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UNDERSTANDING AND MITIGATING THE EFFECTS OF FLOODING IN KADUNA METROPOLIS: THE INTERPLAY OF CLIMATE CHANGE, URBAN EXPANSION, AND EFFECTIVE MANAGEMENT STRATEGIES

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Abstract

Kaduna Metropolis continues to grapple with the impact of seasonal flooding of the Kaduna River, exacerbated by the combined effects of climate change and rapid urban expansion. However, in 2022 despite evidence of rainfall patterns and water levels higher than those resulting in the 2012 and 2015 devastating floods, there were no reported incidents of flooding. This paper explores the complex nexus of rainfall patterns, flood management techniques, the rush to inhabit flood-prone regions, and the execution of dredging as a formidable countermeasure against flood risks.

The proposed solution comprises an integrative approach, enlisting diverse stakeholders in flood control activities, with a focus on dredging - a practice of excavating sediment and detritus from water bodies. This strategy is coupled with structural measures, such as constructing culverts and storm drains, and non-structural approaches, like land-use regulation, flood detection systems, and controlled inundation.

The paper accentuates the necessity of climate-informed flood management strategies, in preparation for potential extreme weather events. Conclusively, managing Kaduna's floods necessitates a comprehensive approach, acknowledging the intricate interplay of climate, human behavior, and infrastructure. This paper lays the groundwork for bolstering flood resilience in Kaduna, offering valuable insights for other urban environments grappling with the tripartite challenges of climate change, urbanization, and flood management.

Keywords: Kaduna, Flooding, Climate change, Urban expansion, Dredging, Flood management techniques, Controlled inundation, Land-use regulation

1 Introduction

The City of Kaduna's history is punctuated by devastating flood incidents that span several decades. Its strategic location along the Kaduna River renders it particularly vulnerable to pluvial floods, with unforgettable episodes in 1988, 2003, 2012, and 2015, causing destruction of homes, infrastructure, agriculture, and displacement of thousands of residents. At the same time, the city continues to attract tens of thousands of new residents from the surrounding region seeking opportunities its unique position and history offers.

In 1950, the city was a modest urban center with a population of 35,000 (Macrotrends 2023), marked by elegant tree-lined boulevards and administrative edifices commensurate with the capital of the entire northern region of Nigeria. Between 1950 and 1960, Kaduna attracted investments totaling tens of millions of pounds, representing substantial government capital expenditure on specialized structures such as the High Court, Stadium, regional medical facility, police college, military barracks, educational institutions, radio, and television stations. These investments catalyzed an unparalleled influx of job seekers, new families, and students (Lock 1967). Kaduna's history and numerous pioneering achievements engendered a rapid urbanization projected to hit 10.2 million by the close of 2023 (Maidoki 2018).

Kaduna State is positioned within Nigeria at geographical coordinates of 10°20′N 7°45′E and encompasses an area of 46,053 km^2. Annual rainfall in the Kaduna State region, varies between 1,600 mm in the southern fringes to about 1,100 mm in the northern fringes and distributed from mid-May to mid-October, with a peak from mid-August to mid-September (Waheed and Agunwamba 2010). Among the 23 Local Government Areas (LGAs) of the state, 14 have been classified as medium risk and flood-prone, encompassing both rural and urban areas, of which four forms part of the city.

Flooding, characterized as the unintentional inundation of typically arid land, materializes when natural or artificial drainage systems are surmounted, engendering undesirable accumulation of water. This eventuality can be ascribed to an array of factors, including but not limited to heavy rainfall, snowmelt, dam failure, coastal storms, or a confluence of these elements. Among the most calamitous natural catastrophes globally, river flooding has exacted a substantial human toll and precipitated unparalleled property damage (Ibrahim and Abdullahi 2011).

Extreme weather triggered by climate change has likely exacerbated the flooding situation in the Kaduna area, worsen by the lack of public infrastructure to match the pace of urbanization. Currently, the State is experiencing population growth at an average rate of 1.99% per annum (Macrotrends 2023), yet public infrastructure and the provision of essential services remain stagnated in the patterns of the 1960s.

In response to these complexities, the re-enacted Kaduna Capital Territory Authority (KCTA), established in 2021 to serve as the City's Administrator (Authority 2022) embarked on structural and non-structural flood management techniques in 2022, with a particular focus on the dredging of the Kaduna River and its tributaries. The initiative involved deepening the basin and widening the banks, in some cases, to mitigate the impact of flash (pluvial) floods that typically occur during the peak of summer between July and September.

2 Literature Review

2.1 Overview the Flood History in Kaduna

In 1988, Kaduna experienced one of its most devastating flood events yet (Odermerho 1988). Heavy rainfall caused the Kaduna River to overflow, resulting in widespread flooding across the city. The floodwaters caused significant damage to infrastructure, homes, and agricultural lands, leading to the displacement of thousands of residents. The year 2012 witnessed another major flood disaster in Kaduna. Intense rainfall over a prolonged period resulted in the overflowing of the Kaduna River and its tributaries. The floodwaters submerged neighbourhoods, destroyed homes, and disrupted transportation and other essential services. The 2015 floods affected many parts of Nigeria, including Kaduna, and were considered one of the worst flood disasters in the country's history. Kaduna experienced consecutive years of flooding in 2012 and 2015 as heavy rainfall during the wet season led to the overflow of rivers and streams, causing flooding in various areas of the city.

2.2 The 2022 Nigeria Floods

In 2022, Nigeria was devastated by one of its worst floods in over a decade, affecting millions of people and causing extensive damage to property and agriculture. The incidences were unprecedented in scale. At least 600 persons were killed, 2.5 million were displaced from their communities, and 330,000 hectares of farmland were lost (Oguntola 2022). The primary causes of the 2022 floods were attributed to climate change, characterized by heavy rains and the perennial release of water from Lagdao Dam in Cameroon. Despite early warnings from the Nigerian Meteorological Agency (NiMet), including its annual climate prediction titled "Strengthening Climate Actions through Timely and Impact-based Climate Prediction for Economic Recovery", (Nigerian Meterological Agency 2022), 26 states were heavily affected, prompting a nationwide response, including emergency relief, reconstruction efforts, and policy changes.

Among these, Kaduna's 2022 proactive dredging activities stood out as a valuable case study, providing unique insights into localized and tailored solutions in mitigating disasters. Kaduna's experience marked a significant turning point in the chronology of flood events within Nigeria and shaped new approaches to flood management, resilience, and preparedness.

2.3 Climate Change and its Impact on Flooding

In Northern Nigeria, the spatial and temporal configuration of rainfall is distinguished by pronounced variability, manifesting inter-annual fluctuations ranging between 15 and 20% (Oladipo 1993). Such alterations in precipitation, whether characterized by escalation or diminution, exert consequential impacts on a multitude of domains including, but not limited to, water resources, agriculture, soil conservation, and climatic extremities such as floods or droughts. In 2019, I.B Abaje & O.E. Olukayode examined evidence of climate change in Kaduna from the analysis of temperature and rainfall data from 1971 – 2016. The study showed an increase in extreme weather events and gradual changes in climate (Figure 1). Figure 1 illustrates an annual increase of 62.74mm for the 46 years period of the study at the rate of 1.36mm per year (Abaje and Oladipo 2019).

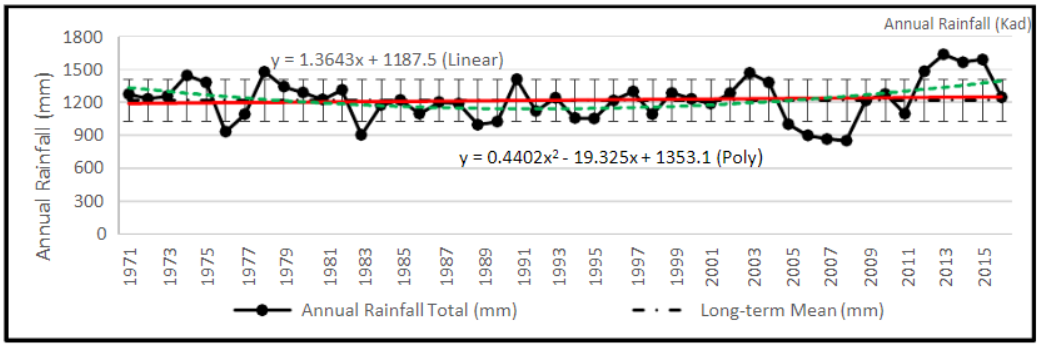

Figure 1. Plotted standard deviation of the 46 years period of annual rainfall for Kaduna.

a. Source: Abaje and Oladipo 2019

The analysis of a 46-year annual rainfall dataset (as shown in Figure 1) reveals variability in precipitation patterns, with 14 years identified as anomalies. Specifically, seven years (1974, 1978, 2003, 2012, 2013, 2014, and 2015) exhibited above-average rainfall, while an equal number of years (1976, 1983, 1989, 2005, 2006, 2007, and 2008) demonstrated below-average rainfall, indicative of drought conditions. Intriguingly, four of the seven anomalously wet years occurred consecutively within the recent 5-year span from 2012 to 2015.

Climate change has likely engendered notable shifts in rainfall patterns, most prominently characterized by the augmentation of both intensity and frequency of rainfall events. Such intense rainfall within abbreviated time frames can swiftly overwhelm Kaduna's drainage systems, resulting in augmented surface runoff and escalated flood risk. Associated with climate change are more frequent and severe weather events, such as torrential rainstorms and prolonged rainy seasons. These events can precipitate rapid water levels, river overflows, and flash floods, compounding flood risk in Kaduna.

2.4 Urbanization and Flooding Risks

Kaduna's urbanization rate, marked at 1.99% annual growth (Macrotrends 2023), has brought about significant changes in land use and urban fabric. From a modest urban center with 35,000 inhabitants in 1950 to a projected population of 10.4 million by 2023 (Maidoki 2018), Kaduna's growth has outpaced infrastructural development.

The rapid urbanization in Kaduna has directly influenced flood vulnerability by encroaching on floodplains and altering natural drainage systems. This impact is visible along the Kaduna River, divided into three reaches: upper, middle, and lower (Waheed and Agunwamba 2010).

1. **Upper Reach**: Extends from the confluence with Kangimi to the Kaduna Eastern Bye Pass Bridge at Malali. It hosts settlements, waterworks, and residential areas, all developed within the floodplain. The presence of small to medium dams for water supply and irrigation has the potential to generate flash floods during the rainy season.

2. **Middle Reach**: Extending from the Eastern Bye Pass Bridge at Malali to the main Kaduna Bridge by the Stadium, this reach is the most urbanized. Hosting the Ahmadu Bello Stadium, GRA, Kigo, and various other locales, the 2012 and 2015 floods had their most devastating impact here.

3. **Lower Reach**: This reach stretches downstream from the main Kaduna Bridge to the Eastern Bypass Bridge. It adjoins industrial areas and includes significant hydraulic structures. Characterized by low flow during the dry season and industrial effluent discharge, rapid physical development is emerging in the floodplain, particularly around industrial areas like Zango and Kudenda and intense farming activities during the dry season.

The intertwining of urban development with the distinct reaches of the Kaduna River illustrates the complex relationship between urban expansion and flood vulnerability in Kaduna. Such encroachments on natural water channels have not only heightened flood risks but also changed the river's behavior and flow patterns, which further exacerbates the flood vulnerabilities. The manipulation of the landscape has culminated in the constraint of channel floodway zones. Consequences of these developments are many for instance flood passage through these areas may results in higher stages and low velocities and shortage of flood attenuation potential. In other reaches, encroachment may impede the downstream progression of the flood wave such that backwater effects may cause high local flood levels. Likewise, conversion of natural permeable surfaces to impermeable structures such as concrete or asphalt diminishes the capacity for water infiltration, augmenting surface runoff and flood risk.

Urbanization, often outpacing the development of suitable drainage infrastructure, aggravates flood risk through inadequate or obstructed drains and culverts. Likewise, unplanned and informal urban expansion has led to encroachment upon floodplains, constraining natural flood storage capacity and amplifying the susceptibility of built-up areas to flooding.

A 2010 study of the impact of urbanization on the Kaduna River flooding concludes that urbanization is progressively modifying the Kaduna River floodplain and its flow and without proper flood protection works will endanger both lives and properties in the floodplain (Waheed and Agunwamba 2010). As such, mitigation strategies must encompass comprehensive urban planning, robust drainage systems, river dredging, floodplain mapping, early warning mechanisms, public awareness drives and community participation.

2.5 Overview of Past Flood Management Techniques in Kaduna

Kaduna's approach to flood management over the years is characterized by a mixture of successes and failures, involving various initiatives and collaborations both nationally and internationally. Some of these include the **domestication of the Nigerian Emergency Management Agency (NEMA)**, passing of the K**aduna Master Plan** and implementation of the **Kaduna Urban Renewal Program** to prioritized infrastructural development, including the construction of proper drainage systems to manage floodwaters, **establishment of Metropolitan Authorities** to manage urban development and related challenges, **collaborations** with the Federal Ministry of Environment, Nigerian Institute of Water Resources, international donor agencies and community leaders, **installation of Early Warning Systems, desilting of drainages** and **community sensitization**

While these efforts might have prevented worse outcomes, they failed to address the complexities of the pluvial floods that are particular to Kaduna's geographical and climatic conditions.

3 Kaduna's Dredging Exercise: A Case Study

3.1 Background and Justification for Dredging the Kaduna River and Its Tributaries

In Kaduna Metropolis, the recurrence of devastating pluvial floods has become a grave and multifaceted concern. The impacts of this problem are extensive and reach across various domains of life. Economic and social consequences are significant; in 2020 alone, Kaduna state faced 15 flooding incidents, affecting over 13,000 people, and leading to 18 fatalities. This has resulted in substantial damage to farmlands, homes, roads, and bridges, affecting 129 communities across the state's 23 local government areas (NEMA, 2020; Kaduna State Emergency Management Agency, 2020). The flooding's health impacts have been dire as well, not only causing injuries and fatalities but increasing the risk of waterborne diseases. An outbreak of Cholera in 2021 resulted in 125 fatalities, putting additional strain on an already fragile health care delivery system (WHO, 2021).

Further complexity arises from the role that the floodplains of the Kaduna River and its tributaries play within the ecosystem. Vital in controlling flooding, sustaining river and wetland ecology, and supporting diverse life forms, any intervention must recognize and respect the integral function of these floodplains. With the challenges posed by pluvial floods, coupled with urbanization and the necessity to preserve the ecological balance, there emerges a critical need for a preventive technique tailored to Kaduna's specific circumstances. Dredging the Kaduna River and its tributaries was identified as a strategic response to these challenges. The decision to dredge is founded on key objectives:

1. Increase the river's capacity to hold more water, reducing the risk of overflow onto floodplains.
2. Improve the capacity of the tributaries to collect excess floodwater in a controlled process to further prevent uncontrolled flooding.
3. Provide immediate relief to vulnerable areas by directly addressing the root cause of the problem.

3.2 Implementing the Dredging of the Kaduna River and its Tributaries

3.2.1 Flood Simulation and Depth Analysis for Strategic Dredging in Kaduna River

KCTA, in collaboration with its implementing consultant Max Lock Nigeria Limited, employed Geographical Information Systems (GIS) to generate flood simulation maps integral to the modeling and analysis of potential inundation scenarios. Leveraging spatial, the team simulated variations in water levels, considering hypothetical increments of 0.5m, 1.5m, and 2.5m in the tidal rose (Figure 2). The exercise was instrumental in informing the decision-making process regarding the optimal depth for dredging. Alas, the water level parameters were not only exceeded at the 2.5m mark but escalated to an unprecedented elevation of approximately 6m.

This revelation was pivotal, underscoring the necessity for data gathering and sharing among public agencies as a mandatory step in project implementation.

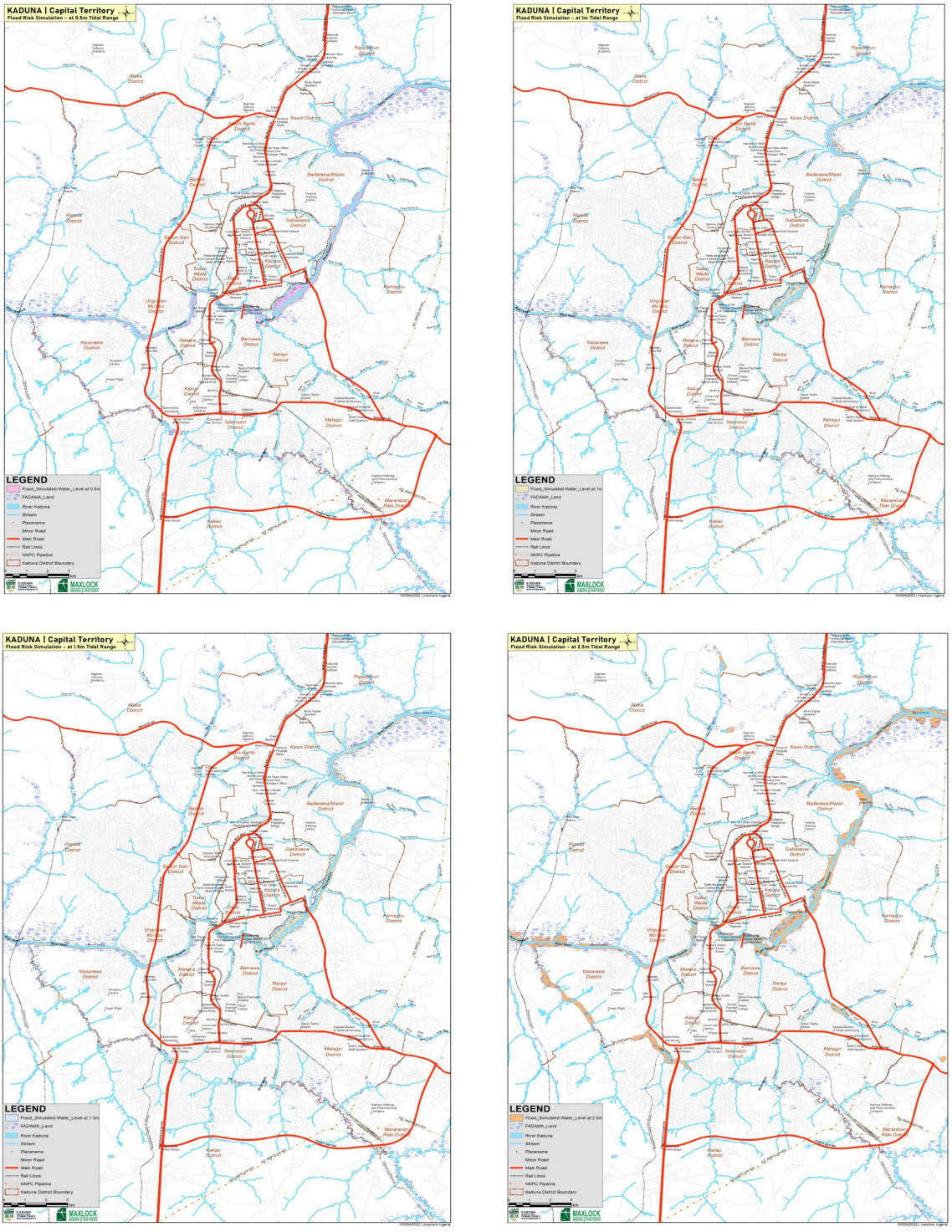

Figure 2. Pre-dredging Flood Simulation Maps utilizing GIS to model potential flooding scenarios based on incremental tidal rises of 0.5m, 1.5m, and 2.5m in the Kaduna River.

3.2.2 Project Area

The dredging of the Kaduna River took place within the Kaduna Capital Territory measuring 50km radius (10,000sqkm) from the central post office located along Yakubu Gawon in Gabasawa District and covers four local government areas (LGAs), that is, Kaduna North, Kaduna South, Chikun and Igabi and forty districts within these LGAs. The project prioritized the underlisted areas identified from all three reaches of the river and typified by human induced triggers such as farming, indiscriminate waste disposal and blockage for the purpose of construction (Figure 3).

a. Angwan Dosa à Angwan Keke
b. Badarawa/Malali
c. Millennium city bridge (Dan Bushia).
d. Gamji Park (Splash Park).
e. Kigo Road.
f. Down Quarters.
g. Nasarawa Industrial Area.
h. Kudenda (behind CGC).
i. Nariya Bridge.
j. Hayin Malam Bello.
k. Gonin Gora Bridge.
l. Romin/Karatudun
m. Yakowa Express (Kamazou)

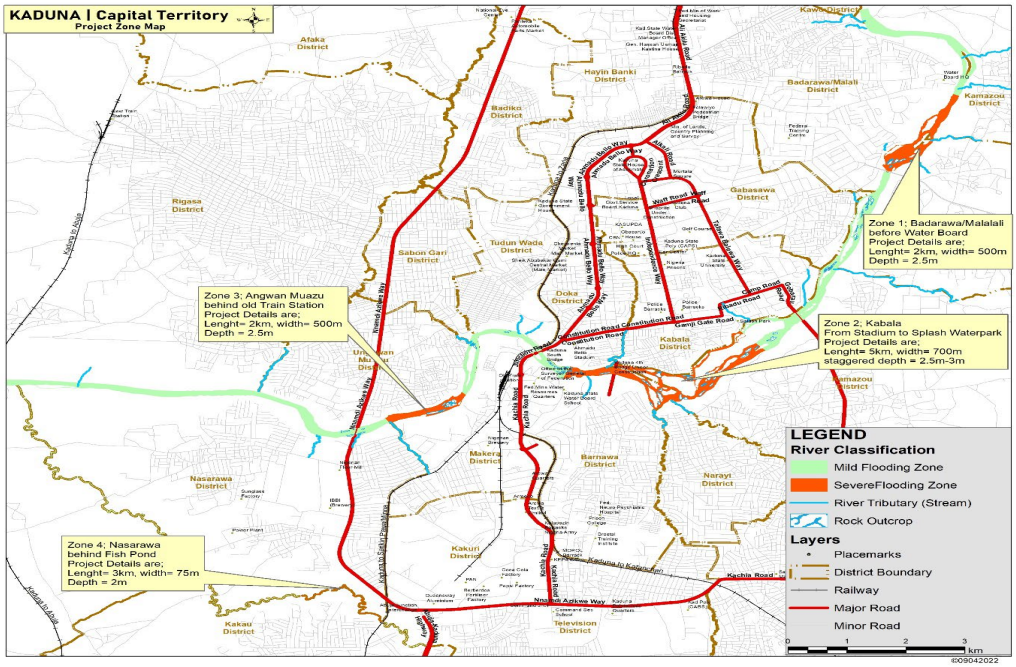

Figure 3. Map showing the coverage areas within Kaduna City and along the reaches of the Kaduna River

3.2.3 The Kaduna River and its Tributaries

The Kaduna River is one of the major rivers in Nigeria, stretching 550 KM from its source on the Jos Plateau near Vom to its confluence with the River Niger at Shiroro Dam. As a tributary of the river Niger, it plays a significant role in the hydrological cycle of the region, with important implications for agriculture, transportation, and other aspects of the local economy.

The river is renowned for its aquatic fauna, including crocodiles, and is characterized by sediments of both igneous and metamorphic rock. To facilitate navigation and other activities along the river, such as the dredging embarked by KCTA, a systematic approach of staggered prioritized locations to deepen the river base was adopted, with particular attention paid to areas with rock outcrops.

Within the Kaduna metropolis, the river extends over 3.5 kilometres, with a minimum width of 300 meters and a maximum of 700 meters. The depth of the river ranges from 1.5 meters to 14 meters, making it a valuable resource for a variety of purposes. The Kaduna River in Nigeria has at least 25 tributaries or streams that contribute to its flow. These tributaries have varying lengths, with selected ones dredged from the confluence to about 500 meters. The confluence point of the tributaries was strategically curved in a 'V-shaped' manner to accommodate more debris or aggregates that will be washed down and systematically shaped to receive and hold water once the catchment of the river Kaduna is exceeded.

3.2.4 Project Scope

The scope of the Kaduna River dredging project was specifically designed to mitigate the historical susceptibility to pluvial floods that occurred primarily between July and September. Commencing on July 6th, 2022, the project aimed to deepen the existing waterline to a specification depth of 2.5m – 3m for the Kaduna River and 1.5m – 2m for its tributaries.

Given the geological stability of Kaduna's soil, the strategy avoided widening the existing floodplain. Instead, the goal was to achieve a new specified depth range within the river channel, in alignment with environmental sustainability principles. This approach was informed by the severe flooding experienced in the Kaduna Urban Area in 2015 and 2012, where the maximum water rising levels were 5.27m and 4.14m, respectively. Thus, the project's optimal dredging depth ranges were determined based on these historical data.

The dredged material, consisting primarily of fine aggregate (sharp and plaster sand) and occasionally coarse aggregate, was strategically placed within an accessible range for evacuation to existing Government construction sites within the city and a significant portion utilized as protective embankments to immediately shield flood-prone communities.

3.3 Findings

The project yielded several critical findings with profound implications for the future management of the river and adjacent areas. These findings are as follows:

1. **Physical Constraints and Characteristics:**
    - **a.** Flood Risk: More prone to the Western side of the Kaduna River than the Eastern side due to the southward flow of water.
    - **b.** Bedrock Constraint: The base of the river has a bed of rock, limiting the dredging activity.

c. Sand Islands: Presence of sand islands that need to be cleared on the waterways at all locations (Figure 4).

Figure 4. Aerial view of Kaduna River showing sedimentation and sand island formation, exacerbated by erosion and agricultural activities over time.

2. Environmental and Health Concerns:

a. Waste Dumping: Indiscriminate dumping of waste (liquid and solid) along the waterways at several locations (Figure 5).

Figure 5. L-R Liquid waste from latrine toilets contained in bags and solid waste obstructing easy flow of water in the Angwan Dosa waterway.

b. Contamination: Deep soil and surface water at specific locations were found to be contaminated by major factories (Figure 6).

Figure 6. Soil and water contamination from effluents by United Textile along Down Quarters Area of Kaduna.

3. Infrastructure and Urban Planning Challenges:

- **a.** Road Construction: Issues with road, drainages, and culvert construction at specific locations.
- **b.** Floodplain Management: Need to secure the river floodplain by clearing or regulating obstructive farming activities.
- **c.** Building Setbacks: Non-compliance with the standard waterway setback of 100m for rivers and 30m for streams was noted in some buildings. Coordination with the Kaduna State Urban Planning and Development Authority (KASUPDA) is needed to rectify these violations.

3.3.1 Impact from the Dredging of the Kaduna River and its Tributaries

The dredging exercise brought about significant transformations in the flood patterns of the Kaduna region. The key impact areas include:

3.3.1.1 Changes in Flood Patterns

1. **Reduction in Flash Floods:** During a year marked by severe flooding in Nigeria, the Kaduna Metropolis experienced a significant diminution in flash flood occurrences along the three reaches of the Kaduna River. This reduction was most pronounced in the historically susceptible areas during the peak flood months of July and September. Despite the Nigerian Meteorological Agency (NiMet) projecting medium to high flood risks for Kaduna and other Northern States in September 2022 due to anticipated higher-than-normal rainfall (Figures 7), the dredging intervention effectively mitigated these risks. By October 2022, as soil moisture content in parts of Nigeria reached saturation levels, the possibility of flash flood events increased, particularly during the 1st and 2nd dekads of October 2022 (Figure 8). However, the success of the dredging exercise in controlling flash floods was evidenced in Kaduna, highlighting the vital role of targeted hydrological interventions in managing flood risk. This analysis affirms the efficacy of the dredging project in enhancing flood management in the Kaduna region. The project's targeted

approach and timely execution provided immediate relief from flash floods, demonstrating a viable model for flood control in similar hydrological settings.

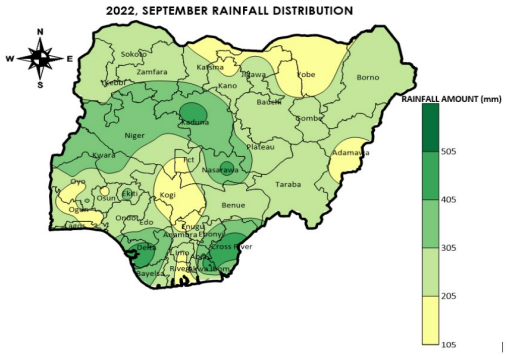

Figure 8. Rainfall Amount Distribution Across Nigeria for the month of September 2022

[b] Source: NiMet

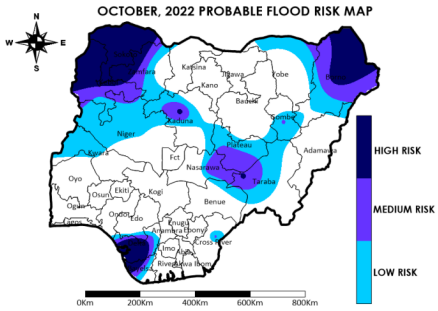

Figure 7. Probable Flood Risk Map Distribution for the Month of October 2022

[c] Source: NiMet

2. **Water Rising Levels**: Historically, overflow of the Kaduna Riverbanks led to devastating floods, notably in 2012 and 2015, when the water-level rose by 4.7m (Table 1). Contrastingly, in 2022, the water-level rose by 5.57m, yet the flood-prone areas encountered only minimal inundation. This remarkable improvement in flood control can be attributed to the strategic deepening of the river and its tributaries, increasing their capacity to hold more volumes of water. Certain exceptions were observed in areas designated for controlled inundation but were inappropriately inhabited.

Table 1. Kaduna Rainfall Data (2010 – 2022)

RAINFALL (mm)													
Year \Month	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
January	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	1.3	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	48	3.6	32.7	95.1	0	0	0	0	0	0
April	29.8	57.1	61.6	74.3	90.8	0	20.1	13.2	0	0	0	44.7	139.3
May	62.5	137.4	212.8	117.6	183.3	89.3	239.8	351.3	109.6	35.1	15.5	152.6	210.9
June	202.8	80.9	140.3	287.1	230.1	112.6	216.5	294	189.2	67.5	132.1	243.2	275.3
July	190.1	233.4	225.6	344.9	183.5	263.1	324.2	386.9	137.6	309.3	321.5	238.2	472.3
August	327.8	208	269.4	317.7	546.8	544	498.1	316	219.4	304.7	305.2	343.4	424.2
September	300.8	298.7	403.4	428.2	354.3	359.4	351.8	273.6	127.9	20.9	171.2	331.6	476.7
October	148.7	135	135.1	37.4	66.5	89.6	35.2	18.8	12.1	24.7	47.6	81.7	157.4
November	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0

[d] Source: NiMet

In the table above, red-colored numbers represent values exceeding 330mm, where the risk of flash flooding commences; even with a recorded rainfall of 472.3mm, 424.2mm and 476.7mm in July, August and September of 2022 respectively, the river's augmented capacity successfully mitigated the overflow risk, illustrating its enhanced ability to hold more water. Figure 9. illustrates this graphically, showing that in 2022, Kaduna had its highest rainfall in a decade.

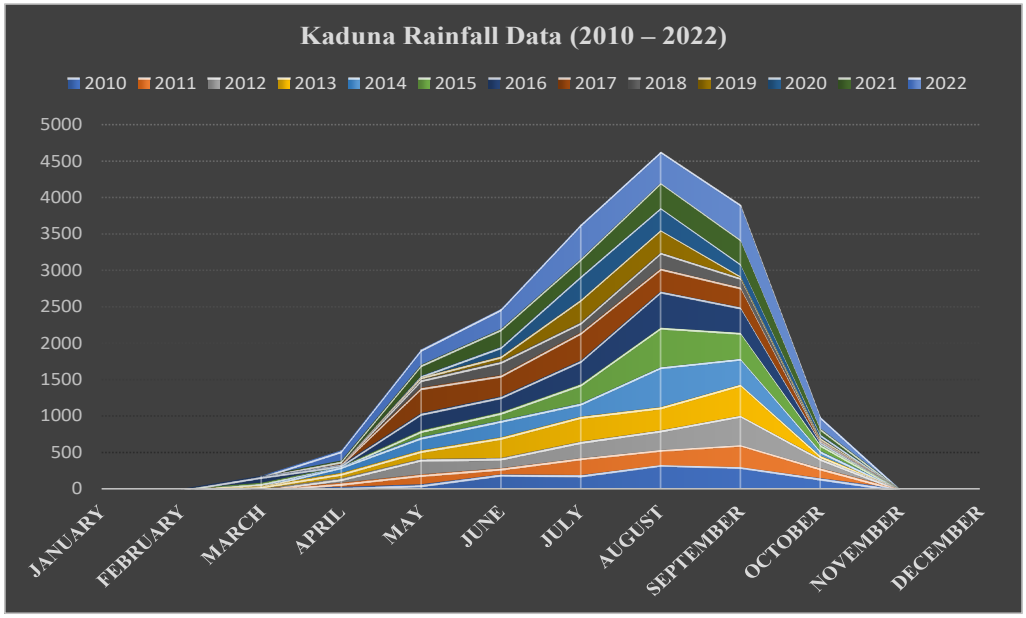

Figure 9. Trends in Annual Rainfall in Kaduna from 2010 to 2022, with a notable peak in 2022 marking the highest recorded rainfall in a decade.

3.3.2 **Unintended Consequences of the Dredging:** The dredging project was concentrated within the jurisdiction of the Kaduna Capital Territory Authority, specifically targeting the city center. To the present date, there is no indication of a shift in flood distribution from upstream to downstream as a consequence of the dredging activities. This early observation is encouraging, suggesting that the measures undertaken have not inadvertently displaced the flood risks to other regions. Nonetheless, the need for further long-term assessment is acknowledged to ensure a comprehensive understanding of the potential impacts and to sustain the benefits observed thus far. Continuous monitoring and evaluation will be vital in elucidating any unforeseen consequences, allowing for proactive measures and adaptations to be implemented as required.

3.3.3 Societal, Economic, and Environmental Implications

The comprehensive dredging of the Kaduna River and its tributaries reveals a landscape punctuated by a confluence of societal, economic, and environmental effects. From the vantage of society, the initiative has not only fortified community integration but has also escalated public cognizance about flood management nuances. This heightened enlightenment has manifested not merely as abstract knowledge but also as practical application, with residents demonstrating an advanced aptitude in discerning flood risks and adopting requisite preventive stratagems. Concurrently, the ripple effect of these flood-mitigating measures has yielded palpable dividends in health and safety matrices,

delineated by a marked decrement in waterborne disease outbreaks and attenuated instances of residential dislocations.

Economically, the intervention showcases a tale of rejuvenation. The waned susceptibility to flooding has conferred a protective aegis over vital infrastructural nodes, bestowing tangible fiscal alleviations in the realms of repair and maintenance. The agricultural domain, too, has been a beneficiary, with erstwhile flood-vulnerable tracts now ensconced in security, thereby catalyzing augmented agrarian yields, and fortifying the local economic scaffold. This economic rejuvenation is further accentuated when juxtaposed with the budgetary outlays; the marginal expenditure on the dredging project, a sliver of the allocated disaster management corpus, stands testament to its cost-efficacious nature.

However, the environmental lens presents a more intricate mosaic. On one hand, the river's augmented volumetric capacity, achieved without an expansion of its floodplain, stands as a bulwark against potential inundation threats, safeguarding adjacent territories. The equilibrium of the ecosystem, too, finds an ally in the dredging, with flood controls acting as deterrents against deleterious soil erosion, thereby preserving the agricultural ambit and indigenous fauna. Yet, this environmental narrative is not devoid of shadows. The act of dredging, while pivotal, introduces perturbations in aquatic habitats, and the sediment extrication processes may inadvertently liberate dormant toxins and heavy metals, potentially imperilling aquatic lifeforms. Further, modifications in the river's intrinsic flow patterns could elicit unforeseen ecological ramifications, necessitating assiduous surveillance and iterative evaluations to pre-empt potential environmental detriments.

The labyrinthine interplay of societal, economic, and environmental dimensions in the context of the Kaduna River dredging underscores the quintessence of multifaceted evaluations and epitomizes the imperatives of crafting interventions that are both responsive and responsible.

3.3.4 Biases in Dredging Evaluation:

1. Selection Bias: Assessments may focus primarily on immediate and tangible benefits, overlooking long-term environmental impacts.
2. Confirmation Bias: Stakeholders invested in the dredging project may unconsciously interpret findings in a way that confirms the positive outcomes, ignoring or downplaying negative implications.

4 Limitations

The findings presented in this study have several limitations that must be acknowledged. First and foremost, the data utilized are preliminary in nature, and the conclusions drawn from them must be interpreted with caution. The scope of the analysis conducted is limited by the availability of comprehensive datasets, and therefore, further research and more extensive studies are required to validate and refine these findings.

Additionally, when dealing with preventive interventions such as dredging, the task of quantifying the effects becomes inherently complex. Unlike other scenarios where direct cause-and-effect relationships can be established, preventive measures introduce an element of uncertainty in the analysis. The absence of a disaster following an intervention does not conclusively establish the efficacy of that intervention, as it is difficult to quantify what would have occurred without it.

In this context, the current approach relies on a comparison with previous disasters, taking into account various factors that might have contributed to similar or differing outcomes. While this comparative analysis provides valuable insights, it may not capture the complete picture, particularly when considering variables that might have changed over time or external factors that could have influenced the results.

In conclusion, while the preliminary findings and comparisons made offer valuable perspectives on the impact of dredging on flood management in the Kaduna region, they should be seen as initial steps in a broader research effort. More rigorous and comprehensive studies are needed to fully understand the complex interplay of factors involved and to develop more precise and reliable strategies for flood control and disaster management.

5 Recommendations

The dredging project in Kaduna has proven to be a highly effective measure in managing pluvial floods, with significant improvements observed in 2022. Nevertheless, for a holistic approach to flood management, the following strategies are recommended:

1. **Integrated Flood Control Activities**: Coordinating among government agencies, NGOs, and volunteers is crucial. This collaboration ensures efficacy in flood control and harmonizes mitigation, evacuation, and water utilization efforts.
2. **Controlled Inundation**:
    a. Structural Measures: This includes constructing culverts, storm drains, and focusing on realignment, erosion control, and embankment fortification.
    b. Non-structural Measures: Emphasizing dredging, clearing waterways, and desilting in key areas, as well as the use of natural embankments.
3. **Flood Detection Systems**: Implement enhanced or newly installed flood warning mechanisms, including water detection systems and urban area sensors.
4. **Land Use Control**: Implementing strict regulations on minimum waterway setbacks, discouraging farming in waterways, and ensuring the proper allocation of floodplains.
5. **Upstream Dam Construction**: A strategically located dam upstream could control water flow and serve as a substantial long-term solution.
6. **Waterfront Development**: Develop waterfront areas designed to harvest excess floodwater, providing both environmental protection and potential commercial opportunities.
7. **Community Resilience Measures**: Promote the capture and storage of rainwater by residents to reduce runoff, and foster community education around environmental stewardship.
8. **Development Codes**: Enforce regulations that prohibit the complete use of interlocking surfaces for houses, preserving natural soil permeability.
9. **Long-Term, Tailored Solutions**: Recognize the immediate relief provided by measures like dredging while emphasizing the need for sustainable solutions tailored to the unique complexities of each region. Consider construction of a dam, waterfront development, community-based initiatives, and comprehensive urban planning, all guided by a coherent long-term vision.

By focusing on these areas, flood management can move beyond immediate responses to create anticipative and adaptive strategies that reflect the unique challenges of climate and urbanization in each area. Such a multifaceted approach will make flood management more resilient, sustainable, and aligned with broader environmental and societal goals.

6 Conclusion

The success of the dredging project in Kaduna represents a solution tailored to the specific nature of pluvial floods, exacerbated by unpredictable weather patterns and urbanization, particularly along the Kaduna River. It stands as an immediate relief measure, but cities looking to adopt dredging must recognize that it's not a one-size-fits-all solution. A careful assessment of the unique flooding characteristics and contributing factors must guide the adoption and adjustment of the dredging procedure. Future interventions must also include mapping and desilting of city drainage systems as an annual project, controlled inundation measures, and rigorous land-use control policies. Complementing these immediate steps with strategic long-term planning is essential for a lasting and resilient flood management solution, reflecting the distinct challenges and opportunities in the Kaduna region and beyond.

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