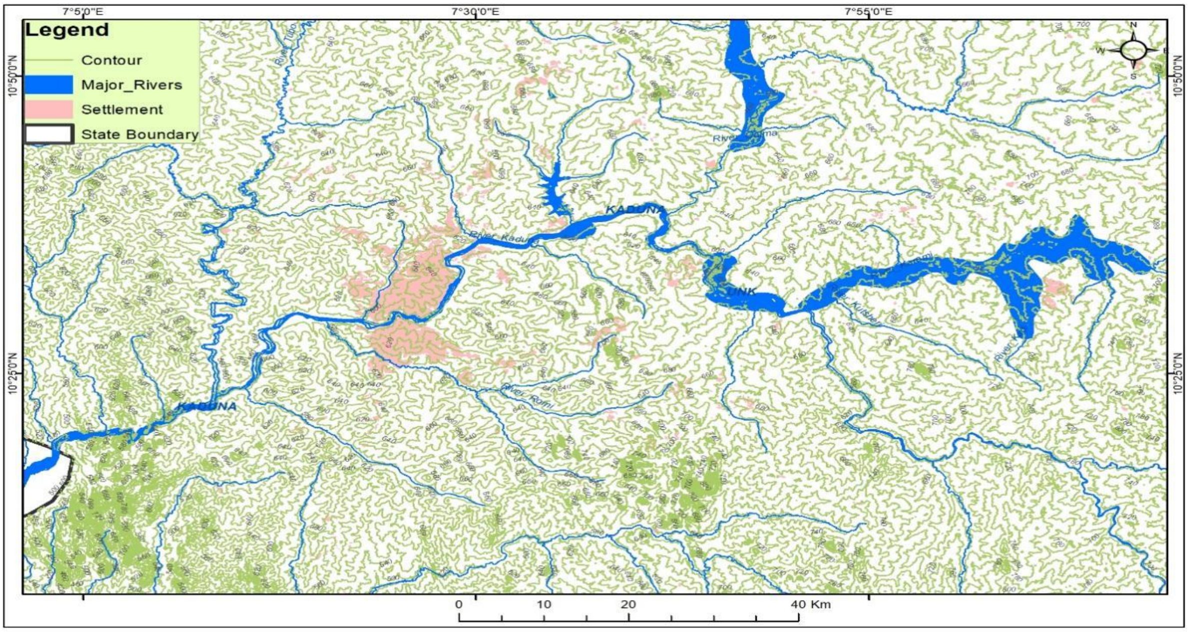


Fig. 4: Catchment area of River Kaduna.

Source: (Field survey 2021)

Fig. 5: Flooding in the Kaduna.

Fig. 6: Flooding in Nigeria.

MATERIALS AND METHODS

The study area considered was Kaduna State. Analytical hierarchy Process of design, questionnaires, and standard method for estimation of the runoff discharge was adopted for this research. The Analytic Hierarchy Process is a way of decision-making that evaluates several options, each with many of criteria to help choose the best option. It is frequently employed for choosing and prioritizing projects. Suitable hydraulic systems were designed for long-term flood control in the River Kaduna catchment area through an analytic hierarchy Process. Fig. 3 presents Kaduna River Basin, Fig. 4 gives the catchment Area of the River Kaduna, and Fig. 5 and Fig. 6 present a case study of flooding in Nigeria.

Velocities of flows were high in some communities (Ferguson et al. 2017). Commonly accepted values for Manning's roughness coefficient, n, are based on materials and workmanship required in the Standard Specifications (Hashim 2018).

Culverts

Culverts are designed for transportation and easy disposal of storm runoff from highways. Fig. 7 shows a typical culvert under a roadway. SWAT simulates different hydrological processes was presented in Fig. 8.

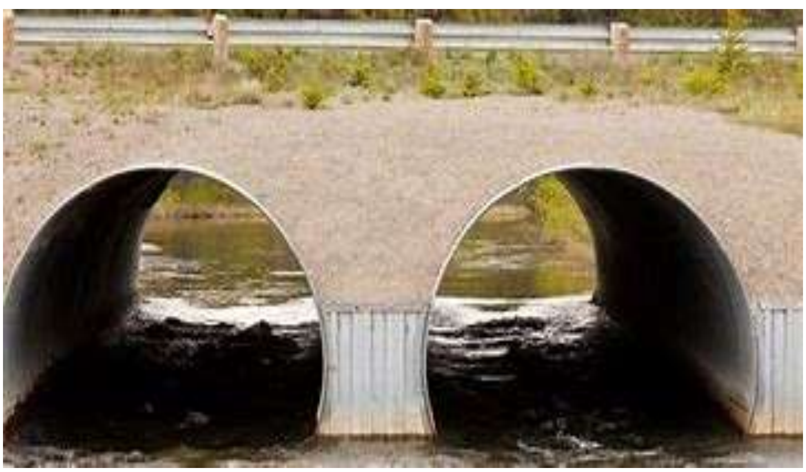


Fig. 7: Culvert under a roadway.

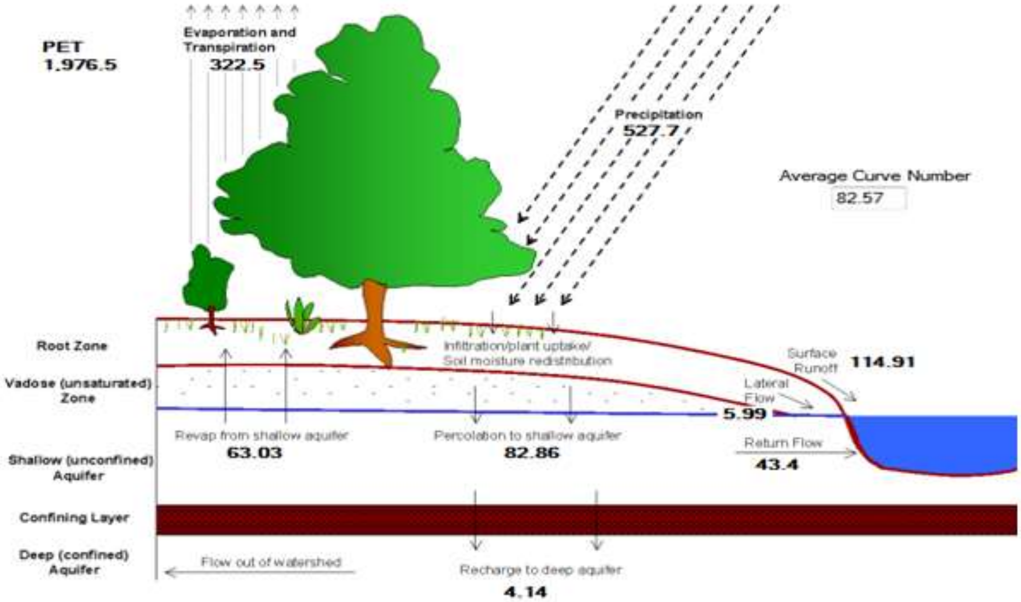


Fig. 8: Schematic representation of hydrologic components by SWAT output.

Hydrological Components and Processes in the SWAT Model

The SWAT enables the simulation of various physical processes in a watershed (Neitsch et al. 2011). Surface runoff, infiltration, evapotranspiration (ET), lateral flow, percolation to shallow and deep aquifers, and channel routing are simulated processes (Arnold et al. 1998). All of these hydrological processes are simulated in shallow and deep aquifers as well as the surface, soil, and intermediate (vadose) zone. The stream flow in the main channel was influenced by the hydrological processes of surface runoff, subsurface or lateral flow, return flow, and base flow. The water balance equation is the foundation for SWAT's simulation of the hydrologic cycle. The water balance equation is the foundation for the SWAT model's simulation

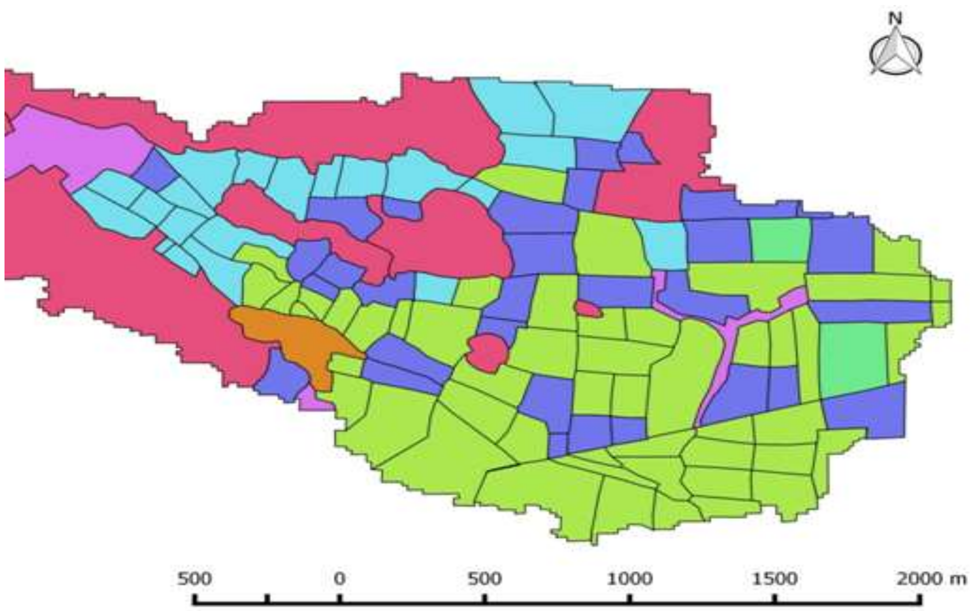


Fig. 9: The land-use map of the watershed.

of hydrological processes. Fig. 9 presented the land-use map of the watershed. The hydrologic cycle simulated by SWAT is based on the water balance equation. The simulation of hydrological processes in the SWAT model is based on the water balance equation.

$$SW_t = SW_o + \sum_{t-1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad \text{... (1)}$$

Design of Rectangular Culverts

The intake (also known as the inlet or fan), the barrel (or throat), and the diffuser are the three components of a culvert (also called the outlet or expansion fan). An accurate calculation of the discharge-frequency relationships is necessary for the construction of road drainage systems. While some facilities need a runoff hydrograph that estimates runoff quantities, others need a momentary peak flow rate. Based on projected design floods, methods for constructing road-crossing drainage culverts should account for essential storm duration. They should also use a hydraulic design methodology to maximize the culverts' size and hydraulic variables (Kang et al., 2009). A bridge is a substantial structure that spans a significant body of water or other physical barriers to allow traffic and people to cross. A box culvert is a structure resembling a tunnel that is erected beneath railroad tracks or roads to facilitate cross drainage from one side to the other. Culverts often have small spans and are buried in the ground. The roadway and the vehicles utilizing it are supported by the soil surrounding the culvert. A bridge contains support structures underneath it, however, there are open spaces between the supports that typically span more than 6 meters. It is crucial to be able to predict the load for projects with heavy backfill and similar tunnels. Designers must take several important aspects into account to appropriately obtain the earth pressure (Li et al., 2020). Fig. 10 indicates Culvert's elements.

For $0 < \frac{H1}{D} \leq 1.2$ …(2)

$$Q = \frac{2}{3} C_B B H_1 \sqrt{g H_1 \frac{2}{3}} \quad \text{…(3)}$$

Table 3: Increment and reduction pattern of annual rainfall.

Period	R_i	R_m	R_i-R_m	% Change
1980-1990	112	111.5	0.5	0.45 %
1991-2001	111	111.5	-0.5	-0.45%
2002-2012	112	111.5	0.5	0.45%

Table 4: Data of statistics for discharge in the study area.

Month	Mean	Runs test
January	244.32	0.11
February	248.46	0.21
March	251.74	0.01
April	227.52	0.217
May	211.33	0.75
June	238.73	0.03
July	340.00	0.22
August	357.64	0.11
September	349.88	0.05
October	348.30	0.07
November	279.01	0.28
December	247.68	0.80

Source: (Abaje et al. 2012, Okafor & Ogbu 2018)

For $\frac{H1}{D} > 1.2$ …(4)

$$Q = C_h BD \sqrt{2g(H_1 - C_h D)} \quad \text{…(5)}$$

The rational formula is given by:

$$Q = \frac{CIA}{Z} \quad \text{…(6)}$$

Where: C is the runoff coefficient, Q is the maximum rate of runoff ($m^3.sec^{-1}$.)

I = average rainfall intensity ($mm.hr^{-1}$.), A = drainage area (in ha), Z = conversion factor, 1 for English, and 360 for metric.

RESULTS AND DISCUSSION

Estimation of Peak Runoff Discharge

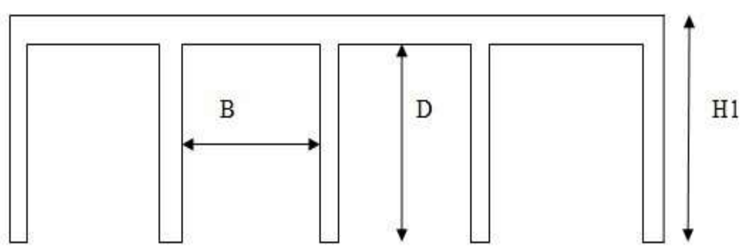


Fig. 10: Culvert's elements.

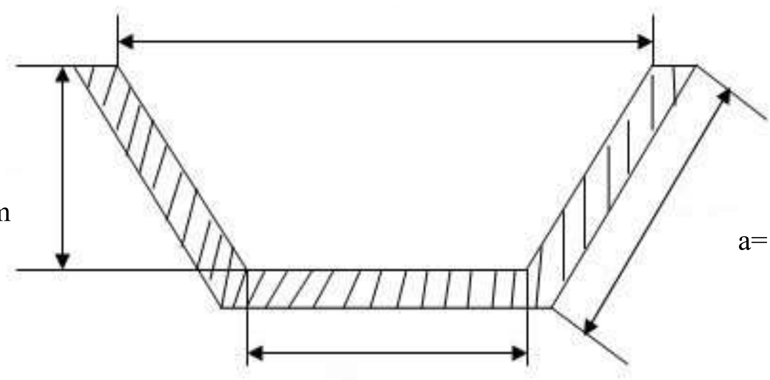


Fig. 11: Cross-section of an open channel.

The rainfall intensity has got to be calculated by using the common rainfall intensity method. The rainfall records of 1980-1990, 1991-2001 and 2002-2012 have a typical rainfall of 111.5 mm, as presented in Table 3.

However, in this research work, the predicted discharge was obtained from (Abayomi et al. 2015), as described in Table 4

The table above shows the mean average discharge determined using the rational method. It is noted that August has the highest discharge of 357.64 $m^3.s^{-1}$, and January has the least discharge of 244.32 $m^3 s^{-1}$. Fig. 11 presented the cross section of an open channel in the existing channel discharge capacity.

The determination of the discharge capacity of an open channel using the mining equation has taken into consideration the calculation of the following parameters:

The area = $(8.5 + 6.7) \times \frac{3.35}{2} = 25.46\ \text{m}^2$

The injected parameter = (2 × 2.4) + 6.7 = 11.5m

The hydraulic radius $R = \frac{A}{P} = \frac{25.46}{11.5} = 2.21\text{m}$ …(7)

Estimated discharge $Q = AV = \frac{AR^{2/3}S^{1/2}}{n}$ …(8)

The main channel slope S = 0.032

Manning's coefficient n = 0.03 because the channel is constructed in stone masonry.

Hydraulic Discharge Capacity

$$= \frac{1}{0.03} \times (25.46) \times (2.21)^{\frac{2}{3}} \times (0.032)^{\frac{1}{2}} = 258.25\text{m}^3/\text{s}$$

The hydraulic discharge capacity of the existing channel at its construction time was 258.25 $m^3.s^{-1}$. For the open channel, it was assumed that the channel is exposed to various use like solid waste dumped and sedimentation of considerable; it was assumed the height of the channel was reduced by 0.30. Therefore, calculating the discharge capacity of the open channel has to be considered the current situation where the channel height becomes 3.05 m.

The area after sedimentation can also be calculated as follows:

$$A = (8.5 + 6.7) \times \frac{3.08}{2} = 23.18\text{m}^2$$

P = (2 × 2.4) + 6.7 = 11.5m

$$R = \frac{23.18}{11.5} = 2.01\text{m}$$

The discharge capacity of the channel has been again calculated by using the formula (Liu et al.);

$$Q = A \times V = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2} \quad \ldots(9)$$

Hydraulic Discharge Capacity

$$= \frac{1}{0.03} \times (23.18) \times (2.01)^{\frac{2}{3}} \times (0.032)^{\frac{1}{2}} = 220.65\text{m}^3/\text{s}$$

The hydraulic discharge capacity of the existing open channel during heavy rain with high sedimentation is 220.65m^3/s.

Design of the New Channel

The maximum predicted discharge is 357.64 $m^3.s^{-1}$. Use n=1.5

Chezy constant c = 65, Q = 357.64 $m^3 s^{-1}$

Hydraulic radius R = $\frac{y}{2}$

Area of flow, $A = \frac{Q}{V} = \frac{357.64}{23.18} = 15.43m^2$

Wetted parameter p = $b + 2y\sqrt{n^2+1}$ (4.14)

$R = \frac{A}{P} = \frac{15.43}{b+2y\sqrt{n^2+1}} = \frac{y}{2}$

i.e. $R = \frac{y}{2}$

$46.36 = y[b + 2y\sqrt{1.5^2+1}]$ = y(b+3.6)

46.36=by+3.6

A= (b + ny) y

S= (b+1.5y) y

by = 1.543 – 1.5y^2

$y = \left(\frac{15.43}{2.1}\right) 1^{1/2}$=2.712m

By Substituting the value of (y = 2.712m) in the equation, we get

46.36 = b x 2.712 + 3.6 x (2.712)^2

46.36 = 2.712b + 26,478

Bottom width, $b = \frac{46.36-26.478}{2.712}$ =7.33m

Top width, $V = C\sqrt{RS}$

$$23.18 = \sqrt{\frac{y}{2}}S = 0.60 = 65\sqrt{\frac{2.712}{2}} \times S = 75.69\sqrt{S}$$

$$S = (\frac{0.6}{75.69})^2 = 6.284 \times 10^{-5}$$

B = b + 2ny

B = 7.33 + 2 + 1.5 × 2.712 = 13.39 m

The channel is assumed to be exposed to different use like solid waste, sedimentation, and dumps of considerable quantities. Thus it was assumed that the height of the channel was reduced by 0.30m

i.e. $Q = AV = \frac{AR^{2/3}S^{1/2}}{n}$

h = 3 – 0.3 = 2.7m, B =13.4m, b = 7.33m

The area = $(13.4 + 7.33) \times \frac{2.7}{2} = 27.98\ m^2$

The wetted parameter = (2 × 2.4) + 7.33 = 12.13m

The hydraulic radius $R = \frac{A}{P} = \frac{27.98}{12.13} = 2.31m$

Estimated discharge $Q = AV = \frac{AR^{2/3}S^{1/2}}{n}$

The main channel slope S = 0.032

$$Q = \frac{1}{0.03} \times (27.98) \times (2.31)^{\frac{2}{3}} \times (0.032)^{\frac{1}{2}} = 291.54m^3/s$$

The hydraulic discharge capacity of the channel after it was reduced by 0.30 due to the exposure to different use like solid waste, sedimentation, and dumps of considerable quantities 291.54 m^3.s^{-1}.

Existing Culvert Discharge Capacity

Fig. 12 presented the cross-section of the culvert. The discharge capacity of this ditch has been calculated by also considering its shape, parameters, and relation $\frac{H1}{D}$.

Dimensions: B=7.2m, D=3.2 m , H_1 = 4m

$\frac{H1}{D} = \frac{4}{3.2} = 1.25m$ > 1.2

$Q = C_h BD\sqrt{2g(H_1 - C_h D)}$

Where:

With: C_h=0.6 for square inlets

g = 9.81 m.s^{-2}

Where: D = The inside Height (in m), B = The inside width (in m)

H_1= The upstream energy Level, relative to the invert level (m)

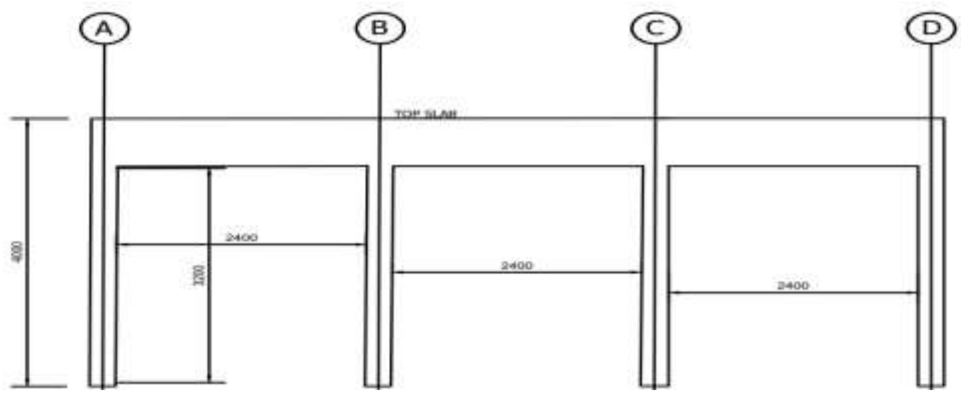


Fig. 12: Cross section of culvert.

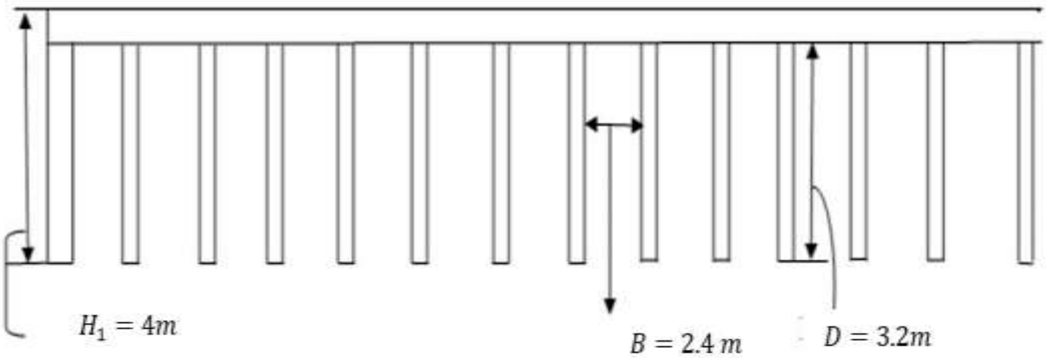


Fig. 13: Designed culverts under the bridge on the Kaduna.

$$Q = 0.6 \times 7.2 \times 3.2\sqrt{2 \times 9.81 \times (4 - 0.6 \times 3.2)}$$
$$= 88.13\text{m}^3/\text{s}.$$

The reduction of its discharge capacity.

$$Q = 0.6 \times 7.2 \times 3.2\sqrt{2 \times 9.81 \times (3.7 - 0.6 \times 3.2)}$$
$$= 81.69\text{m}^3/\text{s}$$

Dimension: D = 3.2m, and H_1= 4m.

$$\frac{H_1}{D} = \frac{4}{3.2} = 1.25\text{m}$$

Since $\frac{H_1}{D} > 1.25m$ then, the following equation has been used

$$C_h BD\sqrt{2g(H_1 - C_h D)}$$

$C_h = 0.6$ $g = 9.81\text{m/s}^2$

$$357.64 = 0.6 \times B \times 3.2\sqrt{2 \times 9.81 \times (4 - 0.6 \times 1.92 \times 3.2)}$$
$$= 12.26B$$

$$B = \frac{357.64}{12.26} = 29.17\text{m}$$

Thus, this culvert's design has been considered for the widening of the existing culvert. The widening had taken reference on the existing opening, which has a 2.4 m width; hence, for an opening of 2.4 widths:

$$b = \frac{29.17}{2.4} = 12.15 \text{ openings} \cong 13 \text{ openings}$$

b = 13 openings.

In conclusion, the culvert under the bridge has to be with 13 openings with the inside width (D = 3.2) and the upstream energy level relative to the inlet level (H1= 4m) for each. Fig. 13 presented the designed culverts under the bridge on the Kaduna.

Levees, floodgates, floodwalls, and evacuation routes are all examples of flood mitigation techniques. Installation of rock beams, rock rip-raps, and sandbags, preserving normal slopes with vegetation or applying soil and cement on steeper slopes, and building or enlargement of drainage systems are also some of the common flood control strategies. Pollution may be abated by adhering to rules created to safeguard the environment. Practices like material substitution, switching to less dangerous materials, process modification, and modifying the production process to increase efficiency can all help to reduce pollution.

CONCLUSIONS

Pollution of the environment can be traced to flooding, climate change, blocking of drainages by illegal solid waste disposal, and lack of enforcement of flood management techniques. There is a great need for optimal evaluation and modification of the current drainage network of the state. It has been discovered that the Kaduna River is a tributary river of the River Niger that flows for 550 km through Nigeria. Data on daily rainfall were collected. Satellite-based remote technology is an effective tool for analyzing drainage networks, studying surface morphological features, and their correlation with groundwater management prospects at the basin level. The peak runoff discharge was 357.64 $m^3.s^{-1}$. The hydraulic discharge capacity of the existing open channel was 258.25 $m^3 s^{-1}$, where the channel had a section of top width (B) = 8.5 m, bottom width(b) = 6.7 m, and height(H) = 3.35 m which would be less when the hydraulic discharge capacity rises to 357.64 $m^3.s^{-1}$ in August from the result obtained. Therefore, a new open channel was designed with a dimension of top width(B) = 13.39 m, bottom width(b) = 7.33 m, and height(H) = 3m. Adequate water resource planning and management will greatly benefit from addressing flood issues in the study area. The existing culverts have a dimension of B (width of culvert) = 7.2 m, D (height of culvert) = 3.2 m, the width of culvert = 2.4m, and H1(height of culvert to top slab) = 4.2m, which was estimated to carry 88.3 $m^3.s^{-1}$ of hydraulic discharge. Still, with the flooding of the study area, the dimension of the trench had to be increased to B (length of culvert) = 29.17m, D (height of culvert) = 3.2 m, the width of culvert = 2.4 m, and H1(height of culvert to top slab) = 4 m. It was also noted that solid waste in the hydraulic structures also leads to clogging, reducing the capacity to be accommodated by the hydraulic structure. This research provides information on the flood vulnerability of infrastructures and mitigation strategies that can be adopted in the study area. The construction of these hydraulic structures in strategic locations will assist in flood control and the environmental health of Kaduna Metropolis. The open-source geospatial techniques were utilized to create different thematic maps of the study area that influence land use, soil, drainage, and slope used as input for the QSWAT model. QSWAT model proves a powerful tool in simulating the hydrology at the micro watershed scale. Estimating water balance components of a micro watershed by employing an efficient, calibrated, and validated SWAT model helps to understand each water balance component. Levees, dams, seawalls, and tide gates are flood control infrastructures that can be used as physical barriers to stop flooding caused by rising or rushing water. Pumping stations and canals, among other strategies, lessen floods.

RECOMMENDATIONS

Suggested recommendations that will contribute to flooding control in Kaduna include:

i. Adequate measures such as mitigation and adaptation programs should be put in place to arrest flooding issues
ii. Multidisciplinary platforms for generating effective strategic policies, adequate funding, and efficient operational mechanisms for flood management should be adopted.
iii. Satellite-based remote technology should be embraced as an effective tool in analyzing drainage networks and studying surface morphological features and their correlation with groundwater management prospects at the basin level.
iv. Routine maintenance should be carried out to determine the condition of the hydraulic structures.
v. Multidisciplinary research on flood control should be adequately funded by appropriate authorities and policy makers. The outcome of such research should be implemented by engineers and other allied professionals.
vi. Larger main drainage channels should be constructed to transport a large volume of water. Regular hydraulic structure cleaning should be done to remove all forms of silt and solid waste that would hinder water transportation to a safe location.
vii. Regulating bodies should discourage building on the floodplain and control the release of potential solid waste into the drainages.
viii. River re-channelization, raising home foundations, land use planning and management, and public education are among recommended flood remedial and management measures to stop activities that contribute to flooding in Kaduna's capital city.

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