



Flood Predictions using Previous Streamflow Magnitudes Applying Geographical Information System and Statistical Tools

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ABSTRACT

Floods constitute 30% of natural disasters globally (1900–2020), causing 19% of fatalities and affecting 48% of impacted populations. In Kaduna State, recurrent flooding of the Kaduna River severely impacts communities like Rafin Gusa, Kabala Doki, Barnawa, and others. This study examines the region's flood history using GPS-based assessments to map flood extents, river profiles, and hydrographs. Results reveal a strong correlation between elevation and distance along the river's flood-prone areas (downstream $R^2 = 0.9267$, upstream $R^2 = 0.8058$), with the downstream being more vulnerable. The river's highest discharge, 22,130 m³/s, occurred in 2012, based on a 16-year hydrograph (2008–2024). Pour point analysis highlights high-risk zones at elevated areas due to faster water flow from steep slopes. The study provides a model to forecast future flooding, offering insights for policymakers to monitor and mitigate flood risks effectively.

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INTRODUCTION

Floods are well-known and declared to be quite devastating all across the world. Hydrological and meteorological data, such as flow rate and rainfall, are utilized to construct hydraulic structures that prevent flooding. Uncontrolled floodwaters are among nature's most powerful and destructive forces. Dams that are not constructed to survive big storms may be damaged, resulting in increased flood damage downstream. This damage is frequently devastating. To protect lives and buildings downstream, hydraulic infrastructure must be built to safely handle an appropriate percentage of the Probable Maximum Flood (Ferdowsi, et al., 2024; Pal, 2023). Floods not only damage properties and endanger the lives of humans and animals, but have other negative effects on the environment and aquatic life. These include soil

erosion, sediment deposition downstream and destruction of spawning grounds for fish and other wildlife habitat

Estimation of Peak Flood Discharge (PFD) at a desired location on a river is important for planning, design and management of hydraulic structures such as dams, bridges, barrages and design of storm water drainage systems

Surface water flooding presents unique challenges to decision-makers due to high uncertainties around predicting the location, timing, and impact of what are typically localized events. Increasing urban populations and aging drainage systems, combined with an increase in intense rainfall events as the climate changes, will result in increasing risk of surface water flooding in the future (Dharmarathne, et al., 2024; Nguyen, et al., 2024). Although it may not be

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possible to prevent flooding from intense rainfall, reliable real-time forecasts are crucial to support improved preparedness and response (Flood Forecasting Centre, 2018). A real time surface water flooding forecasting system requires a combination of hydrological and meteorological modeling (Sene, 2024; Chitwatkulsiri & Miyamoto 2023). For example, hydrological models are required to represent surface runoff, inundation, and water movement and show how water travels via surface, subsurface, urban sewerage, and drainage networks. High-resolution probabilistic rainfall forecast models are required to quantify the uncertainty in forecasting the rainfall, which causes surface water flooding.

Among all observed natural hazards, water-related disasters are the most frequent and pose major threats to people and socio-economic development (Noji and Lee 2005, ICHARM 2009). Over the period of 1900-2006, floods accounted for about 30% of the total number of natural disasters, claiming more than 19% of the total fatalities and more than 48% of the total number of people affected (ICHARM 2009). ICHARM (2009) also reports that water-related disasters account for about 72% of the total economic damages caused by natural disasters, out of which 26% of all the damages are attributed to floods. These losses are expected to escalate in the future due to climate change, land use change, deforestation, rising sea levels, and population growth in flood-prone areas, causing the number of people vulnerable to flood disasters globally to increase to two billion by 2050 (Bogardi 2004, ICHARM 2009, Vogel et al. 2011).

Floods can be of many different types and scales and this drives differences in the architecture and implementation of flood forecasting systems. For example, flood forecasting systems have been implemented at global (Alfieri et al. 2013), continental (Thiemeg et al. 2015), basin (Hopson and Webster 2010), and community scales. In addition, flood forecasting systems have been implemented for different types of floods.

The Kaduna River along with climate, vegetation, geography, and topography has

shaped the development of the Kaduna city and inspired economic developments and social integration through a continuous supply of dependable flow of water for domestic, agricultural, industrial, recreational, navigational and waste disposal purposes to the fast growing population of the City. The City has evolved as the Capital of Northern protectorate during the Colonial Era; Capital of North Central State and now the Capital of Kaduna State. However, flooding has become annual occurrences in the City, especially during the raining seasons, and population growth, urbanization and expansion of structural developments into traditional floodplain areas of the Kaduna River are increasing the flood risk factors (Ladan, 2024; Aiyewunmi, 2023). The attendant damages to socio-economic and infrastructural systems and psychological trauma on affected home owners and residents along the floodplain calls for a more pragmatic approach to flood and floodplain management in the Kaduna City.

Daily Times Friday 8th September 2003 reported that Kaduna River overflows its banks spilling flood waters into the adjoining properties along its floodplain across the City, due to increased water level triggered due to torrential rainfall which occurred on the September 6th 2003. The water stages in the channel and floodplain as well as damages to properties along the floodplain were unprecedented, lives were lost, dead bodies were exhumed from grave yards, properties worth millions of naira were destroyed while thousands of people were rendered homeless in the City by the ravaging flood which brought the socio-economic activities of the city to standstill for three consecutive days before the flood waters receded.

The heavy downpour of rainfall which caused unprecedented flood in Kaduna state in 2012, 2015 and 2020 remain a scourge to inhabitants of the state. The flood during these years under review caused Kaduna River overflow its banks again within the Kaduna metropolis and spilled flood waters into adjoining developments in its floodplains. Over two thousands houses were submerged, rendering

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over 30,000 people homeless (THISDAY September 22, 2015). Report from VANGUARD September 22, 2015, indicates that twelve people feared dead and properties worth of millions of naira were lost to the rampaging flood waters. The extent of damages and coverage 2012 and 2015 floods exceeded those caused by the Kaduna flood disaster of 6th September 2003. The flood disaster in the City of Kaduna, in most cases affect the following flood prone communities, such as Rafin Gusa, Ugwan Rimi, Kabala Doki, Barnawa, Kigo Road, Sardauna Crescent, Tudun-wada, Ungwan Muazu, Nasarawa, Kabala West, Hayin Mallam Dan Mani, and Kudenda areas in the Kaduna North and Kaduna South Local Government Areas. This paper seeks to assess the flood history in Kaduna state and develop both river profile and flood hydrograph which would be used to monitor the incessant flooding in the area.

The Jos Plateau is the source of the Kaduna River, which flows northwest across the Kaduna plains and cuts through a number of gorges in the rocky terrain between Zungeru and Kaduna (Ugwu et al., 2024). After draining over 70,200 square kilometers of land during its 550-kilometer main river course, the river finally flows south through the wide, level Niger valley and empties into the Niger River close to Wuya in Niger State (Ugwu et al., 2024). The FCT, Kaduna, Niger, portions of the Plateau, Nasarawa, and Kano States are all included in the river's reach. The Karami, Galma, Tubo, Sarkin Pawa, and Mariga rivers are some of the major tributaries that join the Kaduna River throughout its path. The Shiroro hydropower reservoir, the only significant dam across the main river, is the only state capital where the main river channel passes through Kaduna. The map of the Kaduna river basin is shown in Figure 1.

Study location

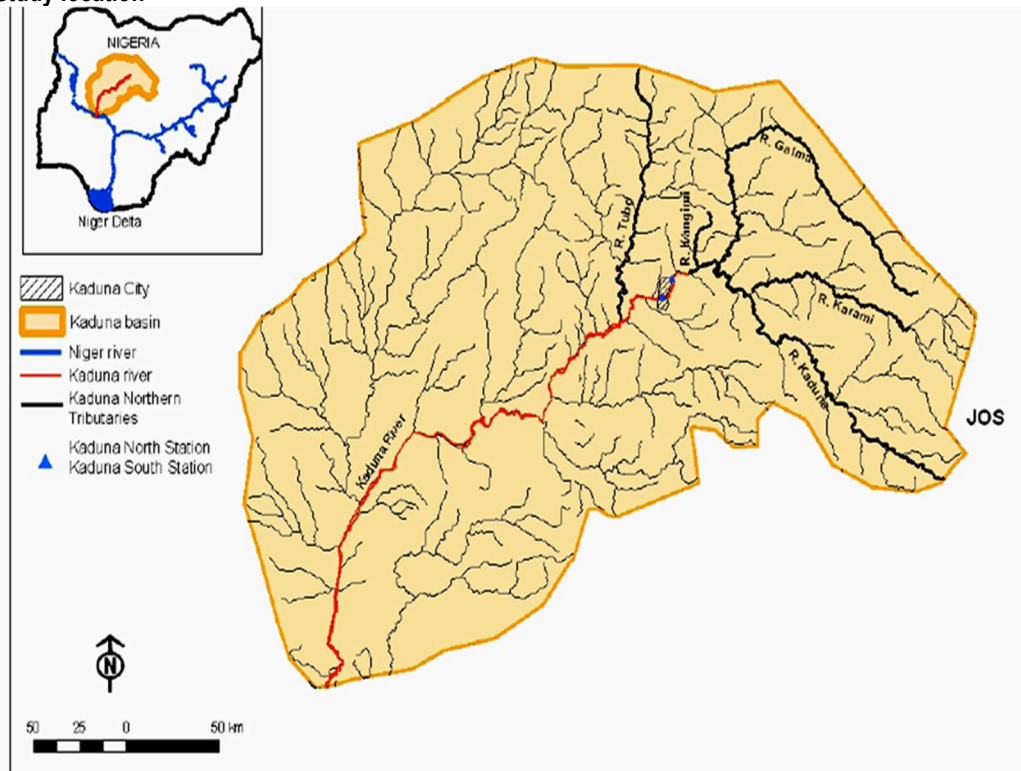


Figure 1: Map of the study area: Source: (Ugwu, et al., 2024)

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MATERIAL AND METHOD

The study used an on-the-spot evaluation with a global positioning system (GPS) to determine flood extent and depict inundated areas. Microsoft Excel was utilized for statistical analysis, and a geographic information system (GIS) was employed to create the inundation map. The primary processes used during the fieldwork are outlined below.

- ascertained the remote and immediate causes of the flood disaster;
- delineation of the maximum shoreline or extent of the flood in all affected Communities were captured using the GPS device and Camera;
- Identification of existing flood control measures (structural and non-

structural) and assessment of their efficiencies;

- Identification of existing good and bad human practices relevant to flood management,
- Development of the Kaduna River floodplain and profile on the dynamics flooding of the Kaduna River.

The digital elevation model, which was converted to triangular irregular network (TIN) in order to represent the terrain data more efficiently and accurately. The TIN, a vector-based model that uses irregularly spaced nodes connected by triangles. It adjusts to terrain complexity, providing a more compact and detailed representation of significant features while using fewer data points in flat areas. The DEM is shown in Figure 2.

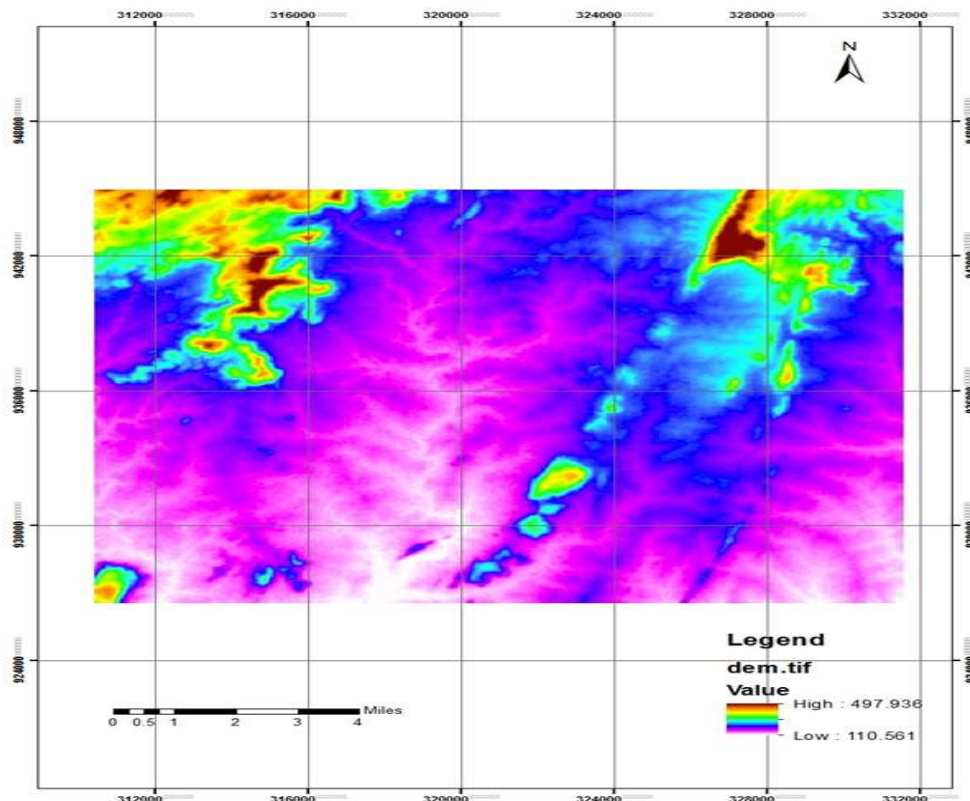


Figure 2: DEM of the study area in TIN format

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RESULTS AND DISCUSSION

The flood in Kaduna in each of the return period was triggered due to prolonged rainfall which increased the water head at the Kaduna River and resulted in spilling of excess runoff along the silted river channel. The belief of the affected residents in the Communities were that the flood was a consequence of excess releases from upstream dams whose operational capacities could not cope with excessive inflows into their reservoir areas, hence the spillway gates were opened. This statement is however not true as all dams upstream Kaduna City are with uncontrolled spillway, thus releases from them are gradual but the fact remains that these dams had retained lots of sediments within them and may not be operating effectively in terms of storage of flood waters. The study of the sedimentation in the Kangimi reservoir by the National Water Resources Institute NWR in 2010

revealed that the reservoir capacity has lost 17.563MCM to sediment (NWRI, 2012) since impoundments. Similar studies by Parkman Nigeria Limited in 2002 indicated that Zaria dam reservoir has also reduced in capacity from the designed capacity of 15.91MCM to 10.577MCM since impoundment in 1971 (KSWB 2002). All these and the recent loss of the Bagoma dam in Birni Gwari are pointers to the facts that both river channels and constructed reservoirs in the Kaduna basin are experiencing capacity losses and can no longer function effectively to reduce flooding. During the flooding of the year under review, communities in Kigo road have appeared to be worst hit as the left embankment to the river is adjacent to the resident and with almost on the same elevation as the embankment. The profile of the river along Kigo road is shown in Figure 3.1.

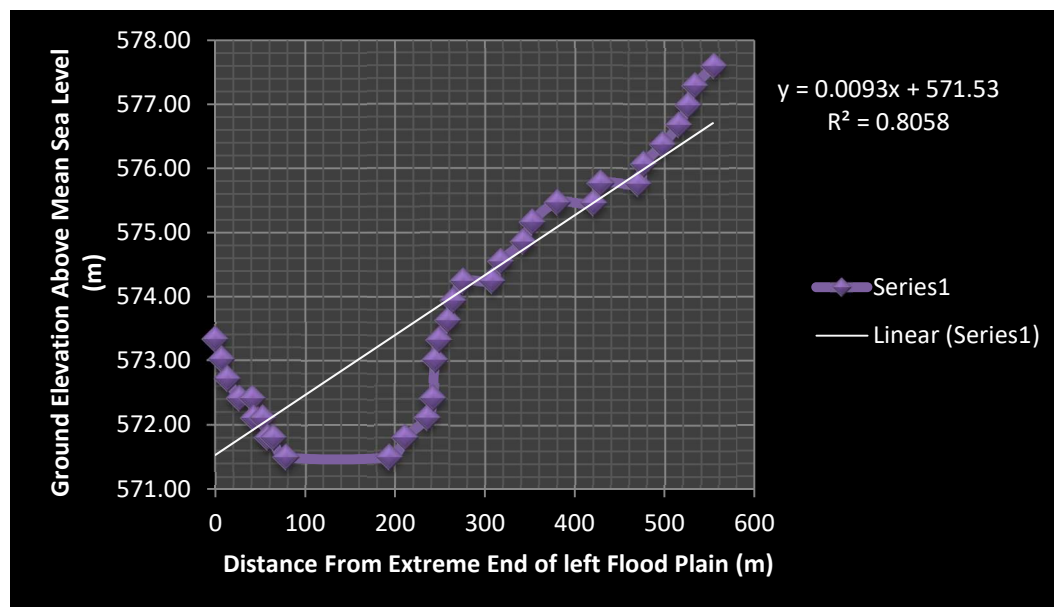


Figure 3.1: Kaduna River profile along Kigo road

The profile shows that as the elevation and distance along the floodplain increases at the immediate vicinity of the river, the elevation is typically lowered, and this is where flooding is most likely to occur during high-water events. Floodplains near the river receive frequent

deposition of sediment, creating fertile areas for agriculture but also making them prone to flooding. As the distance increases from the river, the elevation tends to rise slightly, although it is still generally low compared to the river's headwaters. The floodplain's elevation changes

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gradually and is typically affected by the frequency and intensity of flooding. Areas further from the river may experience less frequent flooding, and as a result, they can accumulate a different mix of sediments or may support vegetation that is more tolerant to less frequent inundation. A statistical correlation test between the elevation and the distance along the flood

plain depicts a high positive coefficient of determination ($R^2 = 0.9267$), which validates the model as the value progresses towards unity.

Sixteen – year Flood hydrograph for the study area depicts the probable maximum flood (PMF) for the years under review as presented in Figure 3.2.

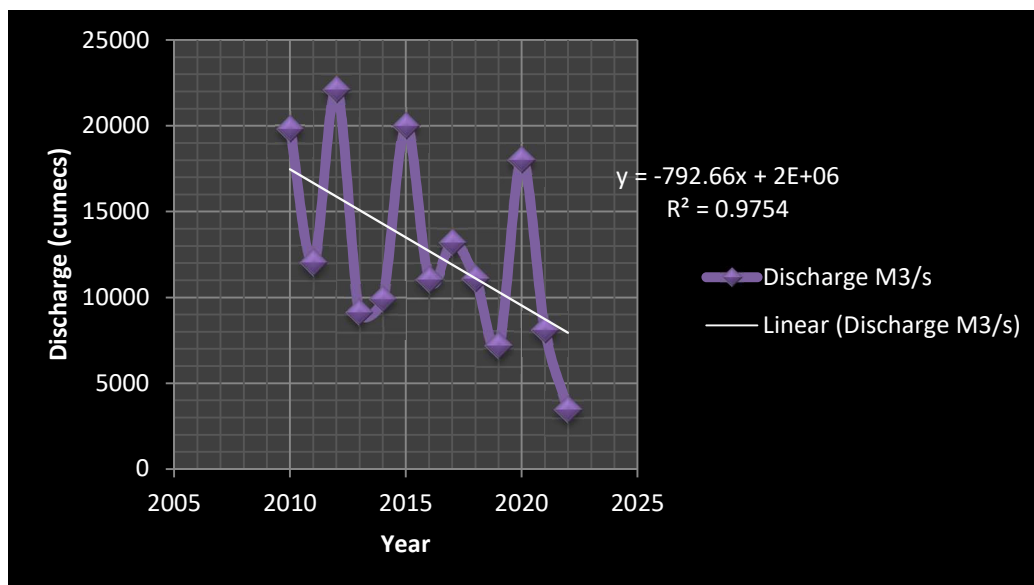


Figure 3.2: Sixteen – Year Flood Hydrograph for Kaduna River

The flood hydrograph for sixteen years (2008 -2024) indicates that the Kaduna river had its peak flow in 2012, followed by 2015 and 2020. The respective flood magnitudes for these years are 22130, 20031 and 18011 cumecs respectively as presented in Figure 3.2. A statistical correlation test between the flood magnitudes and the corresponding years shows

a very high positive coefficient of determination ($R^2 = 0.9754$), which validates the model as the value tends to unity. The flood extent along the upstream of the river is shown in Figure 3.3. The inundation is observed around 576 masl and became steady at a distance of 200 m and 600m from the left bank.

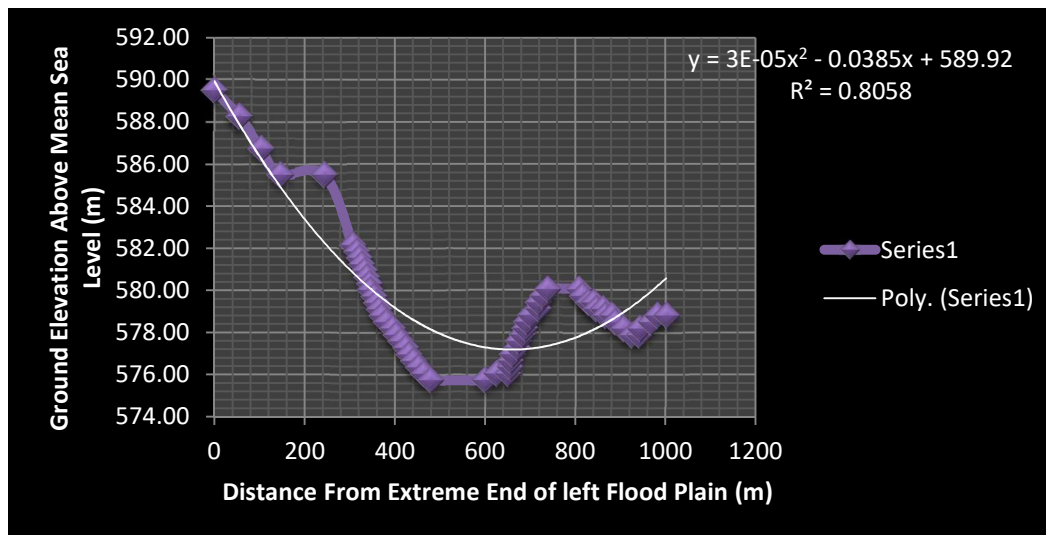


Figure 3.3: Kaduna River profile along the upstream of river Kaduna

The transverse of Kaduna River within the metropolis and possible areas of inundations during the past flooding is presented in Figure 3.4. Highest flood mark extent during the 2015 flood event around Kigo road is shown in the red-dotted spot inside the map shown in Figure 3.4.

The bifurcation of the river has positive and negative impact on the ecosystem as seen in the inundation map. For floodplain communities along the Kaduna River, the effects of the river bifurcation on agricultural land, infrastructure, and settlement patterns can be profound.

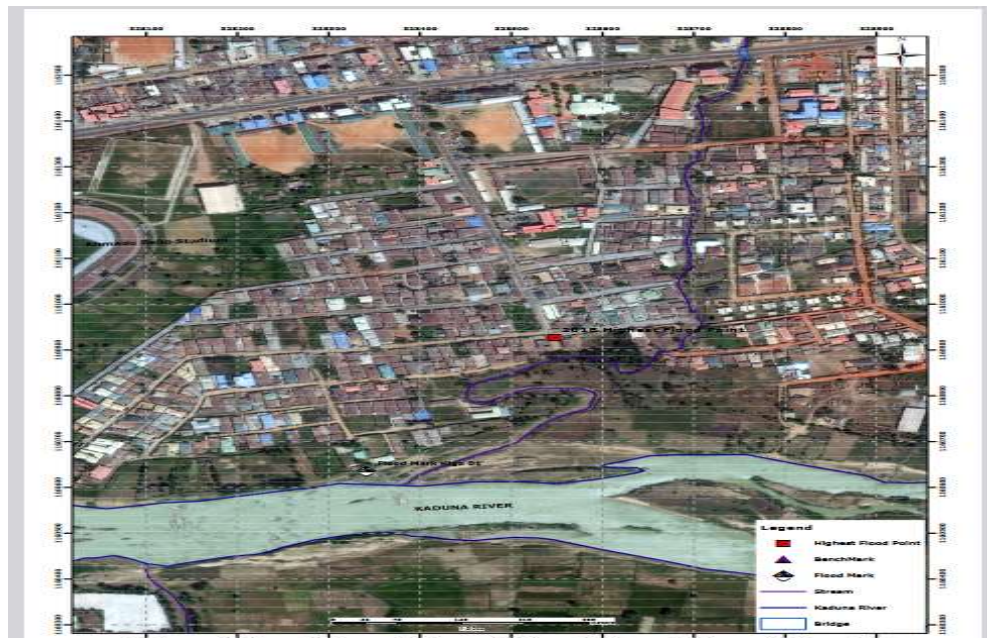


Figure 3.4: Inundation map for areas within the floodplain

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In some cases, bifurcation can reduce the flood risk by dispersing water flow, but in other situations, it may exacerbate flooding, especially if the channels are poorly managed or become obstructed. This could impact communities that rely on the floodplain for agriculture or other economic activities. River bifurcation, whether natural or human-induced, plays a significant role in shaping the characteristics of a floodplain. The redistribution of water, sediment, and nutrients can have profound impacts on the local hydrology, ecosystems, and human communities. While it may offer opportunities for ecosystem diversification and flood mitigation in some cases, it can also present challenges related to flooding, agricultural productivity, and human settlement. Understanding the dynamics of bifurcated river systems is crucial for managing floodplain environments and addressing the multifaceted challenges posed by this process.

Pour points were successfully identified using the DEM data and the snap pour point function in ArcGIS. These points represent the lowest locations in the terrain where water from a given area accumulates and exits. A total of 24 pour points were located within the study area, corresponding to major drainage outlets and stream confluences. These points were converted to polygon as presented in Figure 3, to represent the flood drainage outlet of the study area. The elevation of pour points ranged from 456 masl to 508 masl, highlighting the variation in terrain across the region. Areas above the maximum elevation in the pour points (enclosed polygon) are locations with high flood zones and risk total inundation. This is because pour points at higher elevations typically lead to faster water flow due to steeper slopes. This increased velocity can cause rapid runoff, reducing infiltration and contributing to flash flooding downstream.

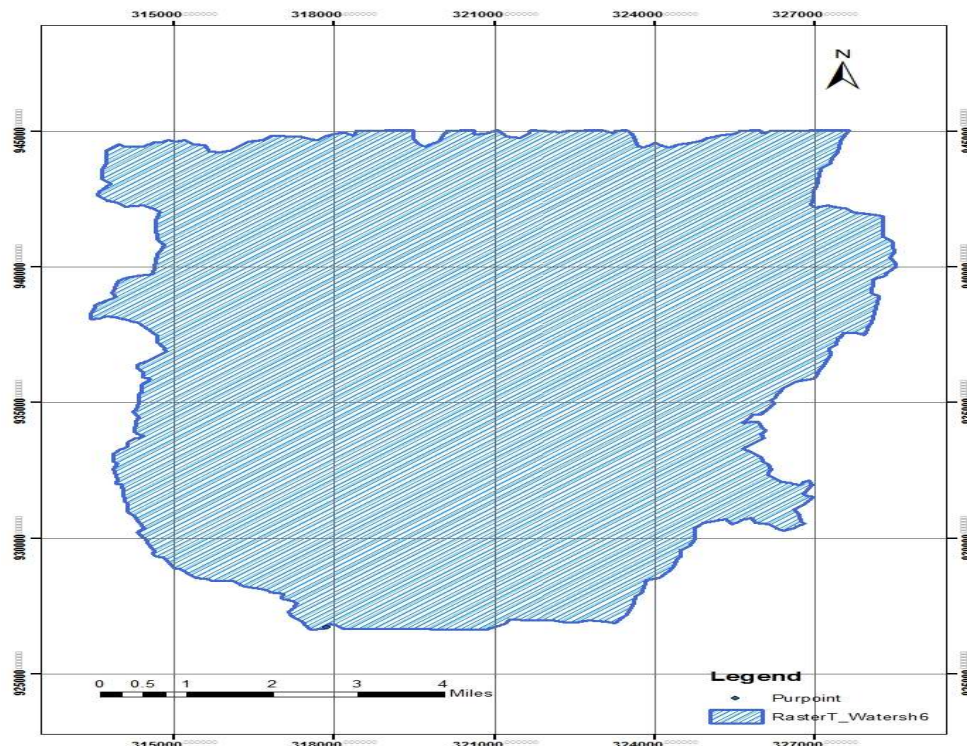


Figure 4: Flood Drainage Pour-point Outlet Map

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CONCLUSION

The study was conducted to assess the flood history in Kaduna state as a means of monitoring flood event and forecasting future occurrence using field record of past flood extent and probable maximum flood for the year under review. River profiles for highly floodplains were plotted establishing the effect of elevation along the Kaduna River and distance along the reach. The correlation between the two variables (elevation and distance along the reach) along the highly flood plain in the downstream and the upstream of the river showed a high positive correlation with coefficient of determination values of ($R^2 = 0.9267$; $R^2 = 0.8058$) respectively. The statistical analysis shows that the downstream has higher positive coefficient of determination, indicating its susceptibility to flooding. The flood hydrograph for sixteen years (2008 -2024) reviewed indicates that the Kaduna river had its peak flow in 2012, with a maximum discharge of 22130 m³/s (cumecs). Pour points analysis shows that areas above the maximum elevation in the pour points are locations with high flood zones and risk total inundation. This is because pour points at higher elevations typically lead to faster water flow due to steeper slopes.

The model developed in the hydrograph can be used to predict future flood establishing a return period in the abscissa axis of the hydrograph. The result of the study should be used by policy makers in the state for monitoring the flood situation and predicting the Kaduna river hydrology to avert unexpected disaster.

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