

Evaluation of Drainage and Stormwater Control Measures in Asaba Metropolis, Delta State, Nigeria

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ABSTRACT

Asaba, the capital of Delta State, experiences recurrent flooding associated with rapid urban growth, changes in land cover and inadequate drainage infrastructure. This study examines the drainage and flood-control conditions in the city and develops an engineering design for selected stormwater channels. An engineering survey was used to map the project area and identify vulnerable drainage routes. Historical rainfall records from three meteorological stations were used to develop rainfall intensity-duration-frequency (IDF) relationships, while supplementary Asaba rainfall data were examined to describe local rainfall patterns. A 10-year IDF relationship was used to estimate peak discharge and to guide the hydraulic sizing of the proposed drainage channels. The assessment identified inadequate drainage capacity, unplanned development, encroachment on waterways and poor maintenance as important factors associated with flooding in the study area. The study therefore combines catchment-specific hydraulic calculations with practical measures such as regular drain maintenance, improved waste management and protection of natural drainage routes.

The findings highlight the need for integrated water management strategies, community participation, policy reform, and investment in resilient infrastructure, alongside the specific engineered channel design proposed in this study.

Keywords: Stormwater drainage; Flood control; Rainfall intensity-duration-frequency; Hydraulic design; Asaba

1.0 Introduction

Rapid urban growth in Nigerian cities has consistently outpaced the development of drainage infrastructure needed to safely convey stormwater runoff, and Asaba, the capital of Delta State, illustrates this problem clearly. The removal of vegetative cover for housing, roads and other infrastructure, combined with the encroachment of construction on natural waterways, has reduced the capacity of the environment to absorb rainfall and has increased the volume and speed of runoff reaching the city's streets. Human activity has also altered rainfall patterns and increased the volume of water reaching rivers and oceans, compounding the flooding problem. Asaba sits on an undulating landform of hills and hydrological basins, with the city centre lying in the lowest part of the terrain; it also receives runoff draining from the neighbouring, more elevated town of Okpanam. Natural waterways that once served as the city's principal drainage outlets, including the Iyi-Abi Stream and the Anwai River, have in many places been altered or blocked by development, forcing successive administrations to plan new drainage routes, often without full implementation. The result has been recurrent and increasingly severe flooding that threatens lives, property, and the economic and environmental stability of the metropolis, most visibly in the major flood events of 2012 and 2018 that displaced residents and damaged infrastructure across the city.

Asaba's vulnerability to flooding has been linked to its low-lying, riverine setting; Ihuah et al. (2018), in a GIS and remote-sensing-based flood vulnerability assessment of the Niger Delta region published in the *Journal of Flood Risk Management*, identified the city's proximity to the River Niger as a key driver of its susceptibility. More recent, locally focused studies have examined the drainage system directly: Ezeah and Eguabor (2024) combined remote sensing, GIS, field surveys, and stakeholder consultation to map and analyse Asaba's urban drainage system, and found that properly functioning drainage is essential to preventing waterlogging and mosquito breeding in flood-prone areas, while Odo (2023) reviewed flood policy and governance in the city and traced the development, since 2005, of a national policy for coordinated erosion, flood and coastal zone management in Nigeria. Complementary work by Olajuyigbe et al. (2015) used GIS-based spatial analysis to assess flood vulnerability in Port Harcourt and found that susceptibility varies considerably even within a single city, underlining the importance of localized, catchment-specific analysis rather than generalized assessments. Public expectations around drainage investment have also been documented: Jakpor and Akpovwovwo (2026) examined residents' perceptions of flooding and mitigation in a periurban area of Delta State and found that residents identified blocked and inadequate drainage as a primary cause of flooding, underlining the ongoing need for new drain construction and the desilting of existing channels, while Ebunilo and Okoro (2023) and Akiyan et al. (2016) both assessed the watershed and soil properties of the Iyi-Abi Stream forest in Oshimili South Local Government Area and identified its potential contribution to both flooding and erosion control if properly managed. For the hydrological design itself, Nigeria-specific rainfall intensity-duration-frequency relationships developed by Oke (1980) for Benin City and by Okwuobi (1980) for the same city provide long-standing reference values that remain in use for the wider Niger Delta region in the absence of a dedicated long-term rainfall record for Asaba.

The studies reviewed above describe the flooding problem in Asaba and several aspects of its drainage and policy response, but they do not provide a catchment-specific hydraulic design for the locations examined in this study. Ezeah and Eguabor (2024) mapped the existing drainage network, while Odo (2023) examined flood policy and Jakpor and Akpovwovwo (2026) considered residents' perceptions of flooding and mitigation. The present study adds an engineering component by combining ground-survey information with rainfall intensity-duration-frequency analysis to estimate peak runoff and size drainage sections for four selected catchments. The resulting designs are intended to provide practical hydraulic information for stormwater conveyance from the identified low-lying areas towards the Iyi-Abi Stream, the Anwai River and the River Niger.

2.0 Materials and Methods

2.1. Engineering Survey

For efficient and effective stormwater control measures, a good knowledge of the topography of the study area is very important. As much as practicable, the survey followed the existing street layouts. The engineering survey conducted enabled hydrological models to be produced from the spot height data obtained from the project areas (Asaba and Okpanam). The engineering survey was conducted using a GNSS instrument. The ground information (spot heights) obtained from the engineering survey work was used to produce the terrain modelling as well as generate a contour map of the entire project area. This map was used to develop the hydrological models, which showed the natural rainfall runoff flow patterns and gave an idea of the natural surface flow for the catchments. A reconnaissance survey was also carried out to ascertain the adequacy and effectiveness of the existing drainage; while conducting the engineering survey, it was discovered that the drainage discharge at Asaba Metropolis has a size of 1200 mm x 1500 mm.

2.2. Engineering Design Analysis

The engineering design of a stormwater drainage system requires a large data collection effort. The data requirements in the proposed stormwater management and control measures for Asaba and its environs include topography, drainage boundaries, imperviousness, soil types, and locations of any existing stormwater drainage channels, manholes, inlets, and outlets. In addition, identification of the type and location of other utilities on the ground is critical. These data gathered enabled the preparation of a new drainage network system that was used in the study and design work. The engineering analysis of the drainage system recommended for this project considered two major aspects of the work: hydrological analysis and hydraulic analysis.

2.3. Hydrological Analysis (Stormwater Estimation)

Rainfall records from three meteorological stations with climatic conditions comparable to the study area were used for the hydrological analysis. The records from Benin City, Enugu and Onitsha were used to establish rainfall intensities for different durations and return periods and to develop the IDF relationships used for the Asaba design. The analysis considered durations of 0.2, 0.4, 0.7, 1.0, 2.0, 3.0, 6.0, 12.0 and 24.0 hours and the return periods reported in the rainfall analysis. The historical station records described in the source material cover the period used for the IDF analysis, while the separate NASA POWER dataset was used to examine the Asaba rainfall series. Rainfall intensity is an important input to the runoff calculation because it influences the rate at which water reaches and moves across the catchment surface.

The most crucial step in the hydraulic design of drainage facilities is the hydrological study of the rainfall data for a specific drainage basin. The study employed different return periods (5, 10, 15 and 25 years) and rainfall data with varying durations (0.2, 0.4, 0.7, 1.0, 2.0, 3.0, 6.0, 12.0 and 24.0 hours) to calculate the rainfall intensities for Benin City, Enugu and Onitsha in order to determine that of Asaba, the study area. Based on the analysis of flood frequency, an annual series was applied to the collected rainfall data from these three meteorological stations, which are close to the study area. Monthly rainfall data for Benin City, Onitsha and Enugu, obtained between 1906 and 1983, with return periods ranging from 5 to 200 years, displays maximum monthly rainfall values and maximum rainfall intensities. The data collected from these three stations was used to determine the maximum rainfall intensity versus duration for different return periods for Asaba, as presented in Table 1.

In order to construct hydraulic structures for this study that should be able to sustain large flood levels without failing, it is necessary to determine the recurrence interval of the maximum rainfall intensities. The average number of years that a flood of a specific magnitude is likely to be equalled or exceeded is known as the return period (T). It is computed using Weibull's method of ranking, expressed as:

where n is the number of years and m is the event ranking, giving the recurrence interval, T . The rainfall intensity-duration-frequency (IDF) curves for different rainfall intensities were created using the obtained data, and these curves were utilized to calculate Asaba's peak discharge (Q_p) at various durations or times of concentration (T_c). The resulting IDF curves are presented as Figures 1 and 2 (Section 3.1).

2.4. Rainfall Data Collection

A separate Asaba rainfall series was obtained from the NASA POWER Data Access Viewer (<https://power.larc.nasa.gov/data-access-viewer/>) for the local rainfall analysis. The monthly dataset reported in Appendix A covers 2010-2021 and was used to examine rainfall intensity at 0.2-hour, 1.0-hour and 24-hour durations. The 'POWER Single Point' tool was used to select Asaba, Delta State, and the precipitation parameters were downloaded in CSV format for analysis in

Excel. This dataset is presented separately from the historical station records used to develop the IDF relationships.

2.5. Channel Selection and Design

Circular, rectangular, square, and trapezoidal shapes are among the many forms and varieties commonly used in stormwater channel selection. They are available in three different forms: precast concrete, cast-in-place concrete, and aluminium sheet. The form and type of hydraulic channel section recommended for use in managing stormwater in the Asaba capital territory was contingent upon the project area's terrain, geology, and flood water levels. In the design of a stormwater drainage system, manholes are the most common appurtenance because of their various uses: providing maintenance access, serving as junctions where two or more pipes merge, providing flow transitions for changes in pipe size, slope and alignment, and providing ventilation.

For use along the various chosen routes, the hydraulic design analysis recommended a variety of stormwater drain channel types, shapes and sizes, including box channel, trapezoidal channel, and precast or cast-in-place reinforced concrete circular sections of 2.7, 2.4, 2.0, 1.8 and 1.2 metres. Stormwater channel design fundamentally involves ensuring that the system can handle and transmit the maximum design load without sedimentation and without reaching damaging outlet velocities. The Lloyd-Davis approach, also known as the Rational Formula, is one of the oldest techniques for calculating flow discharges. This technique can only be used for limited drainage areas up to 80 hectares (0.80 km²), which limits its applicability; more recent methods use computer simulation to determine design discharges. However, due to its simplicity, the Rational formula is the most widely used method for quick estimation of flow discharges, and is written as:

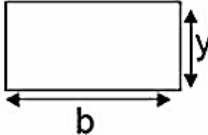
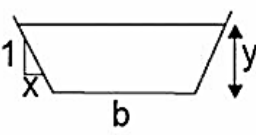
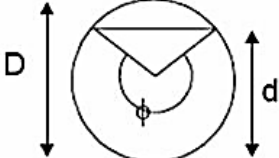
$$Q = CiA \quad (3)$$

where Q is the peak flow discharge (m³/s), C is a dimensionless runoff coefficient whose value depends on the catchment characteristics, i is the rainfall intensity (mm/hr), and A is the catchment area (km²).

2.6. Geometric Properties of Channels

Wetted perimeter (P), area (A), depth (y) and surface width (B) are the geometric properties of channels that can be measured, combining to form two useful factors: hydraulic mean depth ($D_m = A/P$) and hydraulic radius ($R = A/P$). Depth (y) is the vertical distance between the free surface and the lowest point of the channel section; area (A) is the flow's cross-sectional area normal to its direction; the wetted perimeter (P) is the length of the wetted surface measured perpendicular to the direction of flow; and the surface width (B) is the channel section's breadth at the free surface. These geometric properties for rectangular, trapezoidal and circular channel sections are summarised in Table 1.

Table 1. Geometric properties of rectangular, trapezoidal and circular channel sections

	Rectangle	Trapezoid	Circle
			
Area, A	by	$(b+xy)y$	$\frac{1}{8}(\phi - \sin \phi)D^2$
Wetted perimeter P	$b + 2y$	$b + 2y\sqrt{1+x^2}$	$\frac{1}{2}\phi D$
Top width B	b	$b + 2xy$	$(\sin \phi / 2)D$
Hydraulic radius R	$by/(b + 2y)$	$\frac{(b+xy)y}{b + 2y\sqrt{1+x^2}}$	$\frac{1}{4}\left(1 - \frac{\sin \phi}{\phi}\right)D$
Hydraulic mean depth D_m	y	$\frac{(b+xy)y}{b + 2xy}$	$\frac{1}{8}\left(\frac{\phi - \sin \phi}{\sin(1/2\phi)}\right)D$

2.7. Channel Flow and Time of Concentration

Channel flow travel time is determined by dividing the channel distance by the flow rate obtained from Manning's equation. For the channel flow component of runoff, the Kirpich equation is written as:

Applying the formula in SI units:

where t is the channel flow time (hr), L is the channel flow length (m), S is the channel flow slope (m/m), n is Manning's roughness coefficient, and R is the channel hydraulic radius (m), equal to A/P , where A is the cross-sectional area (m²) and P is the wetted perimeter (m), considering the uniform flow velocity based on bank-full flow conditions. The channel flow time can be estimated with

reasonable accuracy from the hydraulic characteristics of the channel. The inlet time recommended by the Federal Highway Administration (1985) is a minimum of 5 minutes where no other data is available, and this value was adopted for the time of concentration calculations in this study.

The time of concentration (t_c) is defined as the longest time it takes rain falling at the most distant point within a watershed to reach the point under reference, and it is one of the most important variables in the estimation of design discharges. In watersheds with flat terrain or low topographic slope, calculation of t_c using commonly accepted equations often results in unreasonably large values, since as the slope approaches zero, the travel time approaches infinity. It is therefore recommended that an adjustment of 0.0005 be made to the slope in both the Kerby and Kirpich methods to allow for more realistic results:

where, if m/m (0.2%), a low-slope condition exists, and adjustment should be made.

One of the common methods for estimating t_c is the Kirpich formula:

where t_c is in minutes, L is the maximum length of travel in metres, and S is the slope of the catchment (m/m) over the total length. The Kirpich method yields conservative (short) times of concentration, resulting in comparatively high peak runoff rates from the Rational method.

An alternative method, the Kerby formula, is expressed as:

The Kerby-Kirpich method of computing t_c is one of the best approaches, producing estimates that are consistent with watershed time values independently derived from real-world storms and runoff hydrographs, and is expressed as the sum of the overland flow time and the channel flow time:

where t_o is the overland flow time and t_c is the channel flow time. The Kerby-Kirpich method for estimating t_c applies to watersheds ranging from 0.70 km² to 389 km², main channel lengths between 1,600 m and 80,000 m, and main channel slopes of between 0.002 and 0.02 (m/m).

3.0 Results and Discussion

3.1. Rainfall Intensity-Duration-Frequency Curves

The IDF curves obtained from the combined Benin City, Enugu and Onitsha rainfall records are shown in Figures 1 and 2 for 10-year and 25-year return periods. In both cases, intensity decreases as rainfall duration increases, while the intensity at a given duration is higher for the longer return period. For the 10-year curve, intensity falls from 159.34 mm/hr at 0.2 hours to 6.35 mm/hr at 24 hours. For the 25-year curve, the corresponding values are 178.59 mm/hr and 7.60 mm/hr. The difference between the two return periods is greatest at the shorter durations. The 10-year relationship was selected for the channel design because it provides the design rainfall input used in the subsequent catchment calculations.

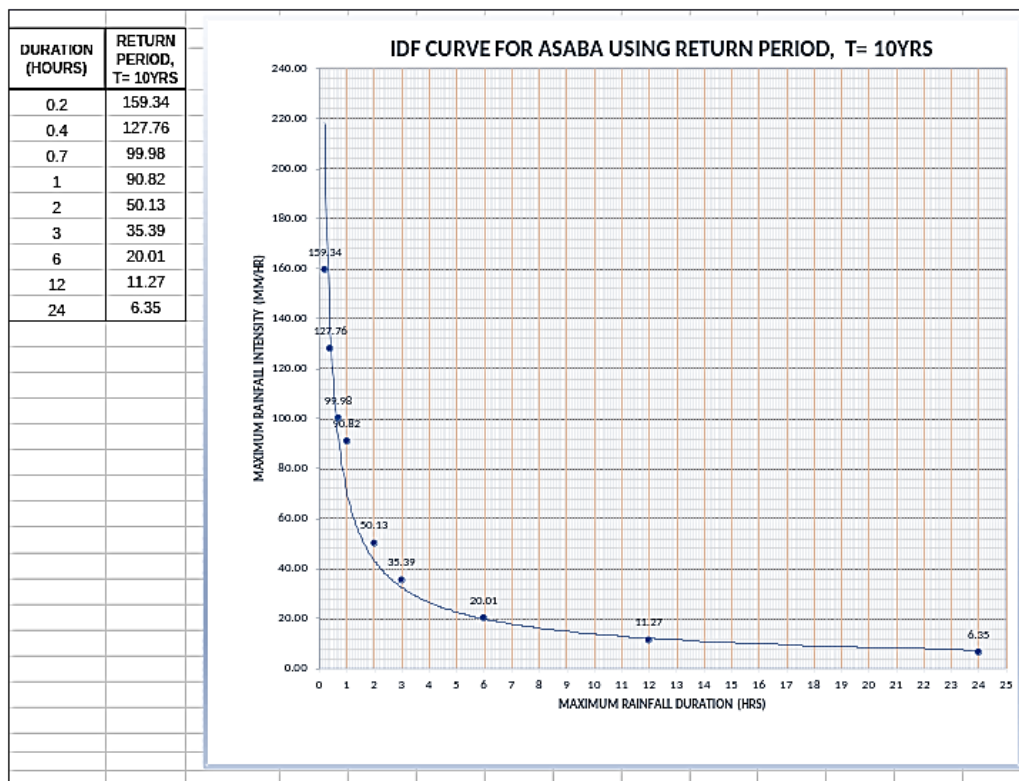


Figure 1. Intensity-duration-frequency curve for Asaba, return period T = 10 years

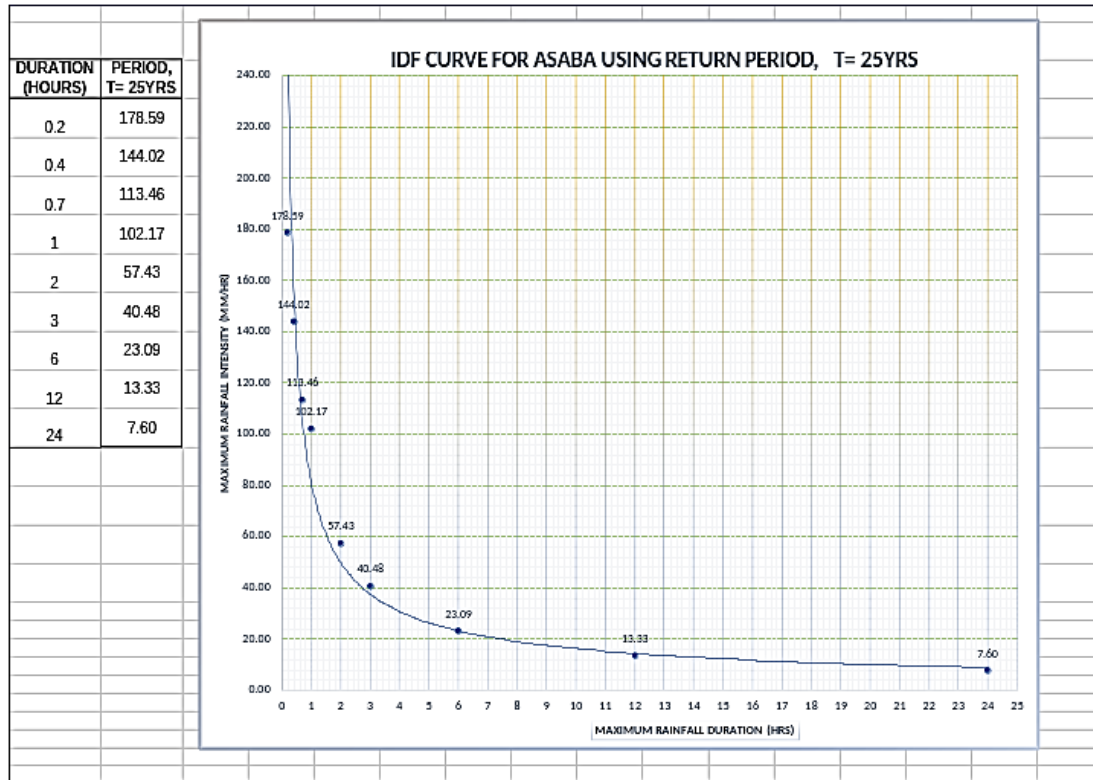


Figure 2. Intensity-duration-frequency curve for Asaba, return period T = 25 years

3.2. Rainfall Intensity for Various Durations

Monthly rainfall intensities for Asaba were computed for the 2010-2021 period at short (0.2-hour), intermediate (1.0-hour) and long (24-hour) durations, using Equation 1. Short-duration intensities are markedly higher and more variable month-to-month, consistent with the convective character of the most intense storms, while the 24-hour values (in Table A3, Appendix) display a more uniform distribution across the year. The complete monthly dataset underlying this analysis is presented in Appendix A (Tables A1-A3).

3.3. Maximum Rainfall Intensity versus Duration for Various Return Periods

The maximum rainfall intensity across varying durations for six return periods, calculated from the IDF relationship, is presented in Table 2. There is a clear correlation between rainfall intensity and return period at every duration: as the return period increases, the maximum expected rainfall intensity also increases, reflecting the expectation that extreme events occur less frequently but with greater intensity.

Table 2. Maximum rainfall intensity (mm/hr) versus duration for various return periods

Duration (hours)	T = 2 yrs	T = 5 yrs	T = 10 yrs	T = 25 yrs	T = 50 yrs	T = 100 yrs
0.2	128.43	144.08	159.34	167.94	178.59	194.49
0.4	109.46	114.87	127.76	135.02	144.02	156.84
0.7	85.42	89.30	99.98	115.99	113.46	123.56
1	74.23	81.83	90.82	95.89	102.17	111.26
2	41.20	44.35	50.13	53.39	57.43	62.55
3	27.55	31.36	35.39	37.66	40.48	44.08
6	15.96	17.57	20.01	21.38	23.09	25.15
12	7.78	9.66	11.27	12.19	13.33	14.51
24	3.08	5.37	6.35	6.91	7.60	8.27

3.4. Hydrological Analysis

The hydrological analysis for this study was carried out using an Excel algorithm to enable efficient computation of the peak discharge for each catchment, based on Equation 3 (the Rational formula). The runoff coefficient, C, a standard parameter, was obtained from established design tables, while the rainfall intensity for each catchment was obtained by calculating its time of concentration and reading the corresponding value from the ten-year-return-period IDF curve (Figure 1). A summary of the hydrological analysis sheet used to compute the peak discharge for each catchment is shown in Figure 3.

NODAL POINTS FROM - TO	GROUND ELEVATION (m)			DISTANCE (m)	SLOPE (S ₀)	PERCENTAGE SLOPE %	AREA (m ²)	RUNOFF COEFFICIENT	TIME OF CONC.	INTENSITY (I)	PEAK DISCHARGE	SUM OF PEAK DISCHARGE
	UPPER	LOWER	DIFF. (m)								Q _p	
								C	(Mins)	(mm/Hr)	(m ³ /s)	Q _p
FROM JONATHAN MONYE DRIVE TO REDEEMER'S STREET	56.460	55.540	0.92	407.1320	0.00250	0.25000	58283.192	0.60	15.0000	180.0000	1.74850	1.74850
FROM REDEEMER'S STREET TO DR CHUCKS CHINWOKWU STREET	56.550	51.020	5.53	661.3860	0.00836	0.83600	60929.474	0.60	33.2700	108.0000	1.09673	2.84520
FROM IBE UDOBI STREET TO DR CHUCKS CHINWOKWU STREET	53.200	50.970	2.23	257.3290	0.00867	0.86700	60669.676	0.60	15.0000	180.0000	1.82009	1.82009
FROM ENGR. JOHN CHIEGBUNIWE DRIVE TO DR CHUCKS CHINWOKWU STREET	56.000	51.070	4.93	718.5330	0.00686	0.68600	106878.648	0.60	15.0000	180.0000	3.20636	3.20640

Figure 3. Hydrological analysis sheet used to compute catchment peak discharge

3.5. Hydraulic Analysis and Channel Design

The peak discharge calculated for each of the four principal catchments (Table 3) was used with the geometric properties in Table 1 and a Manning roughness coefficient of 0.015 to size the drainage channels. Successive square-section sizes were tested until the calculated channel capacity was greater than the required peak discharge and the section satisfied the design checks shown in Appendix B. The resulting channel sizes are summarised in Table 3, with the complete calculation sheets provided in Appendix B.

Table 3. Summary of catchment hydraulic design

No.	Channel location	Length (m)	C	Slope (m/m)	Catchment area (m ² ; converted to km ² for Q _p)	I (mm/hr)	tc (min)	Q _p (m ³ /s)	Provided channel
1	Jonathan Monye Drive	407.132	0.6000	0.0250	58283.1920	180.0000	15.0000	1.7485	0.750m x 0.750m
2	Redeemer's Street	661.386	0.6000	0.00836	60929.4740	124.0000	33.2700	2.8452	1.2m x 1.0m
3	Ibe Udobí Street	257.329	0.6000	0.00867	60669.6760	180.0000	15.0000	1.8200	0.90m x 0.90m
4	Engr. John Chiegbuniwe Drive	718.533	0.6000	0.00686	106878.6480	180.0000	15.0000	3.2064	1.10m x 1.10m

All four trial sections satisfied the discharge requirement at the 10-year design frequency. The selected sections range from 0.75 m x 0.75 m at Jonathan Monye Drive to 1.2 m x 1.0 m at Redeemer's Street. These dimensions should not be described as larger in cross-sectional area than the existing 1.2 m x 1.5 m discharge drain; the proposed sections were selected for the individual catchments on the basis of their calculated design flows and hydraulic checks. The results therefore support catchment-specific assessment of drainage capacity rather than a blanket conclusion that every existing drain in Asaba is undersized. The calculation sheets in Appendix B provide the discharge and channel-capacity values used for each location.

These results are consistent with previous studies linking urban growth, impervious surfaces and drainage performance. Balaian et al. (2024) reported that drainage capacity and maintenance can strongly influence urban flood losses, while Fayomi et al. (2026) emphasised the value of combining structural drainage measures with runoff attenuation and vegetative measures. For Asaba, the results indicate that hydraulic design should therefore be considered together with routine maintenance, control of waste entering drains and measures that reduce excessive surface runoff.

4.0 Conclusions and Recommendations

The survey and hydrological-hydraulic analysis show that effective flood control in Asaba requires both adequate drainage capacity and regular maintenance of existing channels. The study used rainfall intensity-duration-frequency analysis to obtain the design rainfall input and then applied catchment-specific peak discharge calculations to size four drainage sections. The results provide practical design values for the selected locations, while the wider assessment indicates that blocked drains, waste accumulation, vegetation growth and rapid urban development can reduce the effectiveness of stormwater infrastructure.

Based on these findings, it is recommended that existing drains across the various zones of Asaba Metropolis should be desilted periodically. Relevant agencies should also intensify public enlightenment on the hazards of waste disposal into, and blockage of, natural waterways. Natural streams within the study area should be properly and regularly channelized to increase stormwater intake and reduce overspill during heavy rainfall. Furthermore, government agencies responsible for urban development should make it mandatory for property developers to provide adequate vegetated and permeable surfaces rather than extensive concrete and interlocking pavement. Finally, approval of new developments on natural watercourses should be strictly prohibited going

forward.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

AI-ASSISTED WRITING DISCLOSURE

Generative AI tools were used during manuscript preparation for language editing, restructuring and formatting. The authors reviewed the resulting text and are responsible for the accuracy of the data, calculations, cited sources, interpretation of results and final manuscript.

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Supplementary Material: Evaluation of Drainage and Stormwater Control Measures in Asaba Metropolis, Delta State, Nigeria

APPENDIX A: MONTHLY RAINFALL INTENSITY DATA

Monthly rainfall intensity (mm/hr) for Asaba, 2010-2021, at the three durations for which continuous station records were available, computed using Equation 1.

Table A1. Rainfall intensity, 0.2-hour duration (mm/hr)

Year	JAN.	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC.
2010	0	0	63.5	0	92.7	86.4	109.2	95.3	76.2	88.9	0	0
2011	0	0	63.5	0	92.7	82.6	76.2	76.4	76.2	107	134.6	0
2012	0	0	90.2	0	69.8	76	76.2	86.4	63.5	69.1	82.6	0
2013	95.3	0	82.6	88.9	66	69.8	88.9	0	82.5	0	0	0
2014	0	0	69.8	63.5	85.1	88.9	0	0	63.5	0	0	0
2015	0	0	0	0	78.7	76.2	101.6	0	0	120.7	0	0
2016	0	0	99.1	81.3	0	127	63.5	63.5	76.2	63.5	0	0
2017	0	0	0	110.5	0	0	86.5	76	85.3	0	0	0
2018	0	0	0	101.5	82.5	95.5	152.5	77.5	86.5	98	0	0
2019	0	0	0	0	0	0	0	77.5	86.3	98	0	0
2020	0	0	0	81	108	75	127	0	108	0	0	0
2021	0	119.5	76	88.5	101.5	95.5	0	70	76	76	0	0

Table A2. Rainfall intensity, 1.0-hour duration (mm/hr)

Year	JAN.	FEB.	MAR	APR.	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2010	0	0	36.8	0	29.7	39.6	77	31	27.9	31.8	0	0
2011	0	27.2	44.5	0	45.5	37.3	34.5	58.2	43.9	36.3	39.9	0
2012	0	0	27.2	26.9	0	0	37.3	46.5	25.4	53.3	44.5	30.5
2013	39.6	0	41.2	56.4	30.2	34.3	36.6	29.7	44.7	0	0	0
2014	0	38.1	59.2	0	30	35.6	0	0	31.8	34.8	27.4	0
2015	0	0	0	25.4	45.7	29.2	68.6	0	0	47.8	0	0
2016	0	0	68.1	33.5	0	47	30.5	35.3	59.4	44.5	0	0
2017	0	34.5	0	34.5	0	28.2	63.6	33	39.4	0	0	0
2018	0	0	0	51.6	39.4	51.6	54.6	34.2	0	0	0	0
2019	0	0	0	0	0	0	0	41.9	29.5	32.5	0	0
2020	0	0	0	0	34.3	69.8	66	31.5	33.6	25.1	0	33

Year	JAN.	FEB.	MAR.	APR.	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2021	0	29.2	29.2	25.5	38.6	57.9	30.5	0	25.7	31	0	0

Table A3. Rainfall intensity, 24.0-hour duration (mm/hr)

Year	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
2010	0	0	1.4	1.4	1.6	1.7	8.2	5	3.2	0	0	0
2011	0	0	2	0	2.6	1.7	3	3.3	3.1	1.7	1.6	0
2012	0	0	0	3.8	0	0	3.8	3.4	0	2.8	2.1	2.1
2013	2	0	1.7	0	0	2.1	3.8	1.8	3	0	0	0
2014	0	0	2.6	0	0	0	0	0	2	0	0	0
2015	0	0	0	2	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	3.8	3.4	2.1	0	0
2017	0	0	0	0	0	0	6.7	2.1	2.4	0	0	0
2018	0	0	0	0	1.7	2.6	5.6	5.7	0	0	0	0
2019	0	0	0	0	0	0	0	4	4.5	2.1	0	0
2020	0	0	0	0	0	0	0	4	6.9	3	3.4	0
2021	0	0	1.7	0	1.6	2.9	0	0	4.6	3.2	0	0

APPENDIX B: DETAILED CATCHMENT CALCULATION SHEETS

Full hydraulic design calculation sheets for the four catchments summarised in Table 3, using the hydraulic design procedure and Manning calculations described in the main manuscript.

Catchment 1: ZONE 5: JONATHAN MONYE DRIVE	Value
Channel location	Zone 5: Jonathan Monye Drive
Extent	From Jonathan Monye Drive to Redeemer's Street.
Channel length (m)	407.132
Design frequency	10 yrs.
Runoff coefficient, C	0.6000
Ground slope, s (m/m)	0.0250
Manning's roughness coefficient, n	0.0150
Catchment area (m ²)	58283.1920
Rainfall intensity, I (mm/hr)	180.0000
Computed time of concentration, tc (min)	15.0000
Peak discharge, Qp = CiA (m ³ /s)	1.7485
Trial channel section	750mm x 750mm
Wetted area, A (m ²)	0.5625
Wetted perimeter, P (m)	2.2500
Hydraulic radius, R = A/P (m)	0.2500
Minimum design slope provided	0.0025
Designed slope used	0.0250
Designed discharge, Q = (1/n)AR ^{2/3} S ^{1/2} (m ³ /s)	2.3530
Allowable maximum channel discharge (m ³ /s)	2.0001
Provided drain channel	DRAIN Channel of 0.750m x 0.750m
Catchment 2: ZONE 5: REDEEMER'S STREET	Value
Channel location	Zone 5: Redeemer's Street
Extent	From Redeemer's Street to Dr Chucks Chinwo Kwu Street
Channel length (m)	661.386
Design frequency	10 yrs.
Runoff coefficient, C	0.6000
Ground slope, s (m/m)	0.00836
Manning's roughness coefficient, n	0.0150
Catchment area (m ²)	60929.4740
Rainfall intensity, I (mm/hr)	124.0000
Computed time of concentration, tc (min)	33.2700
Peak discharge, Qp = CiA (m ³ /s)	2.8452
Trial channel section	1200mm x 1000mm
Wetted area, A (m ²)	1.2000
Wetted perimeter, P (m)	3.2000
Hydraulic radius, R = A/P (m)	0.3750
Minimum design slope provided	0.0025
Designed slope used	0.0084

Catchment 1: ZONE 5: JONATHAN MONYE DRIVE	Value
Designed discharge, $Q = (1/n)AR^{2/3}S^{1/2}$ (m³/s)	3.8038
Allowable maximum channel discharge (m³/s)	3.2332
Provided drain channel	DRAIN Channel of 1.2m x 1.0m

Catchment 3: IBE UDOBI STREET	Value
Channel location	Ibe Udobi Street
Extent	From Ibe Udobi Street to Dr Chucks Chinwo Kwu Street
Channel length (m)	257.329
Design frequency	10 yrs.
Runoff coefficient, C	0.6000
Ground slope, s (m/m)	0.00867
Manning's roughness coefficient, n	0.0150
Catchment area (m²)	60669.6760
Rainfall intensity, I (mm/hr)	180.0000
Computed time of concentration, tc (min)	15.0000
Peak discharge, $Q_p = CiA$ (m³/s)	1.8200
Trial channel section	900mm x 900mm
Wetted area, A (m²)	0.8100
Wetted perimeter, P (m)	2.7000
Hydraulic radius, $R = A/P$ (m)	0.3000
Minimum design slope provided	0.0025
Designed slope used	0.0087
Designed discharge, $Q = (1/n)AR^{2/3}S^{1/2}$ (m³/s)	2.2533
Allowable maximum channel discharge (m³/s)	1.9153
Provided drain channel	DRAIN Channel of 0.90m x 0.90m
Catchment 4: ZONE 5: ENGR. JOHN CHIEGBUNIWE DRIVE	Value
Channel location	Zone 5: Engr. John Chiegbuniwe Drive
Extent	From Engr. John Chiegbuniwe Drive to Dr Chucks Chinwo Kwu
Channel length (m)	718.533
Design frequency	10 yrs.
Runoff coefficient, C	0.6000
Ground slope, s (m/m)	0.00686
Manning's roughness coefficient, n	0.0150
Catchment area (m²)	106878.6480
Rainfall intensity, I (mm/hr)	180.0000
Computed time of concentration, tc (min)	15.0000
Peak discharge, $Q_p = CiA$ (m³/s)	3.2064
Trial channel section	1100mm x 1100mm
Wetted area, A (m²)	1.3200
Wetted perimeter, P (m)	3.4000
Hydraulic radius, $R = A/P$ (m)	0.3882
Minimum design slope provided	0.0025
Designed slope used	0.0069
Designed discharge, $Q = (1/n)AR^{2/3}S^{1/2}$ (m³/s)	3.8789
Allowable maximum channel discharge (m³/s)	3.2971
Provided drain channel	DRAIN Channel of 1.10m x 1.10m