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Assessing Flood Risk of Heritage Sites in an Urban Area: Impact of Locational Characteristics and Historical Context

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Abstract: This study examines how the locational characteristics of heritage sites influence their current flood risk in an urban environment under changing climate conditions. We studied 1620 heritage sites in the highly urbanized environment of Seoul, Korea; the study first quantified the flood risk of heritage sites, considering the topography and hydrological environment under 10-, 30-, and 50-year return periods of extreme precipitation scenarios. Terrain analyses were then applied to examine the physical locational characteristics of heritage sites related to flood susceptibility, with a literature review on the historical origin and human factors of each site. The evaluation of the location conditions of at-risk sites and their relationship with the construction period and type of heritage sites was conducted. The results show that the physical, political, economic, social, and cultural determinants of location varied depending on the construction period and heritage type, leading to the present spatial distribution of heritage sites. Specific sites in topographical knickpoints and lowlands near streams, which face additional hydraulic pressure and drainage issues from urban development, showed particularly high flood risks. By examining the interplay between historical, physical, and urban development factors, the research provides a holistic understanding of flood risks, essential for sustainable conservation strategies.

Keywords: cultural heritage; natural heritage flood risk; locational characteristics; quantitative risk assessment; Seoul; Korea

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1. Introduction

Cultural heritage sites worldwide are increasingly at risk of flooding due to the impacts of climate change that exacerbates the frequency and intensity of extreme weather events [1–3]. Many countries are therefore emphasizing the importance of site-specific adaptation plans for cultural heritage sites, considering assessment of potential flood damage to the sites [4–7]. One of the bases of such efforts being made in the international community is assessing flood risk of cultural heritage. However, the efforts are in many cases [8–10] based on a qualitative approach due to constraints in information and available resources, and despite these efforts, barriers such as fragmented planning, lack of integration between regulatory organizations, and delays in decision-making continue to hinder effective adaptation and risk management [11,12]. Addressing the flood risks to cultural heritage under climate change requires a multifaceted approach, combining technologies to quantify flood risk, innate vulnerability analysis of heritage sites, and adaptive strategies to ensure the preservation and resilience of these invaluable assets for future generations.

Unfortunately, despite growing concerns worldwide about the impacts of climate change on cultural heritage, many cities and urban heritage sites are not well prepared for these changing circumstances, and Korea is no exception [13–16]. Of the damage to heritage sites in Korea that has occurred from 2008 to 2022, 83% has been due to torrential rainfall and typhoons, and the proportion is gradually increasing [17,18]. This situation is exacerbated

in large cities like Seoul, where a large portion of the surface area is "sealed," leading to a higher risk of inundation. In addition, cultural heritage sites exhibit attributes of historical importance and cultural worth, alongside the maintenance of historical authenticity, in contrast to contemporary architectural structures [19]. They have a vulnerability in that the range of interventions that can be applied to mitigate climate impacts is limited because it is difficult to easily apply modern technologies without damaging cultural identity and historical continuity. In other words, preservation is more difficult than it is for modern infrastructure that can be rebuilt or redesigned with modern materials and techniques. Materials used in heritage sites, such as ancient stone, wood, and plaster, are often already aged and therefore more vulnerable to climate-induced devastation [20]. In addition, many heritage sites are exposed to specific geographical and environmental factors, such as coastal areas or areas adjacent to rivers that are vulnerable to flooding, which may make them more vulnerable to climatic stress [21].

In disaster science, cultural heritage was often disregarded in the comprehensive processes for disaster management [22,23]. Nevertheless, since the first flood map for historic districts was prepared in Italy in the 2000s [23], hazard and risk analyses for cultural heritage have been continuously conducted. Early studies on the threats of floods to heritage sites consisted mainly of flood susceptibility mapping, focusing on the possibility of flood occurrence in a given area [23–25]. Subsequent studies using hydrologic modeling quantified and predicted flood exposure at specific urban heritage sites based on flood hazard maps, considering detailed and complex hydrologic factors [26–31]. However, the innate nature and attributes of cultural heritage significantly influence its vulnerability to floods, necessitating a comprehensive understanding and tailored approaches for effective risk management. For example, geospatial factors, such as the site's elevation, proximity to water bodies, and geomorphological characteristics, play a significant role in determining flood risk [32,33]. In the study of the Marche region in Italy, certain types of cultural assets such as religious buildings showed the highest level of flood damage [33]. Cultural heritage encompasses both tangible and intangible values, such as spiritual, social, and aesthetic aspects, which complicate the evaluation of exposure and vulnerability. The vulnerability of cultural heritage is multifaceted, involving physical, social, and economic dimensions, and is influenced by factors such as building techniques, settlement patterns, and the specific attributes of the heritage assets. Overall, a holistic approach that considers the unique attributes of cultural heritage, coupled with advanced assessment tools and collaborative efforts, is essential for mitigating flood risks and preserving cultural heritage for future generations.

In particular, the flood risk to cultural heritage can be inherently affected by the locational characteristics of each heritage site [33,34]. In Korea, numerous studies suggest that the locational patterns of heritage sites vary depending on the construction period and type, and that sites of particular eras and types show unusually high or low disaster exposure levels [35–42]. For example, in the case of Buddhist temples, most temples built during the Joseon Dynasty during the 14th to 19th centuries are located in mountains, but temples built during the Three Kingdoms Period in ancient times are usually located in old city centers on flat land [38]. Most of the temples built between the 6th and 7th centuries among the temples built in the Gyeongju area during the Silla Dynasty are concentrated in the flat lands of the Seocheon River, which is related to the urban development process formed under the influence of frequent river flooding and afforestation projects to prevent it [35]. It has been revealed that topographical locations of heritage sites differed by the Paleolithic, Neolithic, and Bronze Age periods [36].

Recent research has increasingly focused on the specific vulnerability of heritage sites, considering various factors such as preservation condition, historical damage, rescue plans, legal protection, and heritage type, and assessing the potential risk posed by different levels of hazard and exposure [8–10,15,43–45]. They address the effects that the intrinsic attributes of heritage sites have on the potential hazards to them, but the quantified values are still only relative figures that lack practical meaning, such as financial loss, recovery

cost, or size of the damaged area. Obtaining quantitative results from flood risk assessment of cultural heritage poses a significant challenge, especially within the context of Korea, where the responsibility for safeguarding cultural heritage lies with the government under the Cultural Heritage Protection Act of 1962 [46]. In countries that have delegated this responsibility, these findings can inform tangible actions in terms of prioritization, allocation of resources, and implementation of measures to reduce risks at a national scale.

Our focus delves further into these lines of inquiry and is developed on a broader scale than preceding site-level case studies. The main aim of this paper is to explore how the inherent attributes of heritage sites are fundamentally related to the disaster risk the heritage faces. The study first seeks to identify which heritage sites are at risk of flood by quantifying the present flood risk at each site, considering the topography and hydrological environment of the city and the urban drainage systems under an assumption of extreme precipitation. The paper also aims to investigate what kinds of location conditions characterize the risky sites and why they are so risky, depending on their era and type through a terrain analysis on the physical characteristics and a literature review on the historical and human factors. Ultimately, this research aims to we discern why the unique location of each heritage site was chosen and how this choice inherently influenced flood risk by consolidating the results of these analyses. With these lines of inquiry, our study offers a valuable perspective on how the inherent attributes of heritage sites are fundamentally related to the disaster risk the heritage faces. This study specifically examines the diverse location attributes associated with the construction era and type of cultural heritage that have received insufficient attention in existing literature. This investigation can contribute to understand the linkage between the historical context during the inception of cultural heritage and its architectural type and the contemporary flood vulnerabilities within urbanized settings, leading to ascertain potential variations in their impacts. In this way, we contribute to a relevant discussion of risk management for cultural heritage under climate change and development pressure in both the national and international spheres.

2. Materials and Methods

2.1. Study Area

Seoul is situated within the mid-latitudinal Eurasian continent and is characterized by a temperate continental monsoon climate. The annual precipitation is 1274.2 mm as of 2011–2020, of which more than 50% is concentrated in June to September [47]. Due to the localized intensification of urbanization, the urban heat island phenomenon and localized heavy rains appear as urban climates [48]. The city is geologically located on a basin formed by differential erosion based on the longitudinal difference of gneiss and granite [49]. Many hills are distributed inside the basin, surrounded by mountains with an elevation of about 520 to 830 m, while the topographical features reveal a continuous plain extending in an east-west orientation [49]. Along this topography, the main stream of the Hangang River, which flows from east to west across central Seoul, and three major tributaries and 57 sub-tributaries, with the surrounding mountains as their watersheds, are distributed (Figure 1). The hydrological characteristics such as water level and flow rate of the river and streams vary significantly based on rainfall, season, and urban drainage conditions. Heavy rainfall can raise water levels significantly during the summer months, contributing to flood risks in low-lying areas [50]. The month exhibiting the greatest volume of precipitation is July, recording an amount of 397.3 mm, while the cumulative precipitation during the summer flood season, spanning from June to September, totals 1002 mm, which represents 72% of the total annual precipitation [51]. Conversely, during the non-flood season, the dry days reach 77%, and the number of days with precipitation of 10 mm or less is 96%, resulting in exceptionally low discharge during this period [52]. Consequently, numerous streams exhibit minimal discharge during periods of no rainfall, yet they possess a heightened propensity for rapid flooding and inundation upon the onset of precipitation. For instance, in Jeongneungcheon stream, both the water level and discharge remain diminished throughout the non-flood season (with a median flow rate of

0.083 m^3/s at Yongdu Bridge), whereas the water level experiences a swift elevation during intense rainfall, thereby exacerbating the risk of flood-related damage [52]. The relationship between stage and discharge, alongside the annual runoff depth for the Cheonggyecheon stream basin—which harbors the highest density of cultural heritage sites among the streams within Seoul —are illustrated in Figure 2 [53].

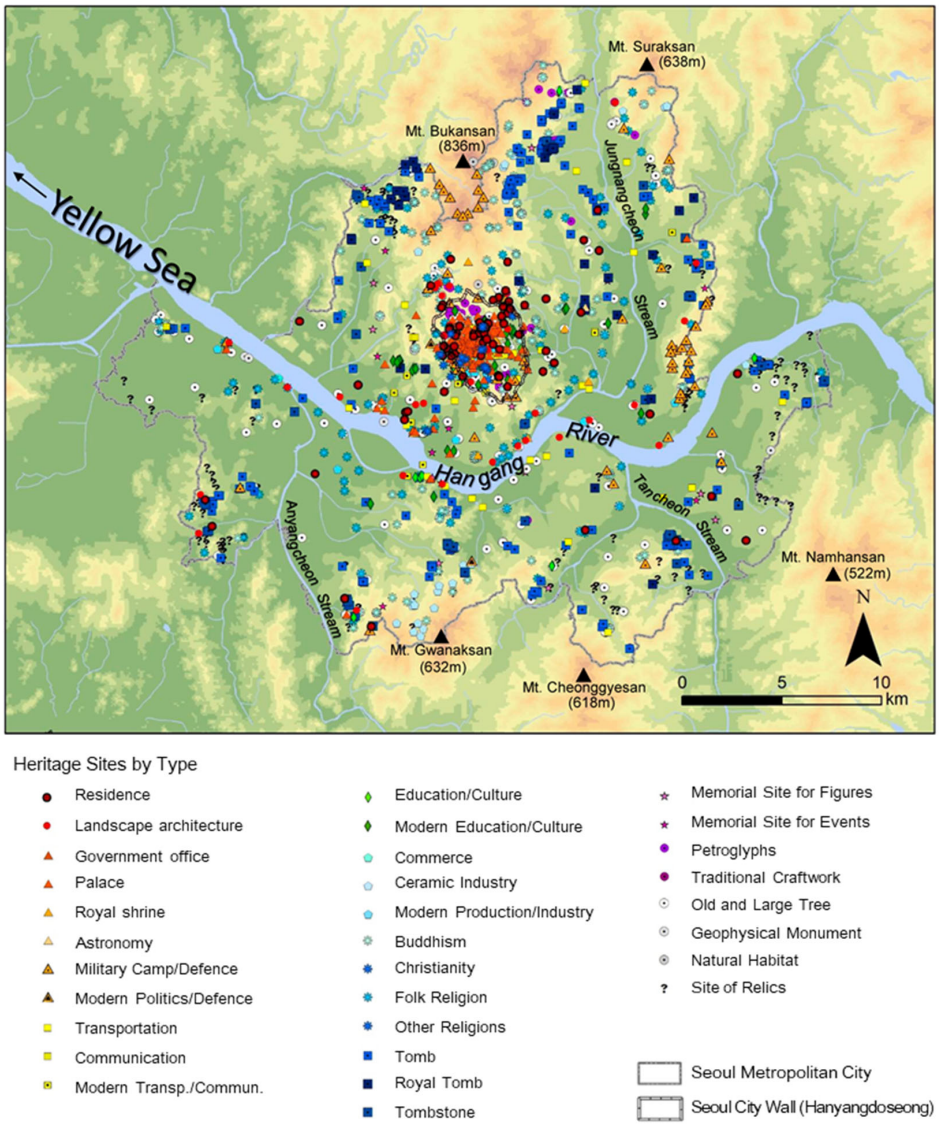


Figure 1. Geographic environment and heritage sites of Seoul.

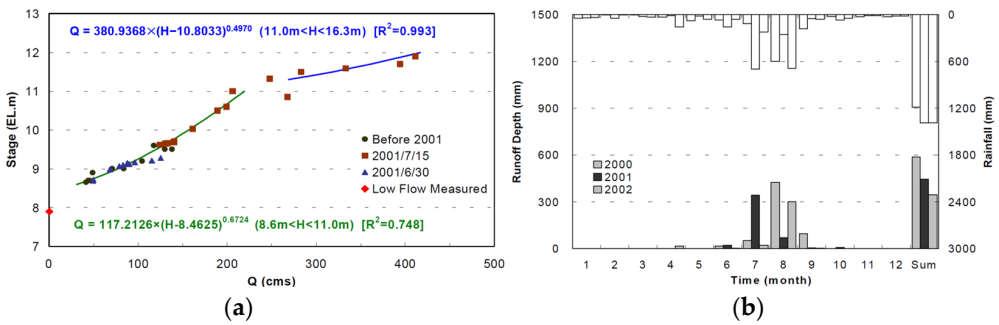


Figure 2. Rainfall and runoff characteristics of Cheonggyecheon stream in Seoul: (**a**) stage–discharge rating curve, (**b**) annual runoff depth. Reprinted with permission from [53]. 2004, S.J. Noh.

Seoul's drainage infrastructure has faced challenges in the past, particularly during monsoon seasons; however, urban restoration initiatives and flood control systems have progressively enhanced flood risk mitigation strategies over time [50]. Since the onset of extensive urban development in Seoul in 1962, the built-up area reached 362.5 km^2 by 2010, representing roughly 60% of the total area of the city [54]. The ratio of land area for agricultural and forest land is decreasing, while the ratio of land area for urban areas and public land is increasing [54].

Under these natural environments, floods are the most frequent disasters that cause the greatest damage. Although cases of river floods increased until the early 1990s when the floods were caused by overflowing riverbanks, as Seoul continuously improved its river management, the majority of the recent floods have been inland floods due to problems with the sewer system [55,56]. Although the primary cause of floods is the concentrated extreme rainfall over a short period of time, the damages are also from the capacity of sewers, lack and defects of discharge, lack of capacity of drain pumps, and the defects of drainage due to soil runoff [55]. However, floods have occurred fundamentally due to problems in the drainage system caused by the thorough urbanization of the city and the deformation of natural rivers by artificial underground waterways [55]. Consequently, Seoul's rich heritage has long suffered frequent damage from floods and storms due to climatic features and the heavily urbanized environment [57].

This area has been an important strategic point since it is adjacent to the Yellow Sea, where China's advanced culture flowed from ancient times; it faces the downstream great plains of the River; and it is surrounded by mountains that form a natural defensive barrier [58]. It was the capital of two dynasties, and in particular, it has been the capital since the founding of the Joseon Dynasty (1392–1910). Consequently, the city preserves much tangible and intangible heritage from ancient to modern times and thus has the highest density of heritage sites in Korea, more than twice the national average [40], and heritage of nearly all types and periods found in Korea are represented in Seoul. The construction period of cultural and natural heritage in Seoul, which encompasses prehistoric, ancient, medieval, and modern times, is categorized into eight divisions based on the respective dynasties. Heritage sites can be classified into 11 primary types and 31 subtypes, depending on their structure and function (Figure 3). These sites, amounting to 1620 sites, are spatially distributed throughout Seoul across 605 km^2 (Figure 1).



Figure 3. Types of cultural and natural heritage sites in Seoul.

When examining the spatial distribution of heritage sites in Seoul, it is noticeable that the cultural properties originating from the Joseon Dynasty (1392–1897) are particularly concentrated within the confines of the Seoul City Wall (Hanyangdoseong). This phenomenon is intricately linked to the positioning of the palaces that were pivotal to urban development during the period when this site was designated as the capital in the Joseon Dynasty, notably the site of Gyeongbokgung Palace, which was the inaugural palace constructed. Historically, the locations of the palaces and their ancillary buildings were deter-mined mainly by traditional ideology, which had a profound influence on the location of cities and buildings in general. Gyeongbokgung, the first main palace built in 1395 with the foundation of the Joseon Dynasty, was located slightly northwest of the capital, where "good spirits" descending from the propitious mountain to the north, Bugaksan Mountain, to the flatland were believed to gather by the propitious stream to the south, Cheonggyecheon, according to feng shui philosophy [59]. Therefore, the palace terrain exhibits a gradual topographical change as the elevations drops, and the slope decreases from the northern mountain ridge to the southern flatland. Following this relief, two streams, Baegundongcheon and Junghakcheon, originating in the northern mountains flow down along the eastern and western walls of the palace and join the Cheonggyecheon stream in front of the main gate to the south. Meanwhile, there are palaces whose location was determined by political, diplomatic, or practical needs, in addition to ideological backgrounds such as feng shui. The location of another palace, Gyeonghuigung, built in the late dynasty, was chosen for various needs mentioned above of the time as well as feng shui [60]. Built in 1616 by King Gwanghaegun (1575–1641), the palace was an important political center of the late Joseon for approximately 280 years [60]. After Gyeongbokgung Palace was destroyed during the Japanese invasions (1592–1598), the king searched for an optimal location for a new palace in which he could effectively assemble central government agencies and properly manage the capital [61]. He also aimed to improve the efficiency of the previously constructed street networks running from the palace to the south and east gates of the fortress [62]. The king also strove to relieve the diplomatic tension between the Ming and Qing Dynasties faced by the Joseon by installing the new palace in the west of the fortress near the entrance used by visiting envoys who had sensitive diplomatic relationships with the Joseon, in order to minimize the exposure of the entire area of the capital on their routes [63]. Since the western part of the capital falls under Inwangsan Mountain and Bukaksan Mountain, they could be taken advantage of as natural barriers to the palace in an emergency, an important concern at that time, given that Japanese troops had recently invaded the fortress through the eastern flatland [61]. Based on the locations of these palaces, government offices, residences for the upper and lower classes, and other urban infrastructure were located within and near the city wall.

2.2. Material

The study utilized six datasets in Table 1. One of the major datasets is the map of cultural heritage sites in Seoul. It includes records of the current status of heritage sites on a 1:5000 topographic map. A digital elevation model and a detailed soil map were utilized for terrain analyses to identify physical locational characteristics of heritage sites.

Another major dataset used in this study is the flood inundation maps from the Comprehensive Plans for Flood and Storm Damage Reduction produced by the Seoul Metropolitan Government [56]. The dataset includes expected flood extent and flood depth under the 10-, 30-, and 50-year return periods of heavy rainfall scenarios. The three return periods of the extreme precipitation scenario were set based on the design frequency of the rainwater drainage facility in Seoul. The 10-year frequency scenario corresponded to 75 mm/h, the Seoul Metropolitan Government's stormwater sewer pipe design standard. The 30-year frequency scenario corresponded to 95 mm/h, which is the design standard for larger drainage facilities such as medium-sized stormwater sewer pipe and rainwater pumping stations. The most extreme 50-year rainfall scenario was adopted the precipitation

event (maximum 99.5 mm per hour) on 14 July 2001, which caused a great flood with the strongest precipitation in an hour since the observation of precipitation began in Seoul [56].

Table 1. Research datasets.

Data	What It Contains	Where the Data Was Used in the Study	Data Source	Notes
Map of cultural heritage sites	Heritage site name, coordinates, address, construction period, type, designation information	Throughout this study	Cultural Heritage Administration of the Republic of Korea	
Digital elevation model	Elevation, slope, streams, etc.	Hazard analysis, Physical locational characteristics analysis	National Geographic Information Institute of Korea	
Detailed soil map	Soil information, geomorphological land type	Physical locational characteristics analysis	Rural Development Administration of Korea	This study reclassified the topographic classification by referring to the research of Lee & Chang [64] to clarify the locational characteristics of each heritage site according to the topographical relief in terms of geomorphology.
Flood inundation maps of the Comprehensive Plans for Flood and Storm Damage Reduction [56]	Expected flood extent and flood depth under the 10-, 30-, and 50-year return periods of heavy rainfall scenarios	Hazard analysis	Seoul Metropolitan Government	For each rainfall scenario, maps were produced using hydrological modeling (SWMM) that is standard for estimating flood frequency in the design of hydraulic structures in Seoul. The maps are the most recent, comprehensive, and reliable results covering the whole city.
Damage records of heritage sites	Heritage site name, address, damage and loss details, damage recovery cost	Vulnerability analysis	Cultural Heritage Administration of the Republic of Korea, Seoul Metropolitan Government	
Flood trace maps from 1984 to 2013	The spatial extent of actual flooded areas during past disaster events	Vulnerability analysis	Korea Land and Geospatial Informatix Corporation	The damaged area of the heritage site was calculated by overlapping this map and the map of cultural heritage sites.

The flood inundation maps were generated in the following order. Employing the FARD2006 program developed by the National Institute for Disaster Prevention, the probabilistic rainfall based on the Gumbel distribution was calculated from the maximum rainfall by duration (10 min, 1~24 h) from the Seoul Meteorological Administration's Seoul Observatory, which has maintained rainfall observation records for more than 30 years [56]. Subsequently, the XP-SWMM model was applied to construct the sewer network and divide the sub-basins, and the estimation of the final flood discharges was derived from the aforementioned three frequency scales of precipitation, culminating in the production of the inundation maps. The discharges derived by rainfall scenarios and the resulting flood level were mapped as the inundation range and inundation depth [56].

The damage records of heritage sites and flood trace maps from 1984 to 2013 were utilized for vulnerability analysis of heritage sites. The flood vulnerability was deduced from the past flood damage data. In this study, in order to construct the flood damage history data of cultural heritage in Seoul, flooded heritage sites were extracted by year by overlapping the Cultural Heritage Distribution Map on the flood trace maps from 1984 to 2013. The final flood damage data of heritage sites was constructed by supplementing the data provided by the Cultural Heritage Administration and Seoul Metropolitan Government on the flood damage of cultural assets from 2002 to 2013.

2.3. Methods

The study consists of three detailed parts. First, to find out which heritage sites are in danger, we applied a Quantitative Risk Assessment (QRA) to quantify the average annual flood risk of each heritage site. The four-step QRA method, as shown in Figure 4, is used in disaster studies to assess the disaster risk of specific objects, such as people and buildings,

in absolute figures unaffected by scale or comparison with other regions [65–71]. In this study, we first conducted a hazard analysis by combining flood inundation maps under 10-, 30-, and 50-year return periods of extreme precipitation scenarios with the heritage site map to identify the specific sites exposed to flood and calculate the extent of their exposure by analyzing the projected flood depth and area (Figure 4 (1)).

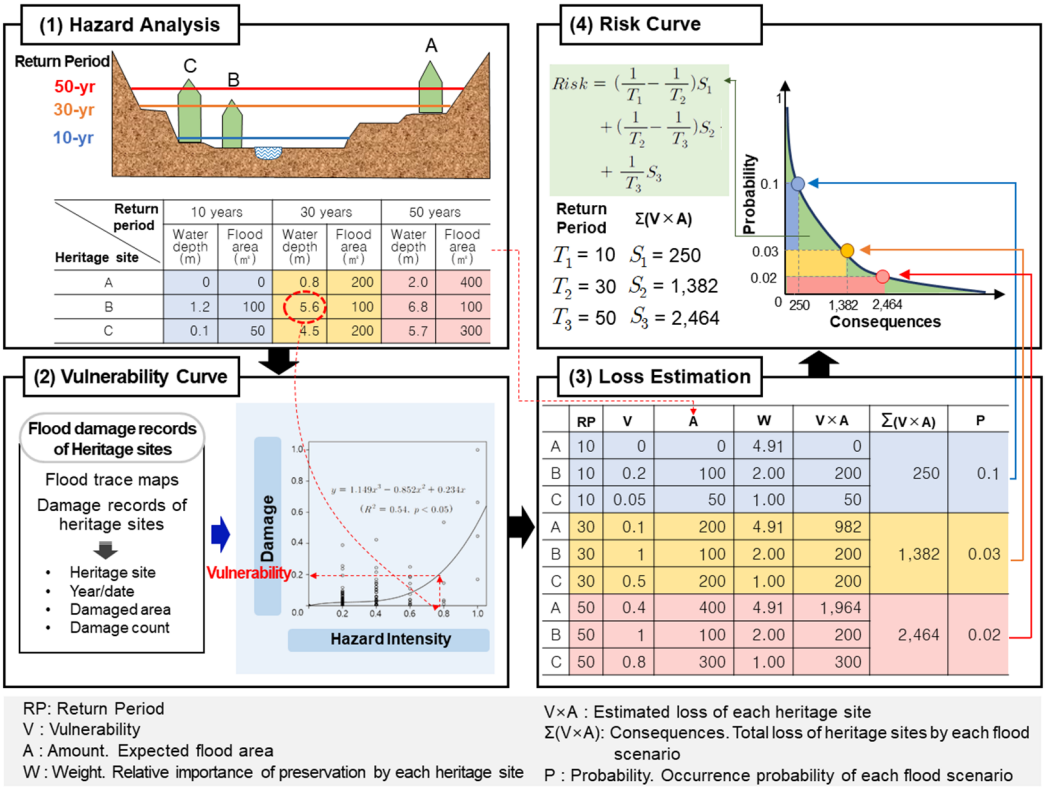


Figure 4. Quantitative risk assessment methodology for the calculation of average annual flood risk to heritage sites. Adapted with permission from Ref. [65]. 2013, C.J. van Westen.

Additionally, a vulnerability curve was estimated from the records of heritage damage and flood intensity in the past. Then, vulnerability indices for all heritage sites were calculated by applying the expected flood exposure identified in the hazard analysis to the curve (Figure 4 (2)). The indices were then weighted by multiplying them by both the projected flood area and the relative conservation priority of individual heritage sites, resulting in a weighted value estimating the potential loss under each rainfall scenario (Figure 4 (3)).

The weight was determined according to the designation types of national heritage as recognized by the national evaluation, in order to fulfill the research objective of identifying heritage sites necessitating urgent mitigation efforts with reference to previous research [43,72,73]. Song et al. [73] determined weights of 0.054, 0.022, and 0.011 for State-designated Heritage, City-designated Heritage, and Unregistered Heritage, respectively, out of the total importance level of 0.087 assigned to each type of heritage designation through the AHP evaluation. This indicates that State-designated Heritage holds a significance of approximately 62.1%, City-designated Heritage accounts for around 25.3%, and Unregistered Heritage represents about 12.6%. Consequently, this study computed the significance of State-designated Heritage and City-designated Heritage relative to Unregistered Heritage (Table 2).

$$Relative\ importance\ level\ of\ Unregistered\ Heritage = \frac{0.1264}{0.1264} = 1$$

$$Relative\ importance\ level\ of\ City\text{-}designated\ Heritage = \frac{0.2529}{0.1264} \approx 2$$

$$Relative\ importance\ level\ of\ State\text{-}designated\ Heritage = \frac{0.6207}{0.1264} \approx 4.91$$

Table 2. Weights reflecting the relative importance of individual heritage sites. Used to estimate the potential loss.

	Weights from Song et al. [73]	Normalized Weights That This Study Applied
State-designated Heritage	0.054	4.91
City/Province-designated Heritage, Cultural Heritage Materials, Registered Heritage	0.022	2.00
Undesignated Heritage	0.011	1.00

By multiplying the annual occurrence probabilities of each scenario by the potential loss, the average annual flood risk index was calculated for all at-risk heritage sites (Figure 4 (4)). The annual occurrence probabilities that a flood scenario with a specific frequency would occur at least once during a given period were calculated as follows [60]. Accordingly, the annual occurrence probability was 0.100 for a 10-year frequency scenario, 0.033 for a 30-year frequency rainfall scenario, and 0.020 for a 50-year frequency scenario.

$$P_e = 1 - [1 - \left(\frac{1}{T}\right)]^n.$$

P_e: The probability that one or more floods occurring during a random period of n years will exceed a given return period

T: Return period

n: Number of years in the period

Then, to identify the physical locational characteristics of the risky heritage sites, i.e., those in environments susceptible to flood, we calculated the slope, elevation, distance to streams and rivers, and topographic location for heritage sites by creating a GIS overlay and conducting terrain analyses with ArcGIS 10.3 and QGIS 3.8. We also performed desk-based qualitative research in the fields of historical geography, history, and archeology to investigate the historical context of each site and the reason why people in the past left each legacy at the present position in the city. The results of this review allowed us to consider locational preferences by era and heritage type and provided insight into the human influences on the locational characteristics, and thus on the flood risk, of the heritage sites.

This study intended to comprehensively integrate not only analyses of potential hazards focusing on the occurrence of floods in the local urbanized environment but also the physical topographic factors and humanities and social scientific data for each heritage site as internal risk factors that reduce or amplify external disaster impacts. Through this, we aimed to qualitatively contemplate the influence of locational characteristics according to the construction period and type of heritage site on the current flood risk faced by heritage.

3. Results

3.1. The Average Annual Flood Risk of Heritage Sites

In the 10, 30, and 50-year extreme precipitation scenarios, a maximum of 44 heritage sites were exposed to flood. The most extensive damage was projected in the Cemetery of the Prince Gwangpyeong Branch of the Jeonju Yi (the royal family's tomb area built in the 15th century), followed by Gyeongbokgung Palace (the main royal palace of the Joseon Dynasty (1392–1910)), both with affected areas over 6000 m^2. Twenty-eight sites, or 63% of the affected sites, showed the lowest level of flood depth, 0.2–0.5 m. Eleven sites were projected to have flood depths of 0.5–1.0 m, three with depths of 1.0–1.5 m, one with a depth of 1.5–2.0 m, and the remaining site with a depth over 3.0 m. The heritage sites with the

deepest expected flood were the Guui-dong Bastion (fortress facility from the 5th century), the Stone Embankment in Mugyo-dong (built along the Cheonggyecheon stream in the 17th century), and Gyeongbokgung Palace. In the most severe scenario, the vulnerability index of the Guui-dong Bastion was calculated to be the highest at 0.23, which means that the damage, when averaged per unit area, to this heritage may be about 23.0% compared to complete destruction.

However, even with the same area flooded, the loss of value and the financial cost of restoration varies greatly depending on the actual existence and importance of each heritage asset. In order to make the result of the flood risk assessment have practical meaning, this study determined the tangible existence of at-risk heritage, and then assigned a relative importance value to each heritage site based on the designation type and estimated the value lost in the flooded area for each flood scenario. As a result, Gyeongbokgung Palace showed the highest loss, 958.12, in the most severe rainfall scenario.

Using the final flood risk index, calculated considering the probability of occurrence and potential loss for each scenario, we identified a total of 16 heritage sites at risk of flood from the three scenarios (Figure 5 and Table 3). The average annual flood risk of these sites was between 0.00004 and 26.08, which indicates the expected annual loss in square meters. Taking Gyeongbokgung Palace, where the average annual flood risk is calculated as 26.08, as an example, the expected loss due to inundation at this heritage site corresponds to about 26.1 m^2 of the palace area damaged per year. The Cemetery of the Prince Gwangpyeong Branch of the Jeonju Yi showed a similarly high flood risk, 11.57.

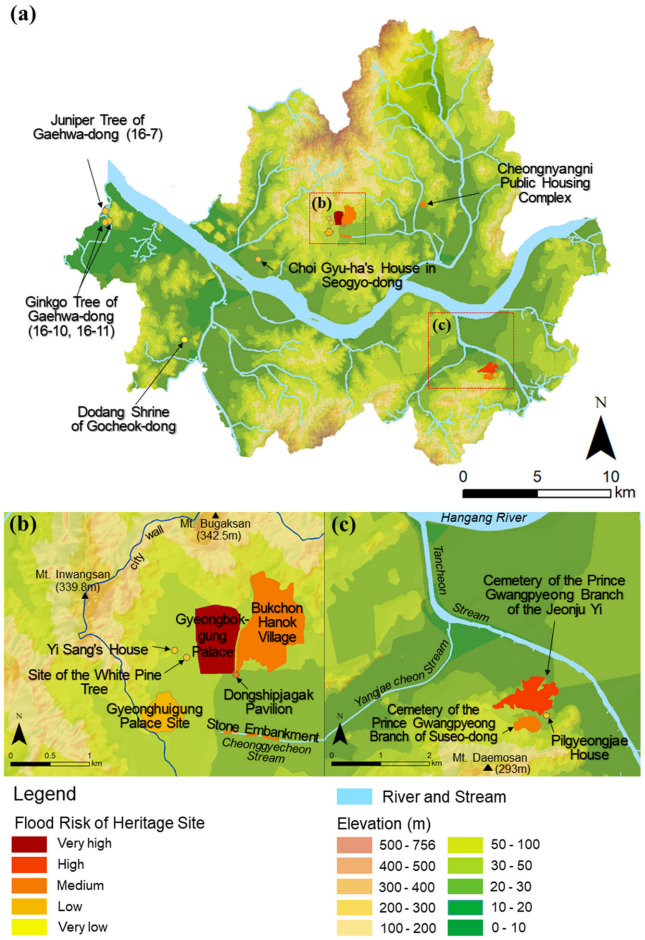


Figure 5. Heritage sites at risk of flood under 10-, 30-, and 50-year rainfall scenarios in Seoul. Spatial distribution of at-risk heritage sites in (**a**) Seoul, (**b**) the Gwanghwamun area, and (**c**) Suseo-dong and Irwon-dong.

Table 3. Average annual flood risk of at-risk heritage sites.

No.	Name of Heritage Site	Return Period	Vulnerability (*V*)	Flood Area (m^2) (*A*)	Weight (*W*)	Loss [a] (*L*)	Probability (*p*)	Risk [b] (R_T)	Average Annual Flood Risk [c] (*Risk*)
1	Gyeongbokgung Palace	10	0.022	145	4.910	15.583	0.067	1.0389	26.07800
		30	0.031	2913	4.910	440.759	0.013	5.8768	
		50	0.031	6332	4.910	958.118	0.020	19.1624	
2	Cemetery of the Prince Gwangpyeong Branch of the Jeonju Yi	10	0.022	676	2.000	29.614	0.067	1.9743	11.57534
		30	0.022	6024	2.000	263.982	0.013	3.5198	
		50	0.022	6938	2.000	304.065	0.020	6.0813	
3	Buhung House of Cheongnyangni-dong	10	0.000	0	1.000	0.000	0.067	0.0000	2.18349
		30	0.022	2528	1.000	55.388	0.013	0.7385	
		50	0.022	3297	1.000	72.249	0.020	1.4450	
4	Stone Embankment in Mugyo-dong	10	0.000	0	1.000	0.000	0.067	0.0000	1.84237
		30	0.031	853	1.000	26.279	0.013	0.3504	
		50	0.082	911	1.000	74.599	0.020	1.4920	
5	Cemetery of the Prince Gwangpyeong Branch of Suseo-dong in Gangnam-gu	10	0.000	0	1.000	0.000	0.067	0.0000	1.68484
		30	0.022	2307	1.000	50.545	0.013	0.6739	
		50	0.022	2307	1.000	50.545	0.020	1.0109	
6	Bukchon Hanok Village in Gahoe-dong	10	0.000	0	1.000	0.000	0.067	0.0000	1.57592
		30	0.031	2584	1.000	79.633	0.013	1.0618	
		50	0.022	1173	1.000	25.708	0.020	0.5142	
7	Dongshipjagak Pavilion	10	0.000	0	4.910	0.000	0.067	0.0000	1.34433
		30	0.022	360	4.910	38.723	0.013	0.5163	
		50	0.022	385	4.910	41.401	0.020	0.8280	
8	Ginkgo Tree of Gaehwa-dong (Tree No. 16–10)	10	0.022	326	1.000	7.137	0.067	0.4758	0.66264
		30	0.022	57	1.000	1.253	0.013	0.0167	
		50	0.022	388	1.000	8.506	0.020	0.1701	
9	Ginkgo Tree of Gaehwa-dong (Tree No. 16–11)	10	0.022	306	1.000	6.695	0.067	0.4463	0.57446
		30	0.022	12	1.000	0.260	0.013	0.0035	
		50	0.022	284	1.000	6.233	0.020	0.1247	
10	Choi Gyu-ha's House in Seogyo-dong	10	0.000	0	2.000	0.000	0.067	0.0000	0.29183
		30	0.022	161	2.000	7.039	0.013	0.0939	
		50	0.031	161	2.000	9.899	0.020	0.1980	

Table 3. *Cont.*

No.	Name of Heritage Site	Return Period	Vulnerability (*V*)	Flood Area (m^2) (*A*)	Weight (*W*)	Loss [a] (*L*)	Probability (*p*)	Risk [b] (R_T)	Average Annual Flood Risk [c] (*Risk*)
11	Juniper Tree of Gaehwa-dong (Tree No. 16–7)	10	0.000	0	1.000	0.000	0.067	0.0000	0.22786
		30	0.022	310	1.000	6.787	0.013	0.0905	
		50	0.022	313	1.000	6.868	0.020	0.1374	
12	Yi Sang's House in Tongin-dong	10	0.000	0	1.000	0.000	0.067	0.0000	0.22201
		30	0.022	304	1.000	6.660	0.013	0.0888	
		50	0.022	304	1.000	6.660	0.020	0.1332	
13	Site of the White Pine in Tongui-dong	10	0.000	0	1.000	0.000	0.067	0.0000	0.21773
		30	0.022	297	1.000	6.503	0.013	0.0867	
		50	0.022	299	1.000	6.552	0.020	0.1310	
14	Gyeonghuigung Palace Site	10	0.000	0	4.910	0.000	0.067	0.0000	0.20008
		30	0.022	56	4.910	6.002	0.013	0.0800	
		50	0.022	56	4.910	6.002	0.020	0.1200	
15	Pilgyeongjae (House of Pilgyeong)	10	0.000	0	1.000	0.000	0.067	0.0000	0.17238
		30	0.022	236	1.000	5.171	0.013	0.0690	
		50	0.022	236	1.000	5.171	0.020	0.1034	
16	Dodang Shrine of Gocheok-dong	10	0.000	0	1.000	0.000	0.067	0.0000	0.00004
		30	0.000	0	1.000	0.000	0.013	0.0000	
		50	0.022	0.1	1.000	0.002	0.020	0.0000	
Total									48.85332

[a] Loss (*L*) = Vulnerability (*V*) × Flood area (*A*) × Weight (*W*). [b] Risk (R_T) = Loss (*L*) × Probability (*p*). [c] Average annual flood risk (*Risk*) = R10 + R30 + R50.

At-risk heritage sites with both high risk and high conservation priority were found to be located in the Gwanghwamun area, Suseo-dong and Irwon-dong, and Seogyo-dong, so we comprehensively reviewed the QRA results along with the physical locational characteristics and human and historical origins of the sites in these areas.

3.2. Comprehensive Interpretation of Flood Risks to At-Risk Heritage Sites

3.2.1. Gwanghwamun Area: Royal Palace Complex of the Joseon Dynasty

The at-risk heritage sites in the Gwanghwamun area include seven sites (Figure 6). These sites are classified as either palaces (Gyeongbokgung Palace, Dongsipjagak Pavilion, Gyeonghuigung Palace Site) or relics related to upper-class residences of the Joseon Dynasty (Bukchon Hanok Village in Gahoe-dong, the Yi Sang's House in Tongin-dong, the Site of White Pine Tree in Tongui-dong, and the Stone Embankment in Mugyo-dong). The accumulation of heritage sites in the Gwanghwamun area, including the seven at-risk sites, begins with the early construction of Gyeongbokgung Palace.

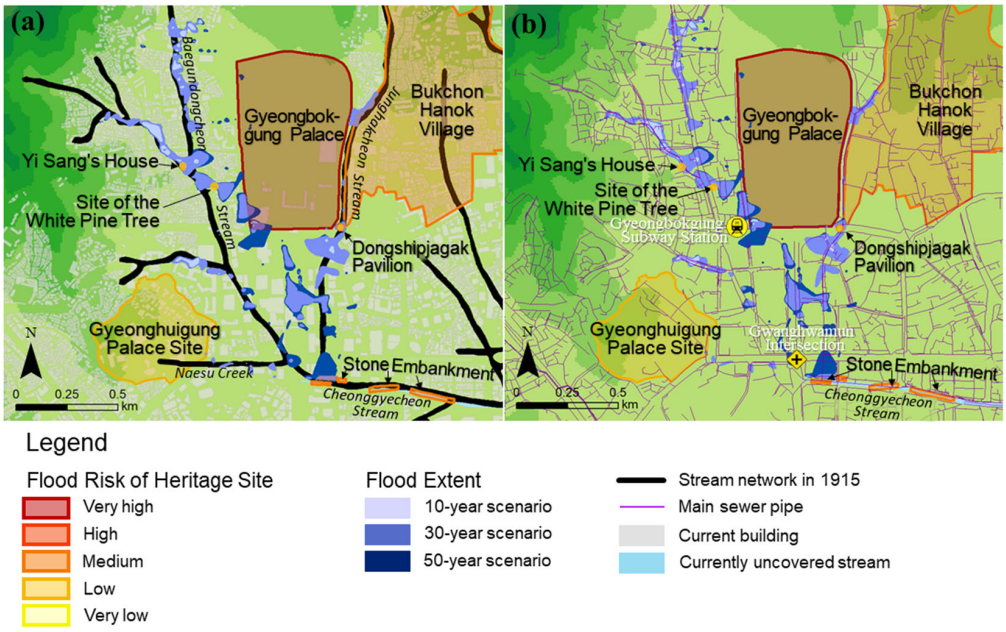


Figure 6. At-risk heritage sites in the Gwanghwamun area. Expected flood extent by scenario with (**a**) historic stream and creek paths in 1915 and (**b**) the locations of currently uncovered streams, main sewer pipes, and major underground structures that affect inundation.

Gyeongbokgung Palace, where the highest level of flood risk was assessed, was located between Bukaksan Mountain to the north and Cheonggyecheon stream to the south according to feng shui philosophy [59]. Following this gradually descending relief, two streams originating from the northern mountain flow along the eastern and western walls and join Cheonggyecheon stream in front of the southern main gate of the palace. If rainwater is unable to drain properly at Cheonggyecheon, the palace area could experience inundation by rising floodwaters upstream. Meanwhile, the location of Gyeonghuigung Palace was chosen for the political, diplomatic, and practical needs of the time as well as feng shui [60]. King Gwanghaegun (1575–1641), who was the king at the time, built a new palace adjacent to a mountainous area that would allow for closer communication with government offices after the Japanese invasions (1592–1598), reduce diplomatic tensions with neighboring countries, and serve as a natural defense in case of emergency [61,63]. As a results, the terrain analysis showed that the Gyeonghuigung site is high and steep, starting at an elevation of 85 m and a slope of 20° in the west and flattening toward the east, reaching an altitude of 39 m and a slope of 0°.

The topographic and hydrologic characteristics of the Gwanghwamun area thus consist of mountains surrounding the back of the two palaces in the north and west, with streams descending from the mountains and reaching the gentle and flat confluence of the Cheonggyecheon stream in the south. Therefore, the results of the QRA flood hazard analysis demonstrated that inundation would start from the stream to the south of the palaces and extend upstream during extreme rainfall events. Gyeongbokgung Palace would then experience broad inundation in the southern part and localized inundations along the east and west walls. With regard to flood depth, the Gyeongbokgung was anticipated to experience a comparatively modest flood depth ranging from 0.2 to 0.5 m for the 10-year frequency scenario, and 0.5 to 1.0 m for the scenarios corresponding to the 30- and 50-year frequencies; consequently, the flood vulnerability index was assessed to be relatively low. Nonetheless, it has been determined that the extent of flood significantly increased depending on the frequency scale of the scenario, coupled with the high significance of the State-designated Heritage, resulting in the highest average annual flood risk among the heritage at risk.

The Gyeonghuigung Palace Site would experience inundation in the lowest eastern area to depths of less than 0.5 m in the 30-year rainfall frequency scenario. The outcomes of the flood hazard analysis indicated that under conditions of a 30-year rainfall recurrence interval or more severe, inundation levels ranging from 0.2 to 0.5 m would occur at the entrance of the Seoul Museum of History, situated to the east of Gyeonghuigung Palace. This particular area represented the lowest elevation within the palace site. According to the hydrological modeling in the hazard analysis, inundation could be attributed to a lack of discharge and processing capacity in the main sewer system and the countercurrent of rainwater. The major cause of inundation would be C-shaped sewer pipes installed at Gyeongbokgung Subway Station and Gwanghwamun Intersection, which were initially straight but replaced by bent lines during construction and repair work on the two structures [74]. Rainwater flowing downhill from the mountains thus would be unable to drain properly, as the flow would be congested due to the curved pipes, resulting in increased upstream water levels. The Gyeonghuigung Palace Site is recognized as a State-designated Heritage, thereby possessing significantly high importance. Nevertheless, the anticipated inundation depth in the flood scenario was minimal, leading to the derivation of the flood vulnerability index at its most negligible level. Furthermore, the area of the projected flood zone was localized in both scenarios, resulting in a low average annual flood risk.

Such results highlight the fact that the flood risks of at-risk heritage sites in the Gwanghwamun area are significantly related to the rapid urbanization of the area since 1960s [75]. As it has been the political, economic, and historic center of Korea for the past 600 years, its underground space has been extensively developed through the construction of subways, underpasses, and the underground floors of skyscrapers since the 1960s. The QRA analysis predicted wide flood areas in all scenarios, and the inundation range is expected to increase rapidly (by 1.5 times) as the frequency scale of extreme rainfall increases, resulting in significantly high flood exposure. Moreover, most sites are State-designated Heritage, meaning that the conservation priority is remarkably high. Consequently, the very high to high average annual flood risks for Gyeongbokgung Palace and the surrounding heritage sites were calculated such that the high conservation priority offset the relatively low vulnerability level due to low flood depths. The Gyeonghuigung Palace Site showed a low annual flood risk because the expected flood depth was in the lowest category. The flood extent was limited in all scenarios, and therefore, the flood risk was low despite the high conservation importance of the palace as a State-designated Heritage.

3.2.2. Suseo-Dong and Irwon-Dong: Royal Family's Tomb Areas of the Joseon Dynasty

The at-risk heritage sites in this area include two large royal family tomb areas and the head family house of the Joseon Dynasty (Figure 7). These tomb areas are City-designated

Heritage, and these sites also have high academic value concerning the royal burial system of the Joseon [76].

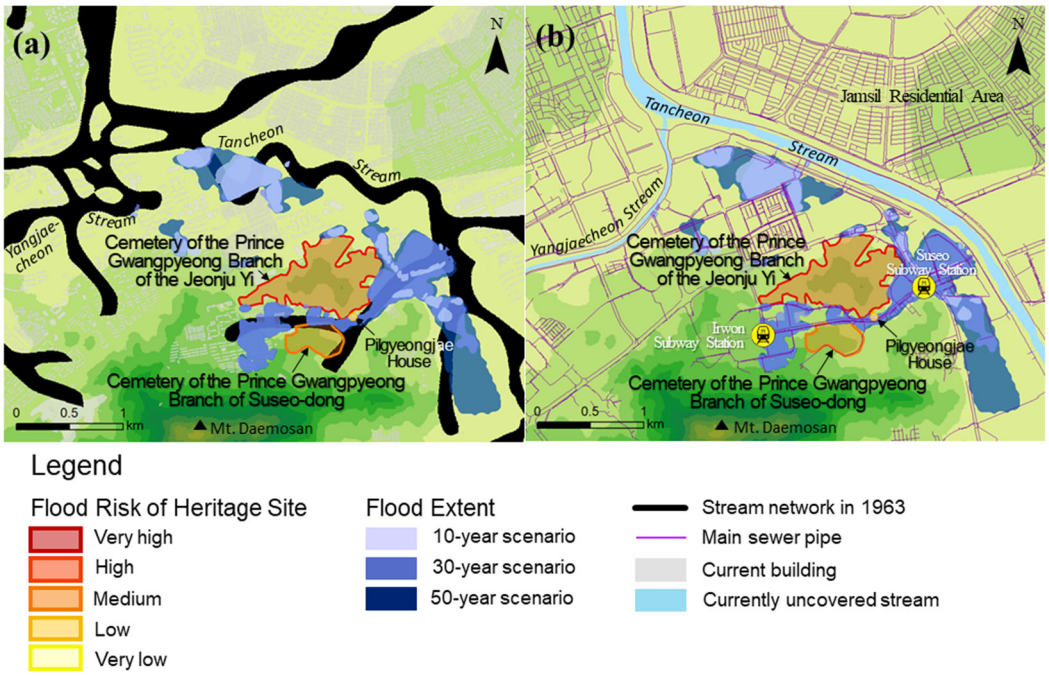


Figure 7. At-risk heritage sites in Suseo-dong and Irwon-dong. Expected flood extent by scenario with (**a**) historic stream and creek paths in 1963 and (**b**) the locations of currently uncovered streams, main sewer pipes, and major underground structures that affect inundation.

The locations of these tombs were chosen to follow Confucian ideals, feng shui, the traditional Korean view of nature as a pursuit of harmony with nature, and the unique capital management policy of Joseon Dynasty that prohibited the construction of tombs within the city walls. The two royal tomb areas in Suseo-dong and Irwon-dong are located in similar geomorphic conditions on the slope of a small basin along the northern foot of Daemosan Mountain, in the southeastern area of present-day Seoul. The elevation of the area ranges from 20 to 79 m, the slope from 0° to 26°, and the distance to the nearest stream from 0 to 445 m. In terms of the topographic and hydrologic environment, the tombs are located at the knickpoint and only outlet, where small creeks from the surrounding mountains flow into Tancheon Stream. Therefore, if rainwater swiftly accumulating in the area is not quickly released into the stream, the area floods owing to the bottleneck phenomenon.

The flood hazard analysis shows that the capacities of the sewer systems are already at their maximum, not including the necessity to accommodate additional extreme rainfall. Therefore, the area will flood under extreme rainfall owing to rapidly accumulating rainwater. Moreover, the connections of sewers near the Irwon Subway Station are poor, leading to manhole overflows. Consequently, the area situated between Suseo Subway Station and Irwon Subway Station, positioned at the base of the mountain housing the tomb, was expected to be flooded across all three scenarios, with specific emphasis on the rapid expansion of the inundated zones in the context of the 50-year frequency scenario. The area consistently fell within the lowest category for flood depth (0.2–0.5 m) across all scenarios, which led to the derivation of a low flood vulnerability index. However, the assessment of the average annual flood risk associated with the heritage sites deemed at risk was determined to be relatively significant, attributable to the extensive anticipated flood area and the augmented consideration given to the relative importance of cultural heritage as City-designated Heritage, resulting in an annual flood risk that was above average.

3.2.3. Seogyo-Dong: A Place of Contemporary Historical Significance

The at-risk heritage site in the Seogyo-dong area is Choi Gyu-ha's house, a Registered Cultural Heritage site (Figure 8). This house, constructed in 1972, was the residence of the 10th president of Korea, Choi Gyu-ha. Its connection with the constitutional history of Korea lends this site historic value [60].

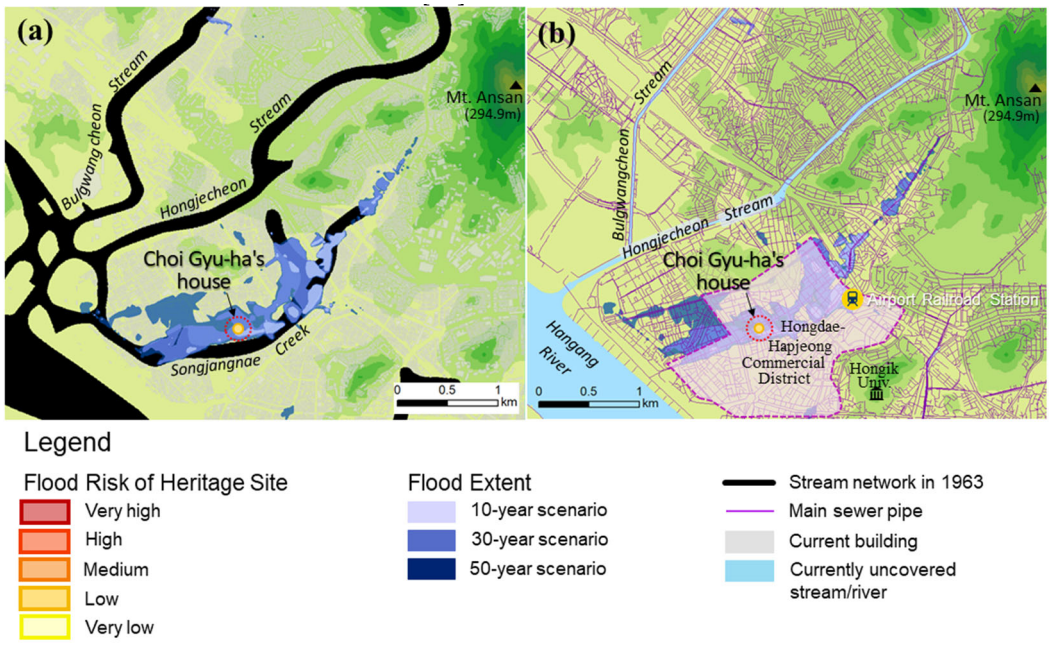


Figure 8. At-risk heritage sites in Seogyo-dong. Expected flood extent by scenario with (**a**) historic streams and creek paths in 1963 and (**b**) the locations of currently uncovered streams, main sewer pipes, and major underground structures that affect inundation.

Seogyo-dong, originally a secluded rural area, was selected as the first area for the government-led land readjustment project to solve the serious population pressure problem in the 1960s after the Korean War, and was transformed into a new high-class residential area in the early 1970s [77]. At the time that Choi Gyu-ha's house was built, former President Choi was the Minister of Foreign Affairs [78], and it is presumed that he moved to Seogyo-dong, a new upper-middle-class residential area close to the city center and the Blue House.

The heritage site is located on flat land and close to many small creeks, including Songjangnae creek, that were covered in the 1970s [79]. Today, they are primarily part of an out-of-date underground sewer system and have lost their natural flood control function. Given these topographic and hydrological conditions, the area was expected to experience widespread inundation under all three scenarios, with Choi Gyu-ha's house at risk of flood during 30- and 50-year rainfall frequency scenarios. This was owing to sewer overflow because of the low capacity of the main sewer pipes and overflowing water already concentrated in low-lying areas failing to discharge into the Hangang River. This area has already experienced frequent flood damage and has been designated as a Flood Vulnerable Area by the local government. The lack of sewer capacity has been reported, and several sewer expansion programs have been attempted. However, expanding the sewer system is challenging because Seogyo-dong is a high-density residential area and representative commercial district of Seoul. Making matters worse, sections of the sewer system were replaced by bent structures during the underground construction of the Airport Railroad Station in the 2010s, further reducing discharge capacity. For this reason, Seogyo-dong and Choi Gyu-ha's house will face significant unavoidable inundations during extreme precipitation events.

4. Discussion

The results emphasize that natural factors of local geomorphology and hydrology, historical factors at the time when cultural properties were created, and modern human factors such as ongoing urban development pressure comprehensively have significantly impacted the heritage sites of Seoul City. Through the defined research methodology, we have recognized that not only the physical environment but also the innate attributes of heritage itself, in terms of vulnerability, play a significant role in determining their susceptibility to flood risks. This provides an opportunity to draw attention to the characteristics of cultural properties that have been relatively unnoticed in the field of disaster science and planning. In particular, the visualization of the influence of the locational characteristics of cultural properties, depending on construction period and type on potential disaster risk, highlights the importance of heritage locational attributes in disasters, which were previously used generally to describe spatial distribution characteristics of relics and estimate potential burial sites in the field of cultural heritage [80–82].

This study analyzed the flood risk posed to heritage sites within a particular spatiotemporal context, situated in a modern built environment with insufficient infrastructure, particularly in a large city, presenting this through three case areas: Gwanghwamun, Suseo-dong and Irwon-dong, and Seogyo-dong. The results of the flood risk analysis can be integrated into the land use and infrastructure development plans of the area [83,84], and the flood impacts of the city center can be reduced by improving the flood drainage system in flood-prone areas near tributaries and low-lying areas in Seoul within the integrated plan. The results of the study can be used to develop flood preparedness and response plans for cultural heritage sites. The average annual flood risk index and related maps can help local heritage managers establish criteria and prioritize the sites that require preferential structural and/or non-structural flood mitigation measures that take into account the local environment and major influencing factors of high-risk areas.

Many studies that have analyzed flood risk of urban cultural heritage focus on the current operation of flood mitigation infrastructure installed in urban areas and the contemporary setting of the urban landscape characterized by ongoing extensive growth and advancement [85–88]. In these studies, the historical and functional context of cultural heritage and the influence of spatial distribution in temporal and spatial dimensions on the flood risk of cultural heritage are relatively overlooked. The regional characteristics derived from the spatiotemporal properties of cultural heritage, which are focused on in this study, are one of the significant flood risk factors, and help us understand the spatiotemporal context of flood risk that cultural properties created in the past face in today's modern urban environment. In these studies, the understanding of the influence of the historical and functional context of the heritage site and its spatial distribution in the temporal and spatial dimensions on the flood risk of the site have been relatively overlooked. The regional characteristics derived from the spatiotemporal attributes of cultural heritage, which were highlighted in this study, are one of the flood risk-influencing factors, helping us understand the spatiotemporal context of flood risk that cultural heritage sites created in the past face in today's modern urban environment. Furthermore, this study focuses on the locational value and cultural significance attached to the geographical or physical location of heritage assets [89], among their various values. This can help policymakers and heritage managers establish measures that are more suitable for the local geographical context by considering the historical and functional context of the region, beyond the mechanical and uniform establishment of risk reduction measures and on-site application at the stage of establishment and application of flood mitigation measures.

The approach used in this study can provide insights for examining the disaster risk of heritage sites from a perspective that integrates natural and social sciences. It covers the past social, political, and cultural contexts; the physical environment and processes of the area; and current issues arising from modern disaster prevention facilities under changing climate patterns. A comprehensive review that considers both the external and the intrinsic characteristics of all heritage sites at a regional scale is essential for understanding the

fundamental flood risk that heritage sites face and how it closely relates to the intrinsic attributes and value of each heritage site [90]. Adapting this approach to other local conditions is a viable option for preserving heritage sites from urban floods. The analysis sequence can be applied to other locations if the input dataset is freely available. This is because the approach focuses on the hazard threats of disasters by considering actual physical characteristics.

Urban growth in Seoul has become increasingly dense, which is exposing residents and historic sites to greater threat of natural disasters [91,92]. In conjunction with the urbanization pattern, the proliferation of impermeable surfaces and the cumulative effects of climate change have intensified the flooding and inundation phenomena within the urban environment [93–95]. According to the SSP5-8.5 climate change scenario, the precipitation in Seoul is expected to increase by 19.9% in the latter half of the 21st century compared to the current annual precipitation [96]. The maximum daily precipitation is also expected to increase by 50.9 mm in the mid-21st century compared to the current level [97].

Flood events not only result in immediate physical destruction but also engender enduring repercussions. This underscores the necessity for proactive strategies aimed at safeguarding the original cultural heritage site structures, rather than depending on restorative actions following damage. Government authorities and heritage preservation organizations ought to implement precautionary measures to mitigate losses of heritage, by enhancing administrative competencies and responsive abilities. In particular, the involvement of local communities is gaining paramount significance in discerning effective approaches to contemporary and prospective flooding and other threats [98,99]. The education of individuals regarding conservation practices is particularly crucial for those engaged in economic endeavors related to cultural heritage in their daily lives [100].

5. Conclusions

This study focused on three regions, the Gwanghwamun area, Suseo-dong and Irwon-dong, and Seogyo-dong, with a high concentration of heritage sites at risk of flood, identified through the QRA methodology. It explored the interconnection between the possible flood risk of each heritage site and the temporal and spatial attributes of heritage such as construction era and geographical positioning, in relation to the surrounding natural and anthropogenic settings. Various natural, social, political, and cultural location factors in the past—including ideologies, geopolitical advantages, urban management policy of the time, and the regional environment being reevaluated due to modern urbanization—caused particular heritage sites to be established in similar topographic and hydrologic environments. These environments are mostly protected lowlands near tributaries or at knickpoints prone to inundation where the slope rapidly transitions from a steep incline to a gentle tilt. Such topographic reliefs and stream adjacency impose an inherent load on modern hydraulic structures. Combined with the defects in the functionality of flood control facilities related to urban development, heritage sites are currently exposed to greater flood risks.

The flood risk assessment results identified 16 flood risk sites in Seoul located generally in protected lowlands near tributaries or at topographical knickpoints. The findings derived from this investigation possess the potential to be applied to historic conservation strategies and flood warning systems within the urban context. Although the vulnerability analysis part of the QRA method presents certain constraints, the successful implementation of the current flood risk assessment approach for urban cultural heritage sites is a key contribution of this study. The approach developed in this study will facilitate the planning of a resilient city, while concurrently fostering socio-economic development and the preservation of heritage.

The integrated approach of natural and human contexts of cultural heritage disaster risk presented in this article can be used to comprehend flood risk for heritage sites. This flood risk approach overcomes the limitations of existing engineering-based disaster risk analysis methodologies that exclude the cultural context of heritage sites. This study estimates the flood risk of heritage sites of all periods and types in the historic city, Seoul, by

combining past flood damage information of heritage sites, urban hydrological modeling results under extreme precipitation scenarios, GIS technology, and a literature review on heritage-related history and humanities. Integrating the elements of natural conditions, spatiotemporal properties of cultural heritage sites, and locational characteristics in a comprehensive approach allows for quantitative and clear assessment of potential flood impacts on cultural heritage sites in the city. The integration of traditional and modern approaches, along with comprehensive risk assessments, provides a foundation for developing effective strategies to manage urban flood risks and preserve cultural heritage for future generations.

Nowadays, heritage sites face enormous challenges concerning their preservation. Future extreme rainfall events may surpass the range of scenarios in this study under climate change, resulting in even greater flooding and inundation risks to heritage sites. In light of this, the existing short-term, disaster-oriented approach found in many national heritage policies needs to be expanded to consider the aspects of climate change that produce global and local impacts together. Human settlements' intensive expansion has significantly increased anthropogenic pressure, posing a substantial threat to the integrity and value of heritage sites worldwide [101,102]. This pressure manifests in various forms, including urbanization, tourism, and industrial activities, which collectively contribute to the degradation of these culturally and historically significant areas [103–106]. Countries with higher levels of economic development, including South Korea, generally exhibit decreasing trends in flood damage, casualties, and victims due to several factors, including advanced infrastructure, effective adaptation policies, and technological advancements. For instance, South Korea has implemented significant flood mitigation measures, such as enhancing retention reservoirs, pumping capacity, and river dike construction, which have collectively reduced flood damage by up to 34.3% [107]. This is due to a growing public awareness of natural disasters, advances in forecasting and forecasting technologies, and pan-governmental natural disaster prevention activities. However, the scale of damage to cultural heritage is indeed increasing in line with the rising frequency and intensity of floods and storms, a trend exacerbated by climate change. Over the past 16 years, 89% of cultural heritage disaster damage in South Korea has been due to floods and storms, with 56% of this damage occurring in the last five years alone [108]. This trend is not isolated to South Korea; globally, floods are among the most frequent and damaging events, affecting cultural heritage due to their intangible values and the difficulty in replacing unique objects. In addition, as confirmed in the case of Seoul, severe and ever-increasing development pressures make it increasingly difficult to liberally apply flood risk mitigation measures to historic sites in densely populated metropolitan areas. Furthermore, the question of balancing active mitigation measures with the principle of minimizing artificial interference in heritage preservation is indeed complex and multifaceted, requiring extensive social discussion.

Climate change and development pressures create synergies with direct, indirect, immediate, and long-term effects on the various materials, objects, buildings, and sites of urban cultural heritage. A key message of this study is that enhanced vulnerability analysis based on accumulated disaster damage records should be prioritized for improving flood risk assessments focusing on heritage areas. Additionally, there is currently a pressing need for the development of extreme rainfall scenarios reflecting changing precipitation extremes beyond the capacity of current urban disaster prevention facilities.

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