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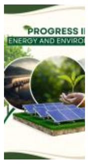

Vol. 31 Issue 03 (2025) 16-26

Original Article

The Concept of Workable Rainwater Harvesting Drainage System in Reducing Flash Flood Risk in Historical City

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Abstract

This study investigates how rainwater harvesting drainage systems can help mitigate flash flood risks in historic urban areas facing increasing threats from rapid development and climate change. Historic cities often have extensive impermeable surfaces, such as roads and buildings, preventing water from soaking into the ground. This leads to greater surface runoff during heavy rainfall, heightening the risk of flash floods. The research evaluates the effectiveness of existing rainwater harvesting drainage systems by combining quantitative data analysis and qualitative case studies. Field data are analysed using the Statistical Package for the Social Sciences (SPSS) to ensure robust results. Key features of successful systems include their capacity to capture, store, and redirect excess rainwater, thus reducing surface runoff volume and speed. Early findings show that rainwater harvesting drainage systems effectively reduce flash flood risk by promoting water infiltration and conserving rainwater for reuse. These benefits align with sustainable urban development goals. Additionally, enhancing drainage infrastructure can protect public buildings, homes, and critical services from flood damage, offering economic and social advantages. The study concludes by recommending improvements in drainage system design, legal enforcement, and urban planning practices. It emphasises the importance of context-appropriate solutions and regulatory compliance to building flood-resilient historic cities. Ultimately, these insights are intended to guide urban planners, policymakers, and developers in making informed decisions for safeguarding heritage cities from urban flooding.

Article Info

Received 5 March 2025
Received in revised form 17 May 2025
Accepted 20 June 2025
Available online 25 July 2025

Keywords

Rainwater Harvesting
Drainage System
Risk of Flash Flood
Historical City

1. Introduction

Urban centres, or cities, are characterised by high population density and various infrastructural developments that support growing populations, often at the expense of infrastructure quality and environmental sustainability [1,2]. The physical development of these areas increases the extent of paved surfaces, slowing natural water infiltration and leading to greater surface runoff, which contributes significantly to flash flood occurrences [2]. Stormwater drainage systems are critical for managing excess water in urban environments; however, their degradation results in serious consequences such as flash floods, pollution, erosion, sedimentation, and other issues that must be urgently addressed [3]. In historical cities, where buildings have withstood centuries of harsh climatic conditions, it is evident that original roof drainage systems were well-designed and functional. Preserving their performance today requires comprehensive studies focused on their materials, discharge components, and drainage capacity, ideally through non-destructive methods to inform suitable maintenance strategies [3]. Over time, urban drainage systems have been perceived differently across cultures and eras: as valuable resources, cleansing tools, flood management mechanisms, or even disease carriers, shaped by factors such as climate, geology, engineering capabilities, and societal values [3]. Recognising this evolution is essential in the modern context. Therefore, this research aims to conceptualise the workability of a rainwater harvesting drainage system in reducing the risk of flash floods in historical cities, through an approach that blends new law with heritage-sensitive design.

Understand and propose design changes that can improve the efficiency of rainwater management systems in urban buildings and ensure that the system works effectively in the face of heavy rain. Urban areas are increasingly vulnerable to flash floods, partly due to climate change and rapid urbanisation, which often disregard natural water retention systems. Hard, impervious surfaces like roads, rooftops, and pavements prevent water from seeping into the ground, leading to increased stormwater runoff that strains urban drainage systems. This has severe environmental, economic, and social consequences, ranging from damage to infrastructure to the displacement of populations [4]. Urban drainage systems are crucial in managing stormwater runoff in urban areas. They are designed to transport the excess surface water from urban areas during the rainy events and reduce floods to acceptable levels of service.

Urban drainage systems are essential for managing stormwater in cities, helping reduce flood risks by channelling rainwater away. They consist of two parts: a major system (roads and gutters) that carries surface water, and a minor system (subsurface drains) that directs the water to areas like rivers or treatment plants. These systems are linked through inlets like manholes. Flash flood also is one of the most dangerous kinds of floods due to the fact of its fast occurrence, without previous warning. The flash flood is a natural disaster with devastating capabilities that destroys houses, infrastructures, properties, cultivated crops, and threatens lives [5]. This research investigates the workability of rainwater harvesting drainage systems in reducing the risk of flash floods in historical cities. With rapid urban development and the growing effects of climate change, Georgetown often faces flash floods that disrupt daily activities and damage infrastructure. Through a more detailed case study, the aim is to assess the current drainage system, its ability to handle heavy rainfall and identify any design weaknesses that may contribute to flooding. By analysing existing drainage systems and exploring potential integration with public water management, this research aims to propose better drainage designs that increase flood resilience, support sustainable water use, and strengthen Georgetown's overall urban water management strategy.

1.1. Literature Review

1.1.1. Rainwater Harvesting and Drainage System Features

Rainwater harvesting is one of the promising ways of supplementing the scarce surface and underground water resources in areas where the existing water supply system is inadequate to meet demand. Rainwater harvesting is one of the measures for reducing the impact of climate change on water supplies [5]. Rainwater harvesting is a promising method of collecting and storing rainwater to supplement surface and underground water resources, especially in areas where the existing water supply is insufficient to meet demand. It is also considered an effective measure to reduce the impacts of climate change on water availability [6]. In Bangladesh, rainwater harvesting is commonly practised in coastal and arsenic-affected rural areas. Still, urban communities remain hesitant to adopt this system due to doubts about potential water savings and the time it takes to recover the initial investment cost. To address severe water shortages, the government of Bangladesh now requires all proposed new buildings in major cities to include rainwater harvesting systems. Although rainwater harvesting from rural and urban catchments has not been widely implemented in Jordan, collecting rainwater from rooftops, roads, and parking lots is a practical solution to increase water availability for domestic use and help combat chronic water shortages [7].

Urban drainage systems are crucial in managing stormwater runoff in urban areas. They are designed to transport the excess surface water during rain events from urban areas and reduce floods to acceptable service levels. In recent years, urban flooding has been more frequent due to climate change and rapid urbanisation, resulting in intense rainfall events with longer durations and significant increases in the impervious layers, especially in large cities. Urban drainage systems are essential for managing stormwater in cities, helping reduce flood risks by channelling rainwater away. They consist of two parts: a major system for roads and gutters that carries surface water, and a minor system (subsurface drains) that directs the water to areas like rivers or treatment plants. These systems are linked through inlets like manholes. Climate change and rapid urban growth have recently led to more frequent urban flooding, as heavier rains and increased paved surfaces overwhelm these systems [4].

1.1.2. Interconnection Between Rainwater Harvesting and Drainage Systems

Integrating rainwater harvesting and urban drainage systems is a practical and sustainable solution to address water scarcity and flood risks in urban areas. Rainwater harvesting involves collecting and storing rainwater for irrigation and industrial processes, reducing dependence on public water supplies [8]. At the same time, urban drainage systems are designed to manage stormwater runoff and prevent flooding. Combining these systems helps reduce the amount of water entering drainage networks during heavy rain, lowering the risk of floods and easing the strain on outdated infrastructure. This approach is especially useful in cities with many paved surfaces, where rapid urbanisation and climate change make managing water more challenging. Examples from countries like Jordan and Bangladesh show that integrating rainwater harvesting with drainage systems prevents flooding and provides an additional water source for daily needs. This combined strategy supports water conservation, improves flood management, and makes cities more resilient to climate challenges [9].

1.1.3. Drainage Deficiencies in Historical Cities That Lead to Flash Floods

Based on the study conducted in Dodola Town, Ethiopia, several key deficiencies in drainage systems were identified as major contributors to flash flood occurrences. One of the primary issues is rapid urbanisation, which has transformed natural landscapes into impervious surfaces such as roads, pavements, and buildings. This significantly increases surface runoff while reducing infiltration, thereby overwhelming the existing drainage systems, not designed to handle such intensified loads. Coupled with climate change, which brings more frequent and intense rainfall events, the volume and rate of runoff have surpassed the hydraulic capacities of outdated drainage infrastructure. These systems were originally built using historical climate assumptions and failed to incorporate future urban growth or evolving weather patterns, resulting in widespread system failures and localised flooding. Simulation results from the study show that under both current and projected conditions, the drainage system could not adequately manage peak runoff, particularly in high-risk zones like urban centres and low-lying areas [10].

In addition to design limitations, inadequate maintenance further compromises drainage performance. Due to neglect, many inlets and conduits are frequently blocked by debris, solid waste, and vegetation, leading to overflow and water stagnation during heavy rainfall. New settlements around the town often lack proper drainage infrastructure, exacerbating flash flood risks by allowing uncontrolled runoff into homes and streets. Other structural issues hinder effective water conveyance, such as improper channel slopes, misaligned junctions, and insufficient conduit depths. Notably, many segments of the drainage network fail to meet the minimum recommended flow velocity of 0.76 m/s, causing sediment accumulation that further reduces capacity. These technical shortcomings result in widespread inundation, especially during return periods of 10 to 100 years, as demonstrated in the hydraulic simulations. These factors underscore the urgent need to redesign drainage systems based on updated hydrological data, integrate proper urban planning for new developments, and implement routine maintenance to build flood resilience in rapidly growing cities [10].

1.1.4. Regulations and Guidelines for Rainwater Harvesting and Drainage Systems.

The Uniform Building By-Laws (UBBL) 1984 and the Street, Drainage, and Building Act 1974 (Act 133) are key legislative frameworks in Malaysia that support sustainable urban water management and flood risk reduction. The UBBL 1984 mandates incorporating rainwater harvesting systems in new developments, including storage tanks and filtration units for non-potable uses such as irrigation, landscaping, and toilet flushing, reducing reliance on municipal water supplies and promoting water efficiency [11]. It also emphasises using water-saving fixtures like dual-flush toilets, efficient irrigation systems, and sustainable drainage designs such as permeable pavements and detention ponds to manage stormwater runoff and mitigate urban flooding [11]. Complementing this, Act 133 specifically addresses the construction and maintenance of drainage infrastructure through its Part III provisions, requiring public and private developments to implement systems like drains, culverts, and retention ponds to effectively channel stormwater, especially during extreme weather events [12]. This Act ensures proper drainage performance and indirectly supports rainwater harvesting by integrating storage systems into well-designed drainage networks, allowing for captured runoff to be reused for non-potable applications [12]. UBBL 1984 and Act 133 provide a legal framework to guide climate-resilient infrastructure, water conservation, and integrated urban water management approaches important for Malaysia’s development [11,12].

2. Methodology

2.1. The Scope of Research

To select a suitable case study for this research, George Town in Penang emerges as an ideal case study. As the vibrant core of a UNESCO World Heritage Site, George Town exemplifies the complexities of historic cities dealing with outdated drainage systems amidst rapid urban development. The town supports a population of approximately 794,000 residents within an area of 306 km², resulting in a population density of about 2,596 people per km². In heritage zones such as the city centre, this density can exceed 6,209 people per km². The study focuses on urban regions prone to heavy rainfall and flash flood events, particularly in coastal or monsoon-affected areas (refer to Figure 1, which shows the parameters of the case study). George Town’s high density and widespread impervious surfaces and hilly terrain significantly intensify surface runoff during intense storms, often overwhelming the century-old drainage infrastructure. Consequently, the city frequently experiences flash flooding, with streets like Jalan Macalister and Jalan Scotland regularly submerged to knee-deep levels.

Figure 1: The areas of Georgetown, Penang.

Critical areas, including hospitals and residential zones near Kampung Sungai Pinang, are also vulnerable during heavy rainfalls. Extended storms with strong winds have further intensified these events, causing property damage and uprooting trees. These recurring floods highlight significant weaknesses in the city's drainage capacity, maintenance, and planning in positioning George Town as a representative model of heritage cities grappling with modern flood resilience challenges (refer to Table 1 showing the statistics of flash floods in George Town).

George Town has experienced frequent and severe flash flood events over the years, with critical areas such as Jalan Komtar and Padang Kota repeatedly affected due to their low-lying topography and ageing drainage infrastructure. In 2007 and 2016, major floods submerged roads like Jalan P. Ramlee and Padang Kota Lama under water depths ranging from 0.3 to 1.5 meters. The most devastating flood occurred on 14–15 September 2017, when 270 mm of rain fell in less than 24 hours, overwhelming over 100 locations, including Jalan Komtar, Ayer Itam, and Padang Kota, with floodwaters rising as high as 3.7 meters and triggering 41 landslides. More recently, flash floods on 1 July 2023 and 17 September 2024 inundated Jalan Macalister, Jalan Magazine, and Jalan Komtar up to 0.6 meters, causing traffic disruptions and property damage. These recurring events highlight the city's vulnerability, especially in dense urban cores where surface runoff exceeds drainage capacity. Including heritage zones like Padang Kota further emphasises the urgency of upgrading the city's stormwater systems to prevent repeated disruptions in historical and commercial districts.

Table 1: Flash Flood Statistics in George Town, Penang.

Year	Date/Event	Rainfall Intensity	Flood Depth	Affected Areas	Remarks
2007	Major flood event	Not specified	Up to 1.5 m	George Town city centre, Jalan P. Ramlee, Jalan Komtar	Benchmark flood until 2017
2016	Multiple events	Not specified	0.3 m – 0.7 m	Jalan Air Itam, Jalan Dato Keramat, Padang Kota Lama	At least 10 major floods recorded in Penang state
2017	14–15 Sept	270 mm in < 24 hrs	Up to 3.7 m	100+ locations; Jalan Komtar, Ayer Itam, Padang Kota, Sungai Pinang	Worst flood in a decade; 41 landslides reported
2023	1 July	Heavy afternoon rain	Up to 0.6 m	Jalan Macalister, Jalan Datuk Keramat, Jalan Komtar	Strong winds uprooted trees; traffic disrupted
2024	17 Sept	Intense short rainfall	0.5 m – 0.6 m	Jalan P. Ramlee, Jalan Magazine, Padang Kota Lama	Flash flood within hours; drains overwhelmed

2.2. Selection of the Data Collection

Three locations in Georgetown, Penang (Padang Kota, Jalan P. Ramlee, and Jalan Komtar) were selected due to their history of significant flooding events in recent years, as shown in Figure 2.

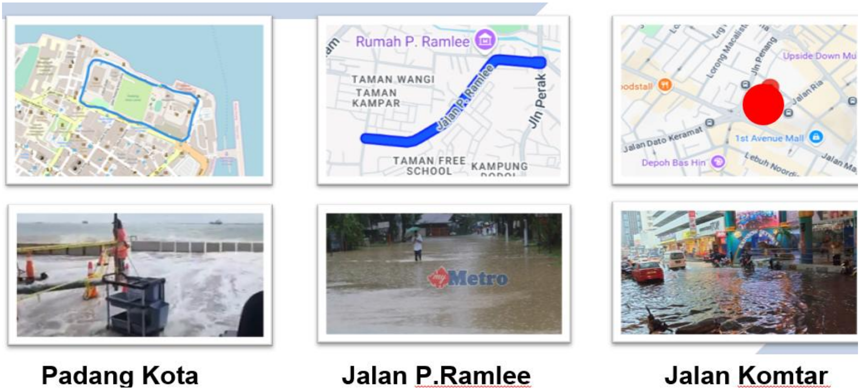

Figure 2: Three Case studies that involve flash floods.

Here's a brief elaboration of what might have happened in each case:

Padang Kota (2024)

In 2018, Padang Kota, a popular waterfront area in Georgetown, was affected by coastal flooding, likely due to high tides, storm surges, or heavy rainfall overwhelming the drainage system [13]. The image shows water pumped out, indicating the authorities' flood mitigation efforts. This type of flooding is common in low-lying coastal areas and can be worsened by rising sea levels and extreme weather events.

Jalan P. Ramlee (2022)

Jalan P. Ramlee experienced severe flash floods in 2022, likely caused by heavy rainfall and poor drainage [14]. The image suggests that the water levels were significantly high, affecting roads and nearby buildings. This area is known for being flood-prone due to its topography and drainage infrastructure. In 2022, Penang saw several instances of urban flooding, highlighting the need for better stormwater management and drainage system upgrades.

Jalan Komtar (2023)

The flooding in Jalan Komtar, a busy commercial area in the heart of Georgetown, in 2023 was likely due to intense rainfall, leading to urban flash floods [15]. The image shows a heavily flooded street with vehicles struggling to move, indicating poor water drainage. This area is a major hub with high foot traffic so that such flooding can have severe economic and social impacts. Flash floods in urban centres are becoming more frequent due to rapid urbanisation, clogged drainage systems, and extreme weather conditions.

2.3. Research Process

This research uses qualitative and quantitative data to understand better drainage issues and the potential for rainwater harvesting systems in George Town. Quantitative data is collected through structured questionnaires distributed to residents and business owners. These surveys gather information such as how often floods occur, how deep the water gets, and how familiar and open people are to using rainwater harvesting systems. The closed-ended responses allow for statistical analysis of flood impacts and community views. Qualitative data is gathered through field observations and semi-structured interviews. Observations help identify visible drainage problems, such as blockages or design flaws. Interviews with local authorities, engineers, and urban planners provide deeper insights into the challenges and possibilities of applying rainwater harvesting in a historical city. By combining both data types, the study creates a more complete picture, blending facts with real-world context to support practical solutions. Table 2 presents the research process used in this investigation.

Table 2: Stage of the research process.

Research Stage	Method	Activities & Focus	Outcomes
Stage 1: Preliminary Analysis	Observation	Conduct field observations in historical areas of George Town to identify visible drainage deficiencies and flood-prone zones. - Review literature on rainwater harvesting systems and stormwater management in heritage urban settings.	A comprehensive understanding of existing drainage conditions and conceptual approaches to rainwater harvesting integration in historical cities.
Stage 2: Data Collection and Analysis	Questionnaire	Distribute structured questionnaires to residents and business owners in George Town to gather public insights on flash flood impacts, awareness of rainwater harvesting, and drainage performance.	Detailed data on local perceptions, key issues, and public acceptance of rainwater harvesting solutions in reducing flood risks.
Stage 3: Development of Strategies and Recommendations	Interview	Conduct semi-structured interviews with local authorities, engineers, and heritage planners to gather expert perspectives on drainage integration challenges and policy feasibility. - Validate proposed framework and mitigation strategies.	A practical and context-sensitive framework supported by expert recommendations for implementing rainwater harvesting drainage systems in historical cities.

2.3.1. Structured Observation of Drainage Infrastructure

This study adopts a structured observation approach to evaluate the physical condition and performance of the drainage system within the historical urban fabric of George Town. The objective is to assess the system's effectiveness in managing stormwater during high-intensity rainfall events, particularly in flood-prone heritage areas.

Several key parameters guide the observation process. First, water depth during flood events is estimated or measured to assess the severity of surface water accumulation and the system’s capacity to manage peak runoff. Flow velocity is also visually observed or using basic measurement tools to determine how efficiently water is conveyed through the drainage network during and after rainfall. The physical dimensions of drainage components, including width, depth, and length, are recorded to evaluate compliance with urban drainage capacity standards. The types of drainage systems (e.g., open channels, closed drains, or culverts) are categorised to determine their suitability for the local topography and flood risk level.

Additional attention is given to obstructions such as debris, vegetation, or solid waste, which can significantly impair flow capacity. The structural integrity of each component is assessed through visual inspection for signs of deterioration, including cracks, erosion, or collapse. The alignment and slope of drainage systems are also evaluated to identify issues contributing to water stagnation or backflow. Observations are systematically recorded using a checklist and spreadsheet. The inventory includes general information such as drainage type, location, dimensions, and condition. Areas with frequent flooding are identified to map vulnerability hotspots. Maintenance records are reviewed, where available, to provide context on historical flood events and repair interventions. The collected data support a comprehensive evaluation of the drainage system’s current status and inform recommendations for improved flood resilience in heritage urban environments.

2.3.2. Stakeholder and Community Interviews

This study utilised face-to-face semi-structured interviews to gain in-depth insights from key stakeholders and residents involved in or affected by urban planning and flood management in George Town, Penang. The interview process targeted two main groups: government stakeholders and community members.

The Majlis Bandaraya Pulau Pinang (MBPP) participants included 2 to 5 professionals, such as urban planners, drainage engineers, and policymakers. Selection criteria required a minimum of 2 to 5 years of relevant experience in infrastructure development, urban planning, or flood mitigation at the municipal level. These stakeholders were interviewed to explore their professional experiences, current flood management practices, and views on the feasibility and effectiveness of implementing rainwater harvesting systems within a historical urban context.

To complement institutional perspectives, interviews were conducted with 2 to 5 residents who had lived or worked in George Town for at least 3 to 5 years. Participants were selected from diverse professional and educational backgrounds, including engineering, infrastructure development, and environmental or community planning. This diversity ensured a broad understanding of public perceptions and lived experiences related to urban flooding.

The semi-structured interview format allowed for both guided and open-ended discussions. The interview protocol included structured items such as Likert scale questions assessing perceptions of flood risk and open-ended questions addressing personal experiences, satisfaction with current drainage systems, and suggestions for improvement. Sample questions covered challenges in managing George Town's drainage network, the perceived potential of rainwater harvesting systems, and recommendations for future flood mitigation strategies. A validity test was conducted prior to data collection to ensure the validity and alignment of interview content with research objectives. This ensured that all questions were relevant to evaluating the effectiveness of rainwater harvesting systems and broader flood resilience planning.

2.3.3. Analysis

This study analysed the collected quantitative data using a combination of Microsoft Excel and IBM SPSS Statistics. Microsoft Excel was primarily used for data organisation, reprocessing, and statistical analysis. Key descriptive statistics, including mean, median, and standard deviation, were calculated to summarise variables such as rainfall intensity, runoff volume, and water storage capacity. Excel was also used to generate visual representations such as charts and pivot tables to identify patterns, trends, and preliminary relationships within the dataset.

For more advanced statistical analysis, SPSS was utilised to perform inferential tests. Correlation analysis was conducted to examine the relationship between the presence of rainwater harvesting systems and the frequency or severity of flash flood events. Additionally, regression analysis was applied to evaluate the predictive influence of variables such as storage capacity, rainfall intensity, and catchment size on the effectiveness of these systems in mitigating flood risk.

This dual-tool approach ensured a comprehensive examination of descriptive and inferential data by integrating the strengths of Excel and SPSS. While Excel facilitated efficient data management and visualisation, SPSS enabled deeper statistical testing. The results of these analyses, presented in the following chapter, form the basis for evaluating the potential of rainwater harvesting systems as a sustainable solution for urban flood mitigation in George Town.

3. Implications

The conceptual framework in this research serves as a foundation that integrates theoretical insights on historical cities, rainwater harvesting, and flood risk management within the context of historical urban settings. As highlighted by various scholars, the conceptual framework functions as a bridge that connects the theoretical underpinnings of the research issue with its practical investigation. In this study, the framework guides the research process by aligning sustainable drainage systems and urban planning theories with the observed realities of George Town's drainage conditions. It provides a structure for formulating the research design, selecting appropriate methods such as observation, questionnaires, and interviews and interpreting the data within a meaningful theoretical context.

More than just a schematic representation, the conceptual framework maps interrelated concepts such as impervious surface impact, drainage efficiency, public awareness, and heritage constraints. These variables are not isolated but interact meaningfully to influence the success or limitations of rainwater harvesting systems in reducing flash floods. By explicitly defining the relationships between these concepts, the framework enhances the coherence and clarity of the study. It emerges not only from a literature review but also from the researcher's reflections on the physical, environmental, and social impacts on the government, society and so on during the observation of the drainage system. In this way, the framework elevates the research from a descriptive condition of drainage issues to a conceptual analysis of how integrated rainwater harvesting systems can function in historical urban environments. Ultimately, the conceptual framework helps present theoretically grounded and practically applicable conclusions, offering valuable strategies for sustainable urban water management in heritage cities like George Town.

4. Applications

The conceptual framework developed in this research plays a crucial role in evaluating the suitability and adaptability of rainwater harvesting drainage systems within historical cities. These cities often face challenges such as ageing and undersized drainage infrastructure, dense urban layouts, limited space for expansion, and strict heritage conservation regulations. The framework helps identify how alternative, low-impact drainage solutions such as rooftop rainwater harvesting, ground-level filtration pits, underground storage tanks, and passive overflow channels can be implemented without altering or damaging culturally significant buildings. It considers factors such as rainfall intensity, runoff behaviour, spatial constraints, and traditional urban design. Doing so enables planners and conservationists to visualise drainage improvements that are both technically effective and sensitive to the historical context. For example, collected rainwater from sloped heritage roofs can be stored in hidden tanks or reused for non-potable landscaping or cleaning, thereby reducing pressure on existing drainage networks. The framework supports a balanced approach, promoting flood resilience while preserving historical cities' aesthetic and cultural values. Table 3 shows the aspects and applications of the conceptual framework in historical towns.

5. Conclusion

This research concludes that rainwater harvesting drainage systems can serve as a practical and sustainable solution to address flash flood risks in historical cities. By using a conceptual framework, the study successfully maps the relationship between heritage conservation needs, urban drainage limitations, and the potential of integrating rainwater harvesting in a sensitive and functional manner. The framework shows that appropriate planning and design can reduce surface runoff, ease pressure on existing drainage infrastructure, and enhance urban flood resilience without compromising the historical and cultural integrity of the built environment. Therefore, the findings support the implementation of rainwater harvesting as a viable strategy for sustainable water management and flood mitigation in historical city contexts.

Table 3: Aspects and Application of Conceptual Framework in Historical Cities.

Aspect	Application of Conceptual Framework in Historical Cities
Heritage Infrastructure Constraints	Assess limitations of ageing drainage systems and identify non-invasive rainwater harvesting solutions.
Architectural Preservation	Ensures system components like tanks or downpipes do not visually or structurally compromise historical buildings.
Rainfall and Runoff Behaviour	Guides the selection of appropriate drainage solutions based on local rainfall intensity and surface runoff patterns.
Urban Space Limitation	Identifies feasible system placement (e.g., courtyards, back alleys) within tight, heritage-protected urban environments.
System Efficiency	Evaluates how integrated harvesting systems can reduce runoff volume and lessen the load on municipal stormwater networks.
Sustainable Water Use	Encourages the reuse of stored rainwater for non-potable purposes, supporting sustainability in heritage settings.
Flood Mitigation	Links historical flood-prone zones with strategic drainage interventions to reduce waterlogging and infrastructure damage.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party on the publication of the current work.

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Acknowledgement

This research was not funded by any grant.

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