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Quantifying the Effect of the Built Environment on Surface Runoff using GIS and Remote Sensing: A Case Study of Ibex Hill-Lusaka

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Abstract
Flash floods are short-period floods with a high peak discharge. Flash floods may be brought about by an increase in rainfall coupled with the rise of impervious surfaces. Accurate estimation of surface runoff and flood depth is therefore a vital task in coming up with ways to intercept and manage excess surface runoff. The study was carried out in Salama Park – Ibex Hill of Lusaka City with a total area of 1,074,822m^2. The research focused on quantifying the surface runoff for the years 2019 to 2021 using the Soil Conservation Curve Number (SCS-CN) method, Remote Sensing and GIS. The excess runoff was calculated to range between 306.787mm to 600.419mm and the flood depth computed ranged between 1.665m to 3.260m. The relevance of this study is to understand the mechanisms and examine the impact of excess surface runoff on the built environment as well as its associated consequences.
Keywords: Flash floods; Impervious Surfaces; Surface Runoff; SCS-CN Method; Remote Sensing; GIS.

1. Introduction

The increasing intensity of extreme weather events, including heavy storms and precipitation, in various parts of the world is attributed to the significant uncertainty brought about by global climate change. A rise in the amount of precipitation and an increase in infrastructure development have led to an elevated risk of flash floods in rapidly urbanizing areas. The expansion of concrete and other impervious surfaces in such areas prevents water from being absorbed into the ground and therefore has been identified as a significant contributor to flash floods (Zhou et al., 2015). Flash floods may be defined as short-period floods with a rather high peak discharge of water in a particular area (Ali et al., 2017). Flash floods can arise due to a combination of factors, including adverse weather conditions due to climate change effects and inadequate urban planning and land use practices that do not adequately consider the necessary drainage infrastructure, surface topography, and the built environment. One of the effective strategies for addressing flash floods is the implementation of proper planning that promotes urban resilience. According to Godschalk (2003), cities lacking resilient physical systems are highly susceptible to disasters. Resilience in a city refers to its ability to adapt to unforeseen events, make necessary adjustments, and preserve existing and potential opportunities through strategic investments(Amen, 2021; Aziz Amen, 2022; Amen et al., 2023; Amen & Nia, 2020). The built environment, consisting of socio-ecological systems, forms complex adaptive systems within cities, which require measures to address socio-ecological threats. Thus, resilience serves as a crucial tool for enhancing the adaptive capacity of a city's built environment (Masnavi et al., 2019).

Furthermore, additional solutions to mitigate flash floods include water harvesting, implementing green infrastructure solutions, and establishing comprehensive planning guidelines that consider surface topology. Rainwater harvesting is practised, particularly in arid and semiarid regions where conventional water sources such as streams, springs, or wells may become unreliable (Alam et al., 2012). By collecting and storing rainwater, a reserve supply can be maintained throughout the year, particularly during periods of drought when boreholes and other water sources become depleted. Preserving water catchment areas while considering surface topology facilitates effective surface water flow, while standardizing building structures, such as fences, can also contribute to flood prevention. Additionally, the implementation of a green solution such as green infrastructure presents another approach to mitigate the effects of flash flooding. Green infrastructures, as defined by the European Union (EU) are networks of intentionally designed natural and semi-natural areas that are strategically integrated with other environmental elements (Sturiale & Scuderi, 2019). These green infrastructures are planned, managed, and operated in a manner that facilitates the provision of a wide spectrum of ecosystem services.

All these measures can be effectively implemented by accurately determining *surface water runoff*. To avoid waterlogging 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. Due to its complex, dynamic, and nonlinear nature, the rainfall-runoff process is influenced by multiple interrelated physical factors. Consequently, researchers have made significant advancements in identifying and developing various methodologies to assess the impact of human-induced changes on surface runoff, particularly during storm events, and their subsequent consequences on downstream activities. Among the numerous proposed runoff simulation models, the Soil Conservation Service-Curve Number (SCS-CN) model has been widely recognized as one of the most effective approaches for estimating the volume of direct surface water runoff (Fan et al., 2013; Agboola et el., 2018). The SCS-CN method was initially formulated by the United States Department of Agriculture and Soil Conservation Service (USDA-SCS) in 1972 (USDA, 1972) to estimate surface water runoff. The popularity of this method stems from its simplicity, flexibility, and reliance on a single parameter known as the Curve Number (CN) for runoff computation (Muthu & Santhi, 2015). Once the capacity of the drainages is determined, the estimation of surface runoff becomes feasible. According to the definition provided by Merriam-Webster, capacity refers to the inherent potential or suitability of an object or system to hold, store, or accommodate something.

The research paper aims to investigate the capacity of drainages in the study area of Lusaka City specifically, the Ibex Hill – Salama Park area, to quantify the amount of water that can be retained by the drainages and the quantity of water that flows as surface runoff. This investigation is significant as it addresses the issue of flash flood alleviation, which has not been thoroughly studied in this particular domain before. The lack of existing research in this area emphasizes the novelty and importance of this study, as it seeks to fill the knowledge gap and contribute to the understanding and potential mitigation of flash floods in the study region. The purpose of this study, therefore, is to quantify the amount of runoff using remote sensing, GIS and the SCS-CN method to mitigate the occurrence of flash floods effectively in newly built-up urban areas by proposing recommendations to be used during planning. To achieve this, the Capacity formula will be employed requiring the dimensions and total length of the drainages, rainfall data, and an estimate of the total rainfall generated by impervious surfaces thereby contributing to a comprehensive understanding of surface runoff dynamics, flood depth, drainage capacity, and flood risks in urban areas.

The organization of the remainder of the paper is as follows. Section 2 provides an overview of the case study area, which is Lusaka City, specifically focusing on the Ibex Hill (Salama Park) residential area. Section 3 describes the materials and methods used in the study. It includes the research methodology employed, outlining the procedural steps followed explaining how data was collected, analyzed, and interpreted. Additionally, this section highlights the limitations and challenges encountered during the research process. The results obtained from the research are presented and analyzed in section 4. Section 5 discusses the results and explores their implications in detail and the conclusions drawn from the research are summarized in section 6.

2. Case Study: Lusaka City – Ibex Hill (Salama Park)

The study area selected for this research is Ibex Hill (Salama Park) (Figure 1), situated within the geographical coordinates of longitude 28°23'12" to 28°23'42" E and latitude 15°23'12" to 15°24'0" S (Figure 1). Ibex Hill is specifically located within Lusaka City, Lusaka Province of Zambia, encompassing a total area of about 1,074,822 m^2. The area of focus has experienced a significant increase in human population, leading to heightened economic development and subsequent intensified land use, particularly in the form of human settlements. This trend of urbanization has resulted in the proliferation of impervious surfaces within the study area. Impervious surfaces, such as paved areas and buildings, hinder the infiltration of water into the ground, creating a situation where surface water collects and exacerbates the occurrence of flash floods.

Figure 1. Ibex Hill (Salama Park) residential area.

The combination of population growth, economic development, and the expansion of impervious surfaces has raised concerns about the increased vulnerability of the study area to flash floods. Therefore, it is crucial to investigate the dynamics of surface runoff and its impact on flood hazards to develop effective mitigation strategies and ensure the sustainable development of the Ibex Hill area.

3. Materials and Methods

The approach taken into consideration to address the issue of flash floods includes *calculating the capacity of already existing drainages* as well as *investigating the surface topography* and *quantifying the amount of surface runoff*. By integrating these components, the research aims to develop a comprehensive understanding of the factors contributing to flash floods. This knowledge will facilitate the formulation of appropriate measures and recommendations to mitigate the impact of flash floods, enhance drainage infrastructure, and promote sustainable land management practices.

3.1. Research Methodology

The conceptual methodology employed in this research encompasses various aspects of data collection, software utilization, and formulas for data manipulation. The study focuses on examining the impacts of both human activities and natural processes that contribute to the occurrence of flash floods. Key components of the methodology include the use of remote sensing, Geographic Information System (GIS), the Digital Elevation Model (DEM), and the Soil Conservation Service-Curve Number (SCS-CN) Method (USDA, 1972) for surface runoff computation.

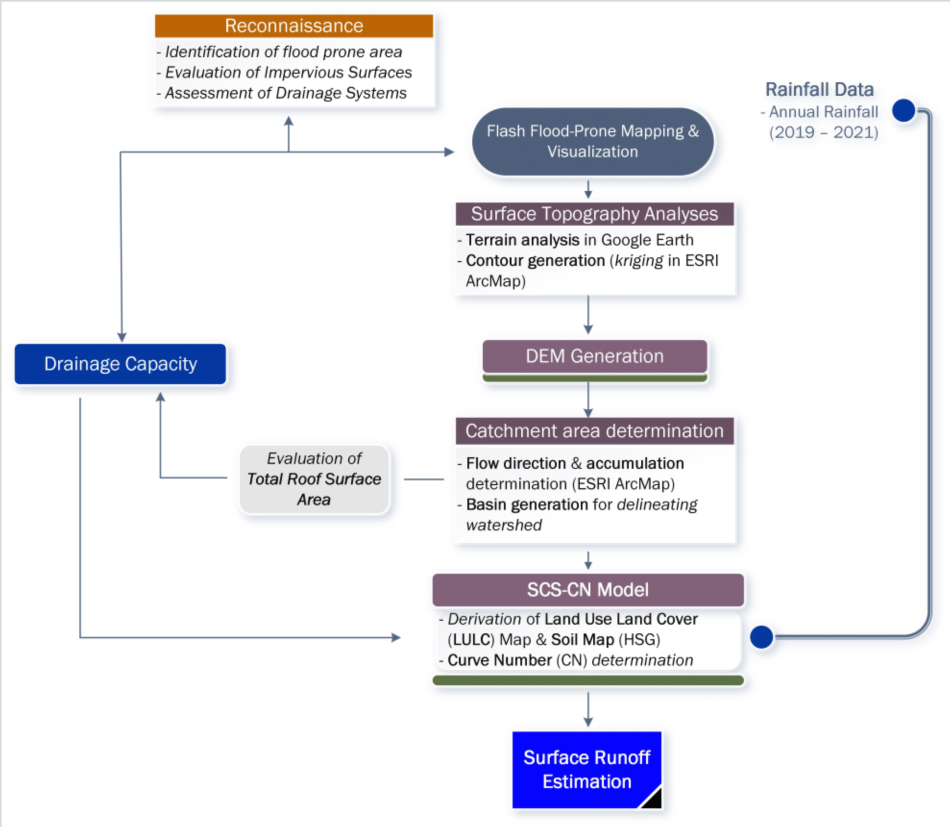

Figure 2. Flow Chart of Conceptual Methodology.

Remote sensing techniques are employed to collect relevant data for the research. This involves utilizing satellite imagery or aerial photographs to capture information about land cover, impervious surfaces, and other environmental variables that contribute to surface runoff generation. Remote sensing, in particular, is used to estimate the total roof surface area by conducting a roof head count. This information is crucial for quantifying the runoff volumes generated by roofs and determining the extent of drainages within the study area. Geographic Information System (GIS) is utilized to analyze and visualize the collected data. GIS plays a pivotal role in determining the extent of the total study area, integrating various geospatial data layers, and conducting spatial analysis and visualization. It helps in examining the relationships between land cover, drainage systems, and surface runoff. The Digital Elevation Model (DEM) was utilized in determining the slope and drainage patterns of the study area. By analyzing the elevation data, the research assesses the topography and terrain characteristics and identifies areas with higher susceptibility to surface runoff and subsequent flash flooding. Additionally, the DEM assisted in delineating the catchment area, providing valuable information for understanding the hydrological processes within the study area. Furthermore, the research utilizes the Soil Conservation Service-Curve Number (SCS-CN) Method (USDA, 1972), which is a widely recognized approach for computing surface runoff. This method incorporates various parameters, such as land use, soil type, and antecedent moisture condition, to compute the volume of surface runoff generated from rainfall events. The SCS-CN Method provides a quantitative assessment of surface runoff, aiding in understanding the hydrological dynamics associated with flash floods. By employing these methodologies and techniques, the research aims to gather and analyze relevant data to assess the impacts of human and natural activities on flash flood occurrences. This comprehensive approach, combining remote sensing, GIS, and the SCS-CN Method, provides valuable insights for effective flash flood management and mitigation strategies.

3.1.1. Drainage Capacity

The methods used for this research included determining the drainage capacity. This involved evaluating the ability of the drainage system to accommodate and convey the generated surface runoff. By assessing the physical dimensions and length of the drainages, the research determined their capacity to handle water flow, helping to identify potential bottlenecks or areas of improvement. Capacity, in this context, refers to the amount of water that a drainage system can hold. It is crucial to have a well-designed and efficient drainage system as it facilitates the unimpeded flow of water and helps prevent the accumulation of water that can potentially lead to flooding. To quantify the capacity of the drainage in the study area, the following formula was utilized:

$$C = \frac{h}{(a+b)L} \quad (1)$$

where,

C = capacity
h = height of the drainage
a = length of drainage
b = breadth of drainage
L = total length covered by the drainage

To determine the capacity of the drainages, several factors were considered, including rainfall data for a specified period, the total drainage capacity, and the amount of water generated by rooftops and impervious surfaces. The physical measurement of the drainages was conducted to ascertain their dimensions and lengths. A measuring tape was used to obtain accurate measurements, while ESRI ArcGIS software was employed to determine the total distance covered by the drainages. In addition, GIS was utilized to determine the total area of rooftops, which contributes to the water generated by impervious surfaces. This allowed for a comprehensive assessment of the capacity of the drainage system, considering both natural rainfall and the water runoff generated by built structures. By incorporating these data sources and measurement techniques, the research aimed to provide a thorough analysis of the drainages' capacity and their ability to effectively manage and accommodate surface runoff.

3.1.2. Surface Topography Investigation

Contours of the study area were generated in ESRI ArcMap by a *kriging* operation to determine the variations in the elevation for a better understanding of the existing terrain. Thereafter, a digital elevation model (DEM) that provides a continuous surface representation of the topography was created in QGIS software to determine the water flow in the established catchment area using the flow direction and flow accumulation functions in ESRI ArcGIS. These functions allow for the determination of water flow patterns across the study area. The flow direction function identifies the direction of water flow from each cell to its steepest downslope neighbour while the flow accumulation function calculates the accumulated flow, which represents the number of cells contributing flow into each cell. By analyzing the flow direction and flow accumulation, valuable insights into water flow patterns and areas of concentrated flow were obtained.

3.1.3. Soil Conservation Service-Curve Number (SCS-CN) Method

The amount of surface runoff was calculated using the Soil Conservation Service-Curve Number method (SCS-CN) which is a commonly and widely used empirical method for estimating surface runoff (Muthu & Santhi, 2015). The formula for calculating surface runoff using the SCS-CN method is given by:

$$Q = \frac{(p-Ia)^2}{p-Ia+s} \quad (2)$$

The SCS-CN Method is based on the *water balance equation* of the rainfall in a known interval of time. The *initial abstraction* (Ia) in mm is a variable that accounts for all losses such as *interception, infiltration*, and *evaporation* before runoff occurs. It is calculated as 30% of the potential maximum retention (S), represented by the equation:

$$Ia = 0.3S \quad (3)$$

The value of S, the *potential maximum retention* in mm, is determined using the Curve Number (CN) obtained from existing CN charts which were established from the land use and soil type. The CN represents the hydrologic characteristics of the land cover and soil conditions in the catchment area. The equation to calculate S is as follows:

$$S = \frac{25400}{CN} - 254 \quad (4)$$

To determine the CN, land cover maps are utilized, which provide spatial information about different physical coverage types on Earth, such as forests, grasslands, croplands, lakes, and wetlands. In this research, the land use map was generated using Sentinel-2 satellites, which provide high-resolution data for land cover use, climate change monitoring, and disaster monitoring, among other applications. For soil information, the Soil Map of the World was prepared in 1961 by FAO and UNESCO at a scale of 1:5,000,000 (FAO, 1961). A soil map provides a geographic representation of soil diversity and different soil types, supporting land evaluation, spatial planning, agriculture extension, environmental protection, and similar projects. In this study, the land and soil map was used to determine the soil and land use of the area, which then aided in establishing the CN from existing charts. Rainfall data is another crucial parameter that was used to calculate the surface runoff using the SCS-CN method. The rainfall data collected over a specific period were averaged and used as the rainfall depth in millimetres (mm). By incorporating these components, including the initial abstraction (Ia), total maximum retention (S), Curve Number (CN) from land cover and soil maps, and averaged rainfall data, the surface runoff was estimated using the SCS-CN method in this research.

3.2. Data Collection, Processing and Preliminary Analysis

3.2.1. Reconnaissance

To assess the flood-prone areas and investigate the potential causes of flooding in the Ibex Hill - Salama Park area, a site visit was conducted. The primary objective was to gather firsthand information about flood-prone areas and identify the contributing factors, with a particular focus on impervious surfaces. Additionally, the existing drainages were observed to understand their functionality and potential impact on flood mitigation. During the site visit, the following activities were carried out:

a) Identification of Flood-Prone Areas: The study area was carefully examined to identify the areas that are susceptible to flooding. This involved visual inspection and mapping of locations where flooding had occurred previously or showed signs of vulnerability. Factors such as low-lying topography, proximity to water bodies, and observed water flow patterns were considered to determine the flood-prone areas.
b) Evaluation of Impervious Surfaces: The presence of impervious surfaces, such as paved roads, concrete structures, and buildings, was assessed to understand their contribution to surface runoff. These surfaces limit the infiltration of water into the ground, potentially leading to increased runoff and flooding. Detailed observations and measurements were made to quantify the extent of impervious surfaces within the study area.
c) Assessment of Drainage Systems: The existing drainages, including stormwater drains, channels, and natural watercourses, were surveyed. Their condition, capacity, and efficiency in conveying water were evaluated. This involved observing the presence of debris, blockages, or inadequate maintenance that could impede water flow and exacerbate flooding. The connectivity and interplay between different drainage elements were also examined to understand the overall drainage system's effectiveness.

The findings from the first reconnaissance survey provided valuable preliminary information regarding flood-prone areas, the influence of impervious surfaces, and the state of the drainage system. These insights formed the foundation for further investigations and analyses in the subsequent stages of the study, aiming to develop appropriate flood mitigation strategies for Ibex Hill - Salama Park area.

3.2.2. Procedures and Preliminary Analysis

By following these data processing steps, the research aimed to narrow down the flood-prone area using a *mobile topographer* application, visualize the study area through digitizing in *Google Earth*, determine the catchment area for generating contours, which were subsequently used to establish a catchment area using ESRI ArcMap so that the source of the surface runoff responsible for the flash floods could be identified, and analysis of the terrain's elevation profiles to gain insights into the variations in terrain height and topography factors contributing to flash floods.

Further, a *terrain analysis* using Google Earth was conducted to obtain the necessary information for generating contours and a digital elevation model (DEM), which were then used to establish the catchment area. Points obtained from the terrain analysis were exported as KML files and converted to GPX format using GPS Visualizer, an online conversion tool, making them compatible with ArcMap. These points were imported into ArcMap, converted into features, and subjected to *kriging* interpolation to obtain the best linear unbiased predictions of unsampled locations based on the available data. Contours were then generated using the kriging results to analyze elevation variations in the study area and subsequently, a DEM was created to define the catchment area for Ibex Hill - Salama Park, which was further utilized to determine flow accumulation and generate a basin delineating the catchment area or watershed (Figure 3).

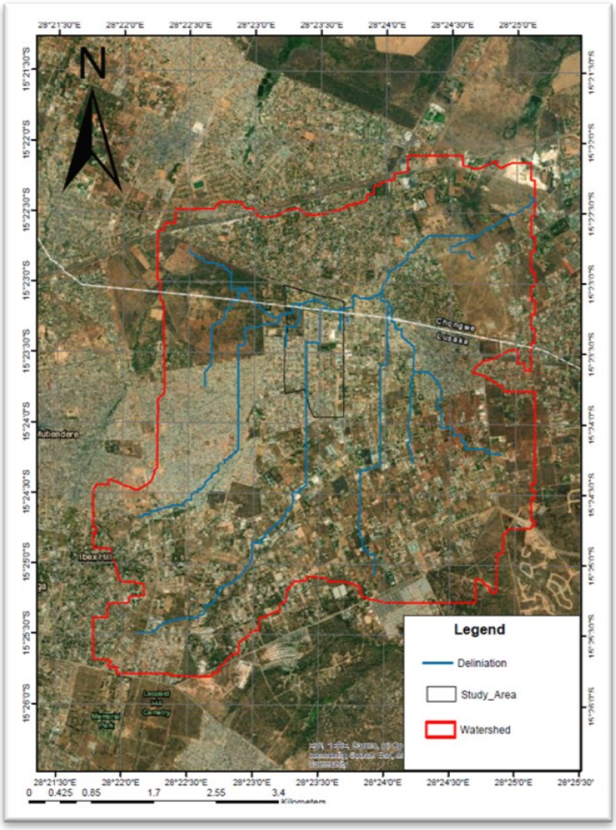

Figure 3. Catchment area delineation in ESRI ArcMap.

The total roof surface area in the catchment was calculated by sampling roofs from high and low-density classes, considering their shapes and calculating the overall volume of roof surfaces. Monthly rainfall data from the Meteorological Department for the period 2018-2022 was collected to understand precipitation patterns in the study area. The rainfall data was used as a parameter in the SCS-CN formula for the computation of surface runoff.

3.2.3. Limitations and Challenges

During this research, several limitations and challenges were encountered. Firstly, some of the drainage systems in the study area were found to contain solid waste and stagnant water, which posed difficulties in accurately assessing their functionality and impact on flood mitigation. Another significant limitation was the availability of insufficient rainfall data from the meteorological department which hindered the precise estimation of surface runoff and the assessment of its contribution to flooding in the study area. These limitations highlight the need for improved management and maintenance of drainage systems in the study area and emphasize the importance of reliable and extensive rainfall data for accurate flood assessment and prediction. Future research endeavours should aim to address these limitations and challenges to enhance the overall effectiveness of flood management strategies.

4. Results and Analysis

4.1. Land Use Map

The land use map (Figure 4), generated from Sentinel-2 land use tiles covering global regions, was utilized to identify the predominant land use in the study area, which was settlements, enabling the determination of the Curve Number (CN) for the SCS-CN formula in estimating surface runoff.

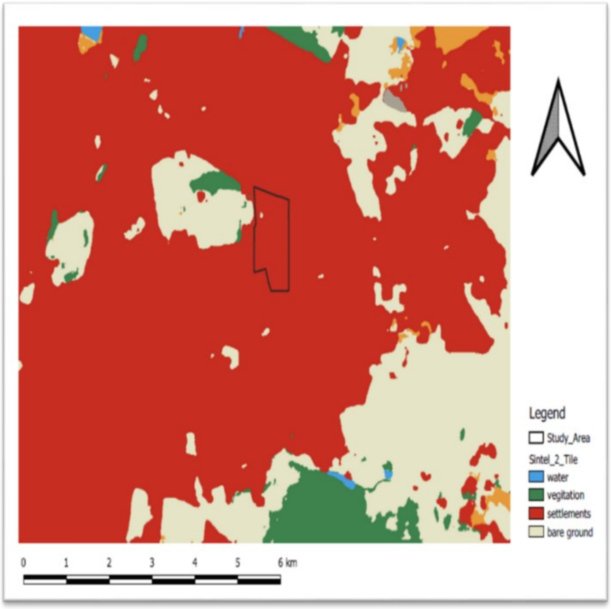

Figure 4. Land use map covering the study region.

4.2. Soil Map

The soil map was derived from the FAO soil map of the world which provides information on different soil types and their characteristics in different locations globally (Figure 5). The Soil map was used to identify the soil type and its features by applying the Soil Conservation Service classification table which was then used in conjunction with the land use classification to determine the Curve Number (CN) for the SCS-CN formula, aiding in the estimation of surface runoff.

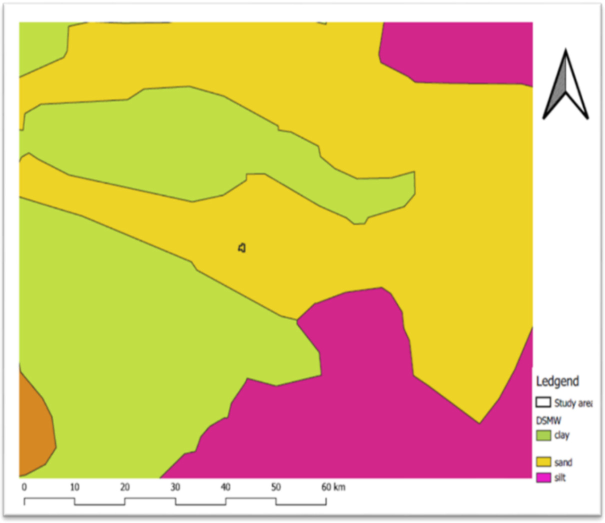

Figure 5. Soil map covering the study region.

4.3. Curve Number (CN) Tables

The CN tables in conjunction with the soil map and land use map were used to determine the appropriate CN values (Table 1). By cross-referencing the soil type and land use information, the corresponding Curve Numbers were identified and then utilized in the SCS-CN formula for estimating surface runoff.

Table 1. 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

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.

Table 2. Curve number for the Ibex Hill – Salama Park watershed. Adopted from (Satheeshkumar et al., 2017)

Land use Cover	Soil type (HSG)	An area in Km^2	CN	% Area	% Area * CN
Barren land	B	8	86	4.44	381.84
Cropland	A	30	72	16.68	1200.96
	B	24	81	13.34	1080.54
Forest land	B	30	68	16.68	1134.24
	C	29.51	79	16.5	1303.5
Fallow land	A	15	74	8.34	617.16
	B	18	83	10	830
Water bodies	-	1.9	100	1	100
Road	D	0.43	91	0.23	20.93
Built up land	A	10	59	5.55	327.45
	B	13	74	7.22	534.28

From the Soil Conservation Service (SCS) CN tables, based on the soil type classified under *Group A* of deep, well-drained sands and gravels indicating low runoff potential and high infiltration rate, and the land use classification of *Built-up land - A*, the CN value is determined to be 59 (Table 2). This CN value will be used in the SCS-CN formula to estimate surface runoff in the watershed.

4.4. Analysis of Results

4.4.1. Drainage Capacity

The drainage capacities of regularly shaped drainage systems (drainage numbers 1 and 2) were computed using the capacity equation, from equation 1 and the following results were obtained:

Table 3. Computations of drainage capacities for the Ibex Hill – Salama Park watershed.

Drainage System No.	Length (m)	Breadth (m)	Height (m)	Total length covered by drainage (m)	Capacity (m^3)
1	0.65	0.68	1.10	9,645	7,055.3175
2	0.38	1.12	0.51	9,645	3,689.2125
3	-	-	-	9,645	10,079.025

For the irregular-shaped third drainage (drainage number 3), the capacity was computed to be 10,079.025m^3. Therefore, the total drainage capacity averaged across the three (3) drainage systems, was calculated to be *6,941.185 m^3*.

4.4.2. Runoff Parameters

4.4.2.1. Rainfall

To estimate the surface runoff in the catchment area, rainfall data from the years 2019, 2020, and 2021 (Figure 6) 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.

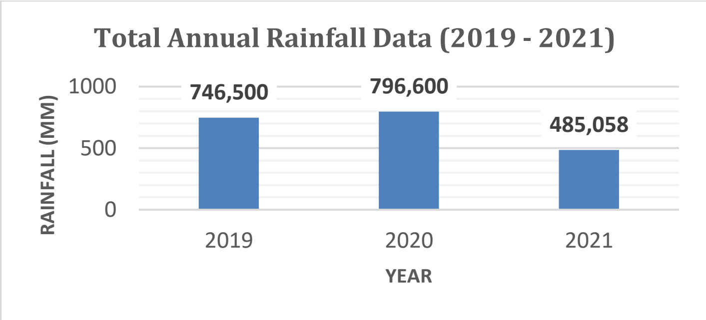

Figure 6. Total annual rainfall data from 2019 to 2021.

4.4.2.2. Potential Maximum Retention

To calculate the potential maximum retention (S), the Curve Number (CN) is used. In this case, the soil type was classified as *deep, well-drained sands and gravel* (classified under *Group A*), and the land use as per the land use table was classified as *built-up land - A*. According to the given information, the CN value is *59*. Using equation 4, the potential maximum retention (S) for the given soil type and land use classification was computed to be *176.508 mm*.

4.4.2.3. Initial Abstraction

To calculate the initial abstraction (Ia), the formula from equation 3 is used. Given that the potential maximum retention (S) is approximately 176.508 mm (computed previously), the initial abstraction was therefore calculated as *52.953 mm*.

4.4.3. Runoff Computations

With all the parameters in check, the surface runoff (Q) was computed using the SCS-CN Method of equation 2 to give the following values as presented in Table 4.

Table 4. Computed Runoff using the SCS-CN method for the Ibex Hill – Salama Park watershed.

Year	P (Rainfall) - mm	Ia (Initial abstraction) - mm	S (Potential maximum retention) - mm	Q (Surface Runoff) - mm
2019	746.500	52.953	176.508	552.847
2020	796.600	52.953	176.508	600.419
2021	485.058	52.953	176.508	306.787

4.4.4. Excess Runoff Calculations

The first step in the excess runoff calculations was to convert the runoff into volumes by multiplying it by the total study area of the catchment. In this case, the total study area is given as 1,704,822 m^2. Having calculated the runoff as 'Q' in millimetres (mm), the runoff is therefore converted into meters (m), by dividing it by 1,000 (Table 5).

Table 5. Computed runoff volume for the Ibex Hill- Salama Park watershed.

Year	Runoff (m)	Total study Area (m^2)	Runoff Volume (m^3)
2019	0.552847166	1,704,822	594,212.297
2020	0.600419599	1,704,822	645,344.194
2021	0.306787287	1,704,822	329,741.725

The second step in the excess runoff calculations involved subtracting the drainage capacity (6,941.185 m^3) from the runoff volume as depicted in Table 6.

Table 6. Computed excess runoff volume for the Ibex Hill – Salama Park watershed.

Year	Runoff volume (m)	Drainage capacity (m^3)	Excess runoff volume (m^3)
2019	594,212.297	6,941.185	587,271.119
2020	645,344.194	6,941.185	638,403.009
2021	329,741.725	6,941.185	332,800.540

4.4.5. Flood Depth

The flood depth in metres was computed by dividing the excess runoff volume by the size of the study area (Table 7).

Table 7. Calculated flood depth for the Ibex Hill – Salama Park watershed.

Year	Excess runoff volume (m)	Total Study Area (m^2)	Flood Depth (m)
2019	587,271.119	1,074,822	1.830
2020	638,403.009	1,074,822	1.666
2021	332,800.540	1,074,822	3.260

The graph depicts the flood depth calculated for the years 2019 to 2021 (Figure 7).

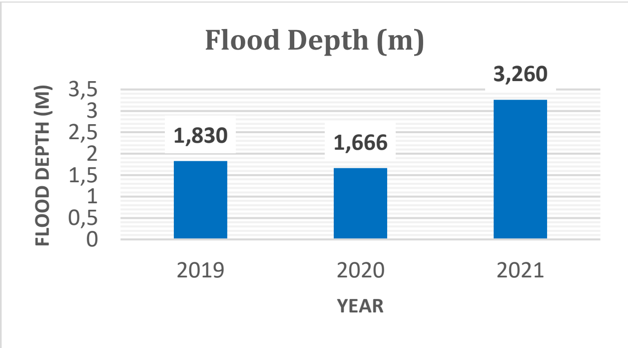

Figure 7. Flood depth from 2019 to 2021.

5. Discussion

The study examined various hydrologic models for estimating the volume of surface runoff from a catchment and the GIS-based SCS-CN model was selected for its popularity and reliability (Hagras, 2023; Shi et al., 2023; Zende et al., 2014). The SCS-CN model that considers environmental factors or parameters such as Hydrologic Soil Group (HSG), land use land cover (LULC) and precipitation/rainfall was applied using annual rainfall data from the Ibex Hill – Salama Park catchment over a three (3) year period (2019 – 2021). The land-use land cover (LULC) and soil map were used to determine the curve number (CN) of 59, for the catchment area, using already existing tables (Tables 1 and 2). Through this approach, the study evaluated the surface runoff determining the values of potential maximum retention (S) and initial abstraction (Ia) to estimate surface runoff in the study area. The findings, presented in Table 7, showed the depths of runoff for each year from 2019 to 2021, where the rainfall ranges from 485.058 mm to 796.600 mm. Applying the appropriate equations and annual rainfall values, the study calculated surface runoff depths ranging from 306.787 mm to 600.419 mm. It was observed that runoff potential varied depending on soil properties and land use, emphasizing the influence of soil moisture conditions on the curve number and the prediction of runoff depth (Ara, 2021).

To determine flood depth, the study calculated the excess surface runoff by subtracting the drainage capacity from the drainage volumes for each year. The calculated excess runoff for 2019, 2020, and 2021 was 587,271.119 m^3, 638,403.009 m^3, and 332,800.5403 m^3, respectively. On average, over the three years, the Ibex Hill – Salama Park catchment area exhibited an excess runoff of 519,491.556 m^3. The flood depth, which represents the actual runoff leading to flooding, was then determined by considering the excess runoff and the total study area. The flood depths for the years 2019, 2020, and 2021 were calculated as 1.830 m, 1.666 m, and 3.260 m, respectively. Notably, the year 2021 experienced the highest flood depth compared to the other years.

6. Conclusions

This study provides valuable insights into the assessment of surface runoff and its implications for water management in Salama Park, Ibex Hill. The findings emphasize the importance of understanding the capacity of drainages to contain surface runoff. By utilizing rainfall-runoff data, it becomes possible to approximate the required drainage capacity and plan for infrastructure improvements accordingly. The Soil Conservation Service Curve Number (SCS-CN) method, employed in this study, proves to be a valuable approach for predicting direct runoff based on rainfall data. This widely used method provides a practical tool for estimating runoff volumes, which can be instrumental in planning land use strategies that integrate green spaces and promotes sustainable water management practices. The significance of this study lies in its contribution to the field of flash floods and surface runoff management. The findings offer valuable insights for local authorities, urban planners, and water management practitioners in Salama Park, Ibex Hill, and similar regions facing similar challenges. Moreover, the study provides a foundation for informed decision-making regarding water management strategies, infrastructure development, and land use planning to mitigate the risks associated with surface runoff and flash floods.

Looking ahead, future research should consider expanding the scope of the study to include a longer period and additional variables, such as land cover changes and soil characteristics, to enhance the accuracy of the runoff estimation models. Additionally, further investigations could explore the potential of innovative techniques and technologies for stormwater management, such as green roofs, permeable pavements, and sustainable drainage systems, to optimize water retention, and infiltration, and reduce runoff.

In conclusion, this research underscores the importance of understanding and managing surface runoff in urban areas prone to flash floods. The findings have practical implications for water management planning, land use decision-making, and sustainable development. By adopting appropriate strategies based on the estimated runoff volumes, it is possible to promote resilience, reduce flood risks, and enhance the overall sustainability of Ibex Hill - Salama Park and similar urban areas.

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Conflict of Interests

The authors declare no conflict of interest.

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