A Comprehensive Review of Studies Focusing on the Intersection of Urban Flooding and Historic Urban Landscapes

A Comprehensive Review of Studies Focusing on the Intersection of Urban Flooding and Historic Urban Landscapes

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Abstract. Due to evolving climate patterns and the deterioration of infrastructure in historic cities, these urban locales confront escalating flood-related risks. A profusion of academic discourse has separately explored the subjects of urban flooding and historic urban landscapes, but an integrative, systematic review of both areas concurrently remains scarce. This review presents a holistic perspective of the convergence between urban flooding and historic urban landscapes, meticulously evaluating 101 scholarly articles sourced from the Web of Science database spanning from 2006 to 2022. The disciplinary classification encompasses 24 categories. A careful examination of the methodologies employed in these articles reveals flood vulnerability mapping as a prevalent tool in urban heritage conservation, while nature-based solutions emerge as potent strategies for mitigating urban flooding challenges. The insights derived from this review shed light on the present state of affairs regarding urban flooding risks in historic cities, and provide a wealth of information beneficial to decision-makers and practitioners engaged in urban stormwater management.

1. Introduction

The Historic Urban Landscape (HUL) approach, endorsed by UNESCO in 2011, promotes a balance between heritage conservation and sustainable development in historical urban areas[1]. These regions, prone to flooding or near water bodies, face increased climate change-induced vulnerabilities, including the escalating threat of urban flooding, with over-urbanization and obsolete drainage systems further intensifying flood risks[2]. Consequently, there's a call for urban risk assessment and mitigation strategies that respect the unique characteristics of these cities. The HUL approach offers such pioneering solutions.

Two distinct yet interrelated fields form the basis of urban flooding research in historical cities. First, urban flooding, though rooted in ancient planning, has become a formal research focus since the 20th century due to city expansion and rapid urbanization. This necessitated advanced flood mitigation techniques, with early efforts like Daniel Hudson Burnham's urban design for Chicago offering valuable precedent[3]. Contemporary scientific algorithms now offer intricate solutions to urban rainwater issues.

The second field focuses on the historic urban landscape. The model propounded by Wittaya Daungthima underscores the primacy of four city constituents - social, economic,

environmental, and physical - acting as critical conduits in the regulation of ecosystem dynamics within heritage precincts[4]. Safeguarding the historical urban fabric becomes imperative, particularly in the light of the impending impacts of climate change and the onslaught of urban regeneration endeavors, to buttress urban resilience and sustain the lineage of cultural heritage.

However, research at the intersection of these domains is scant, with urban flooding studies primarily focused on newer areas. This review probes this research gap and poses critical queries regarding the interplay between historic urban landscapes and urban flooding and the potential integration of findings to bolster the sustainable development of historic cities.

2. Methodology

Adopting the seven-step review process for systematic evaluation and synthesis of research literature[5], this study aimed to maintain rigorous scientific integrity and deliver comprehensive conclusions. The seven-step review, previously validated in climate-related HUL literature reviews[6], is depicted in Figure 1.

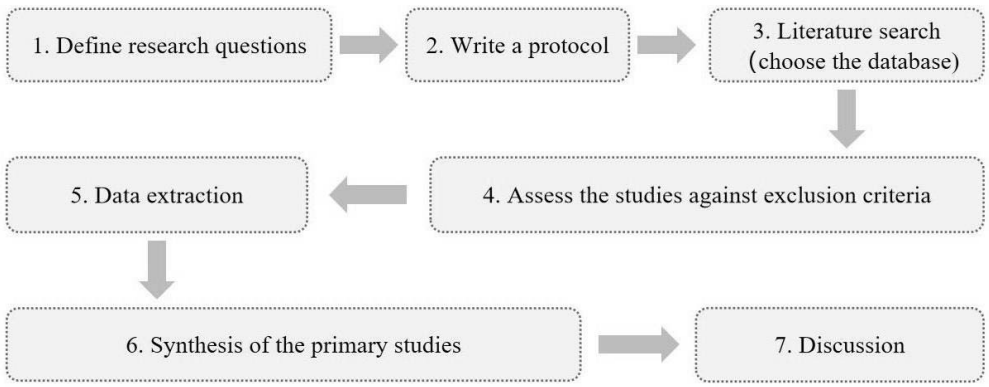

Figure 1. Seven-step systematic review method.

2.1. Selection of Keyword Strings and Publications

The review encompassed English publications investigating historic urban landscape and urban flooding issues, focusing on the keywords "urban flooding" and "historic urban landscapes." The keyword strings included relevant synonyms, such as: TS=(urban flooding* OR stormwater OR urban hydrology OR urban surface runoff) AND TS=(historic urban landscape OR historic cit* OR heritage cit* OR heritage urban landscape).

The Web of Science Core Collection, dating back to 1990, was used for the search, with the scope narrowed to titles, abstracts, keywords, and recurrent phrases in article reference titles. The review spanned studies from 2006 to 2022, with the search performed in March 2023. Exclusion criteria included non-English publications, inaccessible articles, and irrelevant topics. After a preliminary screening and full-text review, 101 out of 211 identified publications were selected for the final review.

2.2. Analysis and Synthesis of Selected Publications

Guided by the research question, the selected studies were systematically analyzed and synthesized to capture their general characteristics, emphasis, content, and identified gaps. A comprehensive review of all selected publications enabled the extraction and classification of relevant information, and the summary of the publications' findings and analysis themes.

3. Overview of the studies

Following the review steps illustrated in Figure 2, the findings of this review are presented in the following order: (1) general information of the selected publications, (2) research focus and contents of the publications, and (3) knowledge gaps and future perspectives.

3.1. General Features of Selected Publications

3.1.1. Publication Statistics and Cooperation Analysis

The inaugural study matching our criteria emerged in 2006, published in IRRIGATION AND DRAINAGE and focusing on Gdańsk, Poland[7], known for its historic old town (Figure 2). The intersection of historical urban landscapes and urban flooding research experienced steady growth post-2011, attributable to UNESCO's HUL recommendation. A surge in studies occurred between 2014-2020, briefly declining in 2021, before rebounding. The last three years contributed nearly half (50 out of 101) of all related studies.

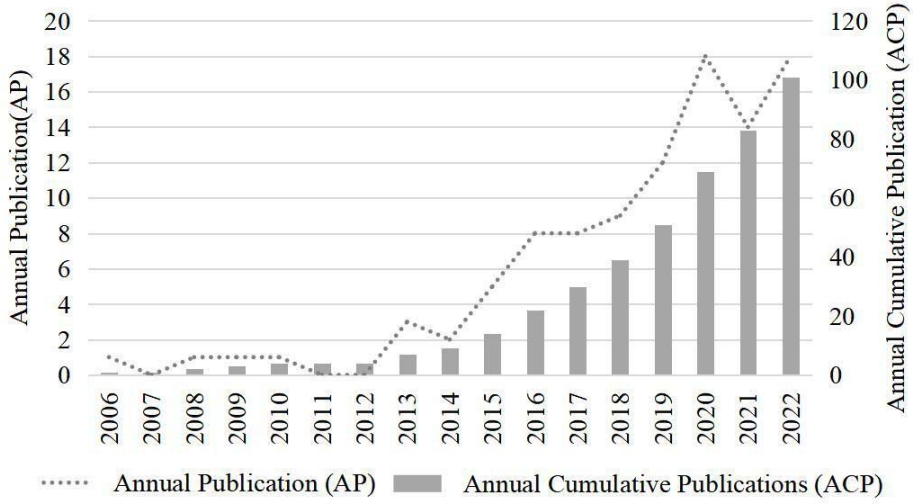

Figure 2. The number of reviewed publications.

In examining author collaboration, a majority contributed to only 1-3 articles, suggesting few researchers specialize in the nexus of urban flooding and heritage cities. Moreover, no researcher's study period surpassed three years, pointing to a dearth of scholars dedicated to interdisciplinary research in urban flooding and historic urban landscapes.

Overall, 164 affiliations, including universities, institutions, government sectors, and companies, contributed to the collected publications. Universities provided 80.4% of contributions, research institutions added 10.9%, while sectors and companies contributed minimally. Affiliation collaborations primarily occurred between universities and research institutions, with sectors and companies underrepresented in the field. Given the interdisciplinary nature of urban flooding and historical urban landscape studies, increased collaboration is recommended.

Italy leads in research, backed by many professional institutions and academia, including renowned entities such as the University of Rome and University of Florence. The data of single country publications (SCP) and multiple country publications (MCP) emphasize Italy's domestic prowess and international collaborations, respectively. Countries with only SCP should strive for more active global exchanges and collaborations.

3.1.2. Publication Types and Journals

The collection of 101 studies is composed of 78 research articles, 21 proceedings papers, and 2 review articles, published across 74 diverse and extensive journals. Certain journals, such as SUSTAINABILITY (6 articles), JOURNAL OF MAPS (5 articles), NATURAL HAZARDS AND EARTH SYSTEM SCIENCES and WATER (4 articles each), and INTERNATIONAL

JOURNAL OF DISASTER RISK REDUCTION, JOURNAL OF ENVIRONMENTAL MANAGEMENT, and NATURAL HAZARDS (3 articles each) published multiple relevant articles.

The multifaceted field of urban heritage protection—encompassing urban planning, sustainable development, and natural disaster risk management—is reflected in the broad spectrum of journals where these studies find publication. For example, SUSTAINABILITY addresses various sustainability aspects, while JOURNAL OF MAPS provides critical spatial information relevant to urban heritage protection. Despite this diversity, only a handful of journals offer an integrative perspective combining theory and practice of urban stormwater management within historic urban landscapes.

3.2. Publication Content Focus

3.2.1. Discipline Classification

Analyzed publications hail from 24 research disciplines, underscoring the topic's interdisciplinary nature (Figure 3). Contributions of particular significance include Ferreira's trailblazing methodology that seamlessly melds hazard and vulnerability maps to conduct urban flooding risk assessments in a UNESCO heritage site located in Portugal[8]. Similarly, Ortiz's pioneering fusion of risk maps for dampness and flooding in Spain[9] constitutes a noteworthy advancement. The diversity and breadth of these studies highlight the dynamic and multifaceted field of urban stormwater management in historic urban landscapes. The top five disciplines—Environmental Sciences & Ecology (31), Science & Technology - Other Topics (14), Geology (14), Geography (6), and Architecture (6)—mainly employ quantitative methods for urban flooding issues in heritage cities.

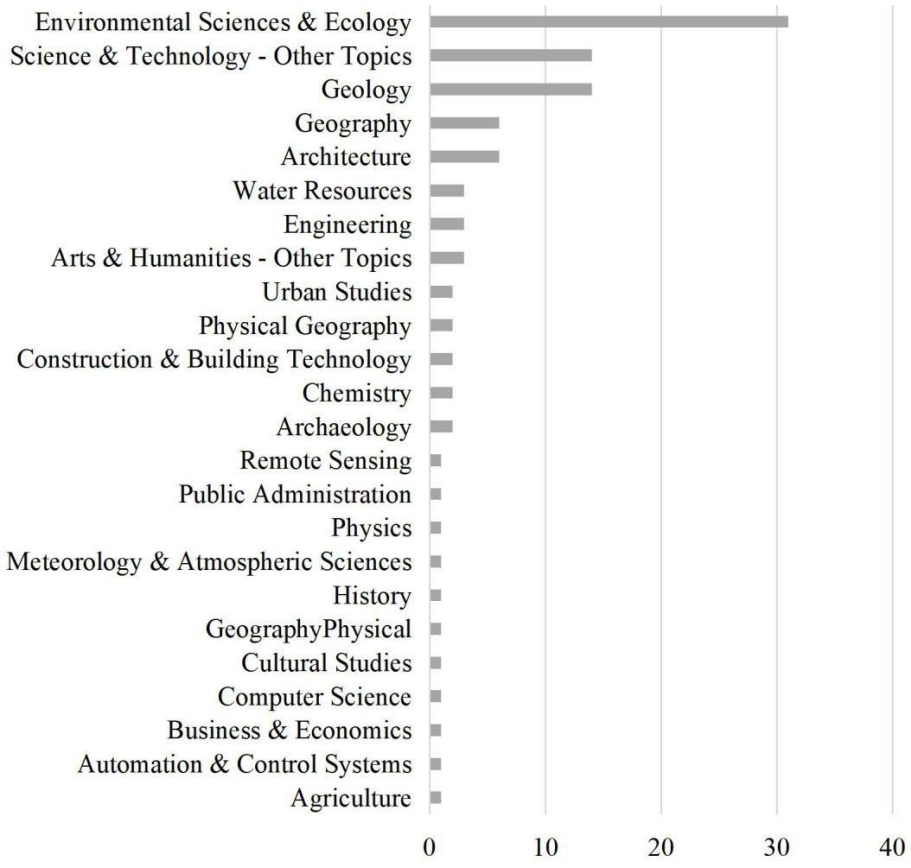

Figure 3. Discipline classification.

3.2.2. Keyword Clustering and Trending Topics

Keyword-based topic identification was facilitated by bibliometric software Vosviewer (Figure 4). Post data cleaning, 22 keywords were clustered into five groups. Cluster 1 (red) emphasizes flood vulnerability in historical urban landscapes, with GIS standing out as a key methodology. Cluster 2 (blue) focuses on climate change, while Cluster 3 (yellow) explores modeling at different scales. Cluster 4 (purple) ties impacts to climate change, and cluster 5 (green) concentrates on flood and risk within heritage urban areas, spotlighting resilience and adaptation strategies.

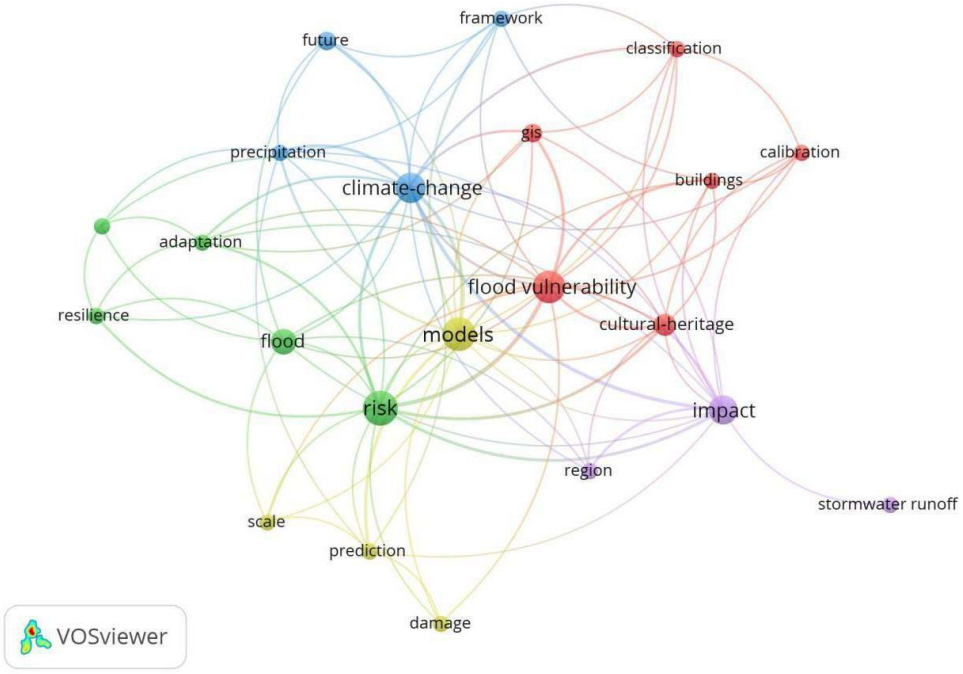

Figure 4. The network visualization.

4. Current States and Prospects

4.1. Urban flooding Studies in Heritage Areas

4.1.1. Flood Mapping as a Prevalent Research Approach

Over the decades, flood risk mapping has evolved into an essential analysis instrument, enabling researchers to examine flood hazard impacts on environmental-physical and socio-economic parameters. Urban flooding hazard and vulnerability assessment constitute two primary methodologies for urban flooding risk evaluation. Initial flood risk mapping was typically confined to the natural and physical dimensions of risk, with an evolution toward integrated methodologies over time. These incorporate geographical information system-analytic hierarchy process (GIS-AHP) methods, commonly employed for global flood risk area identification[10].

Table 1 showcases flood hazard mapping techniques and vulnerability analyses in heritage cities across numerous nations. Researchers often consider topographical and hydrometeorological attributes, including rainfall volume, slope, flood frequency, elevation, and land use, when assessing future flood risks. Vulnerability indicators have also been implemented to examine economic and social facets.

In Asia and Europe, respective researchers developed indicator-based approaches for flood vulnerability assessment in Vietnam's ancient heritage city of Hoi An and combined nature-based solutions into a spatial multi-criteria evaluation to counter urban pluvial flooding in Florence, Italy[11,12]. Australia introduced a cultural heritage risk index for climate change-related risks[13].

Several authors have focused on the evaluation of historic buildings' susceptibility to urban flooding in heritage cities, implementing an array of assessment approaches. Thus, flood vulnerability indicators become crucial to anticipate potential damage, prioritize conservation areas, and guide decision-makers toward effective strategies for community resilience.

Table 1. Flood Hazard Assessment Studies Focusing on Heritage Cities.

Title	Susceptibility indicator	Vulnerability indicator	Method
Flood hazard threat on cultural heritage in the town of Genoa (Italy)[14]	Drainage network, the frequency of flooding episodes	-	Data Collection of the past flood events; GIS
Geological hazards in the UNESCO world heritage sites of the UK: From the global to the local scale perspective[15]	Fluvial, coastal and groundwater flooding	-	Review
Flood hazard mapping and assessment on the Angkor world heritage site, Cambodia[16]	Flood affected frequency, absolute elevation, elevation standard deviation, drainage density	-	GIS-AHP method; The Delphi method; Synthetic aperture radar (SAR) data
Flood susceptibility analysis of the cultural heritage in the Sucevita catchment (Romania)[17]	Slope, profile curvature, soil texture, land-use, lithology	-	GIS-AHP method; The Random Consistency Index
Indicator-based approach for flood vulnerability assessment in ancient heritage city of Hoi An, central region of Vietnam[11]	Average elevation of terrain, average distance to the mainstream of Thu Bon River, percentage of fooded area, average foodwater depth, flood frequency, build-up area, agricultural and fishery area	Population density, number of private business, Number of historical sites, poor/near poor households, kindergarten pupils, elderly and disable people, Unemployment rate, average income, number of people join in trainings, road density, organizations in disaster prevention , historical preservation, number of health services	GIS-AHP method
AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand[18]	Daily maximum rainfall (mm/d), flood in past year (yrs), slope of the area (%), elevation (m), drainage density (km/km^2), watershed area (km^2), run-off (m^3), road density (km/km^2), land-use	Coordination between stakeholders, knowledge exchange, public participation, financial management, rescue system, lesson learned from past events	GIS-AHP method; Questionnaire survey
Planning Nature Based Solutions against urban pluvial flooding in	Imperviousness (IMP), slope (S), hydrologic soil group	Social vulnerability index(ability to react, presence of foreigners,	GIS-AHP method; Spatial

heritage cities: A spatial multi criteria approach for the city of Florence (Italy)[12]	(HSG), density of sewer system (DSS)	access to resources, family composition, population and housing, education	Multi-Criter ia Evaluation (SMCE)
A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia)[13]	Hazard location, probability of occurrence, magnitude, duration	Structural condition, heritage fabric condition (external), historical damage	The Cultural Heritage Risk Index (CHRI)
An integrated approach for assessing flood risk in historic city centres[8]	Flood extent, velocity and depth	Only focus on the building index to flood inundation.	HEC-RAS; QGIS; Equation Risk matrix
Flood risk assessment of heritage building in Semarang City[19]	Historical height of flood inundation	The distance of the building to the river, the area of the affected building, the building structure material, the age of the building, the height of the building from the road, the condition of the building (maintenance), sustainability management	Formula
Flood vulnerability and risk assessment of urban traditional buildings in a heritage district of Kuala Lumpur, Malaysia[20]	Rainfall intensity and river flows	Number of storeys, footprint, height of base, height of stilts, height of door, height of window, building fabric, building condition, drainage system, surface condition, prevention features	2-D hydraulic modelling using JBA's proprietary JFlow® software a digital terrain model (DTM)

4.1.2. Nature-Based Solutions in Urban Heritage Areas

Nature-based Solutions (NbS), strategies integrating ecosystem services to tackle societal issues under the specter of climate change, emerged from the 2012 United Nations Conference on Sustainable Development[21]. NbS has gradually ascended as an essential mechanism promoting global sustainability. Numerous studies have sought to ascertain the efficacy of NbS for managing urban stormwater from diverse perspectives. Keeler et al.[22] for example, constructed a three-dimensional framework encompassing social, ecological, and technological factors to optimize NbS, highlighting their integral role in urban stormwater management.

Conversely, research on NbS application in urban heritage areas remains sparse, likely attributed to NbS's recent evolution. Most studies have adopted a broader perspective, emphasizing climate change studies. Other remarkable endeavors encompass a systematic review[23] and meta-analysis aimed at gauging urban cultural heritage in the ambit of climate change, along with Tianchen Dai's research[6] which masterfully interweaves the notions of climate change and historic urban landscape. Given their inherent vulnerability to natural hazards, historic cities present unique challenges for flood mitigation, emphasizing the potential for NbS as a valuable research direction. Tommaso Pacetti's study, demonstrating the application of a bifurcated methodology for NbS in an Italian heritage city to address urban stormwater issues, deserves special mention[12].

In addition, scholars have delineated their NBS research across various scales, from extensive urban areas to individual heritage buildings. Notable studies[24,25]include examination of NBS performance under varying scenarios and a review on NBS application in historic architectures. The latter accentuated the complexities and obstacles of embedding NBS strategies in heritage urban design, underscoring the need for a thoughtful approach to heritage city protection.

4.1.3. Case Study Analysis

Italy Renowned for its extensive cultural, historical, and artistic heritage, Italy plays a pivotal role in urban flooding management studies, with a broad array of research scales. The majority of these studies (50%) target urban scale, indicating the critical nature of flood mitigation in heritage cities. Researchers have conducted spatial analysis and mapping studies in heritage cities like Rome, Venice, and Florence. Of particular note is Tommaso Pacetti's application of nature-based solutions in Florence, an exemplar of innovative strategies at the intersection of historic urban landscapes and urban flooding mitigation[12]. Equally significant is Cristina Di Salvo's pluvial flood hazard mapping in Rome, underscoring the practicality of flood risk maps for hazard appraisal and emergency planning[26]. Studies on smaller scales largely concentrated on risk assessment.

Ayutthaya, Thailand Ayutthaya, a low-lying historical city in central Thailand, is subjected to frequent flooding. Its authorities have prioritized urban flooding studies and the protection of cultural heritage sites from flood damage. Research in Ayutthaya involves a holistic approach, combining quantitative and qualitative methodologies to evaluate urban flooding risks, emphasizing public participation's crucial role in heritage city flood management. Contemporary research methodologies, such as Structure from Motion (SfM) remote sensing technology, have been utilized for extracting flood watermarks to improve urban flooding simulation. Similarly, the Analytic Hierarchy Process-Geographic Information Systems (AHP-GIS) method has been employed to evaluate flood hazard spatial distribution, and recent studies have incorporated neural network methods to assess flood susceptibility. Consequently, these advancements underscore the potential benefits of novel technologies for future urban design and heritage building conservation.

4.2. Future Priorities

An increase in public understanding and participation in urban stormwater management, coupled with an elevated sense of societal responsibility, can foster a communal endeavor towards mitigating urban flooding issues in historic cities. Regarding future work in this sphere, several salient recommendations are proposed. Foremost, fostering interdisciplinary communication is paramount, considering that successful urban development necessitates the amalgamation of varied disciplines. It is incumbent upon stakeholders from diverse sectors to contribute to policy formulation, promoting a comprehensive approach to the investigation of historic urban landscapes and urban stormwater management. Concurrently, an emphasis on leveraging nature-based solutions emerges as a pivotal strategy. By scrutinizing distinctive environmental conditions of historical cities - from topography and land use to street layouts - innovative stormwater management methods, such as smart urban wetlands, green roof gardens, and rain gardens, can be introduced. These endeavors strive to strike a balance between urban flooding countermeasures and the preservation of historical cityscapes. Augmenting public participation forms another crucial element of the suggested future trajectory. Through the amplification of public understanding and active involvement in urban stormwater management, a robust sense of collective responsibility can be cultivated, fostering a community-wide effort towards mitigating urban flooding issues in historic cities. Finally, promoting diverse, inclusive, and interdisciplinary research themes is suggested. These themes lay the groundwork for a systemic approach, buttressing heritage urban landscape resilience. To this end, establishing an international database of practical case studies, comprising cities of exceptional cultural value engaged in urban stormwater management adaptation, is deemed instrumental.

5. Conclusion

A plethora of extant scholarly discourse explores the theories, methodologies, frameworks, strategies, and case studies pertaining to urban stormwater management and historical city management as separate themes. Notwithstanding, a systematic review fusing these themes remains elusive. This present review delineates the nuanced intersection of urban flooding issue research and historical urban landscape studies. The primary intent of this paper is to underscore the pivotal role of urban flooding mitigation in the study of historical urban landscapes, fostering the integration of antecedent successful practices into future urban planning. This objective aligns with UNESCO's 2011 "Historic Urban Landscape Approach",

advocating the preservation and management of historic urban landscapes. This recommendation accentuates the value of historic cities, repositories of immense heritage value in global history, positing them as exemplary models for ameliorating urban challenges and spurring future urban evolution.

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