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AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand

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ABSTRACT

Thailand faced the worst flooding in half a century in 2011. A previous flood had harshly affected the UNESCO World Heritage Site (WHS) and the surrounding communities. The aims of this study were to assess the spatial distribution of flood hazards and analyze how past experience contributed to community flood readiness. Both GIS analysis and household surveys ($n = 405$) were systematically performed. According to the Analytic Hierarchy Process (AHP) technique, approximately half of the whole community area (52.63%) and the WHS (44.8%) were at high risk of flooding. Pratuchai, the most populated subdistrict, was at the highest flood hazard level. Runoff and road density were the main contributors to flooding in a community. Regression analysis found that there was a negative correlation between past flood experience and residents' flood readiness. According to the cluster analysis, there were two groups of respondents: i) those who had more experience with both flood hazards and the inaccessibility of urban services during a flood and were less likely to prepare themselves for future floods ($n = 313$) and ii) those who had less experience with floods and the inaccessibility of urban services and were more likely to prepare for future floods ($n = 92$). This implies, in short, that the local populace had not learned much from past experiences of a flood disasters. Advance urban flood management, multi-hazard zoning, and effective flood risk communication are urgently needed to improve flood resilience in the WHS communities.

1. Introduction

Almost 1 billion people live in flood-prone areas and floods are considered one of the most destructive hazards in the world [1]. Under projected climate change scenarios, the risks of extreme hydrological events and floods are especially likely to be significant and to increase over time. Based on the HadCM3 climate model, the global flood risk will increase by approximately 187% in 2050 compared to a situation without global climate change [2]. Flood hazards affected the largest proportion of the global population (45%) compared to other natural disasters and caused 5,424 recorded deaths between 2000 and 2017 [3]. Geographically, the greatest increase in future flood risk was found in Asia, America and Europe. Populations residing in the Asian cities that are experiencing the most rapid urbanization, such as Bangkok, Jakarta, Dhaka, and Mumbai, will be especially exposed to coastal flooding by the 2070s and will be extremely vulnerable to flood threats [4,5]. Extreme flooding can lead to many negative impacts on human well-being and economic development and pose a threat to cultural assets [6]. Since late November 2011, Thailand experienced some of the worst flood disasters in history. Sixty-five of Thailand's 77 provinces were declared disaster zones, and over ten million people have been affected thus far. In accordance with the World Bank Report [7], the estimated economic damage of the 2011 flooding in Thailand made it the fourth most costly natural disaster in the world from 1995 to 2011.

For the cultural heritage sectors, the total economic loss during that time period was estimated at over US $250 million [7]. In the existing literature, most studies have focused on the physical impacts of flood disasters on cultural heritage objects [8,9]. Other studies have emphasized the willingness to pay for flood protection at historical sites [7,10]. Despite its importance, research on the vulnerability of cultural

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Table 1
Flood hazard assessments: overview of indicators and methods.

Flood hazard assessments	Flood Indicators	Vulnerability Indicators	Methods
Flood hazard assessment studies in local communities			
Don River Watershed, Great Toronto Area, Canada [20]	Distance to streams, height above nearest drainage, slope, and the curve number	Demographic characteristics (i.e., age, family structure, language proficiency), social economic status (i.e., income, education), land tenure	Multi-criteria analysis, GIS- AHP method
Malda district, West Bengal, India [21]	Geomorphological and hydrological variables (i.e., height, slope, landform categories, distance from river, rainfall pattern, distance from river confluence)	Population growth, household density, land use and land cover, distance from major road, distance from flood shelter and literacy rate	GIS-AHP method
Golestan Province, Iran [22]	Drainage, hill shade, flood intensity, land type, slope, susceptibility to erosion	Human losses, population, residential density	GIS weighting/overlay techniques
Xerias stream, Greece [12]	Slope, elevation, distance from streams, land use and hydrolothological formations	–	GIS-AHP method/Multi-hazard mapping
Athens basin, Greece [13]	Slope, elevation, distance from streams, land cover and hydrolothological formations	–	GIS-AHP method/
Mert River Basin, Samsun, Turkey [23]	Water surface profiles, stream network, flow paths	–	Hydrologic Engineering Center River Analysis System (HEC-RAS)
Subcatchment of the Bulbula River, Ethiopia [24],	Catchment area, elevation, slope, stream length, net rainfall, curve number soil conservation service	–	Digital Elevation Models (DEM)
Arno River, Italy [25]	Area, slope, drainage density, stream density	–	DEM
Coastal communities, Philippines [18]	–	Sustainable livelihood, social protection, financial instrument, health and well-being	Disaster resilience index/AHP method
Flood hazard assessment studies focusing on cultural heritage sites			
Sucevita catchment, Romania [26]	Slope, profile curvature, soil texture, land-use, lithology	–	GIS-AHP method
Angkor WHS, Cambodia [27]	Flood affected frequency, absolute elevation, drainage density, river network	–	GIS and flood hazard index model
Cultural Heritages, Taiwan [28]	Rainfall, slope, elevation, sea levels, tides	–	GIS/flood prone stimulation
Historical sites in San Sebastian, Spain [29]	–	State of conservation, existence of water damage, ground floor typology, existence of basement, structural material, drainage system condition, previous interventions, cultural values, existence of adaptive systems	Integrated Value Model for Sustainability Assessment (MIVES)
UNESCO, WHS UK [30],	Fluvial and coastal geological indicators of flooding, susceptibility to groundwater flooding, mining hazard	–	Quantitative analysis
Historic center of Genoa, Italy [31]	Flood frequency and urban drainage	–	Survey of historic documents and observation of flooding episodes during the last century
Cultural Heritage, Newcastle, Australia [15]	Climate change-related risks	Structural condition, heritage fabric condition, and historical damage	Cultural Heritage Risk Index (hazard analysis, exposure analysis, and vulnerability analysis)
Flood hazard assessment studies linking urban services to flood resilience			
Batica [32]	–	Urban functions (i.e., housing, education, food supply, work, safety and governance, health, leisure and tourism) and urban services (i.e., transportation, water, energy, solid waste and communication networks).	Flood resilience assessment

properties to climate-related disasters has not been well documented [11]. To date, only few studies have attempted to explore how local people perceive flood risk and how they prepare for and withstand the flood hazards faced by their cultural communities. Moreover, the implementation of flood disaster risk reduction in Thailand is often hampered by the lack of up-to-date hazard zonation in flood-prone areas. Preparation of risk maps by defining the affected populations and the areas vulnerable to natural hazards is very important for implementing disaster risk reduction programs [12]. In terms of land management and planning, disaster risk maps provide valuable information on hazard zonation for both safe and unsafe areas for human life, livelihoods and public safety [13]. The application of geographic information system (GIS) in flood risk mapping and in extensive analysis of pre-disaster circumstances is generally considered the single most important process for conducting risk assessments of and understanding flood mitigation strategies for cultural heritage [14,17]. These GIS-based flood hazard assessments can serve as baseline data for the integration of specific strategies into the local flood risk reduction agenda and for the prioritization of flood intervention measures to save cultural heritage [15–17].

Moreover, to increase resilient, the United Nations International Strategy for Disaster Reduction (UNISDR) has recognized the capacity of local communities as the cornerstones of disaster risk reduction. This strategy places more emphasis on how to strengthen the capacity of local people (i.e., what they can do for themselves) rather than focusing on their vulnerability to emergency situations [18]. A deeper understanding of how experience contributes to preparedness, as stated in the Sendai framework recommendations, is urgently required [19]. However, progress towards the implementation of flood risk management strategies in the cultural heritage sector and nearby communities has been slow. The aims of this research were to assess spatial distribution of flood hazards by employing the AHP-GIS method, to evaluate the existing flood risk management plans in the WHS and surrounding areas, to examine the impacts of flooding on local communities and to investigate the relationship among flood experience and the provision of urban services on the flood readiness of local communities. The following four research questions were then addressed: i) What is the spatial distribution of flood hazard in the WHS and surrounding areas? ii) What are the statuses of the existing local flood risk management plans and practices in the WHS and surrounding areas? iii) What are the ways in which flood events have affected local communities? iv) How did the flood experiences and provision of urban services contribute to the future flood readiness of the communities living in the affected areas? Ultimately, the results of this study can provide local decision makers and management officials with a baseline flood hazard assessment to establish the most urgent mitigation measures and gain insight into how local communities near the WHS could enhance their resilience to future flooding.

1.1. Flood hazard mapping and vulnerability assessment

Flood mapping is a crucial element of flood risk management (FRM). Commonly, hazard maps are used to qualify the levels of flood risk based on the geographic coverage of hazards and the likelihood of an extreme event. This method is also effective for assigning indicator weights for both disaster risk and vulnerability indices as well as for rating factors in flood risk assessment models [18]. The AHP-GIS is widely used to identify flood hazard areas worldwide (Table 1). Some morphological and hydrometeorological factors, such as rainfall patterns, slope, drainage, elevation, and types of land use, are commonly considered in estimated of the future flood risk in particular local communities and cultural heritage sites [20–31]. In addition, Samela et al. [24] proposed the use of geomorphic descriptors extracted from digital elevation models (DEMs) for mapping flood-prone areas in an ungauged river basin in Africa. Manfreda et al. [25] also employed a DEM to identify flood-prone areas in the Arno River in Italy. In addition to flood hazard assessment, most work in this area has also focused on implementing vulnerability indicators (i.e., demographic characteristics and demographic statuses) to identify and assess vulnerabilities and coping capacities to flood disasters. For instance, Gandini et al. [29] identified the vulnerability of historical sites by using the Integrated Value Model for Sustainability Assessment (MIVES) and multilevel indicators. In the UK, Walker et al. [33] provided a quantitative assessment of geological hazards affecting a WHS. In Australia, Forino et al. [15] applied a new index, known as the Cultural Heritage Risk Index (CHRI), to assess climate change-related risks to cultural heritage assets. The CHRI was proposed to formalize climate risks as a function of hazard, exposure and vulnerability. Similarly, Orencio & Fujii [18] also proposed an index for assessing disaster resilience in coastal communities in the Philippines based on the AHP technique.

Assessing the resilience of urban systems is considered a way to enhance flood resilience. Information on both urban functions and services is required to better reveal how local communities build resilience to future flood risk as stated in the fourth research question. Some studies have linked urban services directly to flood resilience. For instance, Batica [32] developed a method for assessing flood resilience based on the following five dimensions: natural, physical, economic, social and institutional dimensions. Table 1 presents an overview of the applications of flood hazard mapping techniques and vulnerability analysis in several case study countries.

1.2. Flood risk management and resilience

Flood risk management aims to minimize the potential impacts of flood events and vulnerability of local communities. Resilience is defined as the capacity of a system, community or society to absorb a disturbance make necessary changes to allow the system to maintain the typical functions, structure, and characteristics [32,33]. Specifically, flood resilience is defined as the acceptable level of flood impact that an urban system can either adjust to or tolerate (i.e., the system is able to function during and after a flood). For cultural heritage, the topic of disaster resilience has been recently emphasized in the international agenda. The Sendai Framework for Disaster Risk Reduction (2015–2030) states that “it is urgent to anticipate, plan for and reduce disaster risk in order to more effectively protect communities, their livelihoods, health, **cultural heritage**, and socioeconomic assets, and thus strengthen their resilience” [19]. Risk management strategies (i.e., risk identification and hazard mapping) and disaster preparedness strategies are also urgently required. Although flooding events receive a considerable degree of attention, few studies have examined the relationship among urban services, past flood experiences and disaster readiness in local communities living in at a WHS.

1.3. Flood experiences

Previous research has identified several determinants of individual and community disaster preparedness. One factor, personal experience, can affect self-protective behavior and disaster awareness in different ways [34,35]. Individuals’ reactions to risks associated with disasters might differ depending on their prior experiences [36]. Becker et al. [35] categorized the terms ‘experiences’ into 4 types: (i) *direct experience* (i.e., people who were directly affected or directly impacted by disasters, including experiencing damage), (ii) *indirect experience* (i.e., being indirectly impacted by disasters or not being personally affected), (iii) *vicarious experience* (i.e., experiencing or understanding disasters through the feelings or actions of others), (iv) *life experience* (i.e., personal experience throughout their own lifetime). It is likely that people with direct flood experience show higher levels of perceived flood risk [37]. The perception of risk can be either strengthened or weakened by people’s indirect experience. Obviously, the study of how people become more interested in disaster preparedness (even when they have little prior experience) has been the fundamental question in risk analysis and communication research [38], especially in Thailand.

2. Case study

Ayutthaya city (the whole municipality; locally, the area is simply called Ayutthaya Island) was selected as a case study (Fig. 1). The city is approximately 70 km north of Bangkok and is surrounded by the Chao Phraya River in the west and the south, Lopburi River in the north, and Pa Sak River in the north and the east. The island has a population of more than 50,000, with 20,220 total households in 10 sub districts: Pratuchai, Ho Rattanachai, Kamung, Klong Sa Bua, Hua Ro, Tha Wasukee, Ban Kao, Huntra, Klong Suan Phlu, and Khao Rain. The island is an urban area, and approximately 40% (289 ha) of the total area is protected by as the UNESCO WHS. Geographically, the island has a large number of cultural heritage attractions, including temples, archaeological sites, cultural landscapes, museums and historical landmarks. Two major problems that often occurs on the island are fluvial flooding, which is caused by upstream river overflow, and pluvial flooding, which arises from intense rainfall. As mentioned above, the entire historical island of Ayutthaya and its surrounding area were inundated with flood waters for more than a month; a total of approximately 157 historic monuments in and around the WHS were affected. The WHS is therefore particularly vulnerable to flood hazards. According to the rapid assessment for resilient recovery and reconstruction planning for the 2011 flooding in Thailand that was conducted by the World Bank, Ministry of Finance and Royal Thai Government, the costs of flood damage to the heritage sector in Ayutthaya were estimated at approximately 64.28 million Thai baht (US$ 2.14 million). Ayutthaya city experienced the greatest level of tourism-related damage at cultural sites due to the 2011 flooding in Thailand [39].

3. Research methodology

3.1. Flood hazard map

A flood hazard map of Ayutthaya Island was developed using GIS

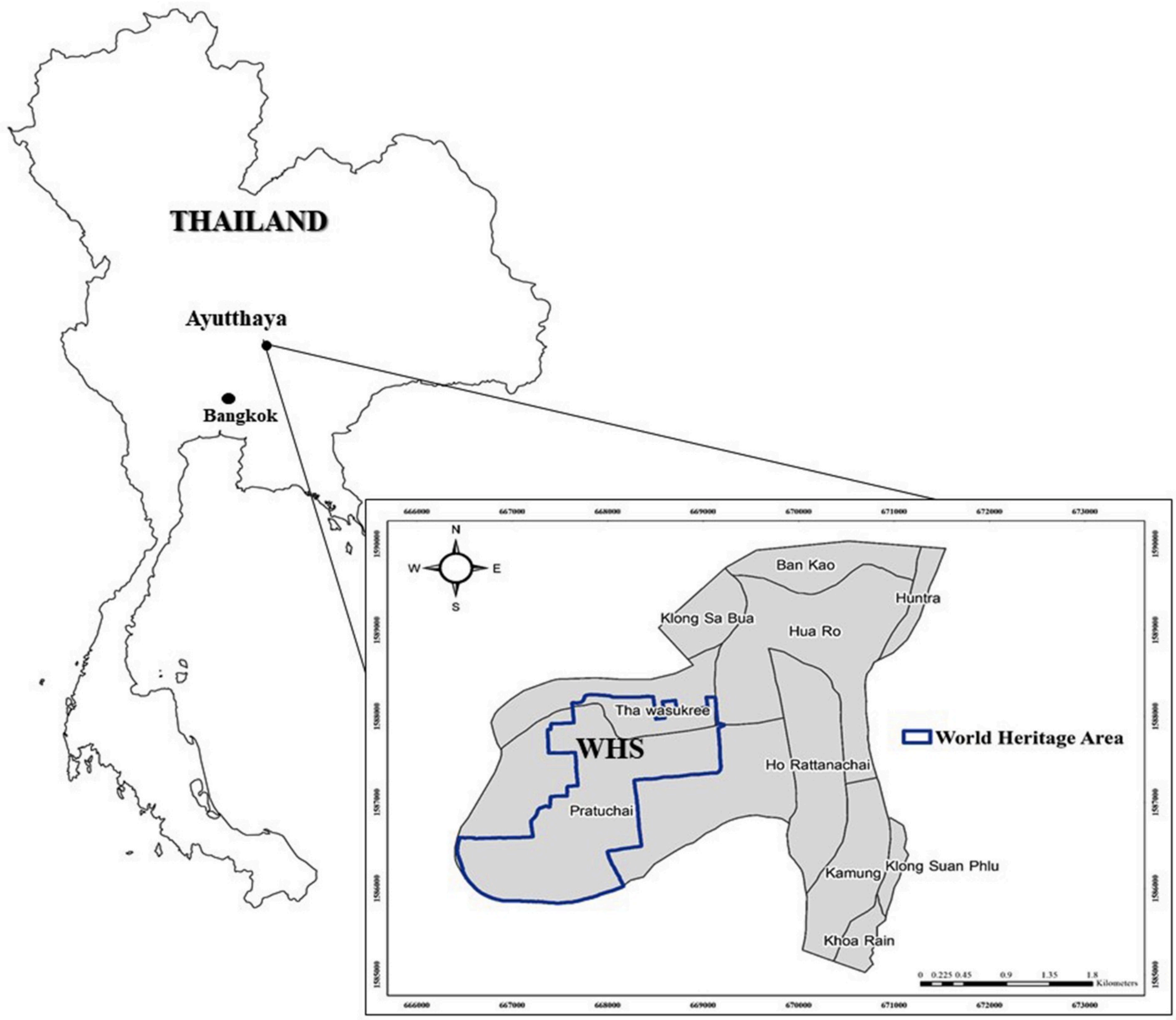

Fig. 1. Research case study: Ayutthaya Island, Thailand.

through the overlay analysis technique, which takes two or more different thematic maps of the same area and overlays them on top of one another to form a new map (Fig. 2). This technique commonly results in a cross-tabulation matrix that describes the main types of change in a study area. The following nine thematic-layer factors were used to estimate the flood-hazard areas by using ArcGIS 9.3: daily maximum rainfall (mm/d), flood in past year (yrs), slope of the area (%), elevation (m), drainage density (km/km^2), watershed area (km^2), run-off (m^3), road density (km/km^2), and land-use. All GIS dataset layers were obtained from the relevant authorities. All nine maps were consequently combined by weighted linear combination (also known as the weighting approach), where the weighted averages of continuous criteria are standardized into common numeric ranges and combined. As shown in Eq. (1), the final map of flood hazard areas was derived from the sum of the weights multiplied by the rate of each individual factor [40,41]:

$$H = \sum_{i=1}^{n} W_i X_i \tag{1}$$

where H is the flood hazard degree,

n is the number of the factors,
W_i is the weight of each individual factor i, and
X_i is the rating of each individual factor i.

The proposed weighting of each factor was based mainly on expert judgment (i.e., representatives from the Ayutthaya Historical Park, local temple, Disaster Prevention and Mitigation Office in Ayutthaya, the Royal Irrigation Department, the Department of Land Development, and the office of the Ayutthaya municipality). All nine factors were judged by the experts regarding the importance of each factor in causing floods in the case study area based on the AHP technique. The main advantage of using the GIS-based AHP by the pairwise comparison method was the possibility of obtaining a reliable hazard map that was more flexible and that was easier to update. Moreover, the method has been applied to a wide variety of decision-making problems with a large number of criteria [42] because of its capacity to integrate a large quantity of heterogeneous data and because it provides the degrees of consistency and inconsistency of the obtained weights of criteria. Theoretically, the weighting coefficients of the selected flood hazard factors in the AHP method were revealed via the following pairwise comparison matrix (Eq. (2)).

$$A = [a_{ij}] = \left\{ \begin{matrix} 1 & a_{ij}\ldots & a_{1n} \\ 1/a_{ij} & 1 & a_{2n} \\ 1/a_{1n} & 1/a_{2n} & 1 \end{matrix} \right\} \tag{2}$$

where $A = [a_{ij}]$ is a representation of the intensity of the expert's preference for one factor over another compared alternative a_{ij} and all comparisons $i,j = 1,2, \ldots, n$.

In the first step, the expert pairwise comparison judgments were

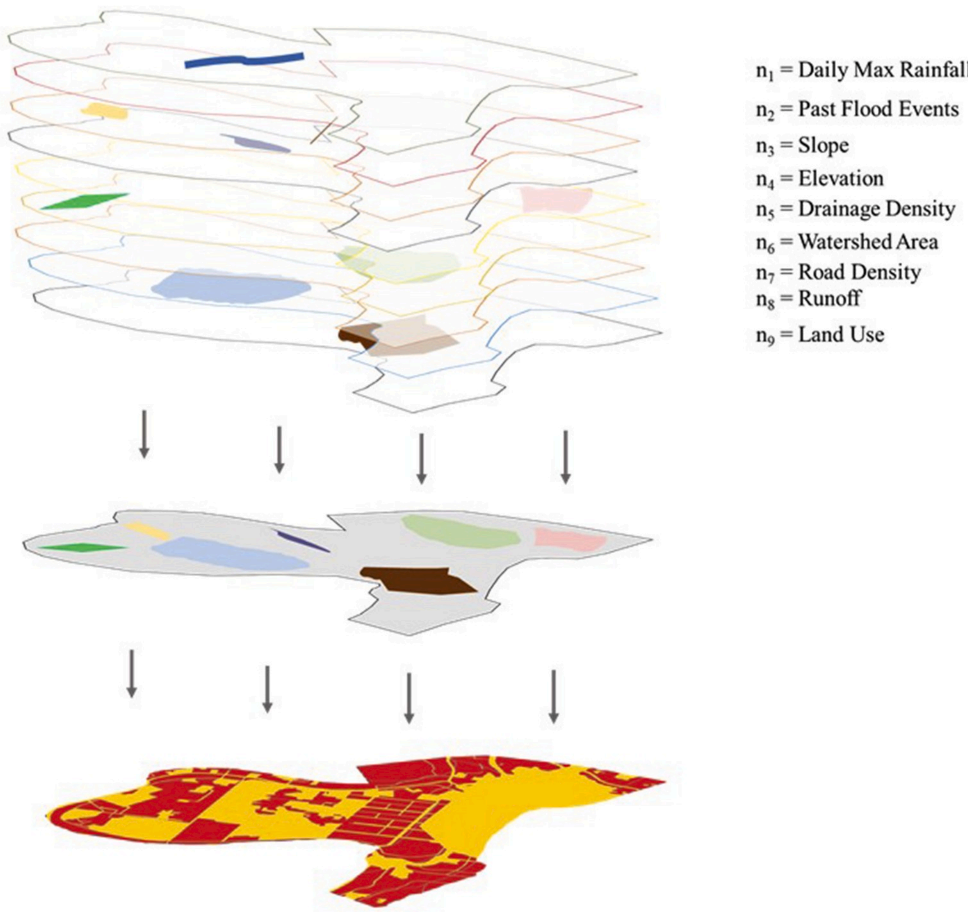

Fig. 2. Flood hazard analysis using the overlay method.

performed by using the nine-point scale [41]. In the construction of the matrix, each flood hazard factor was rated in relation to the other factors, which were each given values from 1/9 to 9 (i.e., less important variables were valued from 1 to 1/9) (Table 2). When the comparison was carried out in the opposite direction, the adopted numerical value was the reciprocal of the first value. All numerical values from the pairwise comparison were then normalized in the AHP by dividing each entry in a column by adding all entries in that column so that they summed to 1. Following the subsequent normalization, the values were averaged across the rows to give the relative importance weight for each flood hazard factor [12,41]. In the last step, to avoid the occurrence of any incidental judgment in the pair-wise comparison matrix, the consistency ratio (CR) was computed using the consistency index (CI) value (Eqs. (3) and (4)). Following Saaty [41], the random consistency index (RI) of 1.45 was selected for the nine flood hazard factors. When the estimated CR was equal to (or less than) 10% (≤ 0.1), the calculated weighting coefficients were acceptable.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3}$$

where $\lambda_{\max}$ is the largest eigenvalue of the pairwise comparison matrix and.

n is the number of factors.

$$CR = \frac{CI}{RI} \tag{4}$$

where *CI* is the consistency index and.

RI is a random consistency index (e.g., the RI for 9 factors is 1.45).

Although AHP has been widely applied to develop disaster hazard maps with reliable accuracy, the results are mainly based on expert judgment and thus might cause uncertainty in criteria weight estimation. In this study, sensitivity analysis was conducted to analyze the sensitivity criteria of flood hazard mapping. The one-at-a-time (OAT) method [43] is adopted by changing the weight of a single factor with a certain percentage interval and then measuring the impact of that change. In this study, the range of percent change (RCP) from an original criterion weight at ±20% was applied to all criteria with a 5% increment in the percent change (IPC) (i.e., plus or minus 5%). The weights of the main criteria at certain percent change levels were estimated by Eq. (5).

$$W(Cm, pc) = W(Cm, 0) + W(Cm, 0)x\ \ pc \tag{5}$$

where *W(Cm,0)* is the weight of the main changing criterion *Cm* in the base run case and.

pc is the percent change level.

Table 2
Rating scale for the AHP pairwise comparison [18,41].

Rating Scale	Judging preference	Description
1	Equally preferred	Two factors contribute equally to the objective
3	Moderately preferred	Judgment slightly favor one factor over another
5	Strongly preferred	Judgment strongly favor one factor over another
7	Very strongly preferred	Judgment very strongly favor one factor over another
9	Extremely preferred	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate preferences	These scales were used to distinguish similarities between alternatives

Consequently, the weights of the other criteria were proportionally adjusted at any percent change level which requires all criteria weight to sum to one by using Eqs. (6) and (7) [42].

$$W(pc) = \sum_{i=1}^{n} W(Ci, pc) = 1, \quad RPCmin \leq pc \leq RPCmax \tag{6}$$

where $W(Ci, pc)$ is the weight of the i-th criterion ci at a certain percent change level,

n is the total number of criteria,
RPC min is the minimum value of the RCP, and
RPC max is the maximum value of the RCP.

$$W(Ci, pc) = (1 - W(Cm, pc)x \ W(Ci, 0) / (1 - W(Cm, 0) \tag{7}$$

3.2. Survey and data analysis

The survey was conducted from January to March 2019 on Ayutthaya Island, Thailand. A questionnaire was designed to evaluate the flood readiness of the local people, especially those who had experienced flood disasters in the past year. The total respondents of 405 households in Pratuchai ($n = 135$), Ho Rattanachai ($n = 89$), Tha Wasukee ($n = 81$), Hua Ro ($n = 44$), Klong Suan Phlu ($n = 18$), Kamung ($n = 18$), Khao Rain ($n = 8$), Huntra ($n = 7$), Klong Sa Bua ($n = 3$), and Ban Kao ($n = 2$) were randomly selected as a target group of this research. During the survey period, the ages of the respondents ranged from 15 to over 80 years. Approximately 52% of the respondents were female, and 48% were male. Their readiness for flood hazards was assessed by means of a five-point Likert scale (5 = very prepared/very ready to 1 = not very prepared/not ready at all). Flooding experience in this study was defined as the frequency of direct experience in the last 10 years from any form of flood damage. The previous 10-year period was chosen to include those affected by Thailand's 2011 flood crisis. Moreover, all respondents were asked to indicate their perception of the availability levels of urban services during a flood as follows: 1 = poor availability – major interruptions; 2 = low availability – interruptions result in minimum availability; 3 = medium availability – small interruptions that are tolerable for the duration for small floods; 4 = medium availability – high interruptions that are tolerable for the duration of long floods; 5 = full availability – requirement fully provided [32]. Regression analysis was conducted to define how personal experiences and urban services were related to readiness to respond to flood hazards. The independent variables were flood experience and the availability levels of urban services during a flood crisis. Flood readiness was the dependent variable. To understand the specific characteristics of the survey respondents, cluster analysis was also analyzed by nonhierarchical cluster analysis (the k-means clustering method) [44].

4. Results and discussion

In answering the research questions, the following section presents results (i) assessing the spatial distribution of the flood hazards and (ii)

Table 3
Spatial data and weight evaluation of the factors affecting the flood hazard areas on Ayutthaya Island, Thailand.

Factors	Weighting (a)	Rank	Sub-factors	Rating (b)	Sources
Run-off (m^3/sec)	0.187	1	> 8,136	8	Average annual run-off during 1989–2018, Royal Irrigation Department, Thailand
			5,636–8,136	6	
			3,136–5,636	4	
			< 3,136	2	
Road density(km/km^2)	0.141	2	> 0.60	8	Department of Environment Quality Promotion, TISTR (1999)
			0.41–0.60	6	
			0.21–0.40	4	
			0.00–0.20	2	
Daily maximum rainfall (mm/d)	0.139	3	> 90.1	8	Annual maximum daily rainfall during 1989–2018, Thai Meteorological Department
			35.1–90.0	6	
			10.1–35.0	4	
			0.1–10.0	2	
Slope (%)	0.136	4	0–5	8	Topographic maps at scales 1:50, 000, Royal Thai Survey Department, ONEP (1998)
			6–10	6	
			11–15	4	
			> 15	2	
Watershed area (km^2)	0.117	5	> 350	8	Royal Irrigation Department (1997)
			251–350	6	
			151–250	4	
			< 150	2	
Land-use	0.106	6	Settlement	8	Land-use data (2018), Land Development Department
			Crop land	6	
			Others	4	
			Forest land	2	
Drainage density (km/km^2)	0.063	7	0.10–0.35	8	Department of Environment Quality Promotion, TISTR (1999)
			0.36–0.70	6	
			0.71–1.00	4	
			> 1.00	2	
Past flood events (yrs)	0.061	8	Flooded ≥ 3 yrs	8	All previous floods during 2005–2017, Geo-Informatics and Space Technology Development Agency: GISTDA), TISTR (1999)
			Flooded ≥ 2 yrs	6	
			Flood in a year	4	
			Never flooded	2	
Elevation (m)	0.049	9	0–100	8	Topographic maps at scales 1:50, 000, Royal Thai Survey Department, ONEP (1998)
			101–300	6	
			301–500	4	
			> 500	2	
	$\lambda_{max} = 10.12$; $CI = 0.14$	$CR = 0.096$			

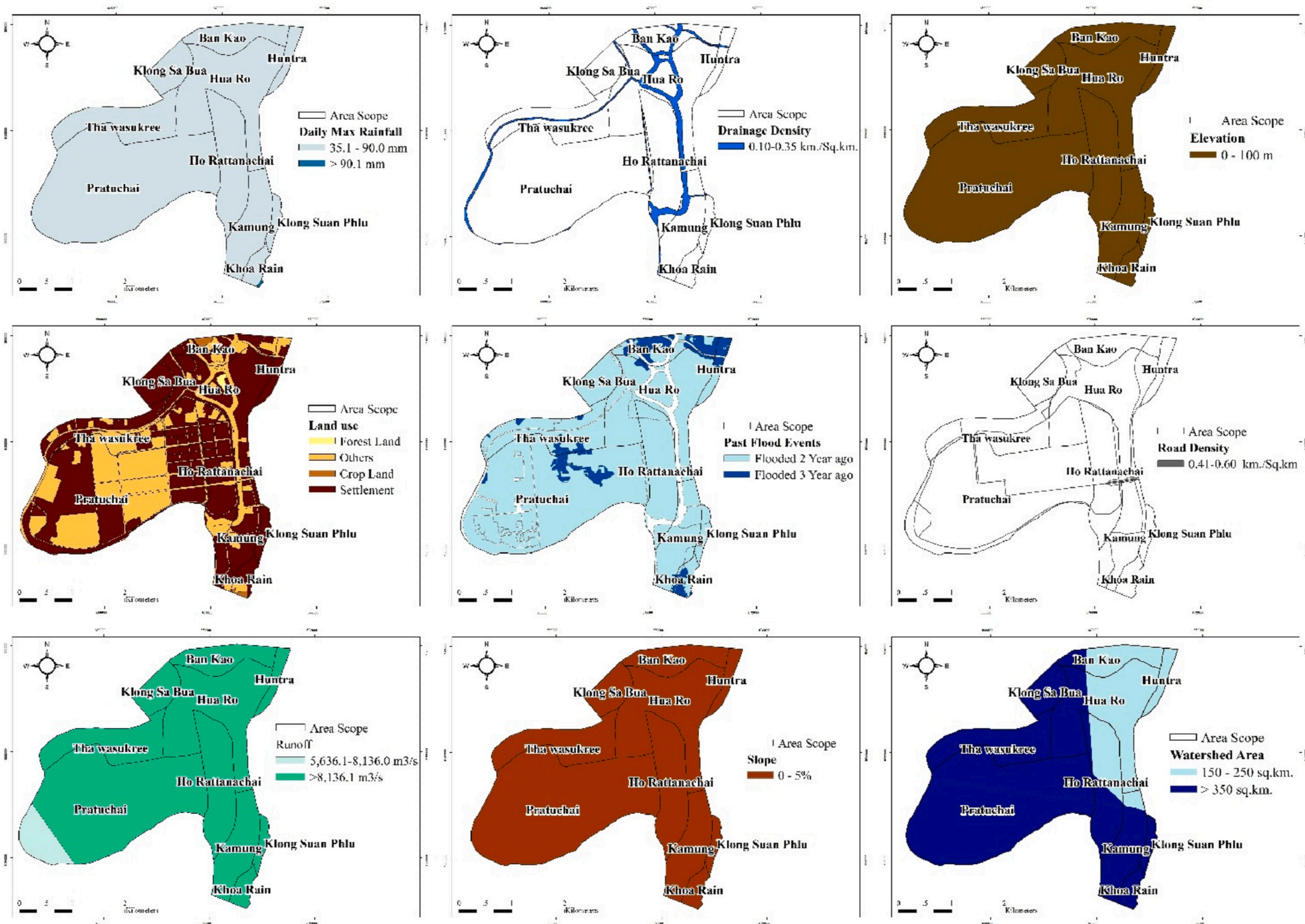

Fig. 3. Nine thematic-layer factors affecting the flood hazard identification.

the status of the existing flood risk management plan, (iii) describing the ways in which the floods affected the local people and (iv) how past experiences and urban services contributed to flood readiness in the affected areas:

4.1. Flood hazard assessment

4.1.1. Factors affecting the flood hazard

The flood hazard map was developed by using the daily maximum rainfall, flooding in past years, slope of the area, elevation, drainage density, watershed area, runoff, road density, and land-use related information. The estimated CR value was 0.096 ($<$0.1, which was acceptable). All spatial data and the proposed weights and ratings of the factors affecting the flood hazard areas on Ayutthaya Island are shown in Table 3. The flood hazards levels were categorized into three classes: high, medium, and low.

By applying GIS-AHP, runoff and elevation were given the highest and lowest criteria weights, respectively. Runoff, road density, and daily maximum rainfall were the third most common causes of flooding in the communities near the WHS in the Historic City of Ayutthaya. Due to the low topography, flood hazard areas with high runoff levels ($>$ 8,136.1 m^3/s) covered 12.9 km^2, accounting for approximately 95% of the entire study area. The high flood hazards in the watershed areas ($>$ 350 km^2) were mainly located in the west and south of the island and occupied 76% of the total area. In terms of the land use, over half of the total area surrounding the WHS (61%) served as settlement. The remaining land uses were governmental areas, agriculture and other land uses. Increasing urban development density is directly associated with intense runoff, which contributes to increasing the vulnerability of flood hazards [13]. As depicted in Fig. 3, the nine maps were combined using a weighted linear combination approach in the AHP-GIS environment.

4.1.2. Flood hazard mapping

As shown in Fig. 4, the total area that was at risk of flooding was approximately 13.51 km^2. By applying the overlay technique, 7.11 km^2 was deemed be at a high hazard level and 6.40 km^2 was at a medium hazard level. The total flood hazard area affecting the WHS was 3.17 km^2, with 44.80% of the area classified at the high hazard level and 55.20% at the medium hazard level. The classifications of the flood hazard categories in each subdistrict are shown in Table 4. According to the AHP-GIS, Pratuchai, where most people live, had the highest risk of flooding. The subdistrict of Pratuchai is classified as a town and includes the governmental, WHS, and commercial areas and the urban services. Tha Wasukee, which is also defined as a town, had the second highest flood risk. As agricultural and semi-urban areas, the Khao Rain, Klong Suan Phlu, and Huntra subdistricts presented the lowest flood risks. As presented in Table 4, the accuracy of the produced flood hazard map was verified using both the historical flood occurrences from 2005 to 2017 and the annual maximum rainfall in the communities near the WHS from 1987 to 2018. The results demonstrated that the vast majority of flood incidents were also located in the high flood hazard areas indicated on the GIS-created maps. Pratuchai (the location of the WHS) was the most flood-prone subdistrict. This may have been because floods are more likely in larger watersheds where the precipitation collects and drains into the body of water. Approximately 39.74% of the watershed area is located in the Pratuchai subdistrict. Moreover, both the high

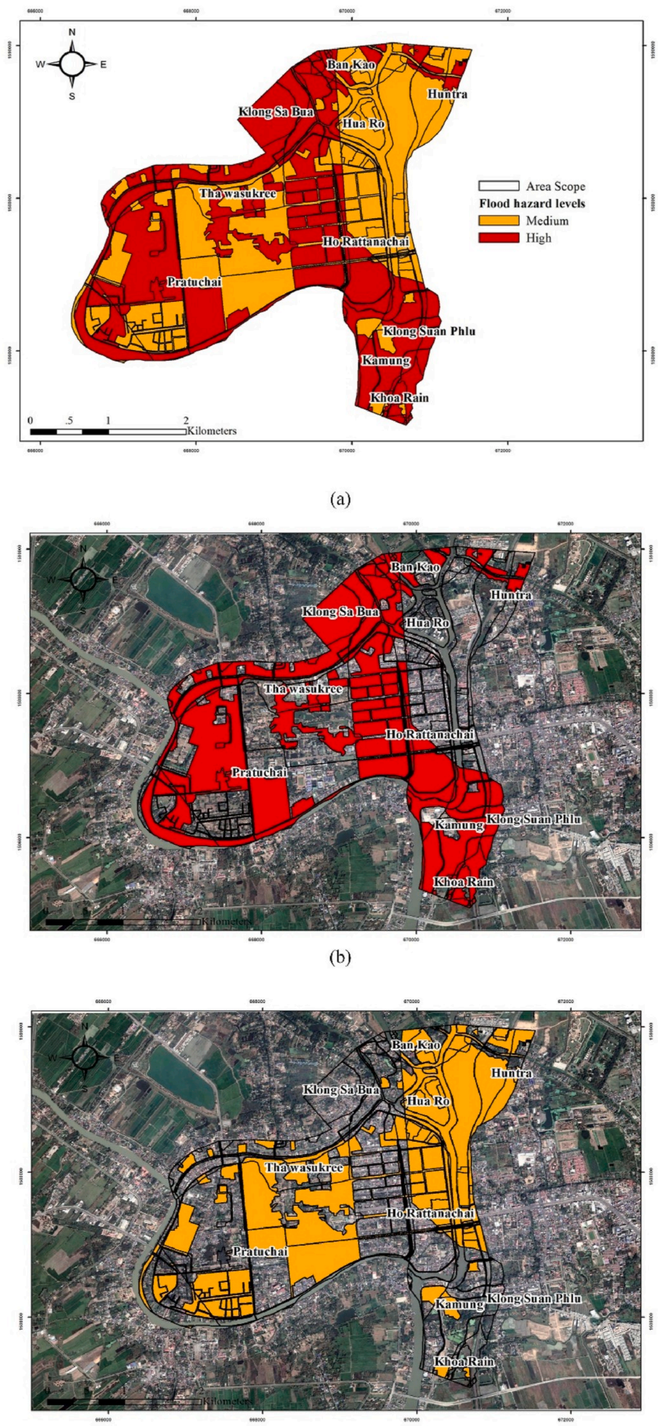

Fig. 4. Flood hazard levels in the WHS and the surrounding communities: (a) AHP-GIS map (b) satellite image (high flood hazard) and (c) satellite image (medium flood hazard).

population (6,344 households) and high road density in Pratuchai (38% of the total area) are closely linked to the degree of urbanization, which increases urban discharge and surface runoff [13] and creates favorable conditions for flooding. Similarly, high percentages of runoff and high densities of road networks have also promoted flood events in commercial and residential areas, namely, Hua Ro, Ho Rattanachai, and Tha Wasukee. Altogether, the flood hazard results aligned with the results of a previous study conducted by Skilodimou [45], who found that the closer the distance was to the drainage network, the higher the correlation with actual flood incidents (e.g., those in the Ho Rattanachai and Hua Ro areas). On the one hand, a less-dense road network could reduce the probability of flooding. In low-risk flood zones, the GIS-produced flood hazard map provided similar results to the historical flood events in the communities. In particular, only 1–2% of the high flood risk areas were in Klong Suan Phlu and Huntra (which are outside the WHS area), and both areas had their lowest annual maximum rainfall levels from 1987 to 2018. Additionally, when compared with the other flood risk assessment methods, the results of the applied AHP method confirmed the findings of Vojinovic et al. [46], who employed the MIKE FLOOD model to indicate the flood risk level in the Historic City of Ayutthaya and found that much of Ayutthaya Island was inundated with more than 0.5 m of water during the 2011 flooding in Thailand; the island had been defined as a medium hazard area. However, much of the WHS was inundated to flood depths of greater than 1.5 m, which was indicative of a high hazard area. Even when applying different methods of hazard identification (i.e., GIS and flood modeling), the findings of this study were consistent with [46], which indicated that the flood risk was highest on the eastern, northeastern and southern edges of the island, while lower flood risks were observed in the middle parts of the island. During the 2011 flood crisis, flood water entered the island through the canals located on the southwestern corner of the island, and polluted wastewater distributed in the community area. This can potentially cause risks to human health due to contact with contaminated wastewater. Therefore, it remains important for local authorities to provide action plans for addressing the effects on the community of excessive flooding of wastewater treatment plants.

In sensitivity analysis, the RPC of $\pm 20\%$ and the IPC of $\pm 5\%$ were applied to analyze the effect of a change in the weight applied to each flood hazard factor. The sensitivity simulation consists of 72 evaluation runs where each run generates a single new flood hazard classification map. Changes in the flood hazard areas at any percent change level were consequently observed as criteria weight sensitivity. The results demonstrated that road density, slope and elevation have the lowest sensitivity among all criteria. Beside this, the variations in flood hazard classification occurred within the -20% of weight changes for both drainage density and past flood event. Watershed and land use showed similar degree of sensitivity in flood hazard mapping at -10% and -5% weighting variation, respectively. Run-off and maximum rainfall caused the flood hazard classification change at the $+5\%$ weighting variation.

4.2. *Flood risk resilience and management in the WHS and the nearby communities*

To understand the status of the existing local flood risk management plans and practices in the WHS and surrounding areas, all dimensions of FRM were investigated as described below (Table 5).

4.2.1. *Policy dimension*

In response to the impacts of Thailand's worst floods in 2011, the Fine Arts Department of Thailand conducted flood damage restoration at 154 archaeological sites. Some restoration projects were completed in collaboration with international organizations (i.e., the German Wat Ratchaburana Safeguarding Project in 2012 and the project to conserve Wat Chaiwattanaram with cooperation from the United States of America). The World Heritage Committee was finalizing the first master plan for conservation and development projects of the Historic City of Ayutthaya (2018–2027). In 2018, the master plan was presented to the Ministry of Culture will be implemented upon approval from the cabinet. Specifically, the disaster mitigation measures include the following activities [47]:

- The Emergency Preparedness and Disaster Planning Department assigned key personnel to be in charge of incident management commensurate to the severity of disasters as specified in the State

Table 4
Historical flood occurrence and flood hazard classification by subdistricts.

Sub-districts	Land-use Characteristics	Flood areas in the past (2005–2017) (%)	Maximum rainfall (1987–2018) (%)	Number of households	AHP-GIS Flood hazard map		
					Hazard levels	Area (km^2)	%
Pratuchai (The WHS area)	Town: WHS governmental, residential, and commercial areas	40.79	39.74	6,344	High	2.83	20.95
					Medium	2.54	18.80
Tha Wasukee	Town: WHS governmental, residential, and commercial areas	9.80	9.49	3,193	High	0.84	6.22
					Medium	0.44	3.26
Hua Ro	Commercial and residential areas	17.53	18.70	4,312	High	0.79	5.85
					Medium	1.74	12.88
Kamung	Commercial and residential areas	7.44	7.73	659	High	0.80	5.92
					Medium	0.24	1.78
Klong Sa Bua	Semi-urban areas (i.e. agricultural and residential areas)	4.12	3.86	116	High	0.52	3.85
					Medium	0.00	0.00
Ho Rattanachai	Commercial and residential areas	10.27	10.18	4,185	High	0.57	4.22
					Medium	0.81	6.00
Ban Kao	Agricultural area	5.04	5.57	448	High	0.32	2.37
					Medium	0.43	3.18
Khao Rain	Agricultural area	1.84	1.67	91	High	0.22	1.63
					Medium	0.02	0.15
Klong Suan Phlu	Semi-urban areas (i.e. agricultural and residential areas)	1.29	1.23	457	High	0.16	1.18
					Medium	0.00	0.00
Huntra	Semi-urban/residential areas	1.88	1.78	415	High	0.06	0.44
					Medium	0.18	1.33

Party's national disaster prevention and mitigation plan (2010–2014).

- Disaster evacuation plan was improved by prescribing an assembly point and evacuation routes.
- Ancient monuments plan has been issued to manage the risk of disaster (e.g., reviving ancient canals, placing foldable flood barriers along the Chao Phraya River, etc.).

The Disaster Prevention and Mitigation Plan of Ayutthaya Province was issued in 2015 and amended in 2019 to provide a coordinated platform for disaster mitigation among the entities from the central, provincial, and local administrations in disaster risk management. The Ayutthaya municipality also issued its own Flood Risk Management Plan (FRMP), including both structural and non-structural flood protection. Communication of flood warnings includes the processes of maintaining constant watch and flood monitoring and emergency warning notification within 120 h and 72 h, respectively. These warnings would be carried out mainly through public address systems, community leaders, social media, and community websites.

4.2.2. Natural and physical dimensions

The flood risk management plan is only applicable to the level of the whole Chao Phraya River basin. There is no local plan available for temporary water shortage in the municipal areas. The excavation of canal networks in the WHS and surrounding communities is one of the most common preparedness measures. Flood protection barriers in the WHS (i.e., in the Pom Phet, Wat Chaiwatthanaram and Dhammaram temples), flood gates and water pumping stations are available to support flood control in the community areas. The flood evacuation routes for the WHS are given in Fig. 5. However, there is still no clear information on flood evacuation routes available to the surrounding communities. There has also been no involvement of local residents in the simulations of flooding scenarios in their communities. It is important to recognize that there is no specific plan at the provincial/municipal level that directly deals with both solid waste and wastewater management during a flood. Obviously, the lack of proactive engagement and participation of the local people was the most significant social challenge in FRM in the communities. The interview results revealed that the local people generally paid more attention to their jobs than to how to prepare themselves for floods in their communities in the future. Given this situation, it seems obvious that the lessons from previous floods have not taught local residents the importance of preparing for future flooding events.

Overall, Table 5 provides a summary of flood risk management in the WHS and nearby communities to gain greater insight into the roles of policies and interventions in shaping FRM in the WHS communities. Integrated watershed management, urban services during and after floods and effective public participation in flood-related issues were considered the key challenges to building flood resilience in this community.

4.3. Survey analysis

This section answers the third and fourth research questions about the ways in which the flood event affected local communities, and how the flood experiences and urban services provision contributed to the future flood readiness of communities living in the affected areas. The results of the community survey conducted on Ayutthaya Island (n = 405) are described below.

4.3.1. Past flood experiences, evacuation and flood-related impacts

Regarding previous flood experiences in the past 10 years, 37% of respondents reported having been affected 3–5 times, 39% of respondents were affected one time, and 0.5% had never experienced flooding (Fig. 6a). For flood evacuation, almost all respondents (84%) indicated their intention to stay in their houses during a crisis (Fig. 6b). Nearly half of the survey respondents were aware of the negative impacts of water quality (e.g., for showering and consumption) (41.5%) and health-related impacts (43.7%) due to flooding. In the past, the dominant health problems during the floods were fungal skin disease (athlete's foot) (31.4%) and mental health problems (e.g., fear, anxiety, and depression) (27.7%) (Fig. 6c). In a similar study, Kittipongvises & Mino [48] conducted an online survey of the perception of Thailand's flood crisis in the Bangkok metropolitan region (BMR), including Bangkok and the five surrounding provinces: Nonthaburi, Pathum Thani, Nakhon Pathom, Samut Sakhon, Samut Prakarn and Ayutthaya in 2011 ($n = 437$); the survey found that over 80% of respondents reported having experienced flooding in their communities. Regarding their perceived likelihoods of being flooded in the future, more than half of the respondents perceived that floods were likely to occur again.

Table 5
FRM and flood resilience in the WHS and nearby communities.

FRM Elements	Indicators	Policy instruments/interventions	Availability		Remark:
			WHS	Com mu nities	
Policy:	FRM plan and related strategies	● Master Plan for Conservation and Development for the Historic City of Ayutthaya (2018–2027)[1]	✓	✓	[1] The Ministry of Culture of Thailand has approved the updated master plan. It is now waiting for approval by the Cabinet (As of 2019).
		● Disaster Prevention and Mitigation Plan of Ayutthaya province	✓	✓	
		● Flood Risk Management Plan of Ayutthaya Municipality		✓	
Natural:					
Resist	River network	● River watershed management	N/ A*	N/A*	* Available only the whole Chao Phraya River Basin.
		● Increased channel-conveyance capacity	✓	✓	
Physical:					
Relief	Flood compartment system	● Capacity to temporarily store flood waters	N/A	N/A	
Resist	Flood protection	● Flood monitoring system	✓	✓	
		● River network monitoring system	✓	✓	
		● Urban drainage	✓	✓	
Resist	Weather forecast	● Real-time monitoring system	✓	✓	
Response	Crisis management	● Crisis management center/Protected locations	✓	✓	* It is observed that there is no involvement of local residents in emergency evacuation exercises in the community.
		● Early warning system	✓	✓	
		● Emergency evacuation routes	✓	✓	
			✓*	N/A*	
Response/ Recovery	Waste management	● Solid waste management	N/A	N/A	
		● Wastewater management	N/A	N/A	
Recovery	Reconstruction system	● Availability of allocation for reconstruction and renovation	✓	✓	
Social:					
Reflect	Coordination between stakeholders	● Information coordination within community	✓	✓	
	Knowledge exchange	● Multidisciplinary knowledge exchange	✓	N/A	
	Public participation	● Participation in FRM	N/A	N/A	
Resist	Financial management	● Welfare availability	✓	✓	
		● Financial supports from the insurance	N/A	✓	
		● Deduction to the taxes of people in flooded areas	N/A	N/A	
Response	Rescue system	● Accessibility and availability of emergency shelter	✓	✓	
		● Accessibility and availability of emergency road network	✓	✓	
Recovery	Lesson learned from past events	● Examination of dysfunction of previous events	✓	N/A	

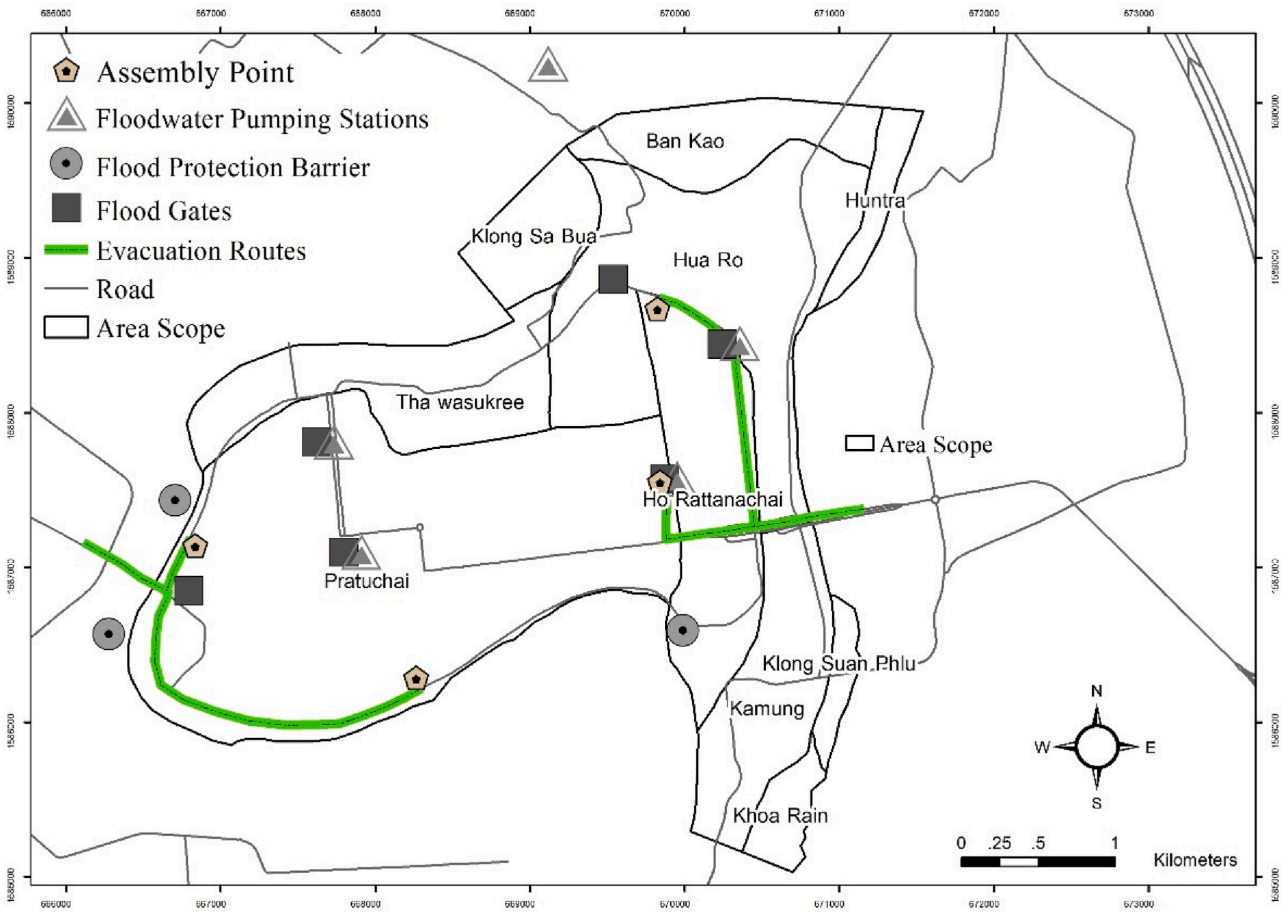

Fig. 5. Flood control facilities and evacuation routes in the WHS.

Flood-related topics also evoked feelings of stress and anxiety (54–56%), as well as powerlessness and fear (31–32%) among the local Thai respondents.

4.3.2. Availability of urban services

As expected, the local communities had difficulty accessing urban services (i.e., electricity, tap water, drinking water, waste management (both solid waste and wastewater treatment) and communication services) during flood crises. The lack of basic facilities, especially food ($\bar{x}$ = 1.29) and transportation access ($\bar{x}$ = 1.51), were the main problems faced by the majority of survey respondents. In the case of the 2011 flooding, most public transport systems on Ayutthaya Island were shut down, and some main roads in several areas were cut off almost entirely. Many people who lived in the community had to travel by boat. This was also one reason why the local authorities encountered great difficulty in extending assistance to the people affected by the flood. Some people also suffered from difficulties in eliminating the solid waste and wastewater/floodwater smell in their area. In support of these findings, a study conducted by Douglas et al. [49] noted that limited access to critical urban services such as safe food and water during a flood was considered to be one of the key factors reducing the ability of local people to withstand and adapt to flood situations.

4.3.3. Sources of information and flood readiness

Approximately half of the targeted respondents in the flood-prone areas had received information on the possibility of flash flooding and had been counseled to move to higher ground immediately and be prepared to evacuate before water levels rose; this information was disseminated through early warning broadcasts (i.e., via television, radio, public address systems) in their communities. Similarly, the survey results on risk perception and the communication of Thailand's flood crisis in the BMR of Thailand in late 2011 by Kittipongvises & Mino [48] revealed that only 40% of all respondents in their survey received early warnings. Of these, over half (65%) reported receiving a warning of less than 1 h, while approximately 24% received information at least 3 h before the flood arrived. In that respect, it should be noted that waiting until the flood emergency is fully established in a community transfers both the risks and consequences of inaction onto the vulnerable groups. Apart from the early warning scheme, very few respondents reported having received any type of flood preparedness information, such as guidelines for flood emergencies or evacuation plans (5.4%), community flood responses and adaptation strategies (4.2%), and community leaders (1.5%). In a potentially surprising finding, as depicted in Fig. 7a, only approximately 2.2% of respondents reported having received information on flood preparedness from relevant experiences and details of lessons learned from the past (i.e., Thailand's flood crisis of 2011). More importantly, when asking the respondents about their preparedness/readiness for future flooding in their community, about half of the respondents (47.9%) said that they felt not quite ready or not ready at all ready, with a quarter (29%) indicating that they felt very ready or more or less ready (Fig. 7b). These results were consistent with the findings of Hoffmann & Muttarak [34], who conducted a survey in Phang Nga, Kalasin, and Ayutthaya, Thailand in 2014 (n = 1,310) and found that only 32% of all respondents reported undertaking disaster preparedness actions. It was seen in this study that most survey respondents tended to allocate responsibility for disaster mitigation and preparedness initiatives to their local government and waited for announcements before taking action. Regarding their perceived ability to prepare for floods, local respondents took no independent action and attributed their lack of response to flood events to

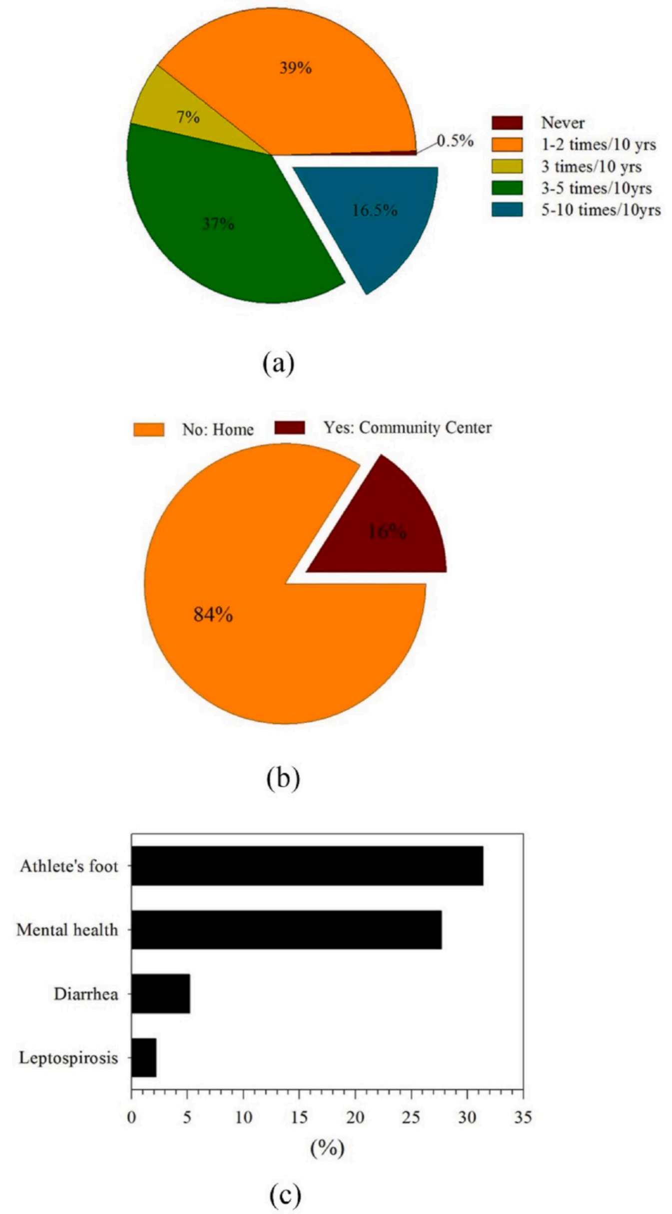

Fig. 6. Questionnaire survey results: (a) past flood experience, (b) flood evacuation, and (c) flood health impacts.

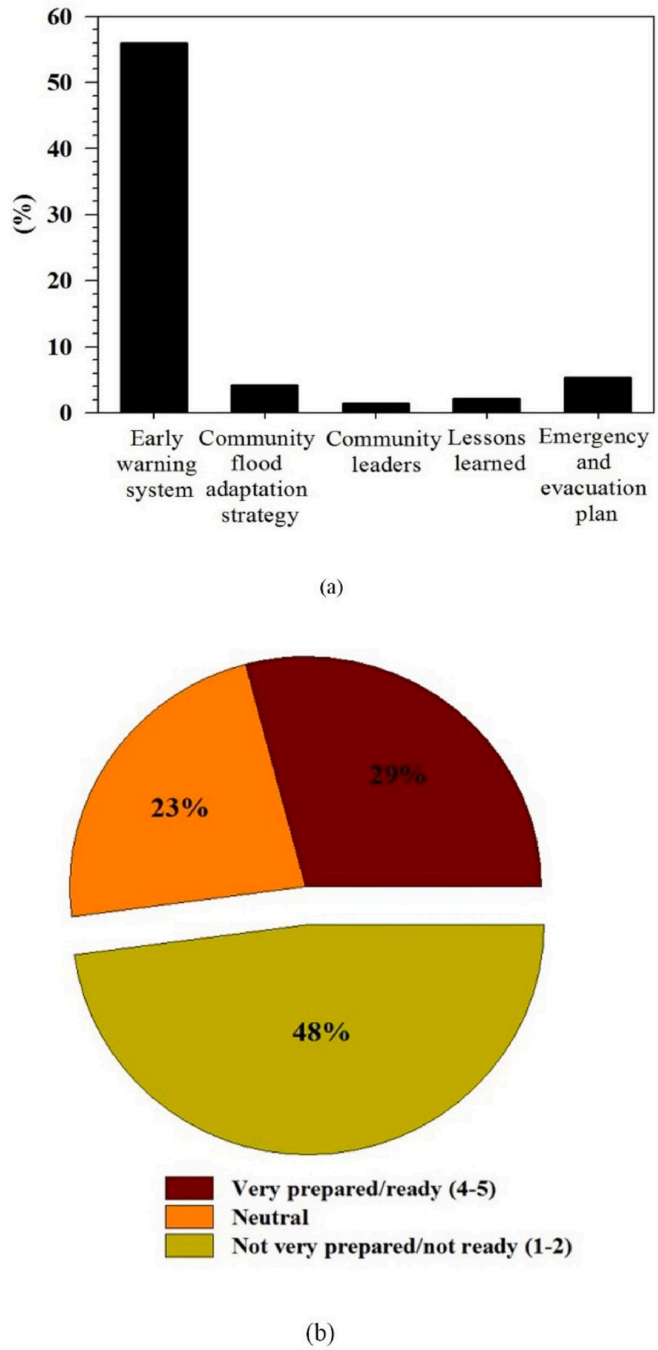

Fig. 7. Questionnaire survey results: (a) sources of flood information and (b) future flood readiness.

the national government. The results of the current study are also consistent with previous research conducted by Chomsri & Sherer [50], which indicated that the local residents living in Ayutthaya believed that they had no choice other than to stay in the swampy area with seasonal flooding, so there was nothing they could do. Some respondents said that they had adapted to living only on the upper floor of their house and did so during Thailand's flood crisis of 2011. This also explained the general feeling of being ignored in flood disaster preparation.

4.3.4. Flood readiness of high-hazard communities

In relation to the question about flood evacuation, most respondents (67–87%) who lived in the high-risk communities (Pratuchai and Tha Wasukee) stayed in their homes during flood crises (Fig. 8a). When asked about sources of information on flood preparedness and response, the local residents in flood hazard areas had not received information about flood adaptation strategies, community training, learned flood lessons, or even emergency and evacuation plans (Fig. 8b). It seemed that only the flood early warning systems helped local respondents prepare for flood events. With regard to their readiness to prepare and respond to a flood event in the future, surprisingly, approximately half of the respondents in high-flood hazard areas still stated that they were not prepared for the possibility of a flood in the future (Fig. 8c).

4.3.5. Regression analysis

Table 6 shows the regression analysis of the relationships among personal experience of flood events, the availability levels of urban services during a flood, and readiness to respond to flood hazards. The results of these analyses show that there was a negative correlation between flood readiness and previous flood experience. Some urban services (i.e., electricity, wastewater, drinking water, and communication platforms) were also negatively correlated with flood preparedness, but there was a weak correlation ($r < 0.5$). The provision of local funding to restore basic urban services and the livelihoods of the flood-affected communities is therefore urgently needed. In addition, in relation to personal experience, the effect of direct experience depends mainly on how the respondents interpreted or what they learned from their flood experiences. Interestingly, previous experience does not always enhance the flood preparedness of an individual, according to the results of this study. One possible reason might be that the lessons from previous severe flooding in their communities (i.e., the 2011 flood crisis) did not seem to have been learned as only 2.2% of respondents reported having learned information on flood response and crisis management from the government. The effect of flood experience on proactive actions might be variable depending on the time elapsed between events, i.e. on the frequency of disaster experience. A previous study by Terpstra [51] pointed out that the positive effects of personal experiences on mitigation actions may disappear several years after a flood event. Experience from a disaster that occurred a long time ago (long floodless period) had a far smaller influence on both the current perception of risk and proactive measures. The perceived seriousness and severity of flood disasters and personal situations are likely to influence precautionary actions [51]. Past research has shown that the relationship between personal experiences and flood mitigation actions can be categorized into 3 groups: i) a positive significant relationship [52], ii) a positive but not statistically significant relationship [53,54], and iii) no significant correlation between the direct experiences and mitigation [55]. Most studies have indicated that experience is often considered to have a powerful impact on both risk recognition and the adoption of mitigation measures; however, the results of this study were inconsistent with previous findings. Apart from their direct experiences, there are a large variety of factors that can potentially influence flood mitigation behavior. A growing body of literature indicates that the following factors always correlate with flood mitigation behaviors: risk perception (both perceived flood probability and consequences), perceived inevitability of flood disaster, perceived severity of losses and perceived self-efficacy [56], emotions [51], fear of flood [57], trust in the authorities responsible for managing flood disasters, knowledge about flood hazards [51,58], and information on floods. In support of these factors, in terms of risk perception, Weinstein et al. [59] stated that local people commonly undertake flood mitigation measures to reduce the risks as they perceive them. However, the lack of an effective flood risk communication plan is considered to be one of the major barriers to implementing flood mitigation actions. Raising flood risk awareness is an important component of an integrated approach to FRM. Some studies argue that individuals may interpret disaster experiences in different ways, depending on whether their experiences evoke negative emotions. Regarding research conducted by Siegrist & Gutscher [60], negative emotions (i.e., feelings of fear, insecurity, and uncertainty) were the key factors affecting flood risk perception and precautionary actions among flood victims. For instance, living in a New Orleans neighborhood that was flooded by Hurricane Katrina could cause an emotional reaction that would naturally be expected to provoke a heightened perception of flood risk. In the Netherlands, Zaalberg et al. [61] found that flood victims, who reported stronger emotions (i.e., worry), perceived themselves as more vulnerable to floods in the future, and had stronger intentions to take proactive actions than nonvictims. Knowledge and information about flood hazards are considered the most important aspects of FRM and communication. A study by Bubeck et al. [56] highlighted that local people who have received more flood protection information are more likely to adopt precautionary actions compared with those who do not have such information. In this study, it was noticeable that only very few of the local citizens who were surveyed reported having received flood preparedness information from the authorities. The following excerpts show the diverse ways interviewees viewed flood perception and preparedness in their living community.

Risk perception (both perceived flood probability and its consequences):

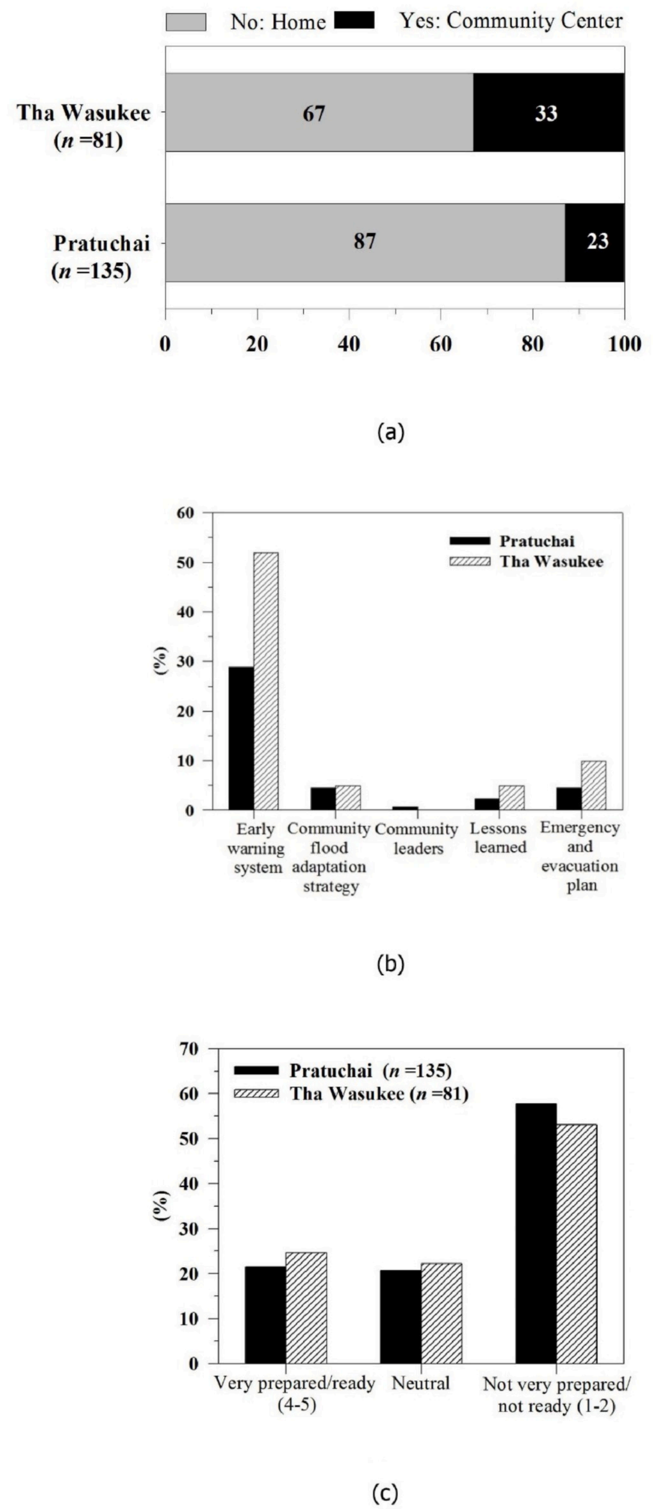

Fig. 8. Questionnaire survey results: (a) flood evacuation, (b) sources of flood information and (c) future flood readiness (high-hazard communities).

"I am always more concerned about my job than about flood preparedness"

Perceived unavoidability of flood disaster:

"We are used to living with heavy floods in our communities, so we can do nothing about"

Table 6
Regression analysis of the factors associated with flood readiness ($n = 405$).

Factors	Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Readiness (Y)	1.000	**−0.199**	**−0.149**	**−0.066**	**−0.006**	0.175	0.175	**−0.142**	0.222	0.228	0.042	0.214
Past flood experiences (X1)	−0.199	1.000	0.189	0.025	0.015	−0.186	−0.189	0.139	−0.216	−0.224	−0.008	−0.202
Electricity availability (X2)	−0.149	0.189	1.000	0.534	0.456	−0.033	0.070	0.443	−0.014	−0.051	0.236	−0.028
Water availability (X3)	−0.066	0.025	0.534	1.000	0.718	0.193	0.254	0.309	0.112	0.133	0.137	0.120
Drinking water availability (X4)	−0.006	0.015	0.456	0.718	1.000	0.227	0.331	0.351	0.163	0.135	0.164	0.163
Solid waste management service (X5)	0.175	−0.186	−0.033	0.193	0.227	1.000	0.697	0.005	0.499	0.456	0.136	0.397
Wastewater treatment service (X6)	0.175	−0.189	0.070	0.254	0.331	0.697	1.000	0.001	0.536	0.470	0.211	0.416
Communication (X7)	−0.142	0.139	0.443	0.309	0.351	0.005	0.001	1.000	−0.139	−0.103	0.351	−0.071
Transportation (X8)	0.222	−0.216	−0.14	0.112	0.163	0.499	0.536	−0.139	1.000	0.660	0.111	0.600
Food availability (X9)	0.228	−0.224	−0.051	0.133	0.135	0.456	0.470	−0.103	0.660	1.000	0.194	0.662
Community facilities (X10)	0.042	−0.008	0.236	0.137	0.164	0.136	0.211	0.351	0.111	0.194	1.000	0.312
Access to urban functions and services (X11)	0.214	−0.202	−0.28	0.120	0.163	0.397	0.416	−0.072	0.600	0.662	0.312	1.000

"We live along the river so there is no way for us to prepare for a flood"

Perceived severity of losses and perceived self-efficacy [56]:

"I am now living with an elderly person, so we are not ready at all for floods to come in the future"

"It (flooding) cannot be solved very easily"

Emotions and dread of flood [51,57]:

"I don't want to leave home during a flood."

"I still have a sense of helplessness with flood-related issues"

"Please let me know if you (or someone) can make it (the flooding) go away from our community"

Knowledge about flood hazard and information on floods [51,58]:

"We don't exactly know how to prepare for or protect ourselves against flooding."

"I have no idea how to prepare myself for a flood in the future"

Other flood perceptions:

"As the temples serve as community centers, we are highly concerned about the impacts of flooding in our community, especially on our religious and moral values."

"In case of heavy flooding, I can stay in the upper floor of my house as we have done in the past" "I bought a new boat (for a future flood)"

4.3.6. Cluster analysis

By using cluster analysis, the results also confirmed that the entire group of respondents ($n = 405$) was classified into the following two groups: i) those respondents who had more experience with both flood-related hazards ($k = 0.181$) and the inaccessibility of urban services and were less likely to prepare themselves ($k = -0.156$) for flooding in the future, ii) those respondents who had less experience with flooding ($k = -0.595$) and urban services inaccessibility and were more likely to take preparedness actions ($k = 0.528$) (Table 7). It was noteworthy that the number people in the first group was much higher than that in the second group ($n = 313$ and $n = 92$, respectively). These cluster findings were also consistent with the regression analysis (i.e., previous flood experience does not always enhance the proactive actions of local residents).

Based on the results of this research, the following recommendations were proposed:

Advance urban flood management and multi-hazard zoning: According to this AHP-GIS method, the most important parameters for flood hazard assessment were runoff, watershed areas, and the density of the road network as a result of urbanization. To reduce urban flood vulnerability in the WHS, comprehensive analysis of flood risk assessments and zoning that considers road environment and all land use change is needed. Recently, Chen et al. [62] proposed an integrated meteorology-land method that used a road risk zoning model (RRZM). The results showed that annual average daily traffic was ranked as the highest criteria weight compared to the designed speed, number of lanes and road administration grade. Additionally, Yao et al. [63] conducted a quantitative study of urban rainfall runoff risk characteristics in Beijing by using the Soil Conservation Service curve number (SCS-CN) model and found that urban areas tended to have the greatest runoff risk compared to other urban functional zones. All information on soil type classification and hydrolithological profiles [45] should be included as flood hazard factors in future studies. As a basis for flood control and disaster relief arrangement, all of the above risk zoning results can be used in the design of new urban infrastructure (i.e., roads, channels and detention structures) and evacuation routes for areas with different risk zoning levels. In this study, the spatial clustering characteristics of the runoff risks among the different urban functional zones must be carefully considered during urban rainwater and flood disaster management. Moreover, it is appropriate to assess all hazards and risks from the impacts of climate change (i.e., meteorology, hydrology and climatology) on several fragile cultural heritage site [15]. Importantly, a comprehensive disaster resilience index should be developed and proposed [18]. All sociocultural and economic variables (i.e., income, gender, education level) must be well incooperated into flood vulnerability mapping, especially in communities with high flood hazards (i.e., Pratuchai, which is the location of the WHS).

Conduct effective flood risk communication and education: In this context, another empirical study conducted in Thailand and the Philippines [34] found that educational programs and emergency training played a vital role in promoting proactive disaster preparedness (i.e., enhancing anticipation skills and abstract reasoning). Thus, education can improve the coping capacity and disaster resilience of local

Table 7
Results of the k-means cluster analysis of the factors associated with flood readiness ($n = 405$).

	Cluster 1 ($n = 313$)	Cluster 2 ($n = 92$)
Past flood experiences	0.181	−0.595
Readiness	−0.156	0.528
Electricity availability	0.004	0.005
Water availability	−0.142	0.498
Drinking water availability	−0.155	0.542
Solid waste management service	−0.326	1.119
Wastewater treatment service	−0.343	1.165
Communication	0.021	−0.055
Transportation	−0.351	1.204
Food availability	−0.385	1.316
Community facilities	−0.113	0.401
Access to urban functions and services	−0.325	1.112

households. They also argued that education, as a channel through which individuals can learn and relate their own experiences to disaster risk, might be a substitute for actual first-hand experience in preparing for a disaster. Education may also strengthen disaster preparedness and preventive actions via social networks. A study by Harvatt [38] highlighted that integrating shared everyday experiences, traditional worldviews and values and shared memories could be effective in fostering and encouraging community participation in disaster preparedness activities. In addition, another important way to improve disaster preparedness was the use of social media and other communication strategies. Top-down communication and campaign efforts have not been very successful in motivating local residents to take immediate proactive actions and flood response measures. As opposed to the concept of a one-size-fits-all government campaign, people-centered risk communication is considered a key factor in disaster risk reduction. It can directly address the heterogeneous needs of individuals or communities. In this particular situation, the role of social networks have become increasingly important for individual flood preparedness and can both serve as a stimuli for taking proactive action and convey flood information. Based on Protection Motivation Theory, the following three flood risk communication strategies are recommended by Haer et al. [64]: i) media preference should be given to people-centered communication over top-down government communication, ii) providing information about how to prepare and cope with floods in specific communities is expected to be more effective than providing flood risk information alone, and iii) propagation of flood information and related protective behaviors should be stimulated dynamically with the use of social media. Last, multistakeholder engagement has also been recognized as an integral part of FRM, which promotes individual opportunities to participate in decision-making about flood risk in the stakeholder communities.

Facilitate creation of community flood evacuation plan: As previously mentioned in Table 5, there was limited information on both flood evacuation routes and related plans (i.e., emergency evacuation training and exercise) in the municipality. Therefore, to develop guidelines for flood preparedness, especially for the local communities in flood-risk areas, flood evacuation routes should be clearly indicated, and an evacuation drill schedule should be routinely announced to the public. Moreover, lessons from previous floods (e.g., Thailand's flood crisis of 2011) or any failure in flood control should be shared directly with the local community. Further research is needed to investigate the influence of psychological and cultural factors that result from floods, especially concerning the cultural biases of fatalism, helplessness and externalized responsibility among the local Thai respondents.

Maintaining urban functions and developing guidelines for flood waste management: It has been suggested that local planning authorities should develop plans and guidelines for critical services (i.e., food, sanitation, solid waste and wastewater management, health, and well-being) so that those urban services can be fully sustained even in prolonged flood events in the WHS and/or in surrounding communities.

5. Conclusion

Ayutthaya UNESCO World Heritage Site is considered as one of the most famous landmarks in the city that plays a significant role in enhancing place identity, community belonging as well as providing an inspirational sense of connection to nearby communities to their past and lived experienced. Flood disasters are difficult challenges to both specific cultural heritage conservation sites and community resilience in general. Importantly, local communities can become the cornerstone of disaster reduction by putting more attention on what local communities can do for themselves and to strengthen their capacity for disaster resilience, rather than concentrating on their vulnerability or their needs in emergency situation. The concept of participatory cultural heritage conservation should be more focused on how community members can be active actors in the restoration of the heritage assets during disaster situations. This study contributed to research on community flood disaster risk reduction in four important ways. First, this research provided flood hazard maps by using the AHP method in the Ayutthaya WHS and surrounding communities, which are important tools to help community officials communicate the risks of flooding and to help them design emergency preparedness and mitigation strategies for different target groups, especially for people who live in high-risk communities (i.e., the Pratuchai and Tha Wasukee subdistricts). The produced AHP-GIS flood hazard map was in good agreement with both the historical flood events from 2005 to 2017 and the annual maximum rainfall in the communities from 1987 to 2018. In summary, the runoff, watershed areas and road densities associated with the intensity of urbanization emerged as important parameters for flood hazard assessment in the communities near the WHS on Ayutthaya Island. Second, by investigating FRM, the results showed that there was no plan available for community flood storage and waste management during flood crises (although recently, the topic of disaster risk reduction has been included in the latest master plan for conversation and development projects of the Historic City of Ayutthaya). Third, the dominant problems during the floods were water quality and health-related impacts. Notably, local communities were faced with the problem of accessing necessary urban services during flood disasters. Fourth, by assessing the interplay among previous flood experience, accessibility of urban services during floods, and respondents' flood readiness in future, regression analysis showed that past flood experiences did not necessarily result in the desired proactive actions in managing flood risk in the WHS and their communities. These results highlighted the challenges of converting flood experience into a sense of preparedness. Developing effective flood risk communication and education as well as designing strategies for integrated urban flood management and multi-hazard zoning should be a public policy priority.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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