

## SUSTAINABLE DEVELOPMENT OF HISTORIC CITIES: FLOOD MANAGEMENT STRATEGIES AND RESILIENCE

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### **Abstract**

*Floods are among the most catastrophic events for contemporary cities, impacting populations, economy and infrastructure while highlighting the urgent need for mitigation and preservation strategies. For historic cities with significant cultural heritage, the need for preservation is even more critical.*

*This paper aims to examine flood risk management strategies for historic cities, which are highly vulnerable to natural phenomena such as floods that are increasing in frequency and intensity due to factors such as climate change and urbanization. Through a systematic literature review of 70 case studies and relevant theoretical contributions, it categorizes the key causes of flood risk into natural, anthropogenic, endogenous, and systemic factors, emphasizing the complex interplay among them. The paper then evaluates a broad range of flood risk management strategies, including structural and technological solutions, policy integration, blue-green infrastructure, and community-based approaches.*

*It highlights how successful resilience planning requires not only technical innovation but also cross-sectoral cooperation, local knowledge, and inclusive governance. The findings advocate for a multidimensional, place-based approach that balances risk mitigation with the preservation of cultural identity, supporting sustainable development in heritage-rich cities facing increasing climate-related threats.*

**Key words:** *Historic Cities, Flood Risk Management, Cultural Heritage, Climate Change, UNESCO World Heritage Sites*

### **The Rising Threat of Floods in Heritage Urban Landscapes**

Floods have been one among the most devastating natural hazards, that affect contemporary cities on multiple levels: population, economy and facilities. In the case of historic cities, urban areas that are recognized for their historical, cultural, and architectural value, the threat is even greater. Those cities typically contain well-preserved heritage sites, such as ancient monuments, historic buildings, and cultural landscapes, reflecting their historical importance, that are particularly vulnerable during and after the floods. Last decades, the intensity and frequency of those flood phenomena have been increased due to climate change, and rapid urbanization that has led to an artificialization of the natural ground. This situation requires modern, innovative techniques of preservation and restoration for both historic and non-historic cities.

This paper explores management strategies for flood risk in historic cities, in order to highlight best practices and technologies that could ensure sustainable development and adaptation to this increasing threat while preserving the cultural identity of those places.

**Literature Review and Data Analysis: Methodological Approach, Case Selection, and Geographic Trends**

The data collection was conducted using various academic publishing platforms, including MDPI, ScienceDirect, Taylor & Francis Online). Keywords such as “historic cities” and “flood risk”, were used to identify studies that explore the concept of historic cities and flooding.

The following criteria were applied in order to include the papers in the meta-analysis: thematic relevance was the primary factor, with priority given to studies focusing on vulnerability, impacts, and flood risk management in historic areas or cities. Language and availability were also key considerations, as only papers that were fully accessible for review and written in English were selected to ensure consistency in the analysis.

According to these criteria, a sample of 70 cases was selected for the state-of-the-art analysis.

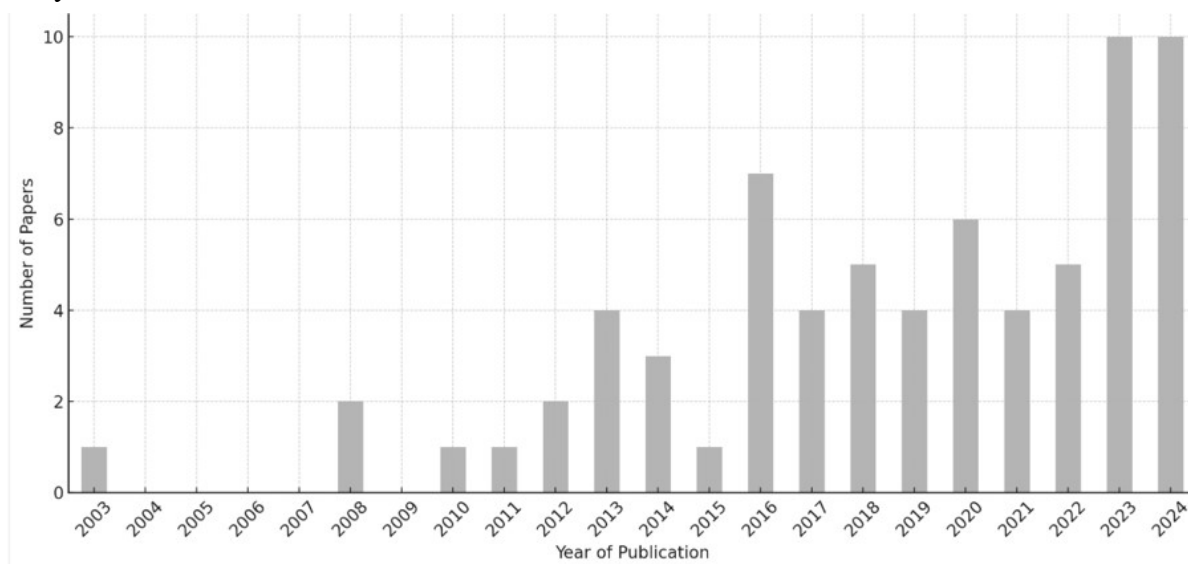


Table 1 Number of analysed papers per year (2003-2024)

As shown in Table 1, the number of analyzed published papers per year shows a clear increase in recent years, particularly over the last decade. This trend is mainly attributed to the overall rise in academic publications across research databases, driven by the growing frequency and severity of flood events due to climate change. At the same time, the urgency to protect and preserve cultural heritage has become more urgent and well known. Additionally, technological advancements in the past decades have become indispensable tools for flood risk management, enabling more accurate analyses and assessments. As a result, more recent publications are often more relevant to current challenges and methodologies, which justifies their prioritization in this review.

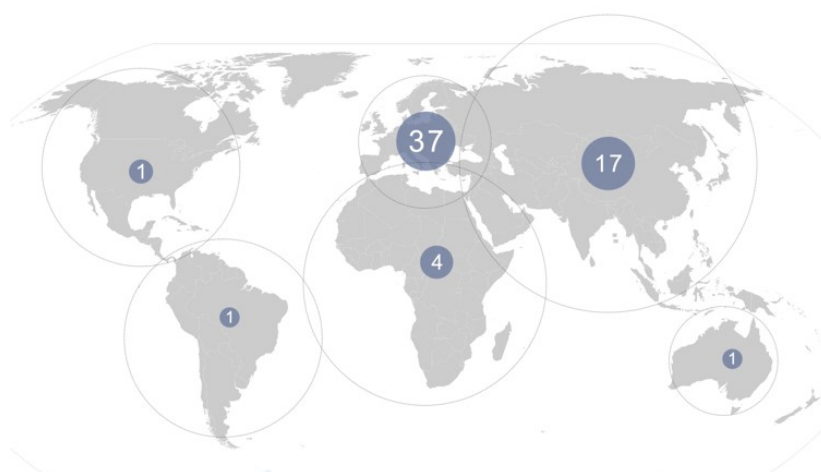
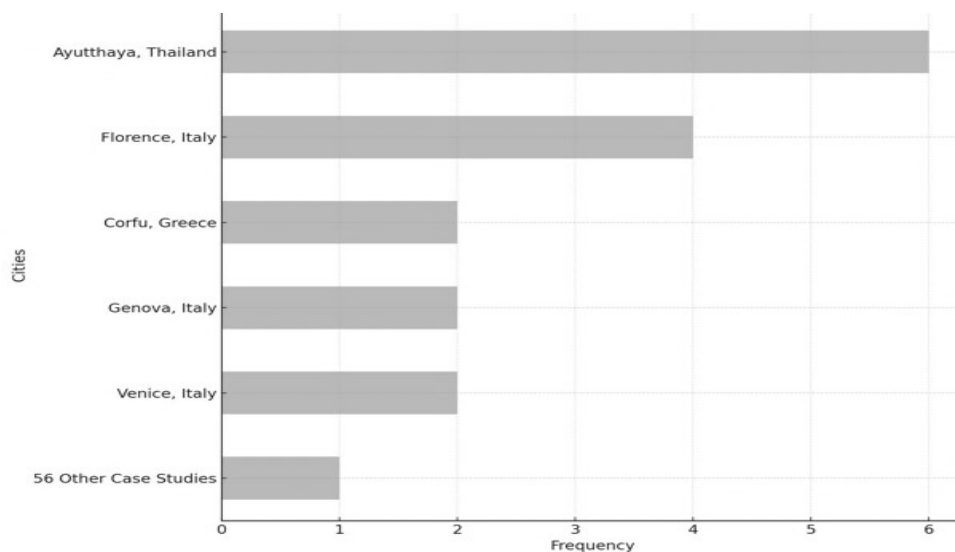


Table 2 Most frequently examined sites

Table 3 Geographic distribution of case studies

The vast majority of the reviewed papers -87% (61 out of 70)- focus on specific case studies, while the remaining publications adopt a more general, theoretical approach to flood risk and heritage preservation, without reference to particular locations. The most frequently examined sites (Table 2) include Ayutthaya in Thailand (6 mentions), Florence in Italy (4 mentions), and Venice, Genoa (Italy), and Corfu (Greece) with 2 mentions each.

Among the selected case studies, nearly half (31 papers) focus on areas that are either entirely UNESCO World Heritage Sites or include such sites. More specifically, 18 papers examine cities whose historic centers are officially named as UNESCO World Heritage Sites (Florence, Rome, Krakow, Prague, and more), while 13 analyze monuments or areas that belongs to UNESCO-listed sites (Athens, Seville, Valencia, Nicosia, and more).

Regarding geographic distribution (Table 3), the 61 case study papers show a notable concentration in Europe (37 papers), followed by Asia (17 papers). The remaining publications are spread across other continents, with each contributing between 1 and 4 papers. This reflects probably the high density of ancient cities with rich architectural, cultural, and archaeological heritage in Europe and Asia. It also indicates a stronger governmental and institutional prioritization in these regions toward the preservation of cultural heritage, supported by broader access to research data, often through open-access platforms. Additionally, many European historic cities were originally established near rivers or coastal

zones for strategic trade and defense purposes, which today contributes to their heightened vulnerability to climate change-related flood events.

### Flood Risk in Historic Cities: A Literature-Based Categorization of Vulnerability Factors

Historic cities are increasingly facing flood risks due to a combination of internal and external factors. Table 4 presents the most frequently cited factors across the analyzed papers, with the most common being increased rainfall, poor or insufficient urban planning, outdated infrastructure and drainage systems, natural topography, and urban expansion or high-density development.

For the purposes of this analysis, the paper categorizes these factors into four main groups: natural, endogenous, anthropogenic, and systemic. While examples of each category appear in the majority of the reviewed literature, it is the interaction and overlap among them that truly defines the current flood risk in historic urban environments.

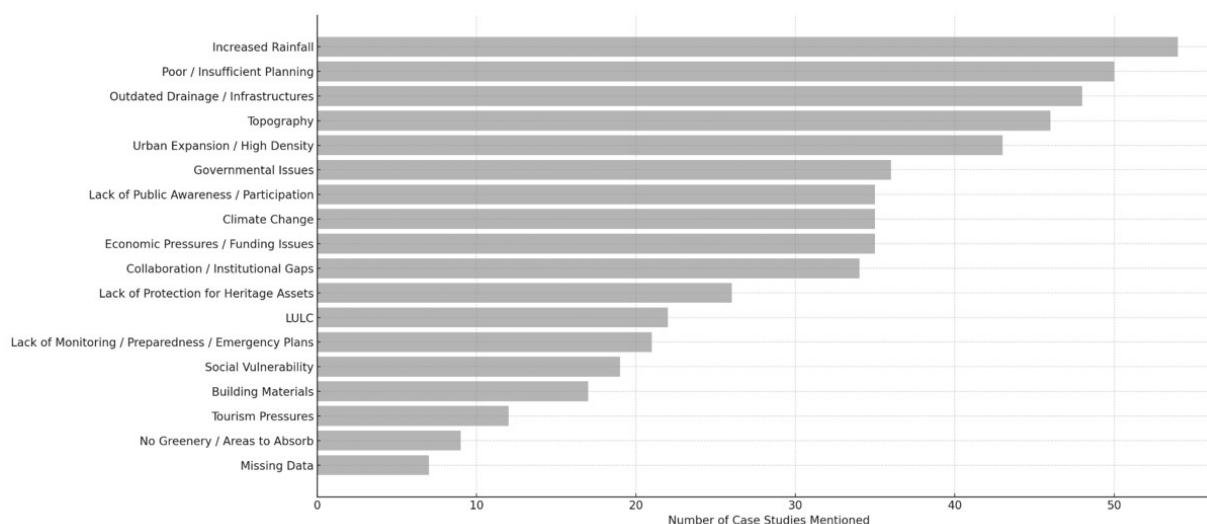


Table 4 Mentions of Flood-Related Factors Across Case Studies

#### Natural factors: Climate Change and Environmental Conditions

Natural factors refer to environmental and climatic conditions beyond human control that contribute to flood risk—such as heavy rainfall, sea-level rise, and geological processes. Among the 70 reviewed papers, 57 identify increased rainfall as a key factor of flood vulnerability in historic cities.

A major contributor to these natural hazards is climate change, which is intensifying both the frequency and severity of extreme weather events. It is cited in 34 papers as a main factor behind more intense rainfall patterns and long heatwaves. These heatwaves dry out the soil, reducing its ability to absorb water and thereby increasing surface runoff during heavy rain event. (Brokerhof et al., 2023; Cisse et al., 2022; Gizzi and Porrini, 2017; Porębska et al., 2019)

Climate change also provokes rising sea levels, due to the thermal expansion of seawater and melting polar ice caps. According to the Intergovernmental Panel on Climate Change (IPCC), global mean sea level rose by 17 cm over the twentieth century and keeps rising at an accelerating rate. (IPCC, 2022) This rise threatens places and World Heritage sites that were not previously vulnerable and can also raise river levels -such as the Thames in London or the

Liffey in Dublin)- leading to significant loss and transformation of their cultural landscapes (Gruber, 2008; Nicolini, 2024; Perez-Alvaro, 2016)

Venice is an interesting example where natural factors are the primary cause of flooding, as the city was built at low elevation within a shallow lagoon, making it especially susceptible to high water events (locally called ‘acqua alta’). (Balan and Bordelon, 2021; Giupponi et al., 2024; Gruber, 2008; Indirli et al., 2014) Despite centuries of engineering efforts to manage acqua alta, Venice still faces severe flood risks due to rising sea levels (from climate change-driven thermal expansion and melting ice), compounded by local subsidence caused by tectonic activity, sediment compaction, and past groundwater extraction.

Similarly, New Orleans is naturally vulnerable to flood events due to its natural position of low altitude near the Mississippi River and the Gulf of Mexico. It is exposed to rising sea levels, land subsidence, and coastal erosion, which together amplify its flood risk. (Balan and Bordelon, 2021; Genova et al., 2020).

### **Anthropogenic Factors: Urbanization and Poor Water Management**

Anthropogenic factors refer to those related to human activities or decisions that have directly or indirectly increased flood risk over the years. Urbanization and land use changes have significantly affected the vulnerability of historic cities to flood events.

Urbanization is considered as a critical factor in many papers (identified in 42 papers), as it often leads to reduced green areas that would normally absorb rainwater (mentioned in 9 papers). More specifically, many studies underline how the artificialization of zones has often led to the loss of natural land barriers -such as wetlands, mangroves, or floodplains- which previously helped absorb or slow down floodwaters. (Balan and Bordelon, 2021; Thanvisitthpon, 2019) In Florence the growth of impervious surfaces because of artificialization reduced the natural infiltration and increased the surface runoff. (Caporali et al., 2023)

Poor or insufficient urban planning (mentioned in 50 papers) -such as building in vulnerable zones, illegal construction, or informal settlements- and changes in land use (mentioned in 24 papers) have also been identified as factors that have increased the urban vulnerability. For instance, in Cesky Krumlov, a historic medieval town in the Czech Republic, ground floors were historically used for service spaces to minimize flood losses, but today they are occupied by shops, hotels, and restaurants, making them more vulnerable to damage. (Nedvědová, 2013)

Canalizations and river modifications, initially intended to reduce flood impacts and regulate water flow, were often poorly studied or underestimated, sometimes leading to the opposite effect. A clear example of how human interventions increased flood risk can be found in Poland. In the 19th century, following severe floods with high casualties, engineers artificially narrowed the Vistula River by 40% and altered its course to protect urban areas. (Cyberski et al., 2006; Porębska et al., 2019; Starkel, 1982) However, these changes reduced the river’s natural flood-absorbing capacity and increased flood risk, putting Krakow’s historic UNESCO-listed center at greater risk today. According to Grela (2023), the false sense of security created by embankments and river modifications led to dense urban development in formerly flood-prone areas of Krakow. His research shows that today, over 32% of the population—more than 250,000 people—are at risk in the event of dam failures or extreme flood scenarios. (Grela, 2023). In Genova, Italy, the modification of natural streams and their transformation into sewers and hydraulic structures, during the last two centuries has significantly increased flood risk and is now considered the primary cause of flooding in the city. (Lanza, 2003)

In the context of heritage sites, there are cases where protective measures are insufficient or poorly maintained. The absence of flood defense infrastructure leaves sites vulnerable to inundation during extreme weather events. (Cuca and Barazzetti, 2018; Forino et al., 2016; Garrote et al., 2020) Tourism pressure also affects the implementation of protective measures, as historic urban fabric is often repurposed for tourism without consideration for climate-related risks. In many cases, preservation requirements driven by heritage or tourism value can limit the possibility of introducing effective flood-proofing interventions. (Bianco and Montedoro, 2023; Pakdeeburee et al., 2011)

### **Endogenous factors: Inherited Urban Form, Infrastructure, and Material Vulnerabilities**

Endogenous are the factors refer to the internal characteristics of a city, including its socio-spatial structure - such as unequal development, marginalization and social vulnerability (19 papers), outdated infrastructure and drainage system (59 papers), topography (mentioned in 49 papers) and materials used in traditional construction (16 papers). These factors developed over centuries and are not necessarily the result of recent human decisions, but rather reflect the historical and spatial evolution of a city.

The drainage system plays a pivotal role into the flood resilience In many historic cities, drainage infrastructures were designed for earlier urban scales and climatic conditions and cannot withstand today's increased rainfall intensity and urbanization. Approximately 70% of the reviewed papers identify old infrastructure and drainage systems as key flood risk factors in contemporary historic cities. For example, the drainage system at the Roman Agora of Athens in Greece, once pioneering and functional, is now ineffective because it is old, partially non-functional, limited in capacity and overwhelmed by the increased runoff due to climate change. (Iliopoulou et al., 2023) A similar situation is observed in Corfu, Greece, where the historic drainage system dates back to the Venetian era, was not designed to accommodate modern extreme weather events (Dimitriou, 2022; Maistrrou et al., 2023).

Historic cities, from Rethymnon in Greece to York in the United Kingdom, or the temples of Bagan in Myanmar, often used locally available materials for construction that are highly susceptible to water damage. These include soft calcareous stones, porous masonry, earth-based materials, limestone, and timber (Chitty and Sprega, 2018; Li, 2024; Ravankhah et al., 2019; Stephenson and D'Ayala, 2014)

The organic growth and morphology of the heritage cities, also affect their vulnerability. **Narrow streets**, a common urban language in heritage sites due to their historical urban benefits, today directly affects how water flows, drains, and accumulates within the city, decreasing the runoff and leave little room for structural adaptations.(Dimitriou, 2022; Maistrrou et al., 2023).

In addition to physical characteristics, socio-spatial factors also shape flood risk. Several articles highlight that areas with vulnerable populations—such as the elderly—or the presence of critical infrastructure, like health facilities, increase the level of risk. (Apro et al., 2016; Di Salvo et al., 2018; Foudi et al., 2015; Gandini et al., 2017; Su et al., 2024)

Quito is a strong example of a city where flood vulnerability stems primarily from endogenous factors. Located in a steep Andean valley, the city's natural topography direct intense rainfall straight into its urban fabric, heightening the risk of flash floods. While some anthropogenic changes—such as the covering of natural ravines during urban expansion—have worsened runoff, the core drivers of Quito's flood risk lie in its internal characteristics. These include its historical development pattern, dense urban form with narrow streets, and the use of traditional building materials like adobe and timber, that are especially vulnerable to water damage. These features, shaped over centuries, were not designed for extreme

rainfalls, due to climate change conditions. The big 2022 flood, led to many casualties and economic losses, revealed how this inherited urban structure and setting contribute to the city's fragility in the face of increasingly intense weather events. (Trizio et al., 2022; UNESCO World Heritage, 2024)

### **Systemic factors: Governance, Policy Gaps, and Institutional Failures**

Systemic factors include the broader political, economic, and governance-related issues that affect the decision-making in flood management. It is about the lack of sufficient long term management plans against flood risk, the cooperation among the stakeholders or the economic structures and funding projects for infrastructure maintenance.

35 papers highlight how governmental issues, such as politician collusion, law system or regulations are playing a pivotal role into the flood risk management as main factors of flood risk response, while others explain the importance of missing important data (7 papers), or slow or even nonexistent monitor and early-warning systems or emergency plans (21 papers) while others explain the importance of national fundings or economic pressures in the risk management plans (34 papers).

Others point to the lack of education; including its capacity to understand, prepare for, and respond to risks like floods as a major systemic factor that affect emergency plans today. (Ginzarly et al., 2024; Munpa et al., 2024; Potdar and Verbakel, 2022)

A widely cited example of systemic failures in flood management is that of New Orleans during Hurricane Katrina in 2005. Despite repeated warnings about the city's vulnerability, government agencies failed to act in advance. The levee system, which was intended to be completed in 13 years at a projected cost of \$90 million, ultimately took 40 years and cost nearly \$700 million, and yet it remained incomplete at the time of the disaster. When the hurricane struck, poorly designed and maintained levees failed catastrophically, specifically, 170 miles out of 350 miles of protection, were breached or destroyed. Simultaneously, disaster response between the U.S. Army Corps of Engineers (USACE), local levee boards, and state authorities was slow and uncoordinated, leaving many residents—especially in low-income areas—without evacuation assistance. Critically, the USACE relied on outdated storm data (the 1959 Standard Project Hurricane), ignoring more recent forecasts and expert recommendations. (Genova et al., 2020; Heerden et al., 2006)

### **An Example of All Factors**

Although in most cases it is not only one category of factors responsible for the increased flood events in the historic areas, rather the combination of them. Most flood risks are due to multiple overlapping factors, as seen in Ayutthaya, a UNESCO World Heritage Site in Thailand. In that case study, flood risk is due to a combination of natural geography, historical urban design, human-induced changes, and systemic governance failures:

Naturally, the city is located on a low-lying floodplain surrounded by three rivers -the Chao Phraya River, the Lopburi River and the Pa Sak River- making it highly vulnerable to seasonal flooding. The basin area is flat, with an average elevation of 1 to 2 m above mean sea level with certain even lowered down to sea level due to land subsidence. (Natural Factors). Human activities such as rapid urbanization, deforestation, and river modifications have reduced natural water absorption, increasing flood risk in the area. Also, the pressure from tourism has led to more construction and paved areas around the heritage sites, which makes it harder for water to drain and increases the risk of flooding. (Anthropogenic Factors). Historic temples were made of vulnerable materials like laterite, stucco, and wood, so they currently suffer severe water damage during floods. (Endogenous Factors) (Daungthima and

Kazunori, 2013; Pakdeeburee et al., 2011; Thanvisitthpon, 2019) The 2011 floods have been devastating for a large number of cultural heritage sites in the area (including museums, temples, archaeological sites, cultural landscapes, and historic landmarks) leading the governance to consider for new flood policies. The governmental polices included flood walls, levees, and an improved drainage system that managed to protect the UNESCO site sufficiently, but ultimately, the measures redirected the floodwaters to surrounding peri-urban areas like Bang Ban, Phak Hai, and Sena, worsening flooding there. (Munpa et al., 2024; Thanvisitthpon, 2019) Finally, a lack of public participation and sufficient coordination between stakeholders, have been continually highlighted in various articles as a critical factor for flood resilience. (Systemic Factors) (Huyakorn et al., 2012; Pakdeeburee et al., 2011; Thanvisitthpon, 2019)

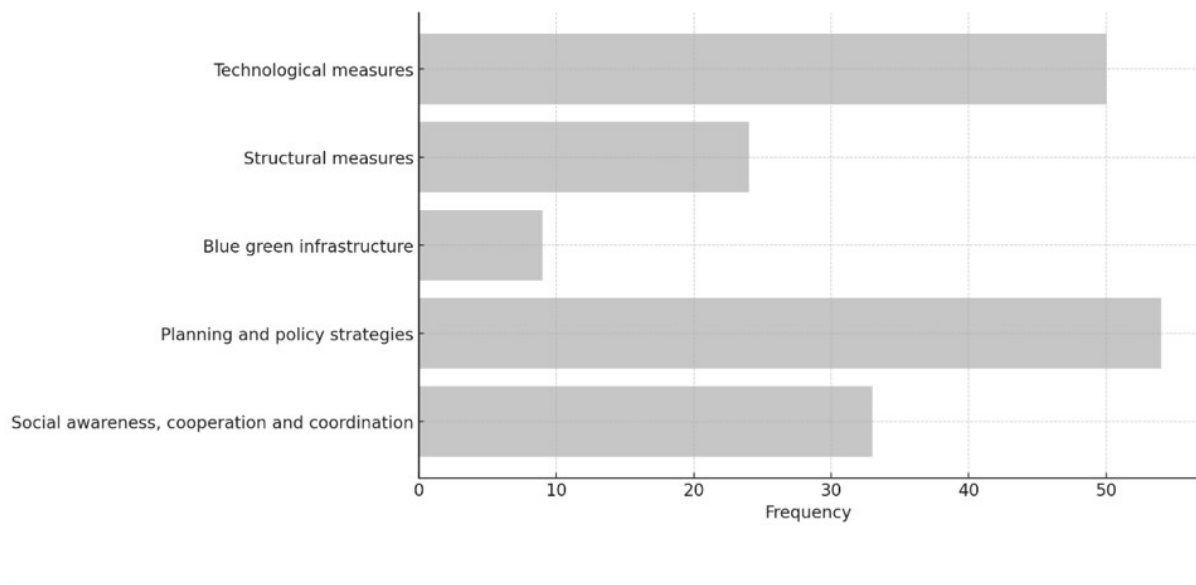
**Toward Resilience: Strategies for Flood Risk Management in Historic Cities**

Flood risk management in historic cities is particularly challenging, as these areas possess high cultural value and are especially vulnerable to natural disasters. Additionally, the implementation of conventional flood protection solutions is often difficult, as they may compromise the historic character of the sites.

The literature typically addresses these challenges through either targeted strategies or holistic approaches. Targeted strategies focus on mitigating specific and immediate problems, such as the protection of critical infrastructure and heritage monuments. In contrast, holistic approaches aim for integrated management, considering cultural, social, environmental, and economic dimensions.

The choice between these approaches depends on local conditions, the nature of the risks, and the availability of resources. Many studies advocate for a combined application of both strategies to achieve the most effective results.

This paper categorizes flood risk management solutions into five main groups: Structural Measures, Technological Measures, Blue-Green Infrastructure, Planning and Policy Strategies, and Social Awareness, Cooperation, and Coordination.



*Table 5 Distribution of Categories in Flood Resilience Solutions*

### **Structural Measures: Physical Interventions**

Structural measures as proposed solutions for flood risk mitigation include physical infrastructure at the urban level -such as flood barriers, dikes, retention basins, or upgrades to drainage systems- and building-level measures -such as reinforcements, flood doors, and building-specific adaptations.

24 out of the 70 papers included these types of solutions to address flood risk. At least half of them underlined the importance of reinforcing and upgrading the drainage systems in cities to manage large volumes of water, surface runoff, and reduce water accumulation. While some papers propose improvements to the existing drainage systems (Jia et al., 2023; Maistrrou et al., 2023; Sesana et al., 2018), others propose alternative approaches. For example, Lanza (2003) suggested the rehabilitation of Genoa's old cisterns as temporary stormwater storage tanks. This would transform the cisterns into a new, functional component of the drainage system, effectively integrating historic infrastructure into a modern flood control plan. (Brandolini et al., 2018; Lanza, 2003)

The construction of dams and levees is also sometimes recommended in areas of high flood risk. A successful project is the Bilancino Dam in Florence, built after the devastating 1966 floods to regulate water flows from the Mugello basin, that has significantly contributed to the reduction of flood risks in the area. (Coli et al., 2013) On the other hand, research on the MoSE dam system in Venice—which has protected the city from sea level rise for several years—considers it economically successful in the short to medium term, but its long-term viability is uncertain due to ongoing climate change. (Giupponi et al., 2024; Sesana et al., 2018)

At a building level, structural reinforcements are frequently proposed in the literature. In Algira, Spain, it was recommended to reinforce earthen buildings with compatible materials to improve their resistance to water infiltration. (Trizio et al., 2020) In Tomar, Portugal, cost-effective retrofitting measures like flood skirts and replastering were assessed through cost-benefit analysis. (Davis et al., 2023) Keller et al. (2016) also proposed technical reinforcements using natural, eco-friendly materials -such as insulating plasters or reinforced retaining walls with gabions- to enhance energy efficiency, structural stability, and climate resilience, while preserving heritage (Keller et al., 2017) A more extreme solution was proposed by Kurniawati et al. (2020) in a flood prone city in Indonesia, suggesting the **elevation of heritage buildings and critical infrastructure**. (Kurniawati et al., 2020)

Soft capping is another technique that helps preventing flood damage and reduce erosion by using natural, permeable materials -such as soil and vegetation- on the surfaces of the sites. These materials slow runoff, increase water absorption, and gradually reduce erosion, making them a sustainable alternative to traditional materials. Soft capping trials conducted in case studies in Yorkshire and Oxford, showing promising results. However, in some cases, the decision to remove vegetation from historic walls led to local controversy, as some community members perceived the removal of plant growth as neglect rather than a conservation effort. (Hanssen and Viles, 2014; Richards et al., 2024)

### **Technological Measures: The Role of Digital Tools, Monitoring, and Early-Warning**

That category includes techniques such as GIS (Geographic Information System) tools, flood hazard mapping and risk simulation modeling, remote sensing or satellite images, early warning, and real-time monitoring systems. The evolution of technology and the accuracy and effectiveness of simulations in today's flood management led 50 out of 70 papers to propose these types of solutions.

Early warning systems and monitoring appeared in at least 25 case studies as possible solutions. Monitoring is used to continuously observe and collect data (such as river levels, rainfall, soil moisture, flow rates), while early warning is responsible for analyzing monitoring data, forecasting possible hazards, and issuing timely alerts to populations and authorities. (Brempong et al., 2023; Coli et al., 2013; Cuca and Agapiou, 2021; Dimitriou, 2022) Wu et al. (2024) developed an early warning system for historic districts, combining building, road, and public evacuation risk models with a 1-hour rainfall intensity index. Using real-time data, it helps protect cultural heritage through targeted warnings and preventive actions. (Wu et al., 2024) Young et al. (2021) developed a color-coded hazard matrix that provides a simple, data-driven early warning tool that links rainfall forecasts to flood risk levels (green to red). It helps authorities and communities in data-scarce cities anticipate pluvial floods and take timely action, enhancing preparedness without relying on physical infrastructure. (Young et al., 2021)

GIS tools were used in one-third of the papers to produce flood hazard and risk maps, explore flood-vulnerable zones, or model future scenarios. For instance, KALOGEROPOULOS et al. (2023) conducted a comprehensive study based on hydrological models using GIS, Digital Elevation Model (DEM), Remote Sensing (RS), Rainfall-Runoff Modelling, and Synthetic Unit Hydrograph (SUH) Development. The goal was to highlight flood-prone areas near the archaeological site of Ancient Olympia, in order to identify vulnerable zones and understand water flow behavior under different rainfall scenarios. (Kalogeropoulos et al., 2023)

AI and machine learning techniques, such as Artificial Neural Networks (ANNs), Machine Learning, Bayesian networks, and Metaheuristics, are newer and continuously evolving approaches proposed in recent papers to deal with missing or complex data, identify patterns, and calibrate the vulnerability of cities to flood events. (Ferreira and Ramírez Eudave, 2022; Grau-Bove et al., 2024)

While technological solutions can offer cost-efficient and rapid means of processing large volumes of data, they still have limitations and risk promoting a purely technical approach that may fail to address the complex, multidimensional challenges of heritage cities in urban environments.

### **Planning and Policy Strategies: Integrating Heritage, Regulation, and Risk Management**

These types of solutions are the most common among the papers, found in at least 54 of them. They include Integrated Management Plan, regulatory framework and tourism impact management.

Integrated Management Plans are at the heart of historic city management strategies. These plans integrate environmental, cultural, social, technological, and institutional parameters, creating a coherent framework that combines flood prevention with the protection and conservation of cultural and historical values. They aim to ensure the sustainability and resilience of historic areas. These plans emphasize a multi-dimensional approach, promoting collaboration between local authorities, communities, and individuals, and they typically incorporate both physical and technological solutions. The literature consistently emphasizes the need to integrate climate adaptation into heritage planning efforts. (Keller et al., 2017; Liu et al., 2019; Sesana et al., 2018) To achieve this, scholars frequently propose specific measures such as incorporating flood risk into urban planning and zoning regulations, and applying systematic inundation scenarios and modeling to support both preservation planning and emergency preparedness. (El-Behaedi and Ghoneim, 2018; Ortiz et al., 2014)

Regulatory frameworks form another important pillar of planning and policy strategies since they provide the legal, administrative, and institutional tools, necessary for the

management, protection, and sustainable development of areas affected by flood risks. Many studies underline the value of aligning national and local strategies with international regulations, like European Directives about floods, UNESCO Convention on the Protection of the World Cultural Heritage, and Historic Urban Landscape or the Intergovernmental Panel on Climate Change (IPCC) guidelines as an important solution towards flood vulnerability. (Chen et al., 2024; Chigurupati, 2008; Kutut et al., 2021; Perez-Alvaro, 2016; Sesana et al., 2018)

Tourism is a critical factor that can have both negative and positive effects on flood risk management and the sustainability of historic cities. On the one hand, tourism development often increases vulnerability by altering the social identity of cities and shifting resources away from long-term strategies like flood mitigation toward short-term economic gains. It can also intensify pressures on cultural heritage already at risk from climate-related hazards. (El-Behaedi and Ghoneim, 2018; Ortiz et al., 2014) On the other hand, tourism can also support flood risk management when it is well-regulated. The literature proposes various solutions, such as controlling the number of visitors or rerouting tour buses away from flood-prone areas. Tourism may also aid in post-flood recovery by generating financial revenue and increasing media visibility, which can attract attention and external support. (Bianco and Montedoro, 2023; Maistrrou et al., 2023; Sesana et al., 2018) Campaigns like #EnjoyRespectVenezia, launched during the International Year of Sustainable Tourism for Development, are aiming to educate tourists on responsible behavior, indirectly promoting respect for fragile, flood-prone heritage. (Balan and Bordelon, 2021) Another innovative proposal is the implementation of voluntary tourist donation systems, such as in Ayutthaya, which offer a low-cost and scalable way to engage visitors in flood protection and heritage conservation. (Sakonnakon et al., 2012)

### **Blue-Green Infrastructure: Nature-Based and Ecosystem Approaches for Urban Resilience**

This category includes softer urban solutions such as eco-corridors and buffer zones, green spaces and wetlands restoration, permeable surfaces, and adaptive urban planning strategies. While structural measures are essential for immediate flood control, blue-green infrastructure offers a more sustainable, adaptable, and environmentally friendly approach. Despite its importance, only 14% of the papers (10 papers) included this type of solution in their proposals. This limited representation is likely due to a combination of factors: historical preference for structural measures, perceived complexity and cost of implementation, limited immediate impact during flood events, integration challenges, and a lack of interdisciplinary expertise. Flood management has traditionally been led by civil engineering and hydrology disciplines, which often favor quantifiable, technical solutions.

Nature-Based Solutions (NBS) were proposed in case studies such as Florence, Corfu, Hoi An City, and Guangzhou. These include rain gardens, urban wetlands, tree planting, and permeable pavements, all designed to regulate rainwater, reduce surface runoff, and improve water infiltration. Such interventions help restoring the natural hydrological cycles within urban environments without disrupting their cultural character. (Caporali et al., 2023; Dimitriou, 2022; Nguyen et al., 2024; Su et al., 2024) Other projects are recognizing the ecosystem service values and highlight the importance of restoring wetlands and coastal areas to act as natural buffers against storm surges and flooding. (Foudi et al., 2015; Genova et al., 2020; Sesana et al., 2018)

In Romania, one proposal involved the transformation of a breached dam lake to a floating park, that could absorb floodwater while also serving recreational purposes. The park would include elevated alleys accessible after rain, wetland-compatible vegetation like reeds and rushes and terraced slopes planted with trees like willows and cypress. (Keller et al., 2017)

## **Social Awareness, Cooperation and Coordination: Engaging Communities and Promoting Shared Responsibility**

At least 33 papers, underlined the importance of community-based approaches, the public engagement and education, the integration of traditional knowledge and the participatory urban planning.

At least 33 papers underline the importance of community-based approaches, public engagement and education, the integration of traditional knowledge, and participatory urban planning.

There is a recurring question in the literature about the inclusion of local communities in planning due to their intimate knowledge of place, lived experiences of past disasters, and capacity to contribute to more context-sensitive, accepted, and sustainable solutions. (Marchetti et al., 2020; Munpa et al., 2024) Specifically, in the examples of Ayutthaya and Corfu, it is highlighted how local knowledge and traditional adaptation practices can preserve the cultural heritage of the areas. (Dimitriou, 2022; Shirvani Dastgerdi and Kheyroddin, 2023)

Inter-collaboration and cooperation are also considered critical in order to produce efficient flood risk plans while preserving the character of the cities; a flood-resilient plan should be a collaborative plan among engineers, architects, heritage specialists, local authorities, and the public. (Kumar, 2020; Kuźmiński, 2016; Nedvědová, 2013; Ortiz et al., 2016)

Education is also highlighted as a fundamental tool for building long-term resilience, not only as a means of raising awareness of flood risks and preparedness but also because it creates a shared sense of responsibility toward the protection of cultural heritage. Several studies emphasize the need for educational programs targeting both residents and decision-makers. (Daungthima and Kazunori, 2013; Maistrou et al., 2023; Pakdeeburee et al., 2011) Banfi et al. used VR glasses simulations for educational purposes to increase awareness by visualizing flood risks and the structural behavior of heritage sites in various environments. (Banfi et al., 2020)

A case study in Reading, UK, demonstrated how integrating local communities alongside technological tools improved flood risk management. The study proposed flood risk maps that combined traditional technical models with participatory insights from local residents in order to create more accurate flood risk maps. The locals were able to better identify areas that had previously flooded, drainage system failures, and social vulnerabilities (such as high-risk, low-income neighborhoods) that purely technical solutions could not evaluate or identify. (Bullen and Miles, 2024)

In Ayutthaya, a Role-Play Gaming Simulation (RPGS) is proposed: a participatory simulation tool where citizens, government, the private sector, and experts take on different roles (such as urban planner, resident, tourist, teacher, merchant) to simulate decision-making for flood management, exchange ideas, brainstorm, and understand the complexity of flood risk management. (Huyakorn et al., 2012)

## **Conclusions: Key Lessons and Future Directions for Sustainable and Resilient Heritage Cities**

Flooding represents an increasing threat to modern societies, particularly to historic cities, where the cultural value of the urban fabric is at risk. In recent years, the academic community has shown growing interest in addressing flood risks in urban environments by proposing sustainable and adaptable solutions.

This paper, through a literature review of 70 case studies, aims to explore the factors that make historic cities vulnerable to flood events, categorizing them into four groups: natural,

anthropogenic, endogenous, and systemic. While the boundaries between these categories are often blurred -due to overlapping causes or differing interpretations- the goal is to emphasize how cities with diverse historical, cultural, topographic, and urban characteristics face similar challenges when it comes to flooding. Climate change has intensified natural hazards, particularly rainfall and sea-level rise, while the natural topography of many historic cities, often located near water for strategic or economic reasons, further increases their exposure.

At the same time, anthropogenic and systemic issues such as rapid urbanization, poor urban planning, aging or inadequate drainage infrastructure, lack of public awareness, and insufficient policy coordination significantly contribute to present-day flood risks. Many of these vulnerabilities originate from within the urban systems themselves, suggesting that they can be addressed through sustainable development strategies.

However, standard flood protection measures cannot always be directly applied in heritage contexts, due to architectural, cultural, and legal constraints. Each historic city presents unique geographic conditions, architectural heritage, and socio-economic challenges. Therefore, flood management strategies must be carefully adapted to each context to simultaneously preserve cultural identity and enhance resilience.

The analysis of proposed solutions through the literature reveals that, while structural interventions (such as dams, levees, and drainage improvements) are sometimes necessary, they may disrupt the aesthetic and cultural character of heritage cities. Such measures must be designed with sensitivity by interdisciplinary teams including engineers, architects, urban designers, and conservation experts. Furthermore, grey infrastructure alone is no longer sufficient to address today's flood risks. Long-term mitigation strategies must include green infrastructure -such as vegetated areas, restored wetlands, and natural drainage systems- which can enhance flood resilience while respecting the specific constraints of heritage sites.

Technological innovations also play a key role in flood prevention, offering tools like GIS mapping, real-time monitoring, and early warning systems. Nevertheless, these must be integrated with local knowledge and cultural heritage considerations to be truly effective.

Community involvement is equally essential. Inclusive, participatory approaches ensure that solutions are not only technically effective but also socially accepted and sustainable over time.

Ultimately, achieving flood resilience in historic cities requires a delicate balance: between modern technologies and traditional knowledge, between hard infrastructure and nature-based solutions, and between international frameworks and local engagement. Only through tailored, context-sensitive strategies can ensure the protection of these invaluable historic cities for future generations.

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