# Assessment of Sub-Watershed Contributions to Flooding in Magarya Catchment, Gombe Metropolis, Gombe State, Nigeria

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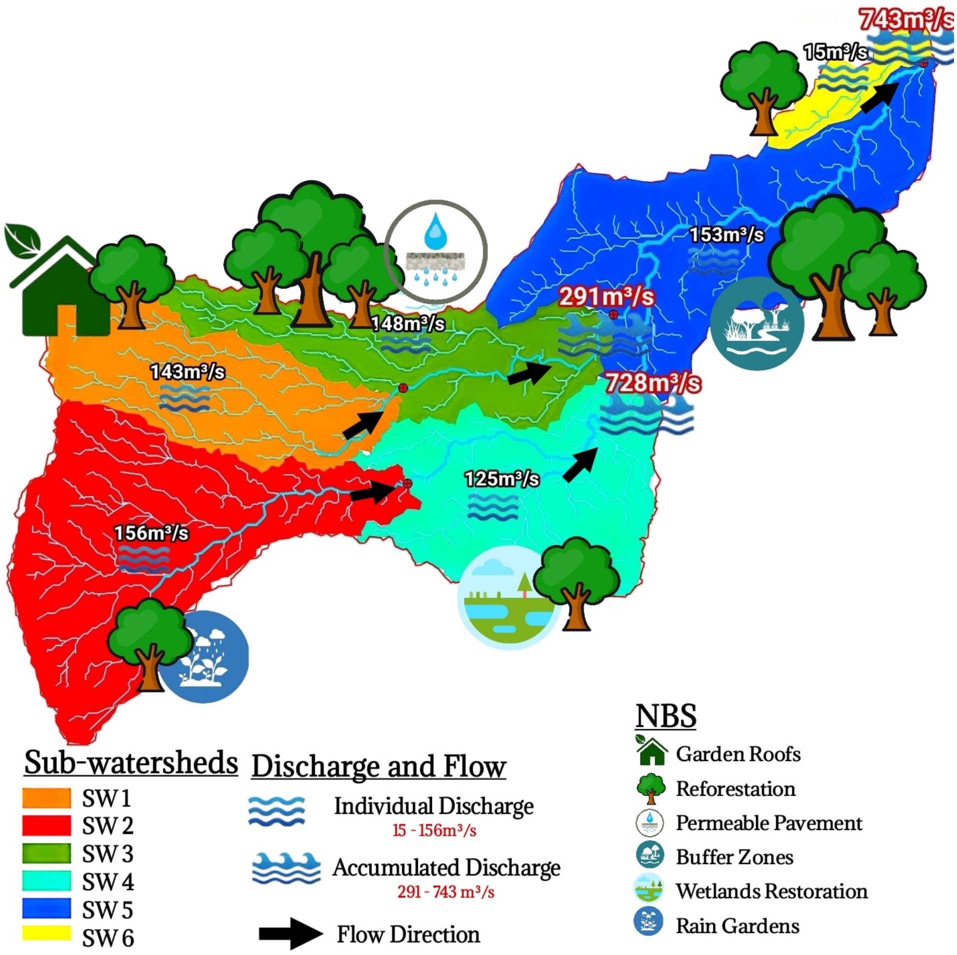
## Graphical Abstract



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**Abstract**

This study investigates sub-watersheds role in contributing to flooding events within the Magarya Catchment, located in Gombe Metropolis, Nigeria. The primary objectives were to delineate sub-watersheds, calculate runoff coefficients, and estimate peak discharges using GIS techniques that integrate digital elevation models (DEMs), land cover data, soil classifications, and rainfall data. The results identified six delineated sub-watersheds ranging from 2.56 to 22.63 km$^2$, with composite runoff coefficients varying from 0.31 to 0.61. Peak discharges ranged from 15.00 to 156.90 m$^3$/s, with Sub-Watershed 3 exhibiting the highest peak discharge. Cumulatively, Sub-Watershed 6 manages a combined runoff of 743.08 m$^3$/s, highlighting critical flood protection needs. The study underscores the potential of Nature-Based Solutions (NBS) in mitigating flood risks. Recommendations include implementing targeted flood management strategies such as reforestation in Sub-Watershed 6 to enhance soil permeability and reduce runoff, and restoring wetlands in regions with mixed land use to buffer peak flows and improve flood resilience. Future studies should focus on continuous monitoring to inform adaptive flood management practices, integrating NBS to promote sustainable water resource management and enhance community resilience to climate change impacts. Keywords: Flooding, Sub-watershed, Runoff Coefficient, Peak Discharge and Magarya

**Keywords:** Flooding;Sub-Watershed; Runoff Coefficient;Peak Discharge; and Magarya

# 1 Introduction

Floods occur when a river's flow exceeds its normal channel capacity, flooding nearby low-lying areas and often affecting agricultural land and urban structures, including residential areas (Strahler and Strahler, 2003). In recent years, flood disasters have been occurring frequently in urban areas, resulting in many lives and property loss. The increase in extreme weather events such as floods is an annual problem in Nigeria, especially in the northern states (Abaje and Giwa, 2010). The effectiveness of urban drainage systems depends on their ability to drain excess wastewater and prevent flooding. Urban areas with inadequate or poorly constructed drainage systems often experience frequent and severe flooding (Abashiya, 2017; Bello, 2018; Mallo, 2021). The National Emergency Management Agency (NEMA, 2013) reported that approximately 7.7 million people in Nigeria were affected by floods between July and October 2012, killing 363 people and injuring 18,282 people. In 2022, floods in Nigeria claimed over 600 lives and affected over 600,000 people (NEMA, 2023). These devastating events were mainly due to heavy rains in different parts of the country. Gombe State, especially its major cities and surrounding areas, also experienced repeated floods. On August 20, 2004, heavy rains triggered an unprecedented flood disaster, the worst in 30 years, killing 35 people, destroying 1,500 homes, displacing over 30,500 people, and causing a loss of more than 2 million Naira (Ibrahim, 2004). Floods in Gombe Metropolis have become an annual event, causing serious damage to residents. On July 25, 2012, an intermittent rainstorm that began at about 2:30 p.m. claimed four lives and destroyed homes and properties worth N11.5 million. The affected areas include Jeka Dafari, Shamaki, Federal Lowcost, Borari, Pantami, Tudung Wada, Barunda, and Kumbia Kumbia (Lawal, 2012). Furthermore, on July 30, 2012, a 59.7 mm rainstorm that lasted about 2 hours caused building collapses in Madaki, Nasarawo, and Pantami areas, killing three people (Anthony, 2012). Similarly, on September 5, 2014, 92.5 mm of torrential rain that lasted just 48 minutes killed six people and caused property damage worth millions of Naira. Most recently, floods occurred in the Gombe Metropolitan area from May to October 2023, killing six people, injuring 34 others, and destroying 13,242 houses (NEMA, 2023). Despite the major impact of floods on the livelihoods of the people living in the low-lying regions of Nigeria, few attempts have been made to delineate the boundaries of flood-contributing sub-watersheds (Asare-Kyei et al., 2015; Daniel et al., 2020). The limited research that was conducted on flood studies in northern Nigeria has used remote sensing data aided by Geographic Information Systems (GIS). However, they lack certain basic principles in hydrological modeling and prediction, which can be added into flood simulation and mapping in the country for better outcomes (Komolafe, Suleiman, & Francis, 2015; Daniel et al., 2020). Considering the severe impact of recurrent floods in the Gombe Metropolis, it is important to assess and identify the sub-basins that contribute most to flooding in the Magarya River Basin. It is neither economical nor feasible to simultaneously manage or reduce floods across a basin. Therefore, using rational methods that consider runoff coefficient, area, and rainfall intensity will help prioritize flood management efforts and develop targeted mitigation strategies for the most affected sub-basins. This research supports the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), by promoting sustainable water management and climate resilience. Additionally, it aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024) by emphasizing innovative and sustainable solutions for water resource management. The potential of Nature-Based Solutions (NBS) in mitigating flood risks is explored, highlighting the importance of integrating ecological approaches in flood management strategies. The aim of this study is to comprehensively assess the contribution of the lower reaches of the basin to flooding in the Magarya River Basin, thereby establishing an effective flood management and mitigation plan in Gombe Metropolis. The specific objectives are to: i. delineate sub-watersheds within the Magarya Catchment; ii. determine the runoff coefficient of different sub-watersheds; and iii. determine the peak discharge of sub-watersheds within the Magarya Basin.

# 2 Methods

## 2.1 Study Area

The Magarya River Basin is located between latitudes 10°11′59″N and 10°20′02″N, and longitudes 11°06′01″E and 11°16′58″E in Gombe Urban Area, Gombe State. The study area slopes towards the east and has relatively flat terrain ranging from 640 to 320 meters above sea level. It is made up of sedimentary rocks such as sandstone, with complex crystalline rocks underneath. These Late Cretaceous sedimentary strata influence the topography and are characterized by dissected sections due to fluvial incision (Ahmad & Wanah, 2023).

The region has a tropical continental climate classified as Köppen's Aw, with a strong seasonal rainfall pattern characterized by distinct wet and dry seasons (Ahmad & Wanah, 2024). Precipitation is concentrated from May to September, peaking in August (Amos, Ahmad, Abashiya, & Abaje, 2015; Ahmad & Wanah, 2023). The average annual precipitation is about 863.2 mm.

Hydrologically, the region is located in the Gongora Basin, part of the Upper Benue Trough Plain in northeastern Nigeria. The inhabitants are primarily engaged in agriculture, raising livestock and cultivating crops for subsistence and export. The most important crops for domestic and international markets include rice, maize, and beans (Ahmad & Wanah, 2023).

## 2.2 Data and Sources

To delineate sub-watersheds within the basin, a digital elevation model (DEM) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the United States National Aeronautics and Space Administration (NASA) was used. This data has a vertical accuracy of 17 meters at a 95% confidence level and a horizontal resolution of approximately 75 meters. Land cover data were obtained from Landsat 8 imagery, which was downloaded from the USGS website. Soil classification data were computed from the Harmonized World Soil Database (HWSD) version 1.2, produced in 2012 by the International Institute for Applied Systems Analysis (IIASA), providing information on soil type and texture classification. Rainfall data were sourced from the Nigerian Meteorological Agency (NiMET), specifically from the Gombe area synoptic station. A topographic map of Gombe Metropolis covering the study area was obtained from the Ministry of Lands and Survey, Gombe.

## 2.3 Runoff Estimation Model

The methodological approach used in this research is diagrammatically summarized in Figure 2, as Asare-Kyei et al. (2015) described.

## 2.4 Sub-Catchments Delineation

A DEM was utilized for sub-catchment delineation and slope analysis. The study area was divided into six sub-catchments using the spatial analyst tools in the ArcGIS environment after all the sinks were filled to ensure accuracy. The filled elevation data layer was maintained and later integrated with peak runoff and elevation data to determine runoff concentration at different elevations. The generated sub-catchments, initially in raster format, were converted to polygon format using the conversion tool under spatial analyst tools. Converting the raster format into polygons was necessary to calculate the areas of the sub-catchments and to build the attribute table within the ArcGIS environment.

## 2.5 Runoff Coefficient Computation

## 2.6 Land Use Classes

The different bands of the Landsat imagery were combined in the ArcGIS environment to form a composite image, which was further processed into a mosaic raster before analysis. Supervised classification was conducted on the Landsat imagery to identify four broad land use/land cover (LULC) classes after training samples and signatures were created using the training sample manager in ArcGIS. The identified LULC classes were: (1) agricultural land; (2) grassland; (3) bare land; and (4) settlements (built-up areas). Training and validation data for these classes were collected from field campaigns conducted between October 2023 and January 2024. Training and validation samples for the classification were generated by overlaying the training and validation data (polygons) on the satellite image and extracting the corresponding values.

## 2.7 Soil Type and Texture

The Harmonized World Soil Database (HWSD) was used for soil classification. This database is an image file linked to a comprehensive attribute database containing information on soil mapping units, soil texture for top and subsoils, and several other soil properties (Food and Agricultural Organization [FAO], 2009). Based on this information, the characteristics of the basin were reclassified into the four main soil hydrological groups defined by the United States Soil Conservation Service (USDA, 2009).

## 2.8 Composite Runoff Coefficient

Each sub-catchment contains multiple LULC types, soil types, and slopes. To find a representative runoff coefficient for a given sub-catchment, average values were calculated based on the different LULC types. The DEM was converted to percent slope in ArcGIS and reclassified into two classes: slope less than 0.5%, and slope between 0.5% and 5%. Table 1 specifies a runoff coefficient for each LULC type, soil, and slope. The average runoff coefficients for each sub-catchment were computed based on the number of LULC types occurring in each sub-catchment. Knowing the runoff coefficients (C), rainfall intensity (I), and areas (A) of each sub-catchment, the discharges (Q) for each sub-catchment likely to cause flooding were calculated.

## 2.9 Determination of peak run-off using the rational model

The rational model belongs to the group of lumped hydrological models, which treats the unit of analysis as a single unit whose hydrological parameters (e.g., rainfall) are considered as average values. The model is given by the equation:

$$Q = C \times I \times A \tag{1}$$

Where:

- $Q$ = Peak run-off rate ($m^3/s$)
- $C$ = Run-off coefficient (-)
- $I$ = Rainfall intensity (mm/h)
- $A$ = Drainage area ($km^2$)

The model operates on a number of assumptions including:

1. The entire unit of analysis is considered as a single unit;
2. Rainfall is uniformly distributed over the drainage area;
3. Estimated peak run-off has the same chances of reoccurrence (return period) as the used rainfall intensity ($I$);
4. The run-off coefficient ($C$) is constant during the rain storm.

# 3 RESULTS

## 3.1 Sub-Watersheds within Magarya Catchment

The Magarya River Basin is divided into smaller units based on topographic data. This process helps identify natural drainage boundaries and assess the contribution of each basin to flooding, allowing for targeted flood control strategies (Haghipour and Burg, 2014). In the case of the Magarya Catchment, analysis of the catchment topography determined flow directions and accumulation points, dividing the catchment into different hydrological units. Each sub-watershed represents an area where precipitation collects at a single outlet within the watershed.

The results show six sub-basins within the catchment:

- SW-1: 13.29 $km^2$
- SW-2: 22.46 $km^2$
- SW-3: 12.85 $km^2$
- SW-4: 16.64 $km^2$
- SW-5: 22.63 $km^2$
- SW-6: 2.56 $km^2$

Total area: 90.43 $km^2$ (Fig. 2). This delineation helps to understand the catchment structure and is crucial for subsequent analyses, such as the calculation of runoff coefficients and peak discharges. Dividing the catchment into smaller units allows for accurate assessment and description of the specific hydrological and flood risk characteristics of each catchment.

## 3.2 Sub-Watersheds Gradient

The gradient or slope of a watershed has a significant impact on runoff and flooding potential. The average slope of the Magarya River basin is 0.033 per km. However, variations are observed in individual sub-basins: SW-1: 0.039 per 1 km, SW-2: 0.034 per 1 km, SW-3: 0.032 per 1 km, SW-4: 0.031 per 1 km, SW -5: 0.023 per km, SW -6: 0.011 per 1 km. SW 1, where the steepest slope is 0.039 per km, may have faster runoff, resulting in higher erosion potential and faster peak runoff during rainfall. This steep slope can increase the risk of flooding, especially in urban areas where impermeable surfaces impede infiltration (Abashiya, 2017). SW 6, which has the lowest slope of 0.011 per km, suggests slower runoff and may have lower immediate flood risk compared to areas with steeper slopes. However, this slow water movement can lead to longer saturation periods, which can impact agricultural land by increasing soil moisture content and potentially delaying drainage (Mallo, 2021; Abashiya, 2017). SWs 2, 3, and 4 have slopes close to the catchment average, indicating a balance between runoff velocity and infiltration potential. Typical runoff behavior may occur in the lower reaches of these basins, with no extremely rapid runoff or significant delays in drainage.

## 3.3 Runoff Coefficient of Different Sub-Watersheds

## 3.4 Land Use/Land Cover Classes

Land use/land cover classes in the Magarya River Basin include urban areas, agricultural land, grasslands, and bare land. Identifying these classes will help understand the influence of both human activities and natural land features on flood dynamics. For example, urbanization often increases runoff, increasing the risk of flooding (Abashiya, 2017). As of 2024, the land use/land cover distribution in the Magarya River basin has been shown to significantly contribute to flood dynamics. 25.20 $km^2$ of this area is undeveloped land and has the potential for high runoff due to low vegetation cover. The residential area is 30.07 $km^2$, which significantly increases the sealing area and the outflow volume. Grasslands with an area of 15.13 $km^2$ generally help reduce runoff through infiltration and absorption. Agricultural land occupies 20.0 $km^2$, but crop types and agricultural practices can have varying effects on runoff and erosion. Understanding these distributions is important for basin flood assessment and flood management. LULC class in Magarya is shown in Figure 4 below.

## 3.5 Soil Classification

Soil classification for the Magarya River Basin classifies soils based on their properties that influence water infiltration and drainage. Different soil types, such as sandy or clay soils, affect how much rainwater is absorbed or drained from the surface, and predict which areas are more susceptible to flooding. Soils such as sand, loamy sand, sandy loam and sandy clay have been identified in the Magarya river basin. Highly permeable sandy soils allow rapid infiltration and reduce surface runoff. Clay sand is also permeable, but it retains more water than pure sand, so there is a better balance between infiltration and runoff. Sandy loam is a mixture of sand, silt and clay with good drainage and moderate water retention, contributing to balanced hydrological conditions. Sandy clays with higher clay content hold more water, which can increase runoff during heavy rains. These soil classes influence flood dynamics by influencing water infiltration and surface runoff.

## 3.6 Composite Runoff Coefficients (C)

The composite runoff coefficient represents the potential for surface runoff to occur in different regions of the Magarya River Basin, influenced by land use and soil type. A high coefficient indicates an area that is more likely to cause flooding. Composite runoff coefficients for each sub-basin of the Magarya River Basin were calculated based on land use, soil type, and slope. Specific values for each land use type within each sub-basin were combined to derive a composite runoff coefficient for each sub-basin. The composite runoff coefficients for each basin indicate significant differences in surface runoff potential, requiring different flood management strategies. SW 3 has the highest composite runoff coefficient of 0.61, which is due to the extensive built-up area combined with sandy loam soils and gentle slopes. This underwater catchment requires significant flood protection measures. Behind it is SW 1 with a combined runoff coefficient of 0.57 due to its considerable developed land area and relatively steep slope. SW 4 has a balanced potential for runoff and infiltration, and SW 2 has a more balanced land use mix with moderate gradients. SW 5 and SW 6 have low composite runoff coefficients, indicating low runoff potential.

## 3.7 Peak Discharge of Sub-Watersheds within Magarya Basin

Peak flow represents the maximum water flow from each basin during a storm and plays an important role in understanding flood dynamics. In the Magarya River Basin, peak flow calculations help identify sub-basins that are most prone to flooding. The average rainfall intensity in August 2023 was 18.92 mm/h, and SW 2 recorded the highest peak runoff of 156.90 m3/s. This reflects the combination of its large area, moderate runoff coefficient of 0.37, and moderate slope. This indicates that the potential for rapid surface runoff is large and requires robust flood management strategies. SW 3 followed closely with a peak discharge of 148.15 m3/s and had the highest discharge coefficient of 0.61 due to extensive built-up areas and special soil properties. The peak flow rate in SW 1 was 143.41 m3/s, highlighting the need for improvement of the drainage system. The peak discharge of SW 5, which has a gentle slope, is 153.75 m3/s, indicating that although the discharge coefficient is low, its large area contributes to a significant discharge. The peak discharge of sub-basin 4 was moderate at 125.87 m3/s, while the peak discharge of SW 6 was the lowest at 15.00 m3/s, reflecting minimal and slow surface runoff. Scenarios of increasing rainfall intensity could result in significant increases in peak flows in all sub-basins, creating an urgent need for adaptive flood management strategies to reduce the impact of extreme rainfall and prevent catastrophic flooding. The need is emphasized. This study is in line with previous studies on flood risk and management in urban catchments (Abaje and Giwa, 2010; Bello, 2018; Abashiya, 2017) and details the flood dynamics of specific underground catchments. By considering current and future scenarios, this study contributes to a comprehensive approach to flood risk management and ensures preparedness for increasingly changing weather conditions

## 3.8 Accumulated Peak Discharge

Cumulative peak flow is intended to provide a unified understanding of which sub-basins are susceptible to flooding. To estimate the cumulative peak value of a sub-basin and highlight the risks of SW5 and SW6, the peak flows of each sub-basin at a specific point were summed. The cumulative peak discharge at the end of SW5 is 728.08 m3/s, which is significantly higher than the peak discharge of the individual basins. This suggests that a significant amount of runoff occurs in SW5 and requires strong flood management strategies to prevent flooding and potential flooding. At the main outlet including SW6, the cumulative peak flow rate is 743.08 m3/s. Although the individual peak flows of SW6 are relatively low (15.00 m3/s), the cumulative impact of all sub-basins contributing to the mainstream highlights the potential for significant flooding. The last subsurface catchment, SW6, has to manage combined runoff, highlighting the need for appropriate flood protection measures at this critical phase.

# 4 DISCUSSION

## 4.1 Impact of Sub-Watersheds on Flood Dynamics

This study elucidates the significant role of sub-watersheds within the Magarya Catchment in influencing flooding dynamics, particularly in urban areas with high impervious surfaces and steep slopes, such as SW-1 and SW-3. These sub-watersheds exhibit accelerated runoff rates, contributing disproportionately to peak discharge during rainfall events. The presence of impermeable surfaces exacerbates flood risks by impeding natural infiltration and promoting rapid surface runoff. Identifying these high-risk areas through topographic data is crucial for developing targeted flood control strategies, aligning with the United Nations Sustainable Development Goal 11 (Sustainable Cities and Communities) by improving urban flood resilience (Haghipour & Burg, 2014).

## 4.2 Nature-Based Solutions (NBS) for Flood Mitigation

Nature-based solutions (NBS) present effective strategies for mitigating flood risks in the Magarya Catchment. Reforestation in sub-watersheds like SW-6, characterized by gentler slopes, can enhance soil permeability and increase water retention capacity, reducing surface runoff volumes. Restoring wetlands in areas such as SW-5, which feature mixed land use and moderate slopes, helps buffer peak flows and enhance flood resilience. Implementing permeable surfaces in urban settings, observed in SW-2 and SW-4, represents another NBS approach that reduces surface runoff and alleviates flood impacts on infrastructure (Abashiya, 2017). These strategies contribute to Sustainable Development Goal 15 (Life on Land) by promoting ecosystem restoration and improving land management.

## 4.3 Comparison with Conventional Flood Management Practices

Compared to conventional flood management practices that rely on engineered infrastructure, NBS offer a flexible and cost-effective alternative. The composite runoff coefficients for each sub-watershed highlight the effectiveness of NBS in improving natural flood attenuation processes. Areas with high composite runoff coefficients, like SW-3, show how NBS interventions can mitigate flood risks associated with urbanization and intensive land use. Additionally, NBS provide benefits such as carbon sequestration, habitat restoration, and recreational opportunities, contributing to Sustainable Development Goal 13 (Climate Action) and Goal 14 (Life Below Water) by enhancing climate resilience and supporting ecosystem health.

## 4.4 Alignment with STISA-2024 and Future Directions

The study aligns with the Science, Technology and Innovation Strategy for Africa (STISA-2024) by integrating innovative solutions that leverage natural processes for flood management. NBS contribute to STISA-2024's objectives of promoting sustainable development and addressing climate change impacts through adaptive strategies. Future research should focus on continuous monitoring and refining NBS approaches to enhance their effectiveness and scalability. Embracing NBS will support the African Union's post-STISA initiatives by fostering sustainable water resource management and improving community resilience to climate change.

# 5 Conclusion

This study underscores the critical role of sub-watersheds in shaping flood dynamics within the Magarya Catchment. Through detailed analysis and delineation, high-risk areas contributing disproportionately to flood events have been identified. These findings emphasize the urgency of implementing targeted flood management strategies to mitigate potential damages to infrastructure and enhance community resilience. To effectively manage flooding in the Magarya Catchment, prioritizing nature-based solutions alongside traditional infrastructure is recommended. Initiatives such as reforestation, wetland restoration, and the promotion of green infrastructure in urban planning should be integrated into flood risk management frameworks. Collaboration among stakeholders, including local communities and governmental bodies, is essential for the successful implementation and maintenance of NBS. Long-term monitoring and evaluation of NBS effectiveness are critical to adapting and refining strategies based on local conditions and evolving climate scenarios. Future research should focus on scaling up successful NBS interventions across similar catchments to assess their transferability and scalability. Investigating the socio-economic impacts of NBS adoption and evaluating community perceptions and engagement can provide valuable insights for enhancing resilience and adaptive capacity. Additionally, exploring synergies between NBS and traditional flood management approaches can optimize resource allocation and maximize flood resilience outcomes. By advancing knowledge in this field, future studies can contribute to more robust and sustainable flood risk management practices globally.

# 6 Acknowledgment

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# Figures and Tables

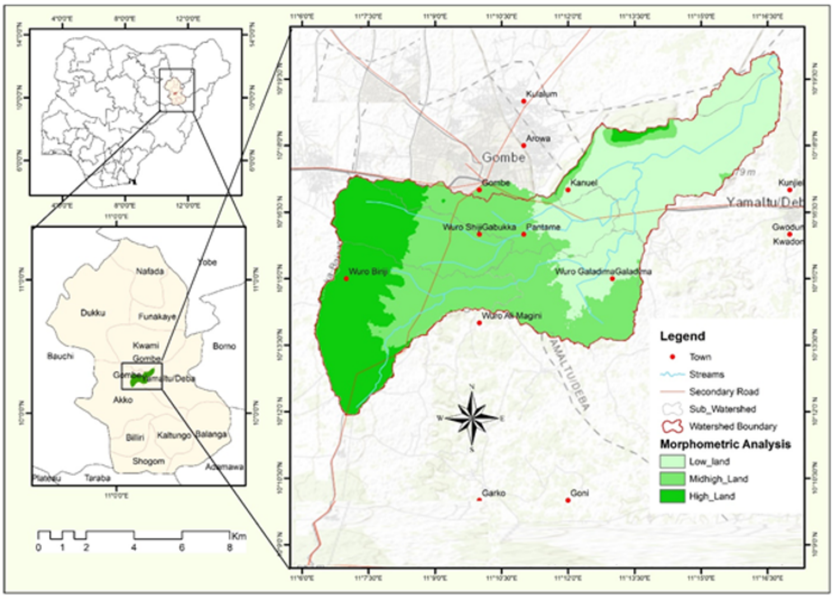


Figure 1: River Magarya Drainage Basin - Source; USGS Earth Explorer, 2023

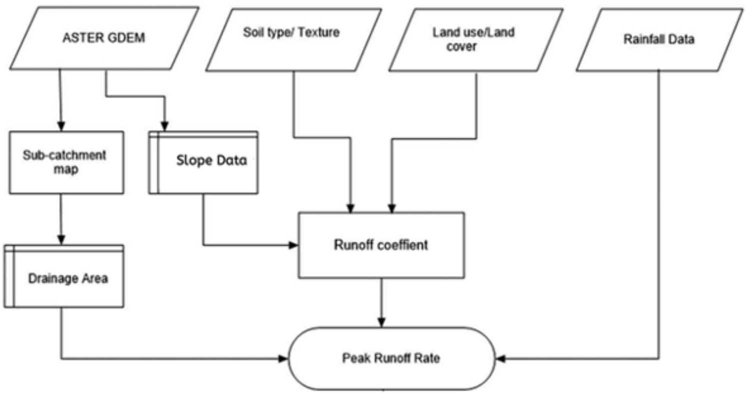


Figure 2: Modified modeling flow diagram for relational-rule-based flood assessment

Table 1: Rational method run-off coefficients by Land use, soil type and slope.

| Soil Type | Sand | | Loamy Sand | | Sandy Loam | | Sandy Clay | |
|---|---|---|---|---|---|---|---|---|
| Landuse/Slope | ¡0.5 | 0.5 – 5 | ¡0.5 | 0.5 - 5 | ¡0.5 | 0.5 – 5 | ¡0.5 | 0.5 – 5 |
| Grassland | 0.13 | 0.17 | 0.17 | 0.21 | 0.20 | 0.24 | 0.43 | 0.47 |
| Farmland | 0.23 | 0.27 | 0.27 | 0.31 | 0.30 | 0.34 | 0.53 | 0.57 |
| Bare land | 0.33 | 0.37 | 0.37 | 0.41 | 0.40 | 0.44 | 0.63 | 0.67 |
| Residential | 0.37 | 0.43 | 0.41 | 0.47 | 0.44 | 0.50 | 0.67 | 0.73 |

*Source:USDA, 2009*

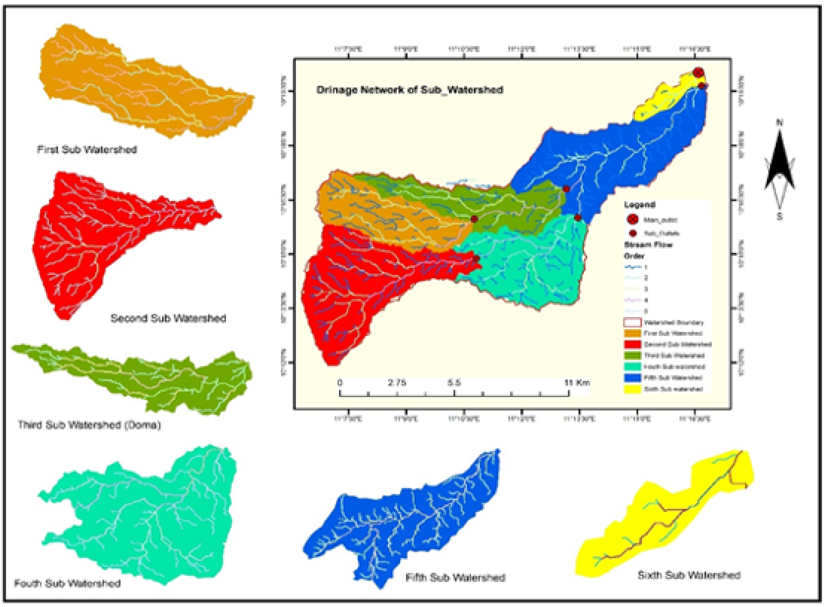


Figure 3: Sub-watersheds within Magarya River Basin Source; USGS Earth Explorer 2024

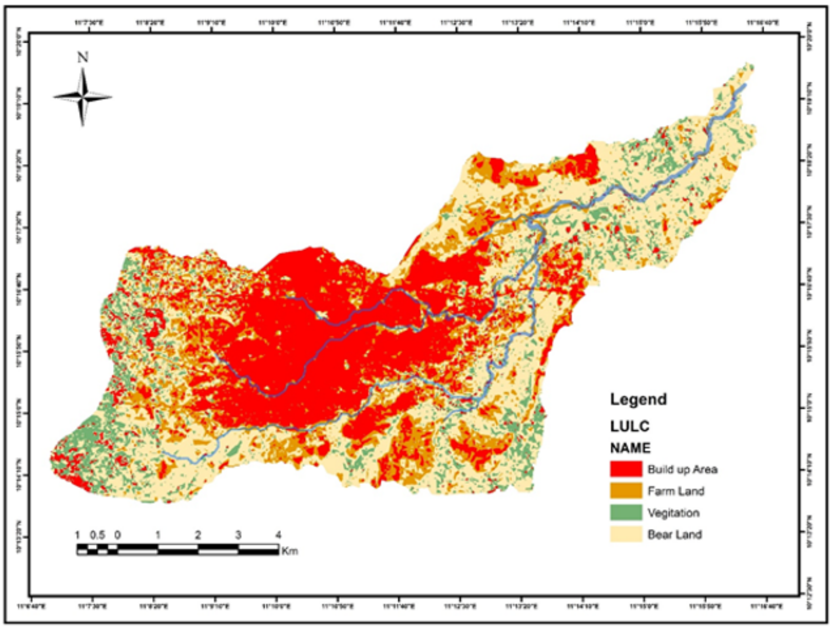


Figure 4: Land Use Land Cover Classes of Magarya Catchment.

Table 2: Composite Runoff Coefficient of Sub-watersheds

| Sub-Watershed | Bare Land (km²) | Built-up (km²) | Grassland (km²) | Farmlands (km²) | Total Area (km²) | Slope | CRE |
|---|---|---|---|---|---|---|---|
| SW 1 | 1.20 | 8.37 | 1.99 | 1.73 | 13.29 | 0.039 | 0.57 |
| SW 2 | 3.82 | 5.61 | 5.84 | 7.19 | 22.46 | 0.034 | 0.37 |
| SW 3 | 0.64 | 10.28 | 0.77 | 1.16 | 12.85 | 0.032 | 0.61 |
| SW 4 | 7.16 | 2.83 | 3.49 | 3.19 | 16.64 | 0.031 | 0.40 |
| SW 5 | 11.77 | 2.72 | 2.45 | 5.66 | 22.63 | 0.023 | 0.36 |
| SW 6 | 0.61 | 0.26 | 0.59 | 1.10 | 2.56 | 0.011 | 0.31 |
| **Total** | 25.20 | 30.07 | 15.13 | 20.03 | 90.43 | 0.033 | |

*CRE is Composite Runoff Coefficient*

Table 3: Sub-catchment discharges based on August 2023 rainfall

| Sub-Watershed | Area (km²) | Runoff Coefficient (C) | Rainfall Intensity (mm/hr) | Peak Discharge (Q, m³/s) |
|---|---|---|---|---|
| SW 1 | 13.29 | 0.57 | 18.92 | 143.41 |
| SW 2 | 22.46 | 0.37 | 18.92 | 156.90 |
| SW 3 | 12.85 | 0.61 | 18.92 | 148.15 |
| SW 4 | 16.64 | 0.40 | 18.92 | 125.87 |
| SW 5 | 22.63 | 0.36 | 18.92 | 153.75 |
| SW 6 | 2.56 | 0.31 | 18.92 | 15.00 |

Table 4: Accumulated Peak Discharge

| Sub-Watersheds | Area (km²) | Outlet | Accumulated Discharge |
|---|---|---|---|
| SW1 & SW3 | 26.14 | End of SW3 | 291.56 |
| SW2 & SW4 | 39.10 | End of SW4 | 282.77 |
| SW1, 2, 3, 4, & 5 | 87.87 | End of SW5 | 728.08 |
| SW1, 2, 3, 4, 5, & 6 | 90.43 | End of SW6 | 743.08 |