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Flood-Loss Reduction and Channel Maintenance along Ogunpa River, Ibadan: Application of Hec-Ras Modelling

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Abstract
Flooding poses a persistent hazard in rapidly urbanizing sub-Saharan cities, worsened by land-use changes and infrastructural deficits. In Ibadan, Nigeria, the Ogunpa River catchment experiences recurrent inundation. This study evaluates the hydrological and hydraulic dynamics of the river to identify critical channel maintenance requirements and flood-loss reduction strategies using integrated multi-model approach. Runoff was estimated using the Soil Conservation Service Curve Number (SCS-CN) method based on daily rainfall data (1970–2021) obtained from the Nigerian Meteorological Agency (NIMET). Spatial analysis and watershed delineation were conducted using ArcGIS 10.3 with Landsat 8 imagery and Digital Elevation Models. Hydraulic behavior was simulated using a one-dimensional HEC-RAS model, parameterized with field measurements of channel geometry and flow velocity. Analysis revealed increasing rainfall variability and a reduction in flow velocity from 0.36m/s upstream to 0.25m/s downstream, indicating significant sedimentation. Complementary socio-spatial data (n=200) identified waste mismanagement and encroachment as key aggravating factors, despite moderate community risk perception (mean = 2.41). The hydraulic inefficiency of the Ogunpa River is driven by both morphological constraints (sedimentation) and anthropogenic interference. Effective flood risk mitigation requires a dual approach: engineering interventions (desilting, channel widening) and policy enforcement (building setbacks, waste management). This study demonstrates the efficacy of coupling hydraulic modelling with social assessment to inform urban drainage planning.

Keywords: Flood risk, HEC-RAS, channel maintenance, Ogunpa River, Ibadan, urban hydrology, flood-loss reduction

Introduction
Floods are among the most destructive natural hazards worldwide, accounting for more than 50% of all weather-related disasters and it remains the second leading cause of hazard-related fatalities after heat waves (Jonkman *et al*., 2024). For instance, between 1995 and 2015 floods affected over 2.3 billion people, making them the most pervasive disaster type in terms of human impact (EM-DAT, 2015). Their occurrence is shaped by rainfall intensity, catchment characteristics, land cover change, and human-induced alterations of natural drainage systems (Lenderink *et al.*, 2025). In sub-Saharan Africa, flood frequency and severity have intensified due to rapid urbanisation, deforestation, limited enforcement of land-use regulations, inadequate urban drainage planning, weak solid waste management systems, and insufficient institutional capacity for flood risk governance, alongside climate variability. In many African settings, flooding has been shown to exacerbate social vulnerabilities, including adverse effects on livelihoods and health, and

heightened food insecurity among rural communities (Ejem & Ben-Enukora, 2025; Enworo, 2026), and broader regional analyses indicate that climate-driven increases in flood frequency and severity are likely to intensify these social impacts (Diop *et al.*, 2025). Nigeria exemplifies this trend, with recurrent floods producing widespread socio-economic and environmental consequences. The 2012 nationwide floods displaced 2.3 million people and killed over 363, ranking among the country's most catastrophic disasters (Nkeki, Henah, & Ojeh, 2013). Annual rainy-season floods continue to damage farmland, interrupt commerce, and strain fragile infrastructure.

Ibadan, the capital city of Oyo State, is among Nigeria's most flood-prone urban centres. Its topography, rapid population growth, and inadequate municipal drainage facilities make it highly vulnerable. The Ogunpa River, traversing densely populated areas, has been the epicentre of multiple disasters. The 1980 Ogunpa flood killed hundreds and destroyed property, while the August 2011 flood again inundated large parts of the city (Agbola, *et al*., 2012). These events reveal the inadequacy of existing mitigation measures. Flooding in Ibadan is driven by both natural and anthropogenic factors. Hydrologically, heavy rainfall and sedimentation reduce channel conveyance capacity. Human activities such as indiscriminate waste disposal, unplanned settlements along floodplains, and encroachment into drainage corridors exacerbate risks. Weak institutional capacity; defined as limited enforcement of planning regulations, inadequate investment in drainage infrastructure, poor inter-agency coordination, and ineffective early-warning systems further compounds the problem (Agbola, *et al*., 2012). These realities align with broader debates in flood management. Traditional structural measures,dams, embankments, and channelization,have proven insufficient under rapid urbanisation and climate variability. Laidlaw & Percival, (2024) advocate a paradigm shift from "flood control" to "flood resilience," integrating structural and non-structural measures, adaptive capacity, and community participation. This resonates with Nigerian contexts where conventional strategies alone have failed to prevent disaster recurrence.

Hydrological and hydraulic modelling tools strengthen this adaptive approach. HEC-RAS, widely applied for river hydraulics and floodplain simulation, when integrated with GIS and remote sensing, enables detailed mapping and channel performance evaluation (USACE, 2016). Throughout the African continent, the model has demonstrated significant efficacy in regions characterized by sparse monitoring infrastructure yet elevated flood susceptibility. Conversely, within the Nigerian context, its application remains constrained and frequently neglects the socio-perceptual dimensions of flood risk. The Ogunpa River catchment, 21.5 km long with an area of 73.3 km^2, offers a critical case study. Its history of catastrophic floods underscores the need for evidence-based interventions. By focusing exclusively on either socio-economic vulnerabilities or rainfall-runoff analyses, existing studies frequently omit the mediating role of channel hydraulics, thereby diminishing its applicability to flood management policy.

This study responds by integrating scientific analysis with community perspectives to evaluate flood-loss reduction and channel maintenance along the Ogunpa River. Unlike earlier studies, it combines physical process analysis with human vulnerability, advancing a dual perspective: diagnosing hydraulic inefficiencies that heighten risks while addressing socio-political realities shaping exposure and response. The objectives are to assess local perceptions of flooding, analyse rainfall and runoff trends, evaluate hydraulic channel characteristics, and apply modelling to identify maintenance needs. In doing so, the study bridges hydrological science and community-based governance, generating actionable evidence for policymakers and planners in Ibadan, with transferable lessons for flood-prone cities across Nigeria and West Africa.

Materials and Methods

Study Area

The research was carried out within the Ogunpa River catchment in Ibadan, Oyo State, Nigeria. The Ogunpa River is a third-order stream with a channel length of approximately 21.5 km and a drainage basin covering 73.3 km². It drains several densely populated areas of Ibadan, which is among Nigeria's largest cities and one of the most flood-prone urban centres (Agbola, *et al*., 2012). Ibadan lies in the tropical wet-and-dry climatic zone, characterised by bimodal rainfall pattern, peaking in July and September.. The mean annual rainfall is approximately 1,400 mm (Ogungbenro & Morakinyo, 2014), while mean temperatures range between 25–30 °C (IPCC, 2021).. The catchment is dominated by lateritic soils and low-lying terrain, but human-induced changes, including informal housing, blocked drains, and poorly regulated construction along floodplains, have significantly reduced the river's natural capacity to convey stormwater (IPCC, 2021). The catastrophic floods of 1980 and 2011 illustrate the severity of flood hazards in the Ogunpa system and demonstrate the importance of assessing both hydrological processes and human drivers of flood risk (Agbola, *et al*., 2012).

Data Sources

Meteorological Data

Daily rainfall records for a 51-year period (1970–2021) were obtained from the Nigerian Meteorological Agency (NIMET). These long-term datasets were chosen to capture interannual variability and long-term patterns in precipitation, which are critical for understanding flood risk in the context of climate variability (Kumar *et al.,* 2024).

Remote Sensing and GIS Data

Landsat 8 Operational Land Imager (OLI) satellite imagery at 30 m resolution and a Digital Elevation Model (DEM) were used to delineate watershed boundaries, map land use and land cover, and derive elevation profiles. ArcGIS 10.3 software was employed for spatial analysis. Remote sensing and GIS methods were particularly relevant given the scarcity of ground-based data and have been widely applied in similar studies to support flood hazard assessments (Ouma & Tateishi, 2014).

Field and Survey Data

Primary data collection involved both physical measurements and socio-perceptual surveys. Hydraulic parameters, including channel width, depth, wetted perimeter, and flow velocity, were measured at representative cross-sections along the Ogunpa channel. Flow velocity was determined using the float method, and discharge was estimated as the product of velocity and cross-sectional area. These measurements provided critical inputs for model calibration. In addition, a structured questionnaire was administered to 200 households in flood-prone communities across the catchment. Respondents were purposively selected based on prior flood exposure, and the survey instrument included questions on flood frequency, causes, and impacts. Quantitative responses were captured using a Likert scale, while qualitative data provided contextual insights into community vulnerability and adaptation strategies.

Quantification and Measurement of Variables

To enable statistical analysis, questionnaire responses were coded into numerical form. Socio-demographic variables such as age and length of residency were grouped into ordered categories and assigned ascending values. Educational level and occupation were similarly coded based on their hierarchical structure, while gender was treated as a binary variable (male = 1, female = 2).

Perception variables, including causes and consequences of flooding, observations, suggested solutions, and satisfaction with management measures, were measured on a four-point Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree). Descriptive statistics, including mean and standard deviation, were computed to summarise response patterns.

Rainfall–Runoff Estimation

Runoff was estimated using the Soil Conservation Service Curve Number (SCS-CN) method developed by the United States Department of Agriculture (USDA, 1986). This method integrates rainfall characteristics, land cover, soil type, and antecedent moisture conditions to estimate stormwater runoff. Given the absence of continuous streamflow records in the Ogunpa basin, the SCS-CN approach provided a practical means of estimating runoff volumes. Curve numbers were derived from the classified land use map and adjusted according to hydrological soil groups present within the catchment. The SCS-CN method has been widely applied and validated in recent hydrological studies, demonstrating its effectiveness for runoff estimation in data-limited environments and diverse climatic conditions (Khattab *et al*., 2025; Afrasiabikia *et al*., 2025; Mulu *et al*., 2025)

Hydraulic Modelling with HEC-RAS

The Hydrologic Engineering Center's River Analysis System (HEC-RAS, version 5.0.7) was employed to simulate river hydraulics along the Ogunpa channel. HEC-RAS is an established modelling platform capable of calculating water surface profiles, velocity distributions, and channel discharge under steady and unsteady flow conditions (USACE, 2016). Cross-sectional data collected during fieldwork and DEM-derived profiles were integrated into the model. Boundary conditions were defined using estimated discharges, and Manning's roughness coefficients were assigned based on observed channel characteristics such as vegetation, sedimentation, and encroachment. Calibration was performed by comparing simulated water surface elevations with field observations to ensure realistic hydraulic behaviour. The model provided a quantitative basis for diagnosing critical sections of reduced conveyance capacity and for assessing the effectiveness of maintenance interventions.

Land Use and Watershed Delineation

Watershed boundaries were delineated from the DEM using ArcGIS hydrological tools. Land use and land cover were classified from the Landsat imagery using a supervised classification approach, with four major classes identified: built-up areas, vegetation, bare surfaces, and water bodies. Classification accuracy was assessed by comparing the outputs with ground-truth data collected during fieldwork. Mapping land cover changes was particularly important given that urbanisation and the proliferation of impervious surfaces are major drivers of flood frequency and intensity in Nigerian urban centres (Echendu, 2020; Umar & Gray, 2022).

Community Perception Survey

To complement the hydraulic and spatial analyses, the community perception dataset was further examined to provide a socio-institutional interpretation of flood risk within the Ogunpa catchment.

The analysis highlights that residents' understanding of flood causation, particularly the role of waste disposal and drainage obstruction, reflects an awareness of anthropogenic risk drivers. However, this awareness does not necessarily translate into effective mitigation behaviour, indicating a gap between knowledge and institutional support. Quantitative findings were therefore interpreted alongside qualitative narratives to reveal underlying constraints such as limited governance enforcement and inadequate infrastructure. This interpretive approach aligns with recent flood risk research, which emphasises that community risk perception is a critical determinant of vulnerability, decision-making, and adaptive behaviour in flood-prone environments (Bhatti *et al.,* 2023; Raikes *et al.,* 2023).

Data Analysis

Rainfall and runoff datasets were analysed statistically to establish temporal variability and long-term trends. Hydraulic simulations generated outputs on water surface elevations, flow velocities, and discharge capacity at selected river sections. Spatial analysis using GIS generated watershed, land use, and elevation maps, which revealed a dominance of impervious urban surfaces and low-lying downstream zones that significantly increase surface runoff and flood susceptibility within the Ogunpa catchment. Survey results were synthesised to reveal both quantitative indices of flood perception and qualitative insights into vulnerability. Integrating these datasets enabled triangulation, which enhanced the robustness of the analysis. Okunola & Olawuni, (2025) informed that such multi-method approaches are vital in urban flood management because they combine physical science with social perspectives, thereby producing evidence that is both technically sound and socially relevant.

Ethical Considerations

All procedures followed ethical standards for research involving human participants. Ethical clearance was obtained from the relevant institutional review board. Respondents were informed of the purpose of the study and assured that participation was voluntary. Informed consent was obtained prior to administering questionnaires, and all responses were anonymised to maintain confidentiality.

Results and Discussion

Rainfall Trends (1970–2021)

Rainfall data for the Ogunpa catchment from 1970 to 2021 reveal a highly seasonal pattern with marked interannual variability. This seasonal behaviour reflects the influence of the West African monsoon system, which governs rainfall distribution across southwestern Nigeria. The region typically experiences a bimodal rainfall regime, characterised by a primary wet season between April and July, a short mid-summer dry spell commonly referred to as the "August break," and a secondary rainfall peak occurring between September and October. This seasonal structure is driven by the north–south migration of the Intertropical Convergence Zone (ITCZ), which controls moisture influx and atmospheric instability over the region (Awode *et al,*. 2025).

In addition to this predictable seasonal cycle, the dataset shows strong interannual variability, meaning that total annual rainfall and event intensity fluctuate significantly from year to year. Such variability is critical for flood dynamics in the Ogunpa catchment, as years with concentrated high-intensity rainfall events (rather than evenly distributed rainfall) tend to produce rapid runoff, exceed channel capacity, and trigger urban flooding (Oawale *et al*., 2024).Table 4.1 presents monthly rainfall for selected benchmark years, alongside annual totals and long-term monthly means.

Table 4.1: Average Monthly Rainfall (mm) for Selected Years in the Ogunpa Catchment

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1970	4	0	113	171	246	170	53	41	312	149	18	0	1,277
1975	0	81	138	177	146	99	132	93	98	193	33	9	1,199
1980	0	17	16	93	131	199	239	605	324	293	50	0	1,967
1985	2	0	103	195	167	148	322	245	201	169	48	4	1,604
1990	20	47	38	179	160	114	287	76	168	168	8	19	1,284
1995	0	11	106	119	257	268	189	204	159	185	37	Tr.	1,535
2011	0	125	133	168	147	187	349	243	185	160	0	0	1,697
2015	30	0	96	126	81	116	221	232	127	216	0	0	1,245
2021	19	2	109	79	197	165	65	128	313	166	18	0	1,261
Monthly Average	8	31	95	145	170	163	201	207	210	189	24	4	1,452
(SD)	11	45	41	42	56	52	107	168	86	44	19	7	-
CV (%)	138	142	43	29	33	32	52	81	41	23	82	184	-

Source: Nigerian Meteorological Agency (NIMET), 2022.
Note: "Tr." indicates trace rainfall below 1 mm.

The long-term mean annual rainfall is approximately 1,452.mm, with most precipitation concentrated between April and October. The months of June, July, and September represent the peak months, each exceeding 160 mm on average. The August "break" is visible in most years, although 1980 stands out with an unusually high August total of 605 mm. This anomalous concentration of rainfall coincided with the catastrophic August 1980 flood in Ibadan, which caused over 200 deaths and extensive property loss (Elujoba *et al*.,, 2025). Similarly, the year 2011 recorded a high annual rainfall total of 1,697 mm, another flood year in which the Ogunpa River overtopped its banks, displacing thousands. In contrast, years such as 1970 (1,277 mm), 1975 (1,199 mm), and 2015 (1,245 mm) were relatively dry, with lower flood magnitudes reported. However, even in these years, short-duration storms still triggered localised flooding, underscoring the role of land use change and reduced infiltration capacity in amplifying runoff. To better understand how representative these mean values are, measures of variability were computed. Standard deviation values indicate considerable dispersion around the mean, while coefficients of variation reveal that rainfall is highly inconsistent in some months, particularly during dry-season months (CV > 100%), and moderately variable in peak rainy months (CV ~50–80%). The variability across years reflects the combined influence of regional climate oscillations and local urbanisation pressures. These findings align with recent evidence that rainfall patterns in West Africa are becoming more variable and extreme under climate change. Large-scale hydrological modelling shows that climate change is intensifying extreme precipitation and flood risk across the region (Diop *et al.*, 2025). Analyses of rainy season dynamics also indicate significant trends in rainfall variability (Mendes, Correia, & Fragoso, 2025). The Intergovernmental Panel on Climate Change (IPCC, 2021) similarly projects a rise in rainfall extremes under future warming scenarios. For Ibadan, this trend implies greater hydrological stress, as the Ogunpa catchment, with its high degree of imperviousness, responds rapidly to extreme storms.

Geometric and Hydraulic Parameters

Field measurements across 18 cross-sections of the Ogunpa River provide valuable insight into its morphological structure and hydraulic efficiency. These parameters are critical for assessing the river's capacity to convey floodwaters during extreme rainfall events. Tables 4.2 and 4.3 present the detailed results of the survey, which included measurements of velocity, channel width, depth, discharge, wetted perimeter, flow area, hydraulic radius, and critical depth.

Table 4.2: Field Measurements of Ogunpa River at Selected Cross-Sections

Location	Latitude (N)	Longitude (E)	Elevation (m)	Velocity (m/s)	Width (m)	Depth (m)	Discharge (m^3/s)
P1	7°44′18″	3°32′03″	285.24	0.36	17.80	0.58	3.71
P2	7°44′20″	3°32′05″	285.40	0.35	17.70	0.60	3.68
P3	7°44′12″	3°31′59″	285.35	0.34	17.60	0.59	3.70
P4	7°44′09″	3°32′01″	285.11	0.33	17.90	0.62	3.66
P5	7°44′15″	3°32′07″	285.30	0.32	17.80	0.61	3.73
P6	7°45′30″	3°38′24″	284.70	0.31	18.20	0.63	3.50
P7	7°45′36″	3°38′30″	284.80	0.28	18.40	0.64	3.40
P8	7°44′25″	3°36′07″	284.80	0.29	18.00	0.69	3.80
P9	7°44′30″	3°36′10″	284.90	0.28	18.10	0.70	3.75
P10	7°44′22″	3°36′11″	284.70	0.31	18.20	0.71	3.85
P11	7°44′17″	3°36′05″	284.60	0.30	18.30	0.72	3.90
P12	7°45′57″	3°36′15″	284.40	0.26	18.00	0.66	3.00
P13	7°45′52″	3°35′59″	284.53	0.24	18.00	0.68	2.94
P14	7°45′55″	3°35′55″	284.70	0.22	18.10	0.67	2.60
P15	7°45′47″	3°35′25″	284.20	0.21	18.00	0.63	2.50
P16	7°45′50″	3°35′10″	284.00	0.27	17.80	0.65	2.70
P17	7°45′38″	3°35′20″	284.10	0.24	17.80	0.59	2.70
P18	7°45′32″	3°35′15″	283.90	0.25	17.70	0.58	2.80

Source: Field Survey.

Table 4.3: Hydraulic Parameters of Ogunpa River at Selected Cross-Sections

Location	Wetted Perimeter (m)	Flow Area (m^2)	Hydraulic Radius (m)	Critical Depth (m)
P1	19.96	10.32	0.52	0.53
P2	19.97	10.62	0.53	0.54
P3	19.98	10.56	0.53	0.53
P4	19.14	11.10	0.58	0.57
P5	19.00	10.86	0.57	0.56
P6	19.48	11.47	0.59	0.59
P7	19.90	11.90	0.60	0.60
P8	19.48	12.49	0.64	0.65
P9	19.50	12.67	0.65	0.66
P10	19.64	12.92	0.66	0.67
P11	19.74	13.24	0.66	0.69
P12	19.32	11.88	0.62	0.61
P13	19.36	12.24	0.63	0.63
P14	19.44	12.17	0.62	0.62
P15	19.26	11.34	0.59	0.59
P16	19.18	11.46	0.60	0.60
P17	19.98	10.48	0.52	0.54

Location	Wetted Perimeter (m)	Flow Area (m^2)	Hydraulic Radius (m)	Critical Depth (m)
P18	19.86	10.33	0.52	0.53

Source: Field Survey.

The field data indicate a relatively uniform channel width (17.95 ± 0.24 m) and depth (0.64 ± 0.045 m) across all 18 sites. Flow velocities decline progressively downstream, from 0.36 m/s at P1 to 0.21 m/s at P15, before recovering slightly at P16–P18. This decline corresponds with reductions in discharge from ~3.7 m^3/s at upstream stations to below 3.0 m^3/s at downstream reaches. Such low velocities ($\leq$ 0.3 m/s in several sections) are below the threshold for sediment transport, encouraging siltation and weed growth, as documented in earlier studies (Elujoba *et al*.,, 2025; Komolafe *et al*., 2015). Table 4.3 further reveals that the hydraulic radius across the sections is generally below 0.65 m, with wetted perimeters exceeding 19 m. This suggests shallow depths relative to channel perimeter, producing high boundary resistance and reducing conveyance efficiency. The highest flow area is observed at P11 (13.24 m^2), coinciding with the maximum depth (0.72 m), but this gain is offset by the low velocity (0.30 m/s), meaning overall flood conveyance remains constrained.

The consistency of critical depth values (0.53–0.69 m) across all stations reinforces the fact that even modest rises in water level during storm events can exceed bankfull conditions. When combined with sediment-laden flows and urban encroachment, this creates a high likelihood of overbank flooding during extreme rainfall events, as witnessed in 1980 and 2011. In summary, the geometric and hydraulic assessment confirms that Ogunpa River has limited capacity for flood conveyance. The uniform channel width, coupled with shallow depths, low velocities, and high wetted perimeters, results in poor efficiency and high susceptibility to siltation. Without continuous desilting, channel expansion, and enforcement of building setbacks, the river will remain prone to recurrent flooding.

Land Use and Elevation Effects

Land Use Distribution

Analysis of Landsat imagery revealed significant changes in land use within the Ogunpa catchment over the study period. Figure 4.1 presents the classified land use map, highlighting the spatial distribution of built-up areas, vegetation, bare surfaces, and water bodies. Built-up land dominates the catchment, with impervious surfaces (roads, buildings, paved areas) expanding markedly along the floodplain corridors. Vegetation and open spaces have declined, especially upstream where agricultural land has been progressively converted to urban settlements.

Figure 4.1: Land Use Map of the Ogunpa Catchment
(Source: Author's GIS Analysis)

The predominance of impervious surfaces directly increases runoff generation by reducing infiltration capacity. The urbanisation-driven land cover change explains why even moderate rainfall events (e.g., < 50 mm/day) frequently trigger flooding in Ibadan. Similar findings have been reported in Lagos, Accra (Komolafe *et al.*, 2015; Okunola & Olawuni, 2025), and Dhaka (Haque 2019), where unregulated urban sprawl intensified flood hazards. In the case of Ogunpa, the absence of effective development control has allowed residential and commercial structures to encroach into natural floodplains, thereby reducing the effective storage capacity of the catchment.

Elevation and Topographic Influences

Digital Elevation Model (DEM) analysis (Figure 4.2) illustrates the topographic variation across the Ogunpa catchment. Elevation ranges from ~286 m at the upstream stations (P1–P5) to ~283 m downstream (P15–P18). Although the gradient appears modest (approximately 2–3 m fall across the surveyed stretch), it is sufficient to generate high-energy flows when rainfall intensities are extreme. However, sedimentation, channel narrowing, and obstruction from waste deposits have diminished the self-cleansing capacity of the channel, especially in flatter downstream sections.

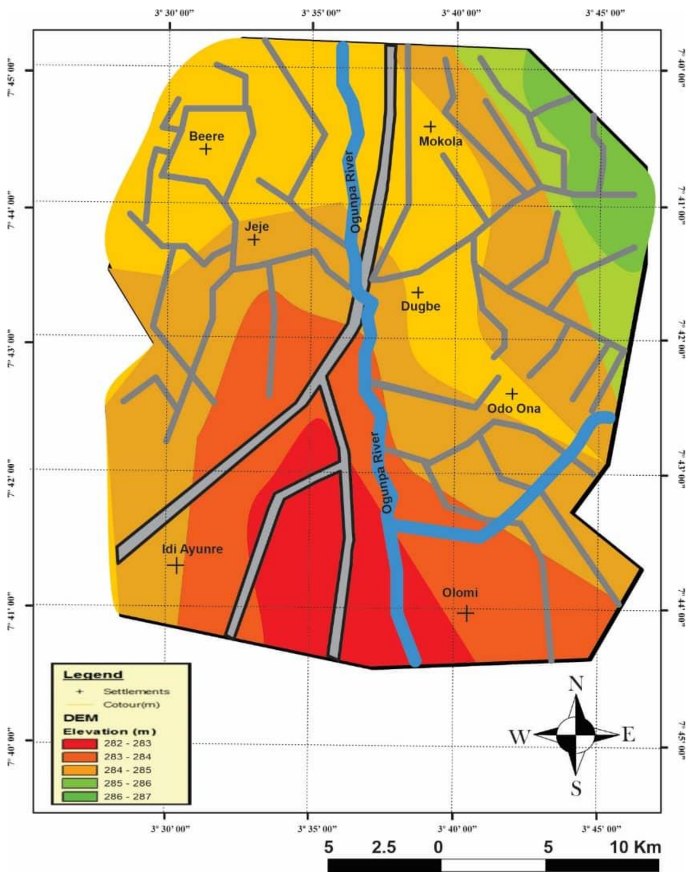

Figure 4.2: Elevation Map of the Ogunpa Catchment (DEM Output)
(Source: Author's GIS Analysis)

The relatively low gradient downstream also promotes overbank flooding, as water tends to back up when conveyance is restricted. This is compounded by encroachment into natural depressions, which historically functioned as temporary flood storage zones. Field observations confirm that areas at lower elevations, particularly Beere, Oke-Adu, and Yemetu, are consistently more flood-prone, corroborating findings by Elujoba *et al*., (2025) and Ezekiel *et al.* (2015) on spatial flood vulnerability in Ibadan.

The combined effects of land use and elevation reveal a highly modified catchment with elevated flood susceptibility. Land conversion into impervious surfaces has intensified direct runoff, while low-lying topography and encroachment into natural storage areas exacerbate exposure. These findings underscore the close relationship between unplanned urbanisation and flood risk. Whereas rainfall intensity is an external driver, it is the internal modifications of the catchment, particularly land use mismanagement and poor waste disposal that amplify flood hazards. In broader perspective, this aligns with urban flood studies across West Africa (Douglas *et al*., 2008; Cobbinah *et al*., 2015), which emphasise that climate variability alone cannot explain recurrent disasters. Instead, it is the combination of socio-economic pressures, poor governance, and weakened environmental buffers that sustains the flood menace. For Ibadan, the Ogunpa catchment exemplifies this trend: despite relatively modest elevation differences, poor land use planning has transformed rainfall extremes into recurrent disasters.

Water Surface Profile Conditions

The analysis of water surface profiles offers a fundamental understanding of the hydraulic regime of River Ogunpa and its implications for flood risk management. In open channel hydraulics, the type of profile is determined by the interaction of normal depth (y_n), critical depth (y_c), and channel slope (S_o). When $y_n > y_c$, the channel exhibits a mild slope profile, characterised by subcritical flow that is relatively deep and slow-moving. In contrast, when $y_n < y_c$, the channel adopts a steep slope profile, dominated by supercritical flow, which is shallow and fast-moving, often leading to unstable conditions. A balance between y_n and y_c ($y_n = y_c$) represents the critical state, a transitional condition between supercritical and subcritical flow. Two less common profiles include the adverse profile, where the slope is negative ($S_o < 0$), and the horizontal profile, where the slope is zero ($S_o = 0$) (Chow, 1959; French, 1985). These classifications are summarised in Table 4.4, which provides the theoretical framework used for the study.

Table 4.4: Classification of Water Surface Profiles

Water Surface Profile	Condition
Mild	$y_n > y\_c$
Steep	$y_n < y\_c$
Critical	$y_n = y\_c$
Adverse	$S_o < 0$
Horizontal	$S_o = 0$

Note: S_o = channel slope, y_n = normal depth, y_c = critical depth.

Field measurements and HEC-RAS outputs of River Ogunpa show that the system consistently exhibits mild conditions. As shown in Table 4.6, across the 18 monitoring points, normal depths ranged between 0.58 m and 0.72 m, while critical depths ranged between 0.53 m and 0.69 m. In every instance, y_n exceeded y_c, confirming that the river operates under a subcritical flow regime.

Table 4.5: Water Surface Profile Conditions in the Study Area

Normal Depth (y_n, m)	Critical Depth (y_c, m)	Profile
0.58	0.53	Mild
0.60	0.54	Mild
0.59	0.53	Mild
0.62	0.57	Mild
0.61	0.56	Mild
0.63	0.59	Mild
0.64	0.60	Mild
0.69	0.65	Mild
0.70	0.66	Mild
0.71	0.67	Mild
0.72	0.69	Mild
0.66	0.61	Mild
0.68	0.63	Mild
0.67	0.62	Mild
0.63	0.59	Mild
0.65	0.60	Mild
0.59	0.54	Mild
0.58	0.53	Mild

The dominance of mild, subcritical flow has critical implications. Subcritical rivers are highly sensitive to downstream conditions; any obstruction, sediment deposition, or encroachment raises the backwater profile, increasing flood risk upstream (USACE, 2016). The findings for Ogunpa align with observations in other West African cities, such as Accra, where Amoako and Boamah (2015) reported that encroachment into mild-profile channels amplified flood inundation. Similarly, recent flood hazard studies in Bangladesh, Choudhury & Yabar, (2025) demonstrate that extensive flood inundation and hazard zones remain a significant concern in urban and peri-urban areas, driven by heavy rainfall, drainage constraints, and landscape vulnerability. For Ibadan, this confirms that the hydraulic character of Ogunpa not only constrains self-cleansing capacity but also magnifies the consequences of anthropogenic interference, making routine channel maintenance essential.

Channel Maintenance Using HEC-RAS

The HEC-RAS model of River Ogunpa provided detailed insights into its hydraulic behaviour and maintenance requirements. The analysed reach spanned approximately 28 km, with cross-sections generated at 400 m intervals. Field surveys confirmed that the channel banks consist primarily of sand and vegetation, supporting the use of a Manning's roughness coefficient ($n = 0.035$), which is typical for natural streams with moderate vegetation (Chow, 1959). The model outputs highlight a gradual increase in depth and cross-sectional area from upper course to the lower courseaccompanied by a decline in mean velocity. Figures 4.3 and 4.4a–c illustrate the longitudinal and cross-sectional variations, showing that the river widens and deepens towards downstream, but with diminished flow energy.

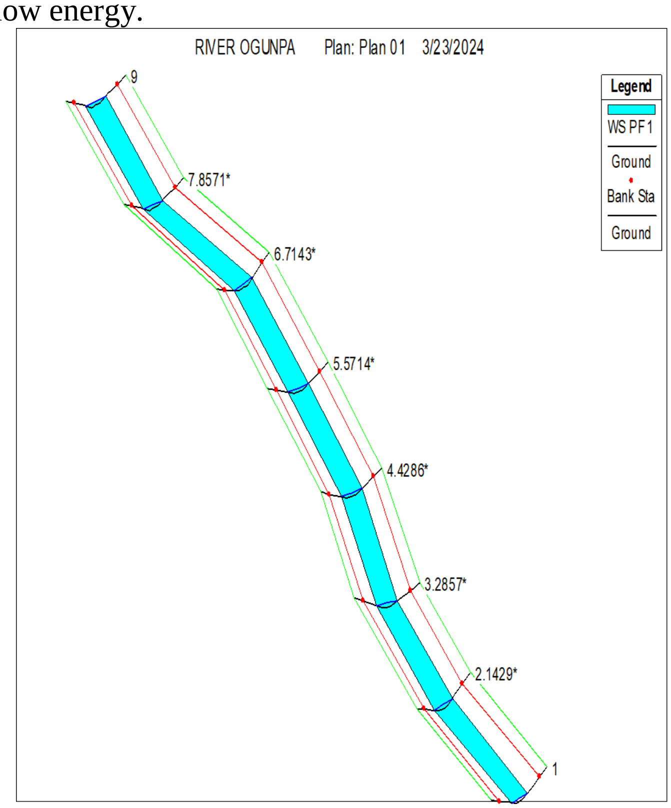

Figure 4.3: Perspective View of Ogunpa River Flow (HEC-RAS schematic)

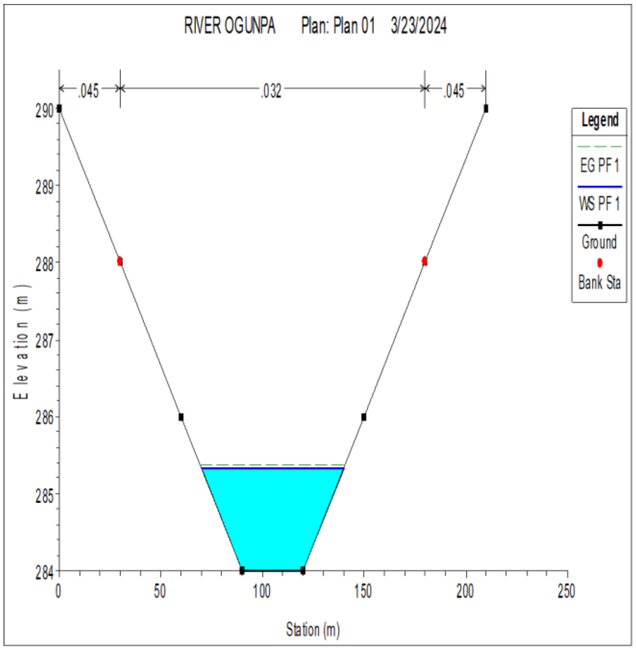

Figure 4.4a: Upstream Cross-section

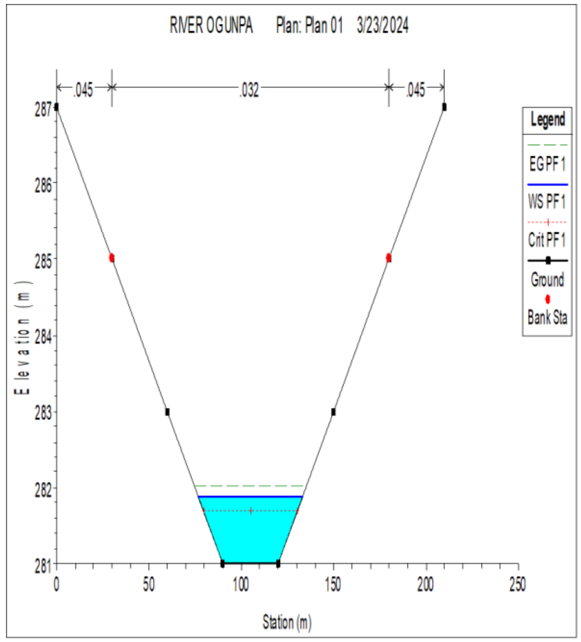

Figure 4.4b: Midstream Cross-section

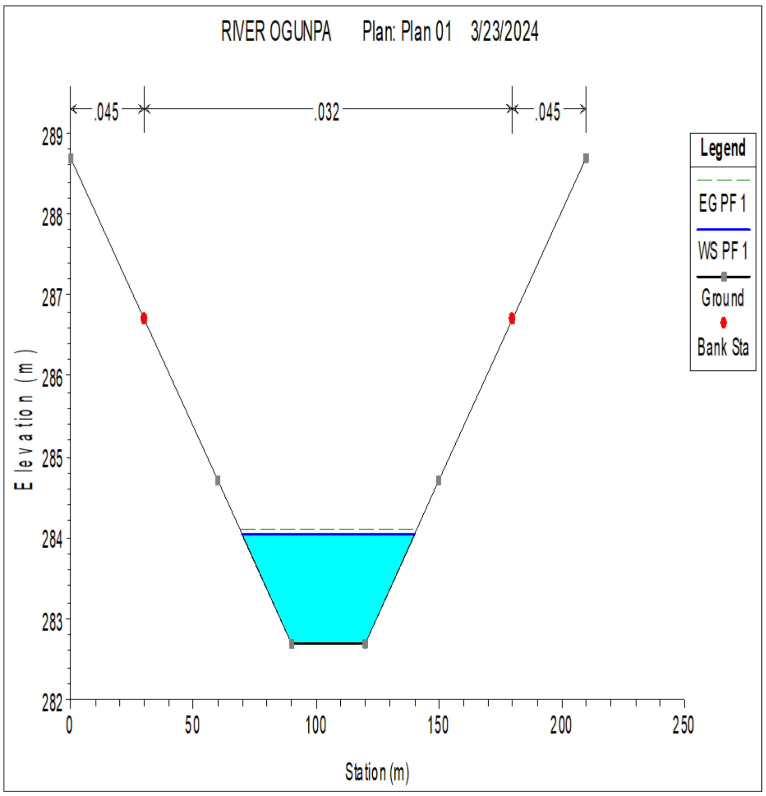

Figure 4.4c: Downstream Cross-section of Ogunpa Down-reach

Hydraulic outputs confirmed that the river flows predominantly under subcritical conditions, with Froude numbers ranging from 0.316 to 0.35. As shown in Figure 4.5, increases in discharge were associated with slight increases in Froude number, but values remained well below 1, confirming a stable but low-energy flow regime.

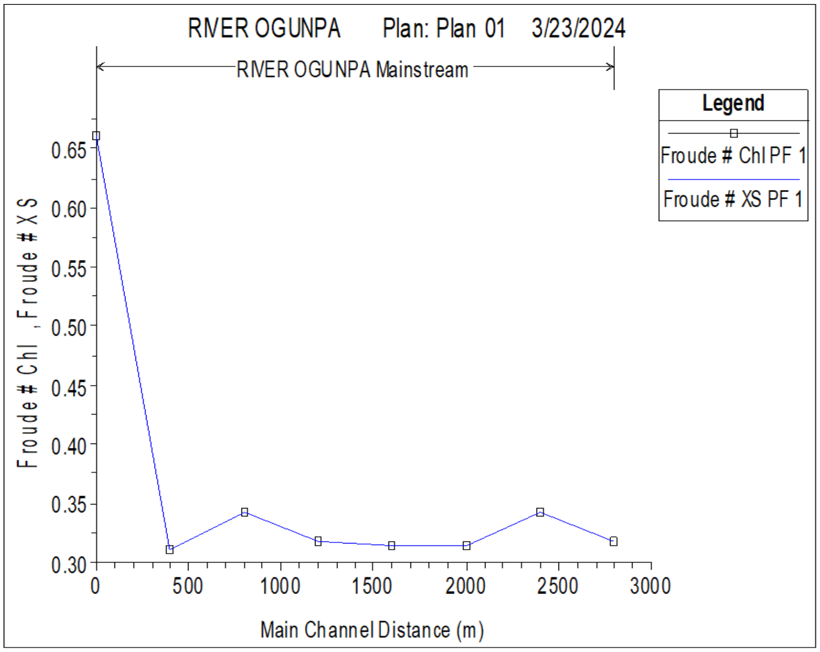

Figure 4.5: Froude Number and Main Channel Discharge along Ogunpa River

Flow area analysis (Figure 4.6) showed values increasing from 43.5 m² near the upstream section to approximately 68 m² within the first 500 m, before stabilising between 63–67.5 m² downstream. These variations reflect both natural channel adjustments and anthropogenic influences, particularly encroachment and sedimentation.

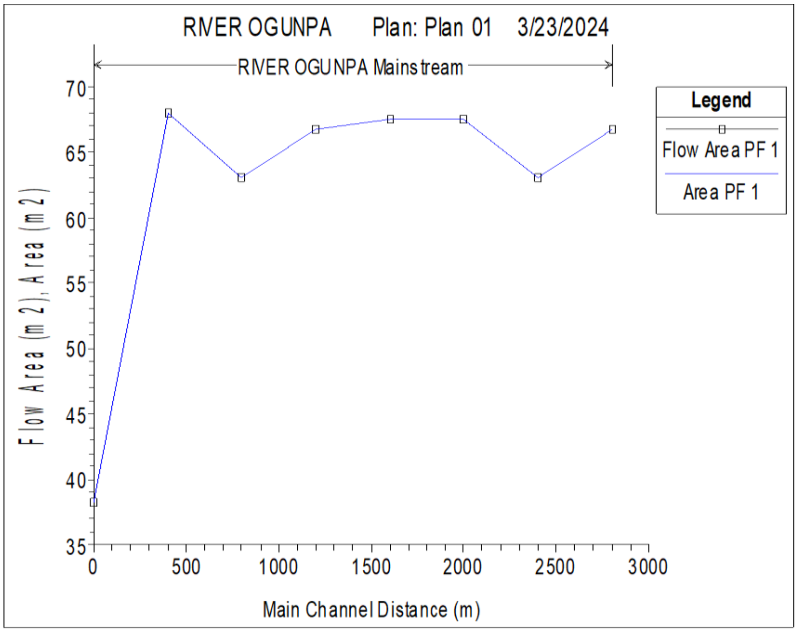

Figure 4.6: Flow Area Variation along Ogunpa River Down-reach

The combined field and modelling results confirm that River Ogunpa's capacity is increasingly constrained by its mild slope, low velocities, and susceptibility to sediment deposition. Subcritical conditions mean that water surface elevations are highly responsive to obstructions, such as waste accumulation and informal structures along the channel banks. This is particularly significant in downstream reaches, where the gentler gradient reduces transport capacity. From a management perspective, the findings underscore the need for regular desilting, vegetation clearance, and enforcement of building setbacks to sustain channel efficiency. Similar interventions have proven critical in Lagos (Olajuyigbe *et al*., 2012) and Accra (Amoako & Boamah, 2015), where unmaintained channels with subcritical profiles consistently failed to convey stormwater during peak rainfall. In Ibadan, the integration of technical maintenance with governance reforms, particularly solid waste management and community sensitisation, remains indispensable for reducing recurrent flood risks along Ogunpa.

Perceived Flood Menace

The household perception survey provided valuable insights into how residents of the Ogunpa River catchment understand and experience flooding. A total of 150 valid responses were analysed, and the descriptive statistics are presented in Table 4.6. The results capture demographic attributes, perceived causes and consequences of flooding, observations, suggested solutions, and levels of satisfaction with current management schemes.

Table 4.6: Descriptive Statistics of Questionnaire Responses on Flooding Menace in the Ogunpa Catchment (n = 150)

Variable	Mean	Std. Deviation	Skewness	Kurtosis
Age (years; grouped)	1.81	0.831	0.363	-1.459
Educational Level	2.75	1.023	-0.212	-1.129
Occupation	2.45	0.902	0.420	-0.671
Gender	1.49	0.501	0.054	-2.024
Length of Residency (years; grouped)	2.86	1.199	-0.342	-1.520
Perceived Causes of Flooding	3.31	1.563	-0.276	-1.415
Consequences of Flooding	2.41	1.194	0.136	-1.343
Observations on Flood Events	2.21	1.007	0.198	-1.141
Suggested Solutions	2.22	1.016	0.207	-1.146
Satisfaction with Current Schemes	3.65	1.094	-0.382	-0.575

Source: Field Survey.

The demographic indicators show that respondents were largely long-term residents of the Ogunpa catchment (mean length of residency = 2.86), corresponding approximately to 11–20 years of residence, reflecting the presence of established communities with extensive experience of flood events. This long-term exposure has heightened awareness of flood drivers and consequences, enabling residents to link environmental changes with specific anthropogenic activities. Educational levels were moderate (mean = 2.75), suggesting that respondents had sufficient literacy to engage with the questionnaire but also that knowledge gaps may influence risk communication and household preparedness. The perception of flood causation yielded a mean score of 3.31, which indicates strong agreement that human activities, particularly indiscriminate waste disposal, blocked drainage, and unregulated construction in floodplains, are the primary drivers of recurrent flooding. This community perspective is consistent with previous research in Ibadan, which identified poor waste management and weak enforcement of planning regulations as critical contributors to flood risk (Agbola, *et al*., 2012). Importantly, the high variability of responses (standard deviation = 1.563) points to differences in vulnerability across neighbourhoods, with the most flood-prone communities expressing stronger views on these causal factors.

The reported consequences of flooding (mean = 2.41) centred on property loss, household displacement, and health challenges. Historical records corroborate these experiences: the 1980 flood, often cited as Ibadan's worst, resulted in over 200 fatalities, while the 2011 flood displaced thousands and caused widespread infrastructural damage (Elujoba *et al*.,, 2025). The survey responses therefore not only reflect individual experiences but also resonate with the documented flood history of the city. A striking finding is the widespread dissatisfaction with existing management schemes, reflected in a mean score of 3.65. Respondents consistently described institutional interventions as reactive and largely limited to post-disaster relief rather than proactive risk reduction measures such as regular desilting of the Ogunpa channel or enforcement of building codes. This perception echoes Okunola & Olawuni, (2025) who observed similar governance failures in Accra and Lagos, where limited municipal capacity and community mistrust weakened resilience. In Ibadan, this gap between community awareness and institutional action appears to have fostered a culture of reactive coping rather than preventive planning.

Overall, the perception results reveal a paradox. Communities recognise that human activities are central to flood causation, and they acknowledge severe consequences, yet institutional shortcomings have normalised reactive coping strategies rather than proactive mitigation. This mirrors patterns in other flood-prone cities such as Accra and lagos, where communities simultaneously identify risks but remain constrained by weak governance and poor infrastructural planning (Amoako & Boamah, 2015; Okunola & Olawuni, 2025). For Ibadan, integrating community perspectives into formal planning is therefore crucial to bridging the gap between local awareness and effective institutional action.

Conclusion and Recommendations

This study examined the persistent flooding problem along the Ogunpa River through a combination of hydrological modelling, GIS analysis, field-based hydraulic measurements, and community perception surveys. The results revealed a convergence between scientific evidence and community experiences. Residents attributed flooding to waste accumulation, encroachment, and poor drainage, while hydraulic analyses confirmed that the river predominantly exhibits a mild, subcritical profile, making it highly sensitive to blockages and sediment deposition. Rainfall trends between 1970 and 2021 further demonstrated intensifying wet-season precipitation, consistent with broader climate change projections for West Africa. These findings indicate that the recurrent flooding in Ibadan is not solely hydrological but is amplified by weak governance, particularly ineffective solid waste management programmes, unregulated urbanisation, and inadequate maintenance of critical water channels. Survey responses highlighted that indiscriminate waste disposal and blocked drains significantly exacerbate flood events, confirming the role of poor sanitation in amplifying flood risk.

The implications are significant. The Ogunpa River retains inherent conveyance capacity, but its stability is undermined by rapid urban encroachment and ineffective management. Comparative evidence from cities such as Lagos, Accra, and Dhaka suggests that technical interventions are insufficient without institutional reforms. Addressing these challenges requires an integrated approach that combines engineering solutions with governance and community engagement. Based on the findings, three recommendations are advanced. First, structural interventions should prioritise routine dredging, vegetation clearance, and restoration of designated channel setbacks. Second, institutional reforms must strengthen waste management systems and enforce land-use regulations to prevent further encroachment on the floodplain. Third, adaptive strategies should be embedded within urban planning, including early warning systems, community awareness programmes, and climate-resilient infrastructure.

In conclusion, the study contributes to bridging the gap between hydrological science and community-based governance. By aligning technical evidence with local perceptions, it offers a practical framework for mitigating flood losses in Ibadan and provides lessons for other rapidly urbanising cities across West Africa.

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