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Urban Flood Modelling: A Geospatial Evaluation of Drainage Systems for Resilient City Planning in Lusaka

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Abstract
This study presents a flood modelling approach aimed at enhancing planning strategies to mitigate flooding impacts in Lusaka City. By integrating factors such as slope, hydrostatic potential surface, and the built environment, a predictive flood model was developed. The methodology involved using Geographic Information System (GIS) techniques and digital elevation models (DEMs) to assess geological features and manmade structures. Precipitation patterns and water demand analyses aided in computing a hydrostatic potential surface through watershed delineation. The generated flood model produced comprehensive flood maps illustrating water drainage in Lusaka, identifying vulnerable areas using Multi-Criteria Decision Analysis (MCDA) techniques. Results highlight the complex interaction between geographical features and human infrastructure in flood dynamics. This study contributes to informing zoning policies and disaster response planning, aiming to reduce the impact of future flooding events.
Keywords: Urban Flood Model; Geographic Information System (GIS); Hydrostatic Potential Surface; Multi-Criteria Decision Analysis (MCDA); Disaster Risk Planning.

1. Introduction

In recent years, urban flooding has been identified as a natural disaster that can have a negative impact on the environment, particularly in urban areas around the world, while also threatening human property and life. The factors that caused urban flooding were rapid urban growth, variation in rainfall intensity due to climate change, and inadequately designed drainage systems (Hassan et al., 2022; Wang et al., 2017; Zhou et al., 2019; Amen & Nia, 2020; Aziz Amen, 2022; Gün, 2023; Odunlade & Abegunde, 2023). In Lusaka, City flooding has been aggravated due to rapid urbanization (Phiri & Nyirenda, 2015). Studies have also noted that the variation in rainfall intensity and urban development in cities affects urban catchment through flooding problems (Huong & Pathirana, 2013; Mzava et al., 2021; Neupane, 2018). According to Wang et al. (2020) and Zang et al. (2019), urban development activities that increase imperviousness have an impact on the urban hydrological process, which increases flood risk and reduces hydrologic response time. Urbanization reduces infiltration rates while increasing surface runoff and flooding volume (Guan, 2015). The change of urban catchment from natural surface cover to impervious areas such as residential, commercial, road, and other paved areas increases runoff and flooding in towns and cities all over the world (Abd-Elhamid et al., 2019; Nigussie & Altunkaynak, 2019). However, this study focuses on constructing a robust flood model for predictive analysis in the Kamwala South area of Lusaka City in Zambia, integrating various factors such as slope, hydrostatic potential surface and the built environment. As the human population and the impending magnitude of global climate change both continue to grow, there is an imperative to better understand the function of cities as ecosystems and their resilience to climate-driven disturbances. Floods are prominent disturbances to urban ecosystems (Grimm et al., 2017; Rentschler et al., 2019). The resilience of urban environments can be increased by properly combining green infrastructure (GI) interventions (Andreu et al., 2015; Hussein et al. 2024; Staddon et al., 2018). A combination of GI measures, instead of single measure usage, could lead cities to gain a higher potential of GI to reach urban resilience facing flooding and other hazards (Voskamp & Van de ven, 2018). While flood modeling initiatives exist, there is a pronounced lack of research directly addressing the complexities of urban flooding in Kamwala South, necessitating an investigation into the specific interplay of geographical features and human-built infrastructure. This research aims to bridge this gap by developing a tailored flood model to aid in urban planning strategies and disaster risk reduction efforts in the region.

Researchers and environmental managers use urban flood models (UFMs) - packages of mathematical equations that can simulate water flow and other flooding processes - to support risk assessment and emergency management and to develop strategies to mitigate future flooding (Rosenzweig et al., 2020). We define urban flood models (UFMs) as numerical models that are capable of representing the features of urban ecosystems and the mechanisms of flooding that impact them. Cities are Social Ecological Technological Systems (SETS) (Markolf et al., 2018; McPhearson et al., 2016), and urban flooding results from the dynamics of their social institutions, natural ecosystems, and built infrastructure systems in response to meteorological drivers. UFMs must be able to represent all three SETS components and their contributions to flood response.

The research question centers on: How can a comprehensive flood model, integrating topographical, hydrological factors, enhance predictive analysis and inform planning strategies in Kamwala South, Lusaka? This inquiry aligns with the imperative to minimize the adverse impact of flooding on lives and resources allocated for disaster management. The research objectives are to develop a robust flood model for predictive analysis in Kamwala South, Lusaka, integrating various factors such as slope, hydrostatic potential surface, and the built environment. Contributing to broader efforts in urban planning and disaster risk reduction in Lusaka. Therefore, simple and quick methods of identifying flood prone areas are needed so as to help classify land in terms of floods, especially in areas with no flow data (Phiri & Nyirenda, 2018). The project's utilization of Geographic Information System (GIS) technologies for data collection and analysis will serve as a valuable template for other developing cities facing similar challenges. This study outlines objectives focused on utilizing GIS techniques for data collection and flood model development, elucidating the intricate relationship between geographical features and human-built environments in flood dynamics. The research design involves studying geological characteristics, assessing DEM data, analyzing precipitation patterns, and delineating watersheds to compute a hydrostatic potential surface. The resulting flood model will generate essential information on floodwater drainage systems in the Lusaka district. The expected contribution of this research lies in providing actionable insights into flood dynamics specific to Kamwala South, empowering urban planners and disaster management authorities with a predictive tool for informed decision-making. This paper is structured to present a comprehensive analysis of the flood model development, emphasizing the integrated approach to understanding and managing urban flooding dynamics in Kamwala South, Lusaka.

2. Case study

The study area was carried out in the suburb of Kamwala South an area within Kabwata Constituency of the Capital City of Zambia, Lusaka. The Constituency is one of the seven constituencies found in Lusaka City, located in the southern part of the City. The Constituency is predominantly an urban area with an elevation of 1,280 metres and a population of 228,022 (Zambia Statistics Agency, 2022). Further, the Constituency has no perennial rivers but experiences flooding frequently in rainy seasons.

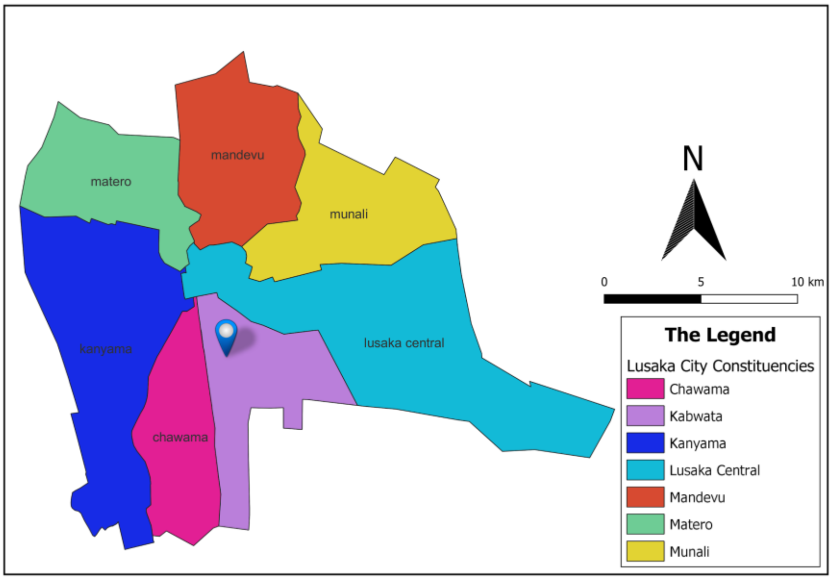

Figure 1. Lusaka Constituencies

3. Literature review

To avoid water logging during severe weather conditions, it is necessary to eliminate surface runoff from built-up areas (Zhou et al., 2015). Surface runoff is an essential hydrological variable that is widely used in water resource research and analysis (Bansode & Patil, 2014). The adverse effects of these flash floods involve the deterioration of buildings, contamination of sunk-in boreholes, and loss of human and animal life to name but a few. Addressing the global challenge of climate change requires nations to develop advanced and improved systems to mitigate its effects. However, in the case of Zambia, the current planning approach to the built environment has overlooked the impact of impervious surfaces and their contribution to waterlogging. This oversight is evident in the frequent occurrence of serious flash floods in various areas of Lusaka City, even with moderate rainfall. Consequently, this research aims to contribute to the alleviation of flash floods within a conceptual framework that recognizes the significance of this issue. The accurate assessment of surface runoff can therefore play a crucial role in mitigating the risks posed by flash floods. It provides valuable insights for the development and implementation of appropriate planning methods and procedures, particularly in the built environment (Nyimbili et al., 2023).

To assess the resilience of urban flooding, it is crucial to determine whether the indicators for urban flood resilience assessment have been objectively and scientifically selected. The data of initial screening indicators include rainfall, slope, flood emergency plan, population density, length of drainage network, road network density, number of pumping stations of storage ponds, imperviousness rate, drainage network capacity, flood emergency response, comprehensive disaster mitigation demonstration community ratio, broadcasting coverage, disaster warning forecast, GDP, per capita disposable income, per capita medical point, social security and employment expenditure ratio, depth of road waterlogging, road waterlogging time length, gross regional product (million yuan), and post-disaster reconstruction management funds. The principles of indicator selection are as follows: (1) Scientificity: It is the basic requirement for any evaluation index system. In urban flooding disasters, due to its large scope of influence and more scattered affected areas, any wrong decision amounts to a huge loss. Thus, an evaluation index system must be of high scientificity. (2) Feasibility: The purpose of establishing the resilience assessment system for urban flooding disasters is to enhance the resilience of cities and municipalities in the face of urban flooding disasters. Feasibility is required to achieve the purpose of assessing the expected results, and the selected factors have strong operability. (3) Purposefulness and relevance: An evaluation index system is established to enhance the resilience of urban flooding disasters, and the typical indices that best reflect the situation of the influencing factors of the content to be evaluated are selected. (4) Independence: Each indicator in the index system should be clear in connotation and relatively independent, and any overlap between indicators should be avoided to the maximum possible extent to ensure the accuracy of the evaluation system (Xu et al., 2023).

The geospatial and drainage-related information are required to carry out urban flood simulations. The geospatial data includes a digital elevation map (DEM), land use/land cover (LULC) map, and soil map. For urban flood modelling, a high-resolution DEM is necessary (Guptha et al., 2021). Focusing on urban flood resilience, it is defined as the capacity of the city to tolerate flooding and to recognize when physical damage and socioeconomic disruption occur, to prevent deaths and injuries and to maintain their current socioeconomic identity (Liao, 2012). Studies on flood resilience assessment are mainly focused on examining the performance of cities and communities under disaster scenarios (Ba et al., 2021; Datola et al., 2022).

4. Research methodology

The research methodology included obtaining meteorological information of rainfall patterns of the last 10 years from Zambia Meteorological Department, Lusaka city airport station. Land use information was gathered from the nation's Ministry of Lands. The digital elevation model was first obtained as a NASA Shuttle Radar Topography Mission (SRTM) image footprint from USGS EarthExplorer. The footprint was masked or clipped by layer extents and further processed in a geospatial environment using QGIS software. An administrative boundary of Lusaka district was obtained from Zambia Datahub and the final result was analyzed and assessed in QGIS.

This study involved the pre-analysis stage of GIS technique, which is studying the geological nature of the study area, its DEM and built environment which refers to the human made or constructed surroundings in which people live, work and engage in various activities. The study also involved studying patterns of precipitation and or water demand in the area, so that a hydrostatic potential surface of water is computed through delineation of a watershed and drainage basins. After the flood model was created we then generated a series of maps indicating a drainage system of floodwaters in Lusaka district. The primary objective of this study was to comprehensively assess the drainage systems in Lusaka, focusing on seepage and ground drainage capabilities. The research questions guiding the study center on understanding the effectiveness of current drainage systems and identifying areas vulnerable to flooding. Field surveys involved physical assessments of soil properties, and ground drainage capabilities. The rainy season was specifically targeted to observe the systems' performance under stress. Lastly social-economic data was acquired from Zambia statistics agency, that perfectly outlined the nation’s demographics.

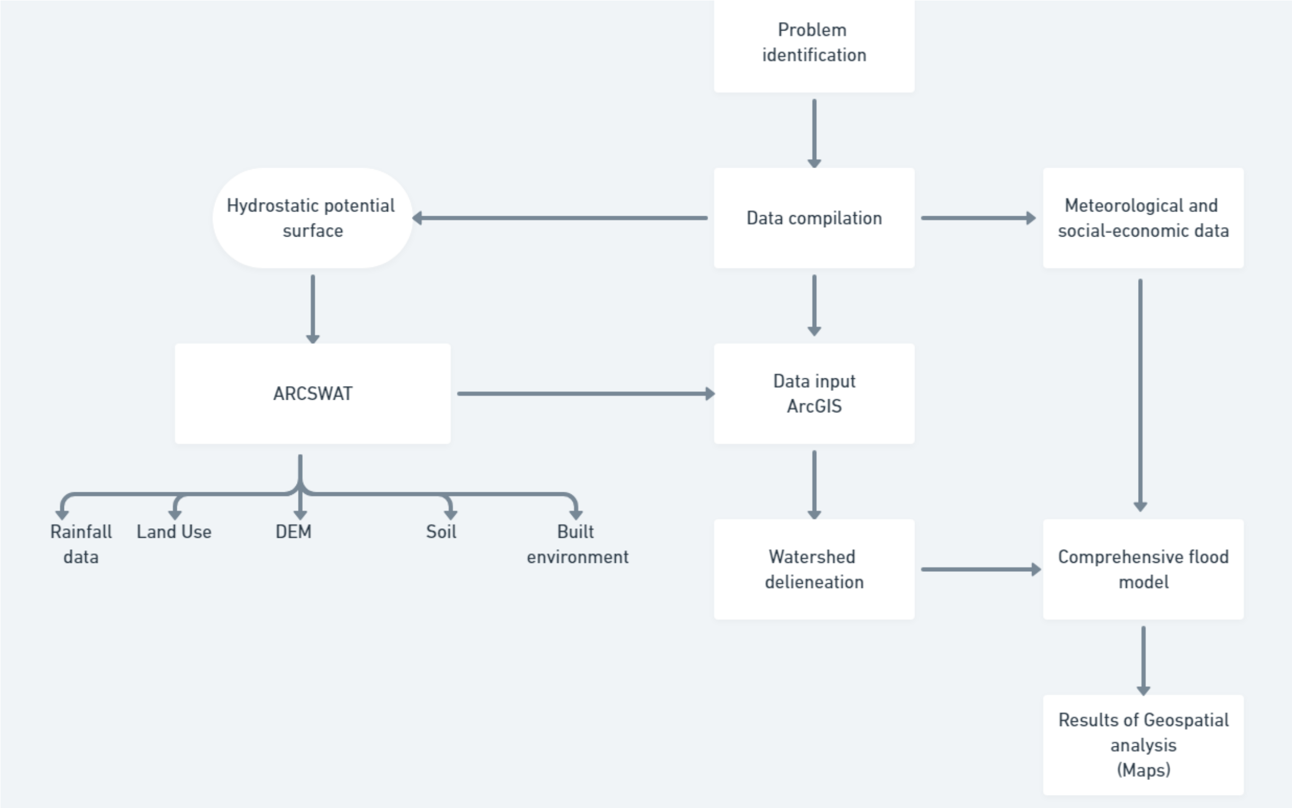

Figure 2. Flow chart of the conceptual methodology

5. Methods and materials

5.1. Digital Elevation Model

The methods used for this research included coming up with a Digital Elevation Model (DEM). A DEM provides detailed elevation data for a study area. It is a digital representation of the topography or elevation of the Earth's surface. In mapping drainage systems, DEM plays an important role in the analysis, allowing us to perform hydrological analysis and to understand flow direction and flow accumulation patterns in these regions and deriving the soil indices (Samapriya, 2013). DEMs are invaluable as they help identify natural topographic features influencing water flow. It is a type of geospatial data that provides information about the height or elevation of terrain at different locations, typically in a gridded format. DEMs are used in various applications, including cartography, geology, hydrology, environmental modeling, urban planning, terrain visualization, flow direction analysis, gradient calculation, watershed delineation and hydrological modeling. This research utilizes watershed delineation and hydrological modeling. In essence, DEMs provide a detailed and quantitative foundation for mapping ground drainage systems, enhancing precision and effectiveness in drainage planning and management.

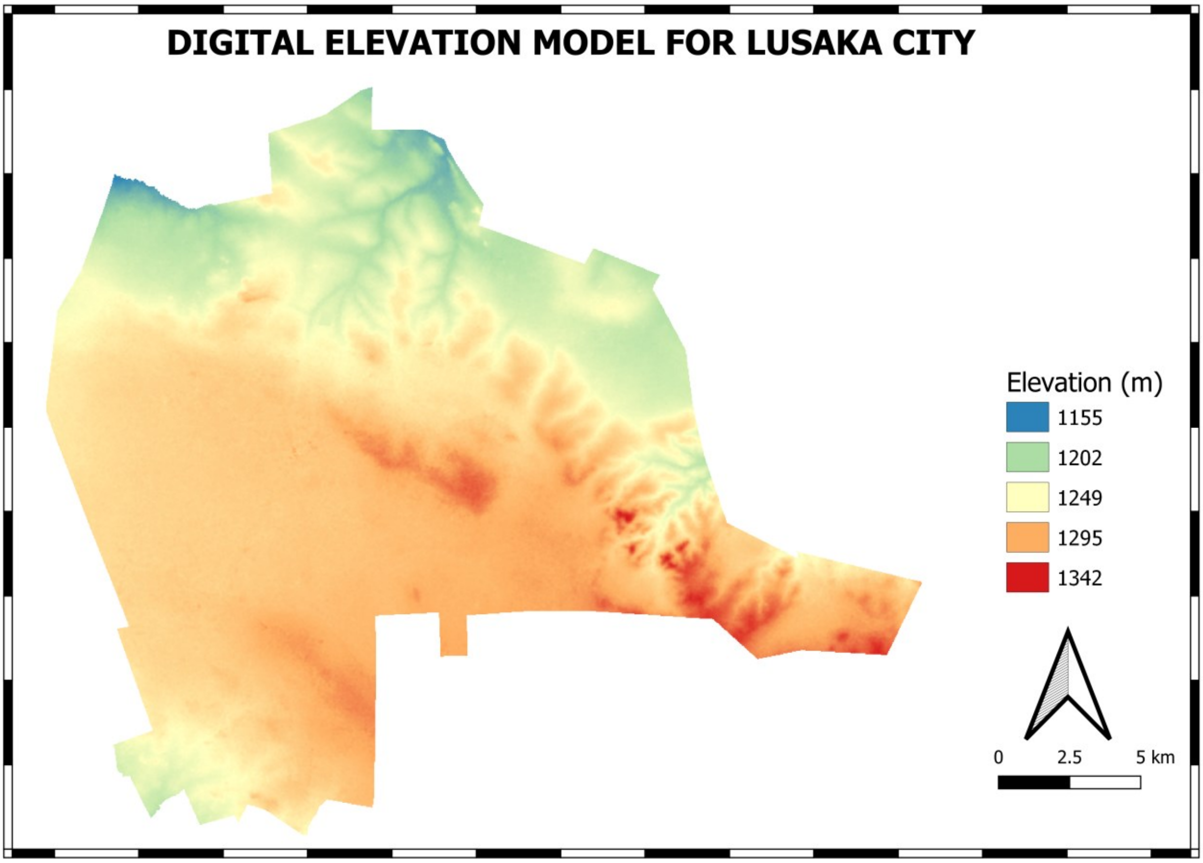

Figure 3. Digital elevation model of Lusaka city district

5.2. Built Environment

The term built environment refers to human-made conditions and is often used in architecture, landscape, urban planning, public health, sociology and anthropology. Engineers can use these features to plan drainage systems effectively. For example, roads often act as conduits for runoff, and Lusaka district planners can divert existing structures to guide water away from vulnerable areas. A 2-year study was undertaken to monitor the rainfall-runoff behaviour of two (2) small catchments representing different types of residential developments in southern England by Macdonald et al. (2022). The results showed that peak flow is most sensitive to 10 min rainfall intensity while antecedent soil moisture is less important. The sensitivity to rainfall is strongest in the most densely urban catchment. In contrast, no relationship between percentage runoff and neither rainfall nor antecedent soil moisture could be detected in the densely urban catchment, while both factors were found to be significant in the less urbanised catchment. These results reported here demonstrate that the layout of the built environment exerts a strong influence on the hydrological characteristics at the local scale of relevance in urban hydrology and further model development of importance when planning flood mitigation measures in urban areas. Built-up areas create impervious surfaces – a threat to groundwater recharge – through which water cannot infiltrate into the soil, thereby increasing the volume, duration and intensity of surface runoff. Areas with an increase in impervious cover will eventually have a reduction of groundwater recharge. To maximize groundwater recharge in the face of urban growth, especially on the western side of the City, the Local Authority should prescribe paved materials for car parks, sidewalks and drainage channels (Phiri & Nyirenda, 2015). The built environment of our study area seems to be a flat residential area, with about 30-50% of the area impervious. Lusaka as a whole being an urbanised area shares the same demographics as our study area in commercial, religious residential and educational subdivisions.

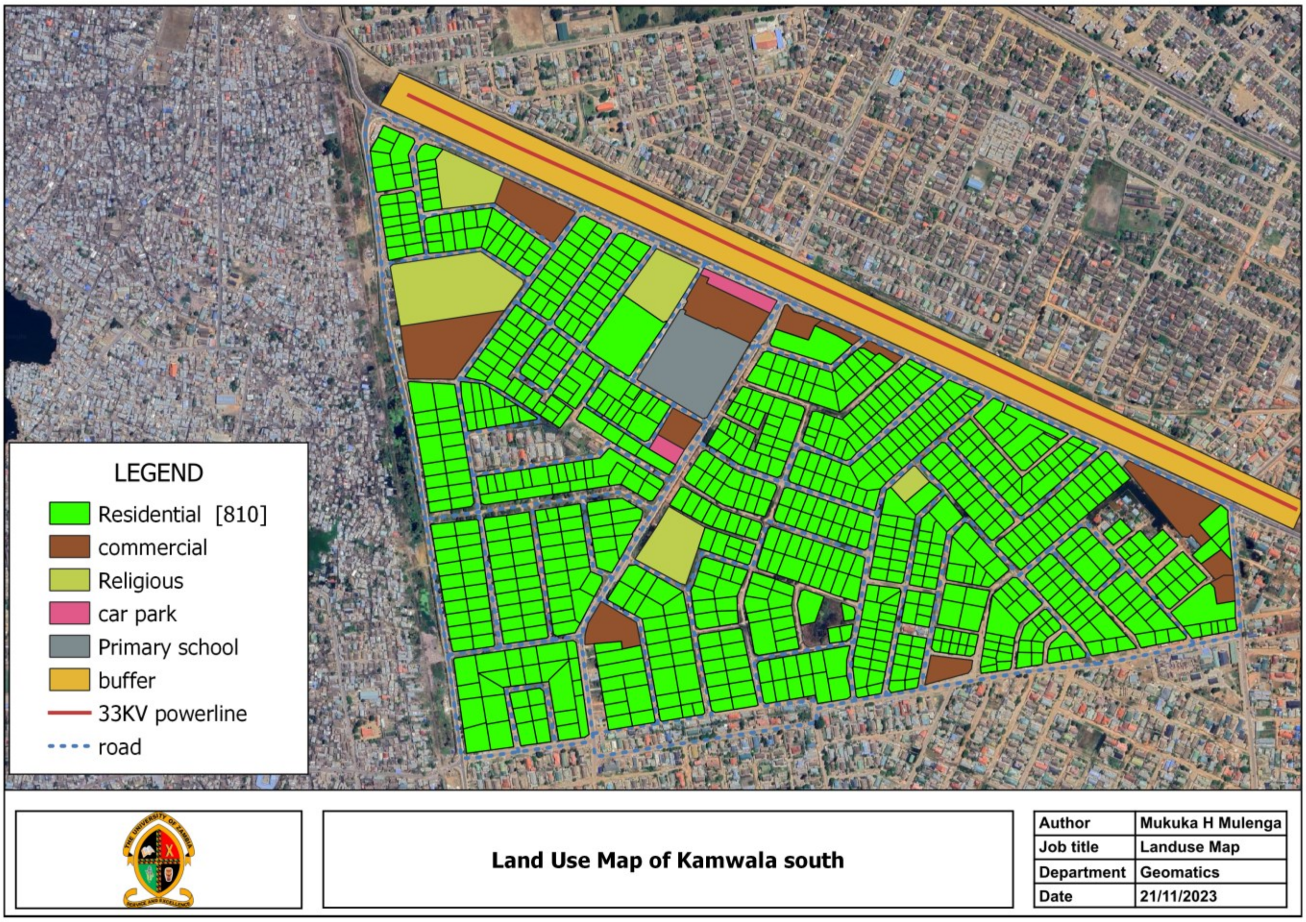

Figure 4. Land use Map of Kamwala South

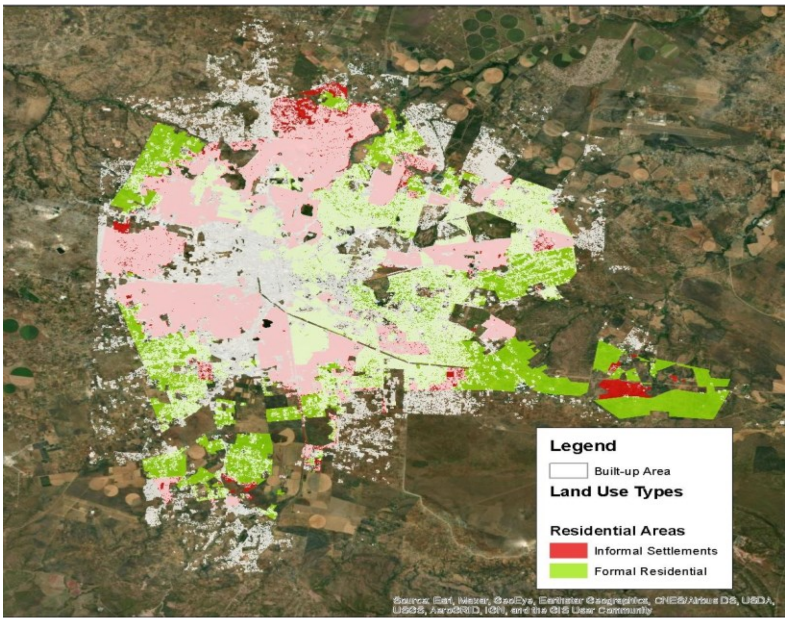

Figure 5. Land use types of built up Lusaka

5.3. Slope

Slope is crucial in mapping drainage systems because it indicates the direction and steepness of the terrain. Understanding slope helps identify natural drainage pathways. Higher slopes generally facilitate better water runoff, preventing waterlogging and minimizing damage to urban infrastructures. Slope determines the current flood velocity, so slope selection is an important evaluation index in the assessment of a drainage system. A slope variation map was made using the Digital Elevation Model (DEM) and QGIS by calculating slope values. The slope values can be calculated using various methods, but a common approach is to use the following formula:

$$Slope\% \Rightarrow \frac{arctan(Zmax - Zmin)}{(horizontal\ resolution \times cell\ size)} \quad (1)$$

Where:
Z_{max} is the highest elevation in a given cell.
Z_{min} is the lowest elevation in the same cell.
The horizontal resolution is typically 1 for a 3x3 cell.
Cell size is the size of the grid cells in the DEM

This formula is already embedded into the QGIS Extraction Analysis program. All that is needed is an input of the DEM layer shape file then a slope map is created by assigning slope classes to the calculated values. The calculated values are then coloured to increase the visual perspective of what we wish to illustrate. The FAO (2006) slope classification table was used as a base table for the slope variation (Table 1). The FAO classification typically ranges from flat to steep slopes.

Table 1. FAO (2006) classification

Class	Description	%
1	Flat	0-0.2
2	Level	0.2-0.5
3	Nearly level	0.5-1
4	Very gently sloping	1-2
5	Gently sloping	2-5
6	Sloping	5-10
7	Strongly sloping	10-15
8	Moderately steep	15-30
9	Steep	30-60
10	Very steep	>60

A careful analysis of areas that have both steeper slopes (e.g., >10%) and proximity to rivers, lakes, or low-lying regions was conducted, as these areas may be more susceptible to flooding (Figure 6). Higher slopes may contribute to faster runoff during heavy rainfall events, which can increase the risk of flash flooding.

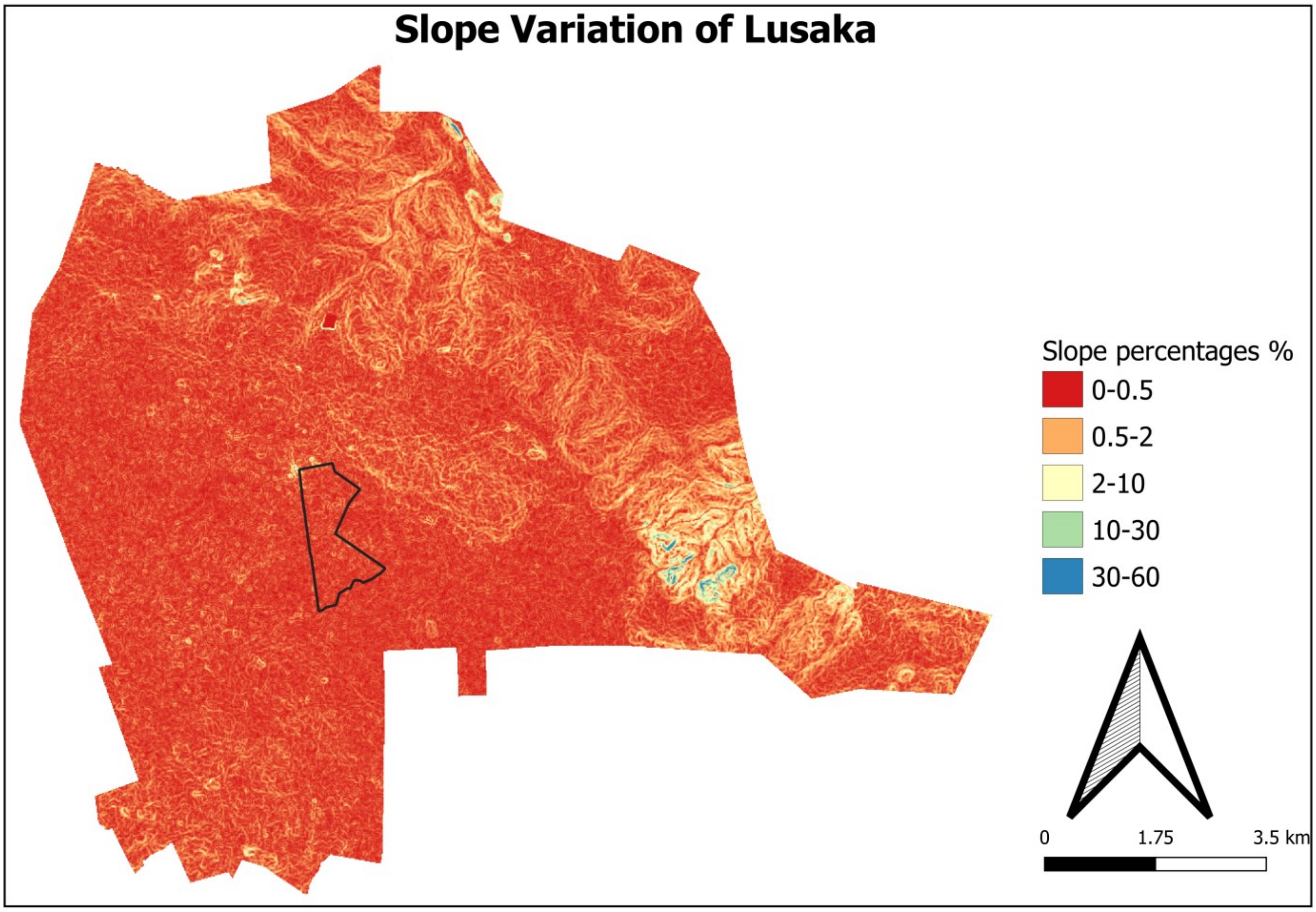

Figure 6. Slope variations map of Lusaka city

A combination of the slope variation map given in Figure 6, with additional data obtained from the nation's disaster management and mitigation unit related to flooding, such as historical flood records, stream networks, rainfall data, and land use information enhanced the accuracy of flood risk assessments.

5.4. Hydrological potential

The hydrostatic potential surface of water is a concept used in hydrogeology to describe the energy distribution of groundwater between two locations because of variations in pressure, soil solutes and other factors. It represents the hydraulic head of groundwater and is a critical concept for understanding the movement and behaviour of groundwater in subsurface environments (Powers & Shevenell, 2000). Anyone who lives on land resides on and interacts with a watershed daily. Because of this exposure to watersheds, it is important to understand what they are, why they are important, and how we can be good stewards of our watersheds. A watershed is an area of land draining into a common body of water, such as a river, wetland, reservoir, or ocean. Rain that falls on land flows to lower elevations and toward a common body of water; the rain transports with it many particulates and pollutants from the land. It collects and channels all the surface water and groundwater within its boundaries to a common outlet, typically a river, lake, or stream. Watersheds are essential components of the hydrological cycle, as they play a crucial role in controlling the distribution of water resources and managing the movement of water across the landscape (Aldridge & Baker, 2017). Our hydrostatic potential involves the processes of watershed delineation. Watershed delineation can simply be defined as a process of identifying boundaries of a drainage basin. By drainage basin we mean an area of land where surface water, such as runoff and/or rain, drains to a common outlet point. Watershed delineation process was done using the DEM we obtained and ESRI ArcGIS software. Using an ArcSWAT plugin incorporated in ArcGIS, soil data, rainfall pattern, land use data and a DEM were used as dataset inputs in the Soil Water Assessment Tool of ArcSWAT as the initial process of watershed delineation. The next step involved streaming pre-processing which is identifying common outlet points within the DEM which was found to have had 145 outlets then watershed delineation was started. After the end of the streaming pre-processing step, watersheds were produced with a full view of narrow pathways that could act as seasonal streams and natural drainages.

5.5. Analytic Hierarchy Process MCDM

The analytic hierarchy process (AHP) is a subjective method to determine weight, proposed by Satty in the late 1970s (Huang et al., 2019). As one of the most widely used knowledge-driven methods, AHP is widely used to calculate the weight of the urban flood resilience evaluation (Bertilsson et al., 2019). The severity of these disasters has prompted recognition of the need for comprehensive and effective disaster and emergency management (DEM) efforts, which are required to plan, respond to and develop risk mitigation strategies. In this regard, recently developed methods, known as multi-criteria decision analysis (MCDA), have been widely used in DEM domains by emergency managers to greatly improve the quality of the decision-making process, making it more participatory, explicit, rational and efficient (Nyimbili et al., 2018; 2023). MCDA is a collection of approaches and techniques for solving decision-making or evaluating complex problems which have many conflicting goals and criteria (Voogd, 198; Zeleny, 1982). GIS-based MCDA, at a principle level, is a set of techniques and procedures that transform and combine geographical data (input or criterion maps) and the decision maker's preferences (criterion weights) into an overall value for each decision/evaluation alternative or decision/output map. This implies that the analysis results do not only depend on the geographical distribution of the alternatives but also on the value judgements incorporated in the process of decision-making (Malczewski & Rinner, 2015; Qin, 2013). The MCDM used is based on slope, elevation, rainfall, soil type, and built environment.

Table 2. Flood causative Criterion and sub-criteria ranges for flood assessment in Kamwala South

Factors	Unit	Class	Ranges	Ratings	Weight
Slope	%	1	Flat	0-0.2	2
		2	Level	0.2-0.5	
		3	Nearly level	0.5-1	
		4	Gently sloping	2-5	
		5	Sloping	5-10	
Elevation	m	1	Very low	<1150	
		2	low	1150-1210	
		3	moderator	1210-1270	3
		4	high	1270-1330	
		5	Very high	1330>	
Rainfall	mm/year	1	Very low	0-30	
		2	Low rainfall	30-150	2
		3	Moderate	150-230	
		4	high rainfall	230-400	
		5	Very high	400<	
Built Environment	level	5	Ideal	5	
		4	Good	4	
		3	Neutral	3	3
		2	Challenging	2	
		1	Unfavourable	1	
Soil type	level	5	Highly suitable	Loam soil	
		4	Moderately suitable	Clay soil	
		3	Neutral soil	Silt soil	3
		2	Less suitable	Sandy soil	
		1	Unsuitable	Gravel soil	
TOTAL					13

The calculated weighted rating for the AHP was 13. Areas susceptible to flooding are areas above 13 while those below 13 are resilient. The underlying motivation for integrating GIS and MCDA emanates from the need to make the capabilities of GIS more relevant for planning and decision-making (Sugumaran & DeGroote, 2011). Using the AHP, the evaluation of flood vulnerability for different regions was shown.

6. Results and Analysis

6.1 Map of Drainage basins

After opening ArcGIS, the DEM was then converted to WGS 84 Mercator from the coordinate system using the define projections toolbox. Then, within a folder in ArcSWAT, the program was allowed to read the input datasets which were land use data, soil data, rainfall and DEM. The watershed delineation process was then run by creating common outlet points. A map was then created in ArcGIS after getting the final product (Watershed delineation) of the delineation process.

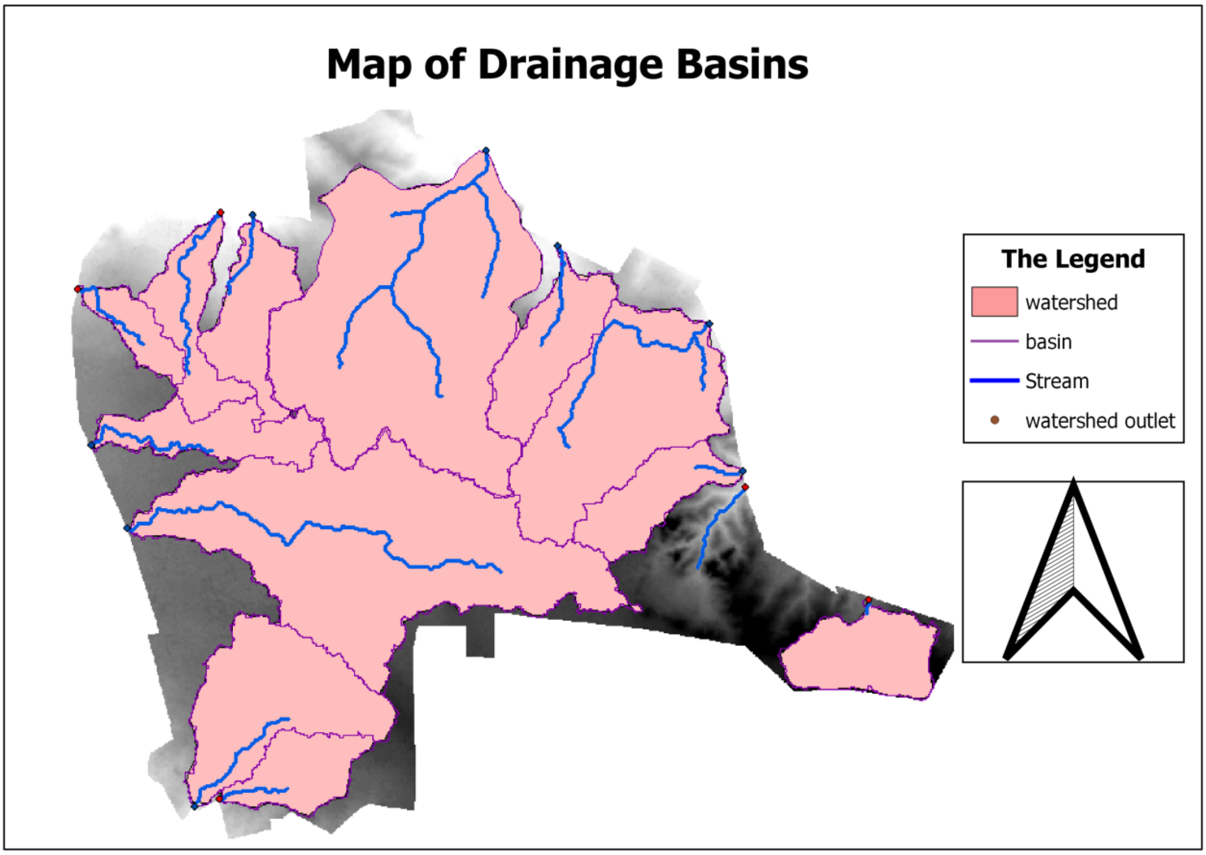

Figure 9. Map of drainage systems

6.2 The Final Map

The final map shows flood-prone areas highlighted, where slope variation and other factors indicated a higher flood risk by using different shading to represent the level of risk or vulnerability. Lusaka's drains and streams were a combined feature on the final map and a residential area shown is the study area. Among the other factors that formed the final map was a rapid flood assessment report made available by the Disaster Management and Mitigation Unit (DMMU), proximity to streams, drains and dams, elevation and hydrological modelling.

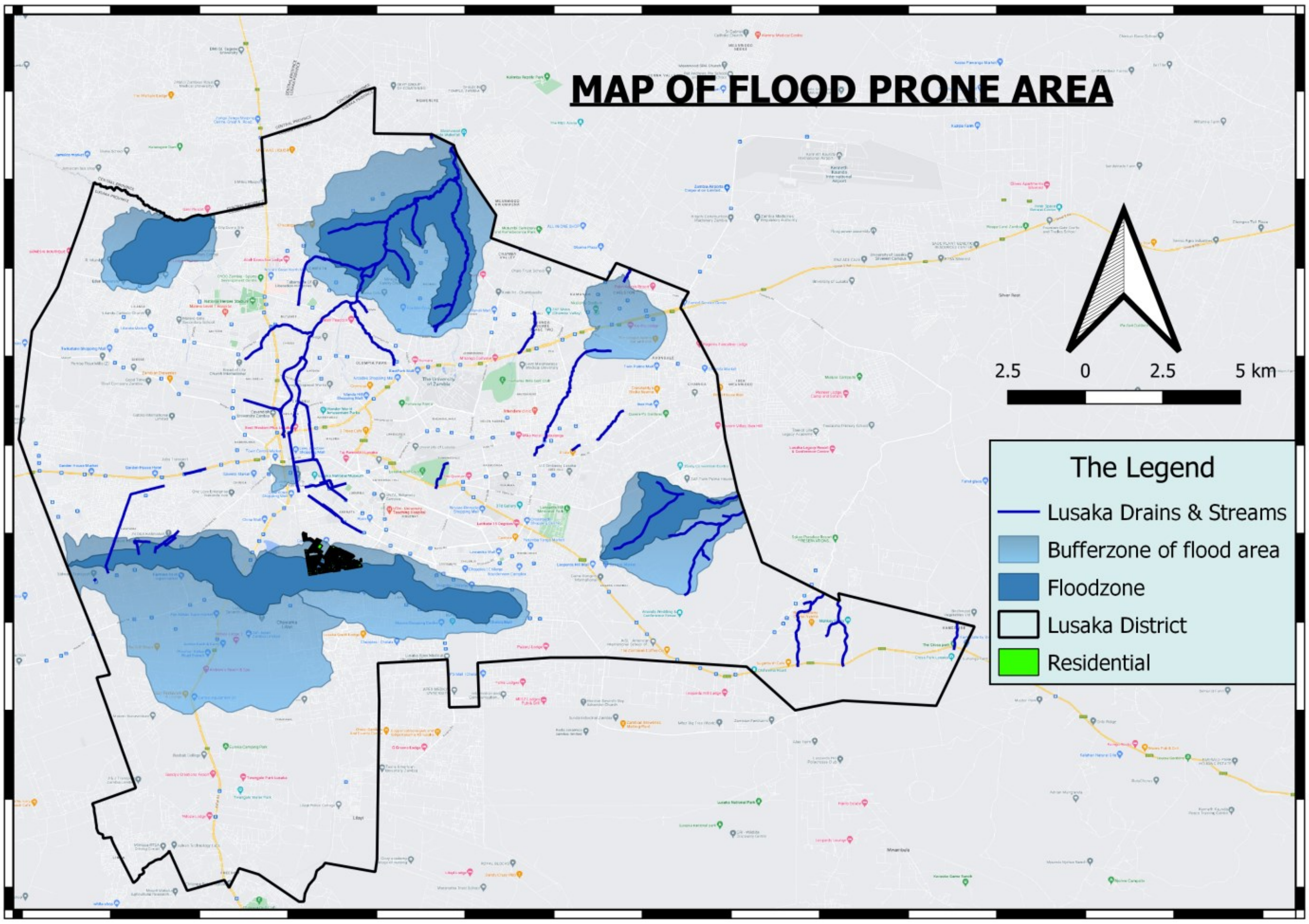

Figure 10. Final Flood map

The flood map (Figure 10) in comparison to Lusaka city's recorded flash floods map (Figure 11) in the 2022/2023 rain season shows quite a similarity which proves that slope, elevation, soil-rainfall data, and built environment are reliable factors in a flood causative criterion decision-making process.

The findings indicate that Lusaka is situated on relatively level terrain, with elevations ranging from 1,155 to 1,342 meters above sea level. The geographical landscape of Lusaka is predominantly flat, with a slight incline observed in the north-eastern region, directing surface runoff towards the Ngwerere catchment area. The majority of the city's elevation surpasses 1,240 meters, resulting in diminished flow of runoff and consequently leading to the risk of floods in watershed catchment zones as indicated on the final flood map.

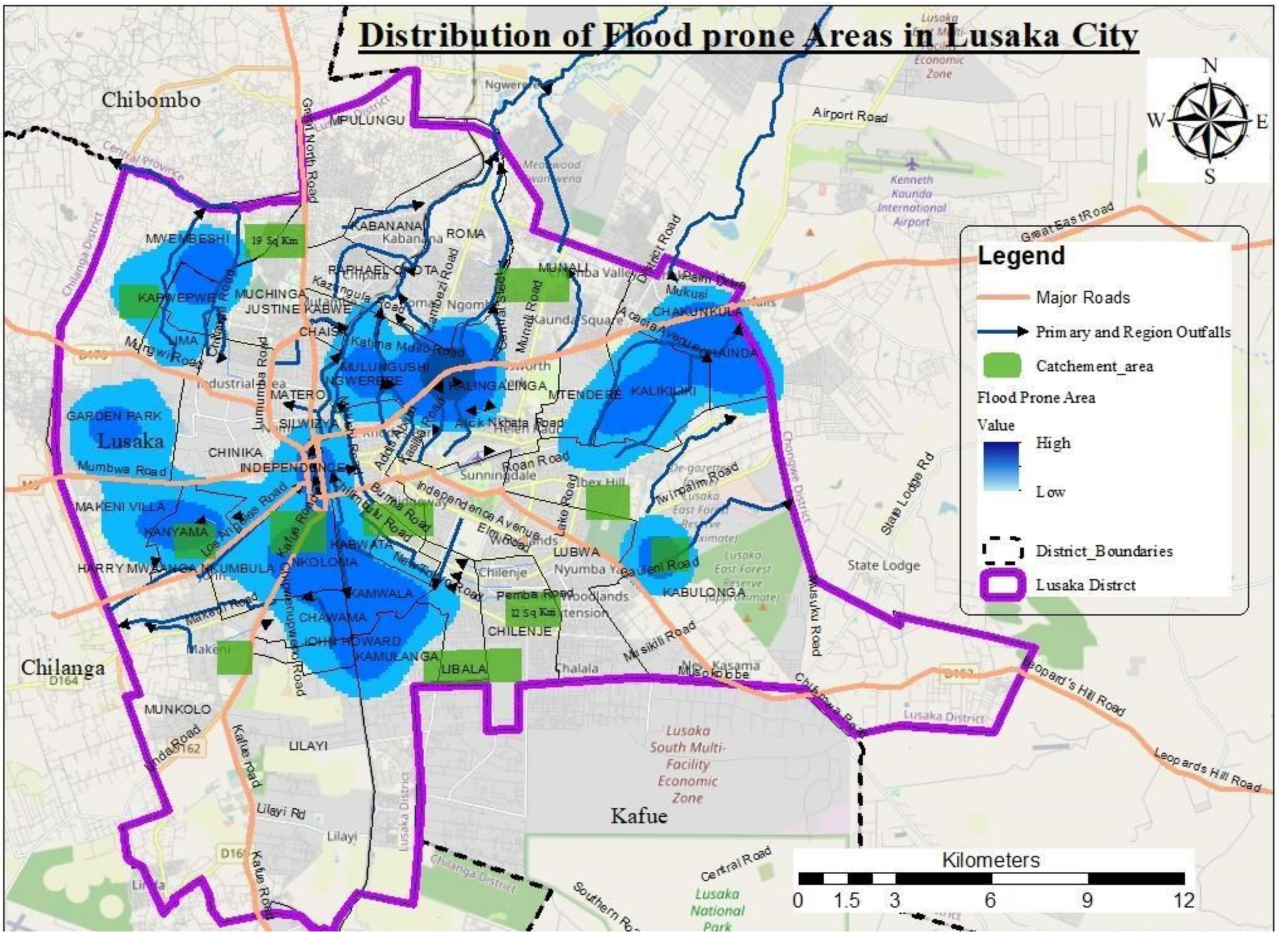

Figure 11. Map of recorded floods (2022/2023 rain season)

6.3 Analysis of Results

6.3.1. Rainfall

Lusaka City airport station data was selected as it is the closest station to the study area. An average of precipitation from the year 2015 – 2022 puts Lusaka with 896 mm/year which falls in the moderate rainfall category. To estimate the surface runoff in the catchment area, rainfall data from the years 2015 to 2022 were used in the calculations. By incorporating data from multiple years, a more comprehensive analysis of runoff patterns and trends over time was achieved, allowing for a better understanding of the hydrological dynamics and the impact of precipitation on the surface runoff within the catchment area.

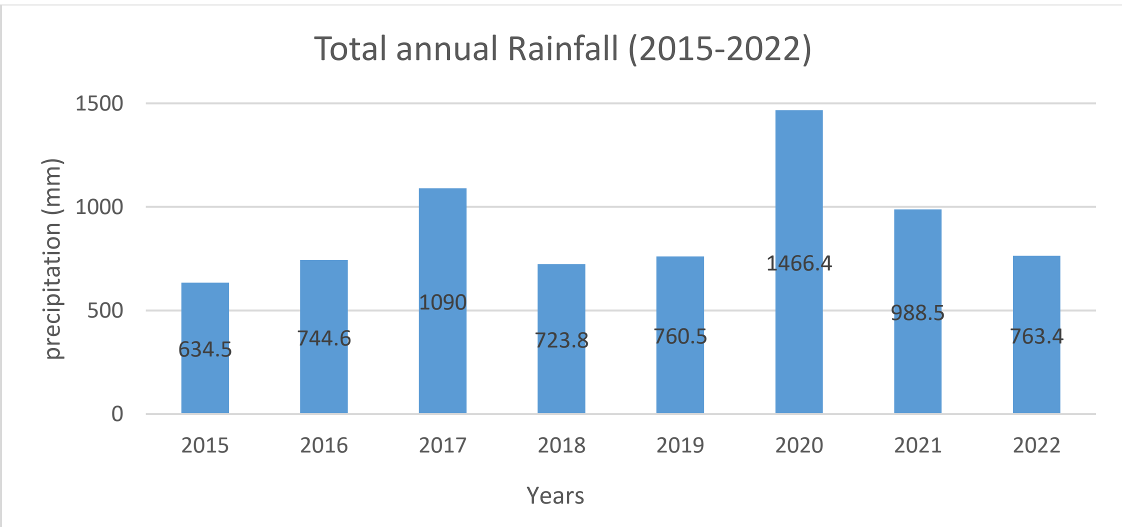

Figure 12. Total annual rainfall

6.3.2 Soil parameters

The soil types in Kamwala South can be a combination of clay and loam soils according to the report on regionalization of soil physical parameters in the Lusaka region (Hennings et al., 2012). The report findings were that the description of dominant and associated soils were, shallow, loamy to clay soils with a humus topsoil deep, and loamy to clay soil with clay leaching.

The classification of soils in the watershed considered the hydrologic soil groups (HSG) A, B, C, and D. These groups were carefully evaluated and assigned to different soil types based on their hydrologic properties, such as infiltration rates and water-holding capacities. This classification helps in understanding the water movement and drainage characteristics within the watershed, enabling better assessment and management of water resources and potential runoff in the area (USDA,1974).

Table 3. Soil Conservation Service classification (USDA, 1974)

Hydrologic soil (HSG)	Soil textures	Runoff potential	Water transmission	Final infiltration
Group A	Deep, well-drained sands and gravel	Low	High rate	> 7.5
Group B	Moderately deep, well-drained with Moderate	Moderate	Moderate rate	3.8 – 7.5
Group C	Clay loams, shallow sandy loam, soils with moderate to fine textures	Moderate	Moderate rate	1.3 – 3.8
Group C	Clay soils that swell significantly when wet	High	Low rate	< 1.3

6.3.3 Time of concentration

Time of concentration (Tc) is defined as the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest in the watershed. Travel time (Tt) is the time water takes to travel from one location to another in a watershed. Tt is a component of Tc, which is computed by summing all the travel times for consecutive components of the drainage flow path. This concept assumes that rainfall is applied at a constant rate over a drainage basin, which would eventually produce a constant peak rate of runoff. For a few drainage areas, a unique situation occurs where the time of concentration that produces the largest amount of runoff is less than the time of concentration for the entire basin. This can occur when two or more sub basins have dramatically different types of cover (i.e., different runoff coefficients). The most common case would be a large, paved area together with a long, narrow strip of natural area. In this case, the PEO shall check the runoff produced by the paved area alone to determine if this scenario would cause a greater peak runoff rate than the peak runoff rate produced when both land segments are contributing flow based on a shorter time of concentration for the pavement-only area. The scenario that produces the greatest runoff shall be used, even if the entire basin is not contributing flow to this peak runoff rate (WSDOT Hydraulic Manual, 2022). The procedure for determining the time of concentration for overland flow, is developed by the Natural Resources Conservation Service (NRCS, formerly known as the Soil Conservation Service [SCS]).

6.3.4 Runoff coefficient

Precipitation is an important cause of flood disaster, so precipitation as an evaluation index is important (Hamidi et al., 2020). The runoff coefficient "C" represents the percentage of rainfall that becomes runoff. The Rational Method implies that this ratio is fixed for a given drainage basin. In reality, the coefficient may vary with respect to prior wetting and seasonal conditions. The use of an average coefficient for various surface types is quite common, and it is assumed to stay constant through the duration of the rainstorm (WSDOT Hydraulic Manual, 2022).

Runoff Coefficient, C, is the coefficient that represents the fraction of rainfall that becomes runoff. The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well-vegetated areas. An important tool in hydrological studies of many engineering projects in urban and rural areas (Şen & Atunkaynak, 2006).

Table 4. Run-off coefficient (Garber & Hoel, 2020)

CT(slope-topography)		CS(soils)		CV(vegetation)	
Very flat (<1%)	0.03	Sand and gravel	0.04	Forest	0.04
Undulating (1-5%)	0.08	Sandy clays	0.08	Farmland	0.11
Hilly (5-30%)	0.16	Clay and loam	0.16	Grassland	0.21
Mountainous (>60%)	0.26	Sheet rock	0.26	No vegetation	0.28
Runoff coefficient C=CT + CS + CV					

Kamwala South runoff coefficient C, is given by equation 2.

$$C \Rightarrow CT + CS + CV \tag{2}$$
$$C = 0.03 + 0.16 + 0.28$$
$$C = 0.47$$

Where, CT= (0.2%-0.5%), CS= Clay and loam, CV= no vegetation.

Table 5. Value of Runoff Coefficients, C. Adopted from Garber & Hoel (2020)

Type of surface	Coefficient, C*
Rural Areas	
Concrete sheet asphalt pavement	0.8-0.9
Asphalt macadam pavement	0.6-0.8
Gravel roadways or shoulders	0.4-0.6
Bare earth	0.2-0.9
Steep grassed areas (2:1)	0.5-0.7
Turf meadows	0.1-0.4
Forested areas	0.1-0.3
Cultivated fields	0.2-0.4
Urban Areas	
Flat residential, with about 30% of area impervious	0.4
Flat residential, with about 60% of area impervious	0.55
Moderately steep residential, with about 50% of area impervious	0.65
Moderately steep built-up area, with 70% of area impervious	0.8
Flat commercial, with about 90% of area impervious	0.8

According to the values of runoff coefficient table under urban areas (Table 5), our study area can be categorized in the range 0.4 < 0.47 < 0.55 which is a *flat residential area*, with about *30% of area impervious*. This coincides with our description of the built environment in the area.

6.3.5 Social economic

Socio-economic data for Lusaka district was obtained from the 2022 Census of population and housing preliminary report by the Zambia Statistics Agency (2022).

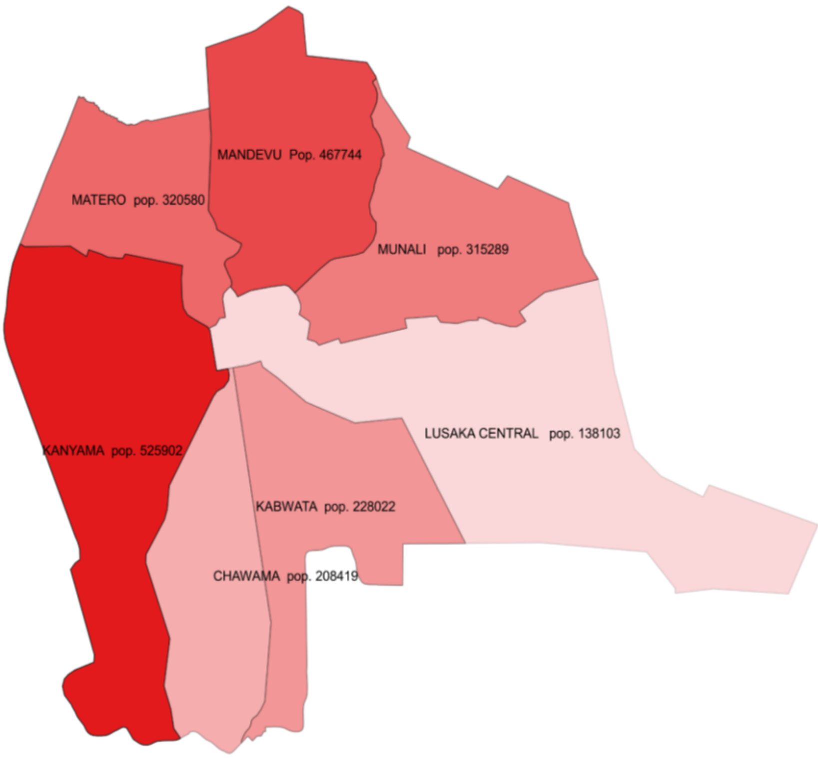

Figure 13. Lusaka population distribution in constituencies

Socio-economic factors play a crucial role in shaping vulnerability, exposure, and resilience to flood risk in urban areas (Marin & Modica, 2017) presented the socio-economic exposure of territories to provide information for risk management strategies in Italy's multiple scales. They analysed the socio-economic exposure territories that can take risks from natural disasters. This analysis concerns the direct and indirect components of exposure. Input-output modelling is a tool to analyse socio-economic factors, especially monetary factors like urban flood resilience, business turnover, capital stock, and productivity. After crossing with the natural disaster, they can provide the multiple scale risk map on the possible economic damages that the municipalities need to concern disaster risk management plan. The socio-economic and natural dimensions are used to develop the risk assessment framework as the decision-making tool for Italian municipalities (Marin et al., 2021). From our analysis, it can be noted that the formal residential areas, which are Chawama, Kabwata, Munali and Lusaka central constituencies are the least populated and also experience the least flooding during rainy seasons. This is attributed to the fact that planning guidelines were implemented in the establishment of these settlements unlike the west of Lusaka which is composed mostly of informal settlements. Integrating socio-economic data with geospatial datasets allows for a more nuanced understanding of flood risk drivers and dynamics in urban areas. It enriches the analysis of urban flood modelling and drainage system evaluation by providing insights into the social dimensions of flood risk and resilience. Incorporating socio-economic data enhances the resilience of urban flood management strategies by addressing socio-economic disparities, promoting community engagement, and fostering adaptive capacity among vulnerable populations. This holistic approach facilitates the development of more effective and equitable flood management strategies tailored to the specific needs of urban communities such as Lusaka.

7. Discussion

The map of drainage systems was made after loading in flow accumulation, stream networks and watershed maps. These parameters were used to mark points on water collection pathways and it was understood that understanding the boundaries of a drainage basin is crucial for managing water flow and potential flood scenarios. Using our findings on slope, built environment, rainfall runoff and soil parameters we showed the evaluation of flood vulnerability for different regions. Regions that seemed to coincide with narrow pathways that were obtained from the delineation of watersheds were shared as flood-vulnerable buffer zones and incorporated into the final map in Figure 10. Implications for urban flood management are that the findings of this study have provided valuable insights into the spatial distribution of flood risk and vulnerability within the city. This information can be used to prioritize flood management efforts, such as the maintenance and upgrading of drainage infrastructure in high-risk areas. Identification of critical infrastructure at risk of flooding, based on integrated analysis of socio-economic and hydrological data, will enable proactive measures to protect essential services and minimize disruption during flood events. Understanding the socio-economic drivers of flood risk can inform targeted interventions to address underlying vulnerabilities, such as improving housing conditions in informal settlements or enhancing community resilience through capacity-building initiatives.

The study's findings will support resilient city planning by integrating flood risk considerations into land use planning, zoning regulations, and infrastructure development plans. This can help prevent future exposure to flood hazards and reduce the vulnerability of urban populations. Incorporating socio-economic data into city planning processes can promote equity and social cohesion by ensuring that flood management strategies prioritize the needs of marginalized communities and address existing disparities in flood risk exposure. Lastly, by highlighting the importance of green infrastructure and natural drainage systems in mitigating flood risk, the study can advocate for sustainable urban development practices that enhance Lusaka's resilience to climate change and extreme weather events.

8. Conclusions

The significance of this project extends beyond the boundaries of Lusaka. It provides a model for urban areas facing similar challenges, where effective drainage management is pivotal to public safety, economic stability, and sustainable development. By addressing the vital problem of urban flooding and presenting a multifaceted approach to solutions, this research not only enhances the quality of life for Lusaka's residents but also stands as a testament to the potential of proactive urban planning and the synergy between technology, science, and community well-being. It underscores the value of informed decision-making and a commitment to resilience in the face of environmental challenges.

Proposed recommendations for policymakers, urban planners and stakeholders are to develop and implement targeted flood management strategies based on the study's findings, focusing on priority areas identified as high-risk zones. Integrate flood resilience considerations into urban planning policies and regulations, including land use zoning, building codes, and infrastructure design standards. Invest in green infrastructure and nature-based solutions to enhance the city's adaptive capacity to climate change and reduce reliance on traditional drainage systems. Strengthen community engagement and public awareness initiatives to foster a culture of resilience and empower residents to take proactive measures to mitigate flood risk. Furthermore, some other notable solutions to mitigate floods include water harvesting, implementing green infrastructure solutions, and establishing comprehensive planning guidelines that consider surface topology.

Limitations to the study are that data availability and quality may pose challenges, particularly in obtaining accurate socio-economic data and hydrological parameters at the required spatial and temporal resolutions. For instance, a compromise had to be made in acquiring soil data as an input dataset for the Soil Water Assessment Tool (SWAT) Model in ArcGIS. Secondly, the complexity of the modelling process may require specialized expertise and computational resources, which could limit the scalability and applicability of the methodology to other contexts. Lastly, the uncertainties associated with future climate projections and socio-economic trends may affect the reliability of long term flood risk assessments and planning decisions.

The study's findings have significant implications for urban flood management and resilient city planning in Lusaka. By addressing the strengths and limitations of the methodology and providing actionable recommendations, policymakers, urban planners, and stakeholders can work together to build a more resilient and sustainable future for Lusaka city.

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Conflict of Interests

The Author(s) declare(s) that there is no conflict of interest.

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