How does flood resistance affect learning from flood experiences? A study of two communities in Central China

Da Kuang1 · Kuei-Hsien Liao2

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Abstract
Property-level flood risk adaptation (PLFRA) has received significant attention in recent years, as flood resilience has become increasingly important in flood risk management. Earlier studies have indicated that learning from flood experiences can affect flood risk perception and the adoption of PLFRA measures; however, it remains unclear whether and how this learning process can be affected by flood control infrastructure—specifically, the level of flood resistance it offers. This study attempts to answer the question: Do people living in environments with different levels of flood resistance learn different lessons from flood experience, manifested in flood risk perception and PLFRA? We present a comparative study of the rural village of Xinnongcun and the urban community of Nanhuyayuan in Central China. In-person interviews with a total of 34 local residents were conducted to understand how flood experiences affect flood risk perception and PLFRA. We find that learning from flood experiences in the highly flood-resistant environment (Nanhuyayuan) does not contribute to flood risk perception but further enhances flood resistance, whereas learning in a less flood-resistant environment (Xinnongcun) leads to a better understanding of flood risk and promotes PLFRA. We argue that flood resistance can affect the learning from flood experiences. High flood resistance can suppress PLFRA through a different learning process that involves learning inertia and path dependency. In the search for flood resilience, this begs society to re-examine the widespread assertion that both structural and nonstructural measures are important in flood risk management.

Keywords Property-level flood risk adaptation · Flood experiences · Flood resistance · Flood risk perception · Flood resilience

Kuei-Hsien Liao liaokh@mail.ntpu.edu.tw
Da Kuang da.kuang@szu.edu.cn

1 School of Architecture & Urban Planning, Shenzhen University, Shenzhen, China
2 Graduate Institute of Urban Planning, National Taipei University, New Taipei City 237, Taiwan
1 Introduction

In the face of climate change, the frequency and magnitude of flooding are projected to increase in much of the world (IPCC 2021). In particular, China is projected to be most impacted by floods at the end of the century, with ~40 million people affected and 110 billion EUR of flood losses incurred per year (Alfieri et al. 2017). In response to the challenge of increasing flood risks, scholars have called for a shift from flood defence to more integrated flood risk management (Thieken et al. 2016; Van Herk et al. 2015). Flood defence aims for flood resistance through flood control infrastructure, such as levees, floodwalls, and dams. These structural measures are often implemented by the government. Flood risk management emphasizes more on non-structural measures, including government measures, such as land use management, building use regulations, and warning systems, as well as private measures implemented at the property level or property-level flood risk adaptation (PLFRA). Recent years have seen the concept of flood resilience gaining tremendous traction in flood risk management (Hartmann and Jüpner 2020), and PLFRA has been argued to be important for building flood resilience (Attems et al. 2020).

Flood resilience refers to the ability to reduce flood losses when flooding occurs and the ability to recover to a functional state when flooding causes substantial damage (Liao 2012). It has been argued that learning from flood experiences is a critical mechanism to enhance flood resilience (Kuang and Liao 2020; McClymont et al. 2020; Zevenbergen et al. 2008), and given that PLFRA is necessary for building flood resilience, this article explores how flood control infrastructure—in particular, the level of flood resistance—affects the learning process to influence PLFRA. In the discourse of flood risk management, it is often argued that structural measures (flood control infrastructure) and non-structural measures (including PLFRA) should work together; however, how the effects of these two types of measures interact is still under-studied. It is known that the provision of flood control infrastructure can impede PLFRA, as people believe they are safe and hence less willing to act (De Marchi and Scolobig 2012). However, how flood resistance influences PLFRA through the process of learning from flood experiences has yet to be systematically studied. This article attempts to fill this knowledge gap.

PLFRA involves flood-proofing measures, including dry-proofing, such as building on fills or pillars and removable flood barriers; and wet-proofing, such as waterproofed building materials and furniture and raised electrical sockets (Owusu et al. 2015). The purpose is to avoid or reduce property damage when flooding occurs, and it involves the continuing adjustment of households’ behaviours to mitigate flood impacts (Joseph et al. 2015). Earlier studies focus on flood experience as an important driver behind PLFRA (e.g. Kreibich et al. 2005; Siegrist and Gutscher 2006). Recognizing the more complex psychological process motivating PLFRA, recent studies investigate more factors, such as self-efficacy, i.e. the perceived ability to implement a certain measure (Grothmann and Reusswig 2006; Bubeck et al. 2013), trust in public flood protection (Terpstra 2011), and behavioural norms (Harries 2012). Through meta-analyses, van Valkengoed and Steg (2019) identify 13 factors motivating climate change adaptation behaviour and find that while flood experience is among the most studied factors, its effect on PLFRA is relatively insignificant. This is consistent with Bamberg et al. (2017), who find that flood experience only acts as an indirect predictor of PLFRA. Nevertheless, it is still premature to conclude what the role flood experience plays in PLFRA, as van Valkengoed and Steg (2019) also find great heterogeneity between
studies that examine the relationship between experiences and adaptation behaviour. Such heterogeneity points to the need to go beyond correlation and further explore the linkage between flood experience and PLFRA. This article addresses how flood resistance mediates this linkage through learning.

Here, flood resistance is defined as the prevention of flooding through flood control infrastructure, and the level of flood resistance is defined by the design capacity. We explore the following question: Do people living in environments with dramatically different levels of flood resistance learn different lessons—manifested in flood risk perception and PLFRA—from flood experiences? This question is highly relevant to resilience-based flood risk management today. Although the sole reliance on flood defence has been challenged and non-structural measures receive increasing attention, it is largely assumed that flood control infrastructure is indispensable, and it still plays an important role in flood risk management practice (Hegger et al. 2016). But can the presence of flood control infrastructure hinder PLFRA through learning from flood experiences? A better understanding of how flood resistance influences this process is necessary to inform more effective policies and strategies to enhance flood resilience.

We speculate that communities of high levels of flood resistance would have lower flood risk perception and are unwilling to take PLFRA measures, while those of lower levels of flood resistance would have higher flood risk perception and are more likely to take PLFRA measures. This article presents a comparative case study between a rural village with low flood resistance and an urban community with high flood resistance in Central China.

2 Analytical framework

Learning from experiences has received increasing attention as an important mechanism for cultivating knowledge and reducing losses from natural hazards (Choudhury et al. 2021). Kolb’s (2014) experiential learning theory postulates that individuals can develop knowledge through reflecting on experiences. While the process of experiential learning is intangible, learning results can be manifested in tangible forms. For example, in an environment subject to prolonged flooding, the prevalence of stilt houses and flood-tolerant crops can be considered a result of learning from flood experiences (Cuny 1991; Liao et al. 2016). The result of such learning can also be manifested in increased knowledge of local flood hydrology and flood impacts (Amoako 2018; Siegrist & Gutscher 2008). However, learning from flood experiences does not always lead to flood loss reduction. A lack of learning motivation, i.e. no reflection on flood experiences, can prevent people from developing knowledge (Kuang and Liao 2020); moreover, highly relying on public flood protection can result in “learning inertia”, i.e. the tendency to learn knowledge that is similar to the past (Liao et al. 2008), which impedes the generation of new knowledge from flood experiences.

Drawing on existing research, this study focuses on the plausible interactions between the following factors in the learning process: flood resistance, flood experiences, flood risk perception, and PLFRA (Fig. 1). We note that the arrows in Fig. 1 do not imply a causal relationship or strong linkage. They only indicate plausible links, which guide our data collection and analysis. The changes in flood risk perception and PLFRA together are considered the “lessons learned” from flood experiences. Learning can occur in different actors
and have different outcomes. Learning by management authorities can result in policy change (Van Buuren et al. 2016), while that by local residents lead to the build-up of local knowledge (Madhuri et al. 2015). This study focuses on the learning of local residents. In the following, we explain the factors, their interactions, and our hypotheses in the analytical framework.

2.1 Flood resistance

The level of flood resistance is defined by the design capacity of flood control infrastructure. A high design capacity (e.g. 200-year flood) dramatically changes the entire natural flood regime, in terms of flood frequency, magnitude, timing, and velocity (see Poff et al. 1997). It could also lead to the phenomenon of “risk transference”—a shift from frequent floods with minor effects to rarer and more serious events when flows exceed the design capacity (Etkin 1999). Those well-protected by flood control infrastructure would experience either no flooding or rare, large flooding of very high impacts. We hypothesize that different levels of flood resistance contribute to different patterns of flood experiences.

We also hypothesize that high flood resistance results in low flood risk perception because of the “levee effect” and “path dependency”. The levee effect refers to the reduced flood risk awareness in the protected area and more development on the floodplain, as a consequence of the false sense of security provided by flood control infrastructure (Tobin 1995). Path dependency refers to the tendency of an institution to develop policies in the same direction as the previous (Van Buuren et al. 2016). When a place heavily relies on flood control infrastructure, its flood governance often exhibits path dependency, which results in flood management continually concentrating on improving flood control
infrastructure and constraining other options (Van Buuren et al. 2016). It also leads to the public expecting the government to deliver more flood control infrastructure (Wiering et al. 2017), which further influences flood risk perception.

### 2.2 Flood experiences

Flood experiences are practical contacts with and observations of flooding. When a person experiences flooding and develops lessons through learning, it more or less influences his/her flood risk perception (Bubeck et al. 2012). A person’s or community’s overall flood experiences are defined by the flood regime (in terms of flood magnitude, frequency, and duration), as well as flood impacts (i.e. disastrous, inconvenient but harmless, or beneficial). Since the flood regime and flood impacts are largely determined by the level of flood resistance, flood resistance directly dictates the pattern of flood experiences, as hypothesized in Sect. 2.1. Higher flood resistance leads to flood experiences dominated by fewer, but high-impact, floods, while lower flood resistance frequent but low-impact floods.

We also hypothesize that different patterns of flood experiences lead to different flood risk perceptions. Experiencing flooding more frequently means more learning opportunities, which help maintain a higher flood risk perception (Ge et al. 2021). In addition, according to the affect heuristic theory (Slovic et al. 2007), emotion plays an important role when people make decisions. Disastrous flooding evokes negative emotions, such as worry, and might lead to a greater change in flood risk perception (Poussin et al. 2014), while non-disastrous flooding, which neither causes damage nor interrupts social-economic activities, might lead to little change (Lawrence et al. 2014). Experiencing only non-disastrous flooding might cause a “normalization bias”—the underestimation of the probability and impact of a major flood (Lawrence et al. 2014).

### 2.3 Flood risk perception

Flood risk perception refers to the interpretation or impression of flooding (Raaijmakers et al. 2008). There is little consensus on what constitutes flood risk perception, but it is often associated with flood risk awareness, the perceived cause of flooding, the perceived responsibility for flood safety, and the worry about flooding (Kellens et al. 2013; Raaijmakers et al. 2008). The change in flood risk perception of the general public could end up changing the level of flood resistance by influencing flood management policies (Buchecker et al. 2016). Therefore, not only does the level of flood resistance affect flood risk perception, as hypothesized in Sect. 2.1, we also hypothesize that flood risk perception would feedback to affect the level of flood resistance. For example, if the public was aware of increased flood risk and preferred structural measures, flood management would be biased toward building more flood control infrastructure.

While flood risk perception has been extensively studied, research findings on its influence on PLFRA are inconsistent (van Valkengoed and Steg 2019). Some studies suggest a strong relationship between flood risk perception and PLFRA. For example, Miceli et al. (2008) discover that hazard preparedness of Italian homeowners is positively associated with their risk perceptions; Osberghaus (2015, p. 43) finds that homeowners are more willing to take PLFRA “if they expect a climate change-induced increase of their personal flood damage in the next decades”. Other studies, however, indicate a weak relationship between flood
risk perception and PLFRA (see Bubeck et al. 2012). The inconsistent findings might be explained by the protection motivation theory (Grothmann and Reusswig 2006): High flood risk perception (or threat appraisal) motivates people to take PLFRA measures only when it is accompanied by high coping appraisal (i.e. perceived effectiveness of a certain measure and one’s ability to take it); high flood risk perception with low coping appraisal results in fatalism and wishful thinking, which prevent people from doing anything. Furthermore, high flood risk perception does not always translate into actual PLFRA measures because there can exist barriers, such as a lack of knowledge and resources to act on PLFRA (Grothmann and Reusswig 2006). As Scolobig et al. (2012) argue, the relationship between flood risk perception and PLFRA is never straightforward. Nevertheless, since existing studies generally demonstrate their positive relationship (van Valkengoed and Steg 2019), we consider flood risk perception to be an important factor in the process of learning from flood experiences.

2.4 Property-level flood risk adaptation (PLFRA)

PLFRA relies on nonstructural measures and adaptive behaviour to reduce or avoid flood losses. The effectiveness of PLFRA measures requires the capacity of the household to ensure the measures are taken timely and done correctly (Attems et al. 2020). It is also important to note that PLFRA measures—like flood control infrastructure—cannot prevent all flooding. In general, dry-proofing cannot cope with a flood depth beyond 1 m and wet-proofing 2 m (Poussin et al. 2012). Nevertheless, PLFRA is still considered cost-efficient in reducing flood losses (Poussin et al. 2015). For example, Kreibich et al. (2015) find that wet-proofing can reduce flood damage by as much as 53% and dry-proofing 60%.

The likelihood of adopting PLFRA has been linked to flood experiences. Harries (2013) shows that people who had experienced flooding more than three times are 1.59 times more likely to take PLFRA measures than those who only experience flooding once. Moreover, when a household practices PLFRA, it can generate feedback—the relief of the worry about flooding—to affect flood risk perception. The worry about flooding stems from the perceived high flood risk and lack of flood preparedness (Raaijmakers et al. 2008). Since PLFRA measures improve flood preparedness, it can reduce worry and further enhance the confidence to adapt to flooding (Begg et al. 2017). Since PLFRA enhances flood preparedness, we hypothesize that it could also change future flood experiences, e.g. flooding would become harmless instead of disastrous.

Overall, our analytical framework suggests that flood experiences, flood risk perception, and PLFRA closely interact, and different levels of flood resistance imply different flood experiences and subsequently different flood risk perceptions, which can affect PLFRA. Using this analytical framework, we empirically explore how lessons learned from flood experiences are manifested in flood risk perception and PLFRA under two dramatically different levels of flood resistance.

3 Research methodology

We carried out qualitative research to address our research question: Do people living in environments with dramatically different levels of flood resistance learn different lessons—manifested in flood risk perception and PLFRA—from flood experiences? We are interested in how the entire learning process (Fig. 1) looks differently under
3.1 Study communities

3.1.1 The choice of study communities

Having experienced flooding in the past, Xinnongcun and Nanhuayuan in Central China are chosen as our study communities (Fig. 2; Table S1). Located in the suburbs of Xiantao City, Xinnongcun is a rural village of low flood resistance, protected by

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Fig. 2 The locations of Xinnongcun and Nanhuayuan (a). The location of the Xinnong polder in Duijiai FRA (b). After the sluice gate at the Han River is open for flood retention, it often takes less than 1 day for floodwater to arrive in the Xinnong polder

dramatically different flood resistance levels, as opposed to exploring the correlations between the factors in Fig. 1.
a 3-m-high polder dyke against a 3-year flood. Nanhuyayuan is an urban community of high flood resistance in Wuhan City, protected by embankments against a 200-year flood. The upstream Three Gorges Dam and other structural measures together are supposed to protect Wuhan against a 1000-year flood. The divergent protection standards of the two communities allow us to explore how dramatically different levels of flood resistance generate different learning processes from flood experiences.

As China occupies a large geographic area, communities in different regions can exhibit large cultural differences. Xinnongcun and Nanhuyayuan are both located in the Jianghan Plain and are only ~60 km apart, such that the possible influence of cultural differences on flood risk perception can be minimized. Furthermore, both communities have a relatively short history, which precludes the influence of flood-related knowledge inherited from the previous generations. The fact that Xinnongcun is rural and Nanhuyayuan urban is a major difference difficult to control for in China because today communities with very low flood resistance can only be found in rural China and those with very high flood resistance can only be found in urban China. Since our purpose is to compare two communities with dramatically different levels of flood resistance, the different context of the study communities is an unavoidable limitation. Nevertheless, we argue that the systematic comparison of the learning processes between Xinnongcun and Nanhuyayuan still provides valuable insights. As socio-economic centres, urban areas are usually of higher flood resistance compared to their rural counterparts, as the investment of flood control infrastructure is often based on cost–benefit analysis. However, to our best knowledge, there has not been any study explicitly addressing how the differences of rural and urban contexts affect two major factors in our analytical framework (Fig. 1)—flood risk perception and PLFRA. While such research is beyond the scope of this study, we will discuss later how different contexts might affect our research findings.

3.1.2 The rural village of Xinnongcun

Built by migrants in the 1970s, Xinnongcun is a small rural village located in the eastern suburb of Xiantao City. Today, Xinnongcun has approximately 400 inhabitants and the major sources of income are aquaculture and agriculture. The village is highly flood prone because it is located within the Dujiatai Flood Retention Area (FRA). FRAs are areas designated to retain and/or divert floodwater during emergency flood events to lower the river stage in order to protect the nearby cities. The Dujiatai FRA functions to divert floodwater from the Han River to Yangtze to protect Wuhan—the largest city in Central China (Fig. 2a). The Dujiatai FRA constitutes of a flood diversion channel with 28 polders on both sides (Fig. 2b). The 28 polders, while consisting of settlements and farmland, function to supplement the flood diversion channel when its capacity is exceeded. During extreme events, some or all of the 28 polders would be flooded to retain excess floodwater. Xinnongcun is in the Xinnong polder (Fig. S1a), which is immediately adjacent to the flood diversion channel. Flood retention could lead to flooding in Xinnongcun between May and October. In some years, Xinnongcun was flooded twice and each flood lasted as long as 1 month and reached as high as 1.5–2 m. Since 1974, Xinnongcun has experienced more than 10 flood events caused by overflowing of the flood diversion channel and 8 by the operation of flood retention when the polder is intentionally inundated. The most recent
flood was caused by overflowing of the flood diversion channel in 2016, resulting in the village being inundated for ~30 days.

### 3.1.3 The urban community of Nanhuyayuan

Nanhuyayuan is a residential compound in Wuhan—the city protected by the aforementioned Dujiatai FRA. Wuhan has a population of approximately 10 million and a rich history of flooding. Extensive flood control infrastructure was constructed after the 1950s. As of 2015, the city was protected by ~807 km of levees, 6 FRAs with a total retention capacity of 6.8 billion m³, and 283 reservoirs with a total storage capacity of 0.88 billion m³ (Wuhan Municipal Flood Control and Drought Relief Headquarter, 2015). Such high flood resistance leads to infrequent riverine flooding, and lakes in the city have been quickly filled to make way for urban development (Du et al. 2011). Reclaimed from the Nanhu Lake in 2000, Nanhuyayuan contains 18 high-rise condominiums with approximately 4000 residents (Fig. S1b). Heavy precipitation events can result in 10–30-cm depth of pluvial flooding. Such flooding often recedes within 2 days with the help of pump stations. In 2016, Nanhuyayuan experienced severe flooding caused by overflowing of the Nanhu Lake. Flood depth ranged between 50 and 70 cm, reaching as high as 1.5 m at some locations. The entire compound was inundated for 9 days. Residents were evacuated, and retail stores, apartments, and parking lots on the ground floor suffered significant damage.

### 3.2 Semi-structured interviews

Semi-structured interviews with local residents in Xinnongcun and Nanhuyayuan were conducted, using a snowball sampling method. Interviews stopped when information reached saturation. In Xinnongcun, a former village head and a village accountant were first interviewed, as they know well the overall conditions of past flood events. Through their references of villagers who have lived in the village for more than 30 years and affected by past floods, a total of 20 in-person interviews were conducted in January 2018 and October 2019. Each interview lasted 40–60 min and took place in the respondent’s front yard. In Nanhuyayuan, in-person interviews were first conducted with two neighbourhood committee staff members, as they know the conditions and impacts of the 2016 flood well; and based on their references, 10 householders were also interviewed in person in October 2019. In March 2020, additional interviews with 4 householders in Nanhuyayuan were conducted through telephone, due to the outbreak of COVID-19 in Wuhan and travel restriction. Ground-floor residents were selected as respondents in Nanhuyayuan, as they were most directly affected by flooding.

In both Xinnongcun and Nanhuyayuan, the interviews focused on the lessons learned—pertaining to flood risk perception and PLFRA—from flood experiences. Respondents were asked to describe their past flood experiences, opinions about flooding, and views on personal responsibility for flood safety. To understand what PLFRA measures the respondents take, they were first asked to describe their past flood losses and then reflect on their subsequent actions to prevent such losses. All interviews were transcribed, and then content analysis was performed. The text was coded using keywords indicating flood risk perception (i.e. flood risk awareness, perceived cause of flooding, perceived responsibility, and worry) and PLFRA. All quotes presented in the following section are translations from Chinese.
4 Research findings: learning from flood experiences

Following our analytical framework (Fig. 1), here we discuss the processes of learning from flood experiences in the rural village of Xinnongcun and the urban community of Nanhuyayuan and lessons learned, as in the changes in flood risk perception and PLFRA.

4.1 Flood risk perception

4.1.1 Flood risk awareness

In hydrology, flooding is simply a phenomenon where water covers the land that is normally dry (Hooijer et al. 2004). However, the term “flooding” has a negative connotation in most societies, including Xinnongcun and Nanhuyayuan. The two communities speak the same local language, where Wushui is used to refer to flooding. Wushui means “submerging” and is associated with actual or potential damage. An event is called Wushui only when floodwater reaches the knee of a person. Most Nanhuyayuan respondents consider themselves to only experience Wushui once in 2016, dismissing nuisance flooding (flood depth 10–30 cm) as Wushui. Xinnongcun respondents claim that they have experienced Wushui more than 10 times but cannot remember the exact number because Wushui occurs very frequently. When Wushui occurs, it usually inundates the village for as long as 30 days with 1.5–2 m of floodwater.

While Wushui is associated with damage, there were nuances with respect to the probability and effect. Xinnongcun respondents’ flood risk awareness changed significantly over time: When they first migrated to the village in the 1970s, they were almost completely unaware of the possibility of flooding. A householder commented, “When we first moved in, we never thought it [Wushui] could be that scary”. Today, all villagers are aware that they live in a frequently flooded area and “flooding could occur any year”. They also distinguish between two types of Wushui: The overflowing of the flood diversion channel caused by backflow is called “waterlogging”, which is different from flooding caused by flood retention when the polder is intentionally inundated. “Waterlogging generally has little effect on fishponds, but [flooding caused by] flood retention would have a big effect”. Waterlogging is less damaging because the flow is much slower, which allows time for preparation, whereas flood retention often leads to significant losses, as floodwater can rise quickly, leaving little or no time for preparation.

In Nanhuyayuan, it did not occur to most respondents that flooding was possible until the 2016 flood. Although the disastrous 2016 flood was still vividly remembered, many respondents optimistically believe that future will not see a similar flood, as the government “has implemented several Sponge City projects in Wuhan last year and upgraded some measures in our community after the flood”. The measures refer to a floodwall erected after the 2016 flood and the improvement of the drainage system. The Sponge City projects refer to stormwater management projects under the Wuhan Sponge City Programme, such as the Wufengzha Wetland Park (Wu et al. 2020). It is convinced that “the government would not allow the community to flood again because it would damage the image of the city, and the government cannot afford the embarrassment”.
4.1.2 Perceived cause of flooding

While speaking of Wushui as an act of God, Xinnongcun respondents can identify that Wushui is caused by either flood retention or backflow. “Flood retention means the water is diverted from the Han River to our area; and waterlogging is the result of heavy rain that causes backflowing of the flood diversion channel”. Heavy rain is an important signal of the advent of flooding in Xinnongcun. Residents pay extra attention to weather forecast in May and June. “If it rains heavily nonstop, there is a certain probability that we would be flooded”.

In contrast, Nanhuyayuan respondents show a limited understanding of the cause of flooding. For example, while a respondent understands that the 2016 flood was caused by the overflow of the Nanhu Lake because of the heavy rain, “I don’t know why the lake would overflow since it never occurred before”.

4.1.3 Perceived responsibility for flood safety

Respondents from two study communities have different perceptions of who should be responsible for flood safety. In Xinnongcun, “no choice” is an expression frequently appeared: “We have no choice. To survive, we have to cope with Wushui by ourselves”. Xinnongcun villagers know that they can only rely on themselves for flood safety. Despite so, many respondents feel confident to cope with future Wushui: “We are all experts”.

In contrast, Nanhuyayuan respondents overwhelmingly believe that the government is responsible for providing them with flood safety. This difference between the two communities is likely associated with the fact that Xinnongcun has experienced frequent flooding such that villagers understand that flooding is inevitable, while Nanhuyayuan seldom experienced flooding, and residents have become accustomed to relying on government-provided flood control infrastructure. In addition, Nanhuyayuan was originally a part of the Nanhu Lake, and “it was the government’s decision to permit the developers to develop here”. Furthermore, the 2016 flood also left an impression that because floodwater rose too quickly that it was simply not possible to prepare for the flood. “It only took around 10 to 20 min [for floodwater] to rise from 30 cm to over 1 m, so there was nothing we can do to respond to it”.

4.1.4 Worry about flooding

Because of the different flood risk perceptions and understandings of and attitudes toward Wushui, the two communities also exhibit different levels of worry about flooding. Xinnongcun respondents constantly worry about Wushui, particularly during June and July, since this is the time after they have made investments in agriculture (e.g. seeds, pesticide) and before they can harvest. Flooding would lead to all investments in vain. They would worry significantly more in the year right after a disastrous flood. “If [disastrous] flooding occurs again, we would have no way out”. This is because disastrous floods in consecutive years make recovery more difficulty. It would be hard for villagers to pay for fish feed and fish larvae. It is common for villagers to purchase these on credit and pay back only after the harvest.

Nanhuyayuan respondents remember that they worried a great deal during and immediately after the 2016 flood. A respondent, who was evacuated during the flood, did not
choose to return home despite floodwater had receded. “I feared that it might flood again”. However, many respondents—when interviewed in 2019–2020—indicated little worry about future floods. “I don’t worry because in the future there won’t be any flooding like the 2016 flood”.

4.2 PLFRA

In Xinnongcun, the lessons learned from flood experiences have been materialized in the flood adaptation of the houses, street forms, and lifestyle, while in Nanhuyayuan in the improvement of flood control infrastructure.

4.2.1 Flood adaptation in Xinnongcun

When Xinnongcun was established in the 1970s, a typical house was built at the ground level with a thatched roof, front yard, and backyard. In 1983, a dyke along the flood diversion channel was breached, destroying nearly every house in the village. Villagers took the flood level in 1983 into consideration when rebuilding their houses. Houses were raised on 2–3-m fills, with soil excavated from the backyard (Fig. 3a). The excavated area would then be used as a pond to raise poultry or cultivate lotus. Trees were planted and fire bricks used to cover the earth foundation to prevent erosion. Today, there are still houses not raised high enough, and the owner would store water-sensitive household items, such as fish feed, medicine, and clothes in a shelf high above the floor.

When all villagers rebuilt their houses on fills, it reshaped its only street (Fig. S2). Xinnongcun is a linear village, where houses line the north of the street, which now has two levels—the lower and upper grounds (Fig. 3b). The lower ground is a mud road that connects the village with nearby towns, and along the mud road stands storage sheds for households to keep the boats, fish feed, motorbikes, and other tools. The front yards on fills of each house together form the upper ground. Ranging from 3 to 5 m in width, the upper ground is the most active place in the village, serving multiple functions, such as raising livestock and social gathering. Importantly, during flooding, the upper ground serves as a corridor for evacuation. Without such a raised street in the past, evacuation had to rely on boats, which was a lot less efficient.

Flood experiences also led to changes in the livelihood in Xinnongcun. Villagers used to rely primarily on agriculture, with corn, soybeans, and cotton being the major crops. These crops would suffer significant losses during flooding, particularly when flooding occurred right before the harvest when the farmland was already heavily invested with seeds, fertilizer, pesticide, etc. After experiencing several disastrous floods in the 1990s, many households shifted from agriculture to aquaculture, as aquaculture is considered more flexible. “In any case we could still harvest some fish before the flood comes, while flooding can wash away all crops, leaving us no income for the whole year”. However, fish that are harvested earlier are not big enough to sell for regular prices. To further reduce income loss from flooding, some fish farmers—whose fish farms are located within the flood diversion channel—have made further adjustments. When the flow stage of the flood diversion channel is rising, the water pressure could breach the dyke of the fishpond. An early solution to this was to simply cut a temporary ditch through the dyke to let in the water to level pressures on both sides. This approach is nevertheless risky as it could cause soil erosion of the dike. After trials and errors in several floods, today the flood adaptation measure for the fishpond has become more sophisticated. It involves inserting pipes in the dyke and
installing filter screens (Fig. S3). Many fish farmers consider it effective. However, it still has limitations, one of which is that it requires constant care during flooding.

4.2.2 Flood adaptation in Nanhuyayuan

Although Nanhuyayuan respondents report that they suffered greatly during the 2016 flood, PLFRA was not implemented as of October 2019. The 2016 flood produced a lot of property damages to ceiling, walls, furniture, appliances, etc. While they were repaired or replaced after the flood, none of the Nanhuyayuan respondents has done anything to their properties to prepare for future flooding. The walls are still painted with similar materials and appliances placed at similar levels as before the flood. Most Nanhuyayuan residents have used sandbags before to cope with nuisance flooding; however, they know little how to avoid losses from a large flood and doubt the effectiveness of PLFRA measures. A respondent was sceptical: “Are those measures useful? I tried sandbags before. They didn’t...
work for the 2016 flood. They cannot prevent water from entering the house once the flood becomes larger”.

While there were no changes at the property level after the 2016 flood, Nanhuyayuan residents organized a community campaign, calling for the government to improve the drainage system and construct a floodwall to prevent future flooding, which the government efficiently did. Previously connected to Nanhu Lake, Nanhuyayuan’s drainage system was re-routed to connect to the municipal system to avoid backflow from the lake. A ~750-m-long, 1.3-m-high floodwall surrounding the compound was erected to defend against the overflowing of the lake. As of October 2019 when the in-person interviews were conducted, the floodwall had not been tested by an actual flood. Nevertheless, its presence has already prompted a sense of security. “It is constructed very deep into the ground and totally made by concrete—It is very solid”. “You can see it directly in our community. Water from the lake will not overtop the wall”.

5 Discussion

The divergent levels of flood resistance—the rural village of Xinnongcun protected against a ~3-year flood and the urban community of Nanhuyayuan against a 200-year flood—lead to different patterns of flood experiences, resulting in different learning processes. Here we discuss how the learning processes differ and also consider the limitation of this study. While we present lessons generalized from our findings, we note that because of the major contextual difference—Xinnongcun is rural and Nanhuyayuan urban—the different levels of flood resistance might not be the only factor affecting flood risk perception and PLFRA.

5.1 The level of flood resistance affects flood risk perception

There have been many studies on how flood experiences influence flood risk perception (e.g. Osberghaus 2017; Siegrist and Gutscher 2008); however, most do not explicitly consider the role flood resistance plays. Our study shows that the level of flood resistance can influence the lessons learned from flood experiences, through affecting flood risk perception and PLFRA. High flood resistance can hinder the learning of flooding in the first place through having limited flood experiences, and when flooding does occur, despite being an emotional experience, it can produce little changes on flood risk awareness, perceived cause of flooding, and perceived responsibility for flood safety. In Nanhuyayuan, the high level of flood resistance results in residents only experiencing the 2016 flood, after which flood resistance became even greater. The respondents have limited awareness of future flood risk and tend to place responsibility of flood safety on the government. This finding is consistent with previous studies (e.g. Ge et al. 2021; Ludy and Kondolf 2012). Ludy and Kondolf (2012, p. 838) argue that people protected by levees often have low risk perception as they assume “because the government allowed them to live in a given area implied that the government considered that area safe”. Similarly, Nanhuyayuan respondents generally believe that the government would not allow flooding to occur in the future. In Xinnongcun, respondents used to have little flood risk awareness, but after experiencing frequent flooding, they now well understand the causes and impacts of flooding and are willing to take responsibility for their own flood safety. Previous studies also find that people in low flood-resistant environments have a good understanding of flood risk (Liao et al. 2016).
The level of flood resistance also influences the worry about flooding. In both Xinnongcun and Nanhuyayuan, while the level of worry increased significantly right after flooding, the worry lasted only shortly in Nanhuyayuan. To be sure, flood memory disappears over time, but when flooding is infrequent, the strong emotion associated with the last flood decays even faster (Baan and Klijn 2004). Flood memory further decays when flood control infrastructure is enhanced such that flood risk is perceived to be “eliminated” (Collenteur et al. 2015). In short, Nanhuyayuan suffers from what Pryce et al. (2011) call “amnesia” (the erosion of risk awareness with fading flood memory) and “myopia” (the tendency to underestimate the future risk), together resulting in unwillingness to learn from flood experiences. Although the worry about flooding is often considered negative, as it affects happiness or welfare (Hudson et al. 2019), it is conducive to enhancing flood preparedness, as mentioned earlier. This suggests that in a highly flood-resistant environment, the best time to promote PLFRA would be right after a disastrous flood while the worry still lasts.

5.2 High flood resistance impedes PLFRA

Different levels of flood resistance also affect the adoption of PLFRA measures. In Nanhuyayuan, the disastrous 2016 flood led to the reinforcement of flood control infrastructure and no PLFRA measures implemented whatsoever. The limited awareness of future flood risk among Nanhuyayuan respondents may lead them to dismiss the necessity of PLFRA. Moreover, ownership might play a role, as research has found that tenants are generally less willing to pay for PLFRA measures (Botzen et al. 2009a). Most of the Xinnongcun respondents are homeowners, while most of the Nanhuyayuan respondents are tenants. However, it is unclear how much the lack of ownership contributes to the lack of PLFRA in Nanhuyayuan.

Learning from flood experiences in a highly flood-resistant environment can result in people calling for an even higher level of flood resistance, as seen in Nanhuyayuan. Nanhuyayuan demonstrates “learning inertia”, where people learn about and solve problems by resorting to conventional, familiar measures because it saves time and effort and is perceived to be able to prevent mistakes (Liao et al. 2008). People who are used to the protection of flood control infrastructure and enjoy the convenience of a mostly flood-free environment are likely to consider flood control infrastructure as the only approach to flood safety. Therefore, learning inertia steers the lessons learned from flood experiences towards enhancing flood resistance. Moreover, such learning inertia can also be reinforced by the lack of knowledge on the alternatives. Nanhuyayuan respondents have neither the knowledge about nor the practical experiences of PLFRA (except for using sandbags). As a result, they are sceptical of the effectiveness of PLFRA measures for a large flood.

Path dependency also plays a role in this learning inertia. As noted earlier, when flood management already depends on flood control infrastructure, this path is highly likely to continue because of public pressure. This is exhibited by the community campaign in Nanhuyayuan, where residents called for more flood control infrastructure. When the call was answered by the construction of a floodwall, it further enhances the trust in flood control infrastructure. As the floodwall is higher than the flood level in 2016, Nanhuyayuan respondents believe that it will easily prevent a similar flood in the future (see Terpstra 2011). It can be said that Nanhuyayuan exhibits “cognitive dissonance” (Festinger 1957), which refers to a psychological state of discomfort arising from new information that is inconsistent with the current belief (Harmon-Jones and Mills, 2019). Cognitive dissonance explains why even if flood control infrastructure fails and “betrays” people’s trust, people
still do not question the belief that flood control infrastructure can deliver flood safety (Cologna et al. 2017).

On the contrary in Xinnongcun, learning from a lot more flood experiences enhances PLFRA, as evidenced by the reconstruction of the houses, change in livelihood, and adjustments of the fishponds. In Xinnongcun, flood experiences enhance the motivation for PLFRA; more importantly—and rarely mentioned in previous PLFRA research—flood experiences cultivate knowledge and skills to develop new and optimize existing PLFRA measures. Self-efficacy plays an important role to enhance PLFRA in Xinnongcun. Given that flooding occurs more frequently in a low flood-resistant environment, people can continually practice PLFRA and learn through the feedbacks provided by floods (i.e. whether a particular PLFRA measure is effective or not). Such learning-by-doing incrementally enhances self-efficacy and the ability to live with floods.

5.3 Divergent levels of flood resistance generate different learning processes

Overall, our findings support the “Learning from Floods” model, which postulates that people living in environments with different levels of flood resistance would learn differently from flood experiences (Kuang and Liao 2020). In terms of flood risk perception, learning in a highly flood-resistant environment neither enhances flood risk awareness nor sustains the worry about flooding, whereas in the low flood-resistant environment, it makes people more aware of flood risk. Learning in a highly flood-resistant environment does not promote PLFRA, only resulting in the enhancement of flood control infrastructure, whereas in the low flood-resistant environment, it promotes PLFRA.

5.4 Study limitations

However, these findings must be considered in light of the limitations of this study. Besides their levels of flood resistance, Xinnongcun and Nanhuayuan vary in many other aspects, which might also play a role in the process of learning from flood experiences. Firstly, Xinnongcun has a history of ~52 years while Nanhuayuan only ~22 years. If Nanhuayuan were to have a longer history comparable to Xinnongcun’s, the flood experiences might be different despite the high flood resistance. There might be a few more disastrous flood events, as opposed to just one, and this might lead to greater motivation to adopt PLFRA. Secondly, people living in single-family detached houses can modify the house more easily for PLFRA (Lechowska 2018). Since Xinnongcun villagers live in detached houses, while Nanhuayuan residents in multi-story buildings, this difference might also play a role in their divergent PLFRA situations. Thirdly, Xinnongcun is rural and Nanhuayuan urban, and the population density is dramatically different. In China, rural residents are generally less educated than urban residents (Li 2020). A lower education level is associated with less access to information, which can affect flood risk perception (Botzen et al. 2009b). Moreover, major Chinese cities such as Wuhan, where Nanhuayuan is located, often have a lot more resources during emergencies. The perception that the government can respond to flooding more quickly might also reduce the willingness of urban residents to protect themselves. In the complex world, it is challenging to control for all influencing factors, particularly for qualitative comparative studies. More empirical studies are required to further understand the learning processes arising from different levels of flood resistance.
6 Conclusion

Learning does not always produce the same lesson, and flood resistance can affect the learning from flood experiences. As flood risk management discourse is increasingly emphasizing PLFRA and flood resilience (Attems et al. 2020), the effective promotion of PLFRA to enhance flood resilience requires a better understanding of the processes encouraging and discouraging PLFRA. Complementing existing literature on the factors influencing PLFRA (e.g. Gotham et al. 2018; Siegrist and Gutscher 2008), our study indicates that high flood resistance can suppress PLFRA through a learning process that involves learning inertia and path dependency.

If flood control infrastructure can impede PLFRA, it begs society to re-examine the widespread assertion that structural measures are equally important in flood risk management. This is particularly urgent in the face of climate change, where extremity and uncertainty have made flood risk management increasingly challenging. China is highly susceptible to flooding and constitutes almost 10% of the global flood losses between 1990 and 2017 (Kundzewicz et al. 2019). In particular, Central China along the Yangtze River has a long history of disastrous floods. Despite extensive modern flood control infrastructure, large floods continue to occur. The most recent event in the Yangtze River watershed in 2020 affected ~63.46 million people, destroying ~54,000 houses and causing ~178.96 billion RMB of direct economic losses (Sun 2020). Given that most of the flood damages were building-related (Scawthorn et al. 2006), the importance of PLFRA cannot be overstated. More research should be done to better understand the interactions between the effects of structural and nonstructural measures because there can be tradeoffs.

In the face of climate change, learning-by-doing is the most effective approach to resilience-based flood risk management because it creates opportunities for continuing improvement (Pahl-Wostl 2007). While appearing less progressive and desirable in modern society, low flood resistance is nevertheless conducive to learning-by-doing and to promote PLFRA. This raises an important, but difficult, question for society to ponder: How does society nurture flood resilience in the prevalence of flood control infrastructure? As cities are most vulnerable to disastrous flooding, how do cities—which have been heavily relying on flood control infrastructure—nurture flood resilience? In the era of extreme storms, it is urgent to address this question. Our study points to an entry point: Learning plays an important role. It is important for flood risk management to foster a learning process that is conducive to nurture flood resilience. We call for more attention to learning in flood risk management.

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Code availability Not applicable.

Material availability Not applicable.
Declarations

**Ethics approval** This research was approved by the Survey and Behavioural Research Ethics Committee at The Chinese University of Hong Kong.

**Informed consent** Informed consent was obtained from all respondents.

**Competing interests** The authors declare no competing interests.

References

Alfieri L, Bisselink B, Dottori F, Naumann G, de Roo A, Salamon P, Wyser K, Feyen L (2017) Global projections of river flood risk in a warmer world. Earth’s Future 5:171–182

Amoako C (2018) Emerging grassroots resilience and flood responses in informal settlements in Accra, Ghana. GeoJournal 83:949–965

Attems MS, Thaler T, Genoves E, Fuchs S (2020) Implementation of property-level flood risk adaptation (PLFRA) measures: choices and decisions. Wiley Interdiscip Rev Water 7:e1404

Baan PJ, Klijn F (2004) Flood risk perception and implications for flood risk management in the Netherlands. Int J River Basin Manage 2(2):113–122. https://doi.org/10.1080/15715124.2004.9635226

Bamberg S, Masson T, Brewitt K, Nemetschek N (2017) Threat, coping and flood prevention—a meta-analysis. J Environ Psychol 54:116–126

Begg C, Ueberham M, Masson T, Kuhlicke C (2017) Interactions between citizen responsibilization, flood experience and household resilience: insights from the 2013 flood in Germany. Int J Water Resour Dev 33(4):591–608. https://doi.org/10.1080/07900627.2016.1200961

Botzen WJ, Aerts J, van den Bergh JC (2009) Willingness of homeowners to mitigate climate risk through insurance. Ecol Econ 68(8–9):2265–2277. https://doi.org/10.1016/j.ecolecon.2009.02.019

Botzen WJ, Aerts J, van den Bergh JC (2009b) Dependence of flood risk perceptions on socioeconomic and objective risk factors. Water resources research 45.

Bubeck P, Botzen W, Kreibich H, Aerts J (2013) Detailed insights into the influence of flood-coping appraisals on mitigation behavior. Glob Environ Chang 23:1327–1338

Bubeck P, Botzen W, Aerts J (2012) A review of risk perceptions and other factors that influence flood mitigation behavior. Risk Anal 32:1481–1495

Bucheker M, Ogasa DM, Maidl E (2016) How well do the wider public accept integrated flood risk management? An empirical study in two Swiss Alpine valleys. Environ Sci Policy 55:309–317. https://doi.org/10.1016/j.envsci.2015.07.021

Choudhury M-U-I, Haque C, Nishat A, Byrne S (2021) Social learning for building community resilience to cyclones: role of indigenous and local knowledge, power, and institutions in coastal Bangladesh. Ecolology and Society 26.

Collenteur R, De Moel H, Jongman B, Di Baldassarre G (2015) The failed-levée effect: do societies learn from flood disasters? Nat Hazards 76(1):373–388. https://doi.org/10.1007/s11069-014-1496-6

Cologna V, Bark RH, Paavola J (2017) Flood risk perceptions and the UK media: moving beyond “once in a lifetime” to “Be Prepared” reporting. Climate Risk Management.

Cuny FC (1991) Living with floods: alternatives for riverine flood mitigation. Land Use Policy 8:331–342

De Marchi B, Scolobig A (2012) The views of experts and residents on social vulnerability to flash floods in an Alpine region of Italy. Disasters 36:316–337

Du Y, Xue H-P, Wu S-J, Ling F, Xiao F, Wei X-H (2011) Lake area changes in the middle Yangtze region of China over the 20th century. J Environ Manage 92(4):1248–1255. https://doi.org/10.1016/j.jenvman.2010.12.007

Etkin D (1999) Risk transference and related trends: driving forces towards more mega-disasters. Glob Environ Change Part b: Environ Hazards 1(2):69–75. https://doi.org/10.3763/ehaz.1999.0109

Festinger L (1962) A theory of cognitive dissonance. Stanford University Press

Ge Y, Yang G, Wang X, Dou W, Lu X, Mao J (2021). Understanding risk perception from floods: a case study from China. Natural hazards, 1-22https://doi.org/10.1007/s11069-020-04458-y

Gotham KF, Campanella R, Lauve-Moon K, Powers B (2018) Hazard experience, geophysical vulnerability, and flood risk perceptions in a postdisaster city, the case of New Orleans. Risk Anal 38(2):345–356. https://doi.org/10.1111/risa.12830
Grothmann T, Reusswig F (2006) People at risk of flooding: why some residents take precautionary action while others do not. Nat Hazards 38(1–2):101–120. https://doi.org/10.1007/s11069-005-8604-6
Harmon-Jones E, Mills J (2019) An introduction to cognitive dissonance theory and an overview of current perspectives on the theory.
Harries T (2012) The anticipated emotional consequences of adaptive behaviour—impacts on the take-up of household flood-protection measures. Environ Plan A 44:649–668
Harries T (2013) Responding to flood risk in the UK. Cities at risk. Springer, 45–72.
Hartmann T, Jüppner R (2020) Implementing resilience in flood risk management. Wiley Interdiscip Rev Water 7:e1465
Hegger DLT, Driessen PPJ, Wiering M, van Rijswick H, Kundzewicz ZW, Matczak P, Crabbe A, Raadgever GT, Bakker MHN, Priest SJ, Larrue C, Ek K (2016) Toward more flood resilience: is a diversification of flood risk management strategies the way forward? Ecol Soc 21:52
Hooijer A, Klijn F, Pedrolı GBM, Van Os AG (2004) Towards sustainable flood risk management in the Rhine and Meuse river basins: synopsis of the findings of IRMA-SPONGE. River Res Appl 20(3):343–357. https://doi.org/10.1002/rra.781
Hudson P, Pham M, Bubeck P (2019) An evaluation and monetary assessment of the impact of flooding on subjective well-being across genders in Vietnam. Climate Dev 11(7):623–637. https://doi.org/10.1080/17565529.2019.1579698
IPCC, (2021): Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.
Joseph R, Proverbs D, Lamond J (2015) Assessing the value of intangible benefits of property level flood risk adaptation (PLFRA) measures. Nat Hazards 79(2):1275–1297. https://doi.org/10.1007/s11069-015-1905-5
Kellens W, Terpstra T, De Maeyer P (2013) Perception and communication of flood risks: a systematic review of empirical research. Risk Analysis: an Int J 33(1):24–49. https://doi.org/10.1111/j.1539-6924.2012.01844.x
Kolb DA (2014) Experiential learning: experience as the source of learning and development. FT press, US
Kreibich H, Bubeck P, Van Vliet M, De Moel H (2015) Flood loss reduction of private households due to building precautionary measures—lessons learned from the Elbe flood in August 2002. Nat Hazards Earth Syst Sci 5(1):117–126. https://doi.org/10.5194/nhess-5-117-2005
Kuang D, Liao K-H (2020) Learning from floods: linking flood experience and flood resilience. J Environ Manage 271:111025. https://doi.org/10.1016/j.jenvman.2020.111025
Kundzewicz Z, Su B, Wang Y, Xia J, Huang J, Jiang T (2019) Flood risk and its reduction in China. Adv Water Resour 130:37–45. https://doi.org/10.1016/j.adwres.2019.05.020
Lawrence J, Quade D, Becker J (2014) Integrating the effects of flood experience on risk perception with responses to changing climate risk. Nat Hazards 74(3):1773–1794. https://doi.org/10.1007/s11069-014-1288-z
Lechowska E (2018) What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements. Nat Hazards 94(3):1341–1366. https://doi.org/10.1007/s11069-018-3480-z
Li F (2020) Research on the educational level of rural population in China. Management for Economy in Agricultural Scientific research:9.
Liao K-H (2012) A theory on urban resilience to floods—a basis for alternative planning practices. Ecol Soc 17(4):48. https://doi.org/10.5751/ES-05231-170448
Liao K-H, Le AT, Van Nguyen K (2016) Urban design principles for flood resilience: learning from the ecological wisdom of living with floods in the Vietnamese Mekong Delta. Landsc Urban Plan 155:69–78. https://doi.org/10.1016/j.landscape.2016.01.014
Liao S-H, Fei W-C, Liu C-T (2008) Relationships between knowledge inertia, organizational learning and organization innovation. Technovation 28(4):183–195. https://doi.org/10.1016/j.technovation.2007.11.005
Ludy J, Kondolf GM (2012) Flood risk perception in lands “protected” by 100-year levees. Nat Hazards 61(2):829–842. https://doi.org/10.1007/s11069-011-0072-6
Madhuri A, Tewari HR, Bhownick PK (2015) Ingenuity of skating on marshy land by tying a pot to the belly: living with flood is a way of life. Environ Develop Sustain 17(6):1287–1311
McClymont K, Morrison D, Bevers L, Carmen E (2020) Flood resilience: a systematic review. J Environ Planning Manage 63(7):1151–1176. https://doi.org/10.1080/09640568.2019.1641474
Miceli R, Sotgiu I, Settanni M (2008) Disaster preparedness and perception of flood risk: a study in an alpine valley in Italy. J Environ Psychol 28(2):164–173. https://doi.org/10.1016/j.envpsych.2007.10.006
Osberghaus D (2015) The determinants of private flood mitigation measures in Germany—evidence from a nationwide survey. Ecol Econ 110:36–50
Osberghaus D (2017) The effect of flood experience on household mitigation—evidence from longitudinal and insurance data. Glob Environ Chang 43:126–136. https://doi.org/10.1016/j.gloenvcha.2017.02.003
Owusu S, Wright G, Arthur S (2015) Public attitudes towards flooding and property-level flood protection measures. Nat Hazards 77(3):1963–1978. https://doi.org/10.1007/s11069-015-1686-x
Pahl-Wostl C (2007) Transitions towards adaptive management of water facing climate and global change. Water Resour Manage 21(1):49–62. https://doi.org/10.1007/s11269-006-9040-4
Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, . . . Stromberg JC (1997) The natural flow regime. BioScience 47(11):769-784.https://doi.org/10.2307/1313099
Poussin JK, Botzen WJ, Aerts J (2015) Effectiveness of flood damage mitigation measures: empirical evidence from French flood disasters. Glob Environ Change-Human Policy Dims 31:74–84. https://doi.org/10.1016/j.envsci.2014.12.007
Poussin JK, Botzen WW, Aerts JC (2014) Factors of influence on flood damage mitigation behaviour by households. Environ Sci Policy 40:69–77. https://doi.org/10.1016/j.envsci.2014.01.013
Poussin J, Bubeck P, Aerts J, Ward P (2012) Potential of semi-structural and non-structural adaptation strategies to reduce future flood risk: case study for the Meuse.
Pryce G, Chen Y, Galster G (2011) The impact of floods on house prices: an imperfect information approach with myopia and amnesia. Hous Stud 26:259–279
Raaijmakers R, Krywok J, van der Veen A (2008) Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation. Nat Hazards 46(3):307–322. https://doi.org/10.1007/s11069-007-9189-z
Scawthorn C, Flores P, Blais N, Seligson H, Tate E, Chang S, . . . Jones C (2006) HAZUS-MH flood loss estimation methodology. II. Damage and loss assessment. Nat Hazards Rev, 7(2), 72–81. https://doi.org/10.1061/(ASCE)1527-6988(2006)7:2(72)
Scologib A, De Marchi B, Borgia M (2012) The missing link between flood risk awareness and preparedness: findings from case studies in an Alpine Region. Nat Hazards 63(2):499–520. https://doi.org/10.1007/s11069-012-0161-1
Siegrist M, Gutscher H (2006) Flooding risks: a comparison of lay people’s perceptions and expert’s assessments in Switzerland. Risk Anal 26(4):971–979. https://doi.org/10.1111/j.1539-6924.2006.00792.x
Siegrist M, Gutscher H (2008) Natural hazards and motivation for mitigation behavior: people cannot predict the affect evoked by a severe flood. Risk Anal: Int J 28(3):771–778. https://doi.org/10.1111/j.1539-6924.2008.01049.x
Slovic P, Finucane ML, Peters E, MacGregor DG (2007) The affect heuristic. Eur J Oper Res 177(3):1333–1352. https://doi.org/10.1016/j.ejor.2005.04.006
Sun J. (2020). The 2020 flood affected 63.46 million people and cause178.96 billion RMB of direct economic losses. Chinanews. Retrieved from https://www.chinanews.com/cj/shipin-cn-d/2020/08-13/news685240.shtml
Terpana T (2011) Emotions, trust, and perceived risk: affective and cognitive routes to flood preparedness behavior. Risk Anal: Int J 31(10):1658–1675. https://doi.org/10.1111/j.1539-6924.2011.01616.x
Thieken, A. H., Kienzler, S., Kreibich, H., Kuhlcke, C., Kunz, M., Muehr, B., . . . Schroeter, K. (2016). Review of the flood risk management system in Germany after the major flood in 2013. Ecology and Society, 21(2). https://doi.org/10.5751/es-08547-210251
Tobin GA (1995) The levee love affair: a stormy relationship? J Am Water Resour Assoc 31(3):359–367. https://doi.org/10.1111/j.1752-1688.1995.tb04025.x
Van Buuren A, Ellen GJ, Warner J (2016). Path-dependency and policy learning in the Dutch delta: toward more resilient flood risk management in the Netherlands? Ecol Soc 21(4). https://doi.org/10.5751/ES-08765-210443
Van Herk S, Rijke J, Zevenbergen C, Ashley R (2015) Understanding the transition to integrated flood risk management in the Netherlands. Environ Innov Soc Trans 15:84–100. https://doi.org/10.1016/j.eist.2013.11.001
Van Valkengoed AM, Steg L (2019) Meta-analyses of factors motivating climate change adaptation behaviour. Nat Clim Chang 9:158–163
Wiering M, Kaufmann M, Mees H, Schellenberger T, Ganzevoort W, Hegger DLT, . . . Matczak P (2017). Varieties of flood risk governance in Europe: how do countries respond to driving forces
and what explains institutional change? Glob Environ Change, 44, 15-26 https://doi.org/10.1016/j.gloenvcha.2017.02.006

Wu H-L, Cheng W-C, Shen S-L, Lin M-Y, Arulrajah A (2020) Variation of hydro-environment during past four decades with underground sponge city planning to control flash floods in Wuhan, China: an overview. Underground Space 5(2):184–198. https://doi.org/10.1016/j.undsp.2019.01.003

Wuhan Municipal Flood Control and Drought Relief Headquarter (2015). Emergency Plan for Flood Control in Wuhan (in Chinese)

Zevenbergen C, Veerbeek W, Gersonius B, Van Herk S (2008) Challenges in urban flood management: travelling across spatial and temporal scales. J Flood Risk Manage 1(2):81–88. https://doi.org/10.1111/j.1753-318X.2008.00010.x

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