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Identifying the drivers of private flood precautionary measures in Ho Chi Minh City, Vietnam

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Abstract. Private flood precautionary measures have proven to reduce flood damage effectively. Integration of these measures into flood response systems can improve flood risk management in highly vulnerable areas such as Ho Chi Minh City (HCMC). Since uptake of such measures is voluntary, it is important to know what drives householders to implement precautionary measures. Protection Motivation Theory in combination with the Transtheoretical Model was applied to survey data collected from 1000 flood prone households in HCMC. Data analyses by ridge and elastic net regression revealed that, education, degree of belief that the government will implement effective flood protection measures and degree of belief that one has to deal with the consequences of flooding by themselves positively influence the proactive implementation of non-structural flood precautionary measures. Experienced increasing flood damage leads to reactive implementation of measures. But when the perceived severity of flood damage in the future was high, it discouraged implementation of structural flood precautionary measures even after experiencing a serious flood event. These important aspects should be considered when developing risk communication or incentive campaigns to promote proactive implementation of private flood precaution in HCMC.

1 Introduction

Floods affect 54 million people and cause 58 billion EUR of damages globally per year (Alfieri et al., 2017). During the last decades, the intensity and frequency of extreme events has increased (Munich Re, 2021) and they are predicted to rise further in the future due to climate change (Botzen, et al., 2019(a)). Extreme precipitation events leading to pluvial, urban flooding or local flash floods as well as long-duration events resulting in large-scale fluvial floods are predicted to occur more frequently due to intensification of the hydrological cycle (Donat et al., 2016; Alfieri et al., 2017). Also storm-surge and coastal flooding are expected to increase in frequency and intensity due to sea level rise (Asian Development Bank, 2010). Historically, Asia has endured 62% of global flood losses between 1980 to 2015 according to the EM-DAT database (Bubeck et al., 2017), with the majority of the events affecting developing coastal cities (Chan, et al., 2018). Among the Asian countries, Vietnam is considered the most climate-vulnerable country in the world (Dasgupta et al., 2007; Mendoza et al., 2014) with floods being the most damaging hazard (Nguyen, et al. 2021(b)). Developing countries are more severely impacted by flooding due to their limited capacity to lessen the effects of disaster (Hagedoorn et al., 2021) and the hindrance posed to their economic growth due to the consequences of large flood events (Botzen, et al., 2019(a)). In the case of coastal cities of Vietnam such as Ho Chi Minh City (HCMC), increasing exposure and vulnerability driven by population increase and urban development in flood zones (Asian Development Bank, 2010), inadequate infrastructure (Asian Development Bank, 2010), and land subsidence (Cao et al., 2021) further exacerbate flood risk. Yet, most of the studies prioritize physical and environmental drivers of flood risk over social, economic or governance related drivers (Nguyen et al., 2021(a)). To counteract the trend of increasing flood risk due to global change, improved flood risk management is necessary.

Flood Risk Management mainly consists of three phases: (i) Preparedness, (ii) Response, and (iii) Recovery (WMO et al., 2008). Among these, preparedness attempts to reduce the flood risk via protection and adaptation measures. Inadequate understanding of flood risk prompts Asian countries to excessively invest in flood protection only after a major flood event (Nguyen et al., 2021(a); Ishiwatari and Sasaki, 2021). Chan et al. (2018) has indicated the necessity of proactive implementation of flood risk management strategies. However, owing to the rapidly changing flood hazard levels, conventional large-scale flood protection structures such as dikes and retention basins may fail (Botzen, et al., 2019(a); Nguyen et al., 2021(a)) exposing the growing urban areas to flooding. Therefore, it is necessary to complement these structural measures with adaptable, non-structural flood risk mitigation measures such as private precautionary measures, land-use planning and insurance to achieve an effective integrated flood risk management strategy (Du et al., 2020; Scussolini et al., 2017; Yang, et al., 2018).

Private precautionary measures have demonstrated effectiveness in reducing flood damage (Sairam et al. 2019) and it is increasingly being adopted in contemporary flood risk management strategies (Kreibich et al., 2015). These measures include elevating buildings, shielding with water barriers, waterproof sealing, fortification, flood adapted use, flood adapted interior fitting and safeguarding of hazardous substances (Chinh et al. 2016). Knowledge is scarce about the level of flood preparedness and uptake of private precautionary measures in coastal cities in Asia (Deen, 2015; Yang, et al., 2015; Krongthaeo, et al., 2021). For example, the effectiveness of elevating households and dry-proofing buildings in HCMC was found to reduce expected annual flood damages by 52-55% and 82% respectively (Scussolini et al. 2017). Another study conducted in Shanghai by Du et al. (2020) reported 69% reduction in expected annual flood damages from wet-proofing. Despite evidence demonstrating the loss-reducing potential of private precautionary measures, their implementation is commonly voluntary and hardly any official funding is provided (Barendrecht et al. 2020; Chinh et al., 2016). Past surveys have indicated that householders are often not willing to take the responsibility and fail to implement property-level precautionary measures (Bamberg et al., 2017; Barendrecht et al., 2020). Experiencing repeated flooding can change this attitude (Bubeck et al., 2018; Chinh et al., 2016). To achieve an effective integrated flood risk management, it is essential to investigate the readiness of individuals and the factors influencing their risk reduction behavior in the given policy framework (Weyrich et al., 2020). These insights can guide the design of targeted risk communication campaigns and incentives to improve flood preparedness (Botzen, et al., 2019(b)).

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

Among coastal cities, Ho Chi Minh City is ranked among the top 10 cities in the world to be most severely affected by climate change (Asian Development Bank, 2010). In this study, we aim to identify the drivers that promote risk reduction behavior among households in HCMC, Vietnam and subsequently, evaluate how these drivers are associated with the willingness of households to adopt private flood precautionary measures. In this respect, we develop an empirical data-driven approach complementing theoretical protection motivation theory and transtheoretical model frameworks. Elucidating the process behind precaution uptake has the potential to influence flood risk management policy such as strategies to incentivize and motivate uptake of private precautionary measures.

2 Study area – Ho Chi Minh City

Ho Chi Minh City is located in southern Vietnam. It is the largest city and also the economic, trade, transportation and cultural center of Vietnam. The city sits in the northeast of the Mekong Delta covering an area of 2,095 square kilometers and its center is about 80 kilometers away from the sea. As of 2020, the resident population was about 9 million including an estimated 2 million migrant workers (Woetzel et al., 2020). The city's population is expected to grow even faster in the coming years.

HCMC has a tropical monsoon climate, the rainy season is from June to November, and the dry season is from December to May. It has a high annual rainfall of about 2,000 mm and a mild climate with an average annual temperature of 27 degrees Celsius. HCMC frequently suffers from tidal and river flooding since 65% of the city is less than 1.5m above sea level (Cao et al., 2021). It also exhibits an increasing trend of precipitation events (Khoi and Trang, 2016; Phi, 2007). Thus, HCMC has a history of regular flooding and floods are a common part of life (Woetzel et al., 2020). The flood risk is exacerbated by climate change, ongoing urbanization, increasing population and infrastructure density leading to a higher proportion of sealed surfaces (Woetzel et al., 2020). Further accumulation of people and assets is attributing to greater exposure. During the rainy season, a combination of high tide, heavy rains, high flow volume in the Saigon River and Dong Nai River results in regular flooding in several parts of the city. Beyond that, the observed mean land subsidence rate was 3.3 mm per year over the city, with a maximum local subsidence of 5.3 cm per year (Duffy, et al., 2020). A once-in-100-year flood would cause 23% of the city to flood (Woetzel, et al., 2020). Protection of livelihood from flood events has a high priority and it is leading to high investments in extensive flood defense systems (Kreibich et al., 2015; Weyrich et al., 2020). The government of HCMC has been pursuing formal flood adaptive measures such as building ring dykes, sluice flood gates and pumping stations, along with a major drainage project funded by the Japan International Cooperation Agency (JICA) which has been in construction since 2001 (Cao et al., 2021). However, these drainage systems are becoming overloaded due to rising water level in rivers, and increasing rainfall-runoff ratios (Phi, 2007). In this respect, flood risk management approaches have recently shifted from preventive measures to integrative and adaptive strategies. For example, the current Master Plan for HCMC being revised by the Department of Urban Planning and Architecture (DUPA) aims to integrate climate change issues into the new urban plan (Vachaud et al., 2018).

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

3 Data and methods

3.1 Theoretical frameworks

Protection Motivation Theory (PMT) was first proposed by Rogers W. (1983) to explain the effect of fear appeals on health-related behavior in health psychology. Gradually, its application was extended to research in natural and environmental hazards, such as droughts, earthquakes, volcanic hazards, tornadoes, wildfires and flood risks (Babcicky and Seebauer, 2019). Bamberg et al. (2017) provides a meta-analysis synthesis of PMT application to understand flood prevention. PMT was implemented to identify the drivers that motivate individuals to adopt protective measures. It has a clear structure consisting of two cognitive processes, threat appraisal and coping appraisal, which determine the changes in an individual's coping intentions (Babcicky and Seebauer, 2019; Bubeck et al., 2018; Grothmann and Reusswig, 2006). Grothmann and Reusswig (2006) described 'threat appraisal' as a person's assessment of a threat's damaging potential to valuables, assuming no personal change in behavior. While 'coping appraisal' is described as the person's evaluation of their ability to cope with or avert the threat. In this study PMT is extended to include household characteristics, dependency of a household on the government and their past flood experience (Figure 1). Effectiveness of the PMT framework is limited as a household's willingness to adopt protective measures in flood risk areas is not considered. Therefore, a dynamic protection motivation framework is developed by combining PMT and Transtheoretical Model (TTM) (Weyrich et al., 2020). TTM is a behavioral change model which emerged from clinical psychology and represents decision stages which indicate an individual's degree of readiness to act upon danger to protect themselves from a risk (Bočkarjova et al., 2009). The PMT-TTM model was first introduced by Block and Keller (1998) and this combined approach had the ability to identify and influence the change in decision stages (Bočkarjova et al., 2009). The conventional ordered decision stages are pre-contemplation, contemplation and action stages (Block and Keller, 1998; Poussin et al., 2014) but they can be modified in relevance to the objective of the intended research. For instance, Weyrich et al. (2020) developed different risk reduction stages to focus on the quality of protective behavior while Bočkarjova et al. (2009) implemented intention stages to understand the risk reducing behavioral intention. This framework aims to identify drivers that prompt proactive response to flood risks among households and hence we developed two risk reducing stages, namely, the proactive stage and reactive stage. Proactive stage defines individuals who voluntarily participate in risk reduction measures even before experiencing a serious flood event while individuals from reactive stage undertake protective measures only as a response to a serious flood event (Figure 1).

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

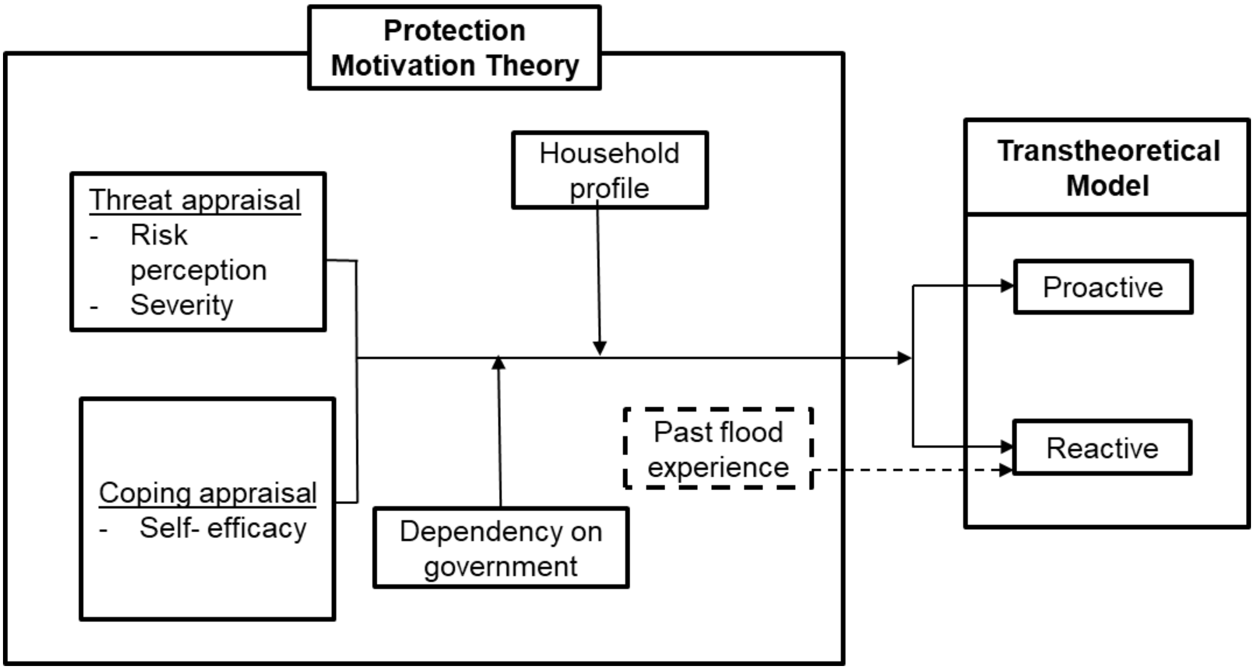


Figure 1: Protection Motivation Theory and Transtheoretical model framework

3.2 Data

The primary data used in the study were obtained from a structured household survey in selected districts of HCMC during September - October 2020. A total of 8 wards in 4 districts were covered which includes Binh Thanh, District 8, Binh Tan, and Nha Be. The survey collected 1000 valid responses from local households who suffered from floods in the recent 10 years. The questions were drafted based on expert knowledge from flood risk researchers, social scientists and local stakeholders in HCMC. The survey locations were established in order to cover a broad range of socio-economic profiles and flood types such as tidal, fluvial, pluvial and compound flooding in the city. A survey pre-test involving 60 households from three districts (Binh Tan, District 7 and District 2) was run in December 2019 in order to test the validity of the questionnaire. The questionnaire was revised, based on the responses from the pre-test. The questionnaire covered aspects concerning two past flood events experienced by the households - the most recent and the most serious event in the last 10 years. The questions pertained to the hazard and damages suffered by the households, implementation of precautionary measures, early warning quality and lead time, household risk perception and household's socio-economic profile. Following the PMT-TTM framework, survey responses that potentially influence the uptake of precautionary measures were selected as follows. PMT comprises six aspects: (1) risk perception, (2) severity, (3) self-efficacy, (4) household profile, (5) dependency on government, and (6) past flood experiences (Figure 1). Each of these aspects is determined by a cluster of explanatory variables, acquired by a relevant question from the questionnaire (Appendix A). TTM investigates which risk reducing stage a household belongs to. To classify households to different risk reducing stages answers to the following question was used.

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

Question: Which of the following precautionary measures (Table 1) have you implemented and when?

Response: Did you implement it:

[1] Before the serious event

[2] Before the recent event

[3] Before both events (serious and recent)

[4] After both events

[5] Did not implement

Table 1: Categorisation of private flood precautionary measures

Measure	Description	Category
Elevate	Elevating the building ground floor or foundation to prevent the water from entering the building.	Structural measures
Install flood protection	Installation of flood protection systems for sealing doors, windows and basements.	
Dry proofing valuables	Protecting valuables and expensive contents such as electronics/computers by placing them at elevation above flood water level.	Non-structural measures
Water barriers	Purchasing water barriers to prevent the flood water from entering the house.	
Pumping equipment	Purchasing pumping equipment to pump out flood water.	
Water resistant material	Using water resistant material for the house, e.g., water resistant paint.	
Electricity control at higher level	Installing electricity control system such as power supply boards and meter boards at higher elevation.	

Each precautionary measure is grouped into the structural or non-structural measures category (Table 1). For each precautionary measure category, if a household implemented any one of the measures before the serious event [1] or before both events [3], the household is grouped into the proactive risk reducing stage. If a household implemented any one of the measures before the recent event [2] or after both the events [4], the household is grouped into the reactive risk reducing stage. Therefore, a household that belongs to the proactive risk reducing stage for structural measure category can belong to the reactive risk reducing stage with respect to non-structural measure category. From these two levels of classification, risk reducing stages and precautionary measure categories, four groups of households were formed as illustrated in Figure 2.

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

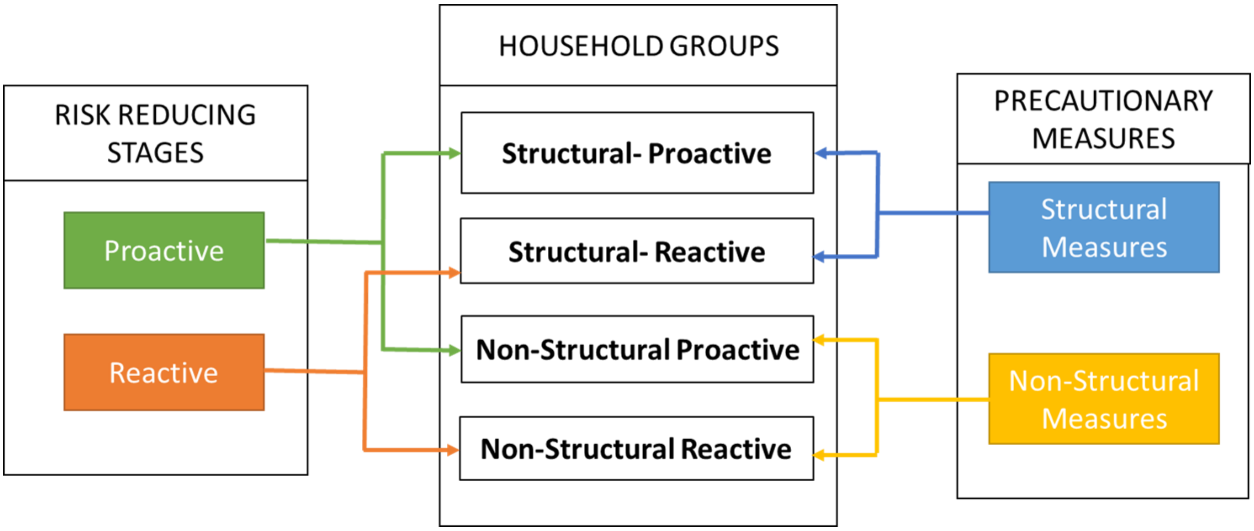


Figure 2: Derivation of four household groups from two levels of classification representing structural proactive (SP), structural reactive (SR), non-structural proactive (NSP) and non-structural reactive (NSR) households.

3.3 Data-driven feature selection

To identify drivers that have the most significant influence on the decision of a particular household group to adopt protective behaviour, lasso and elastic net regression models are applied. These models determine the relationship between the explanatory variables representing one of the aspects in the PMT-TTM framework and response variables indicating if a precautionary measure was implemented or not, for reach household group. The response variables follow binomial distribution. The analysis is performed in the R programming language using glmnet R package and the goodness-of-fit is measured using deviance.

Lasso regression performs variable selection while maintaining the stability by imposing a penalty on the size of regression coefficients (Tibshirani, 1996). It minimizes the residual sum of squares subject to the sum of absolute value of the coefficients being less than a constant. The nature of this constraint tends to produce some coefficients that are exactly equal to zero and eliminates the explanatory variables corresponding to these coefficients (Tibshirani, 1996). The lasso estimate is defined by Eq. (1) (Hastie et al., 2008):

$$\hat{\beta}^{lasso} = \underset{\beta}{argmin} \left\{ \frac{1}{2} \sum_{i=1}^{N} (y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \right\} \quad (1)$$

However, when a number of explanatory variables (p) is greater than the number of observations (n), only n variables are selected before lasso saturates and when a group of variables have high pairwise correlation, then lasso randomly selects one variable from the group. Therefore, net-elastic regression is introduced as illustrated in Eq. (2) (Zou and Hastie, 2005). The L1 lasso penalty term performs automatic variable selection while L2 ridge penalty term encourages grouped selection and stabilizes random sampling, thereby improving predictions (Ogutu et al., 2012).

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

$$L_{enet}(\hat{\beta}) = \frac{\sum_{i=1}^{n}(y_i - x_i^J \hat{\beta})^2}{2n} + \lambda(\frac{1-\alpha}{2}\sum_{j=1}^{p}\hat{\beta}_j^2 + \alpha\sum_{j=1}^{p}|\hat{\beta}_j|) \quad (2)$$

Hyperparameter α weights each of L1 and L2 penalties and assigns a value between 0 and 1. It is used to weight the contribution of the L1 penalty and one minus alpha value weights the L2 penalty. Another hyperparameter λ, controls the weighting of the sum of both penalties, 1 implies the penalties are fully weighted while 0 excludes the penalties (Zou and Hastie, 2005). Therefore, it is capable of overcoming the limitations of lasso regression.

Cross-validation resampling is applied to these models to assess their generalization ability. In this study, 10-fold cross-validation is implemented to the available dataset by partitioning 10 disjoint subsets of approximately equal size by randomly sampling data from the dataset without replacement. The model is trained using 9 subsets and validated with the remaining 1 subset. This procedure is repeated until each of the 10 subsets has served as a validation subset and the average of their performance measurements is the cross-validation performance. Thereafter, deviance is employed to measure the performance of lasso and elastic net regression models by applying the assess.glmnet function. It measures the difference of likelihood between a fitted model and a saturated model. Likelihood of a saturated model is one as the number of estimated parameters is equal to the number of data points. Therefore, the formula of deviance is as presented in Eq. (3).

$$D = -2log\ lik\ (\hat{\beta}) \quad (3)$$

It is used to measure the goodness-of-fit of models and it ranges from 0 to infinity, where lower deviance value indicates the model has a better data fit.

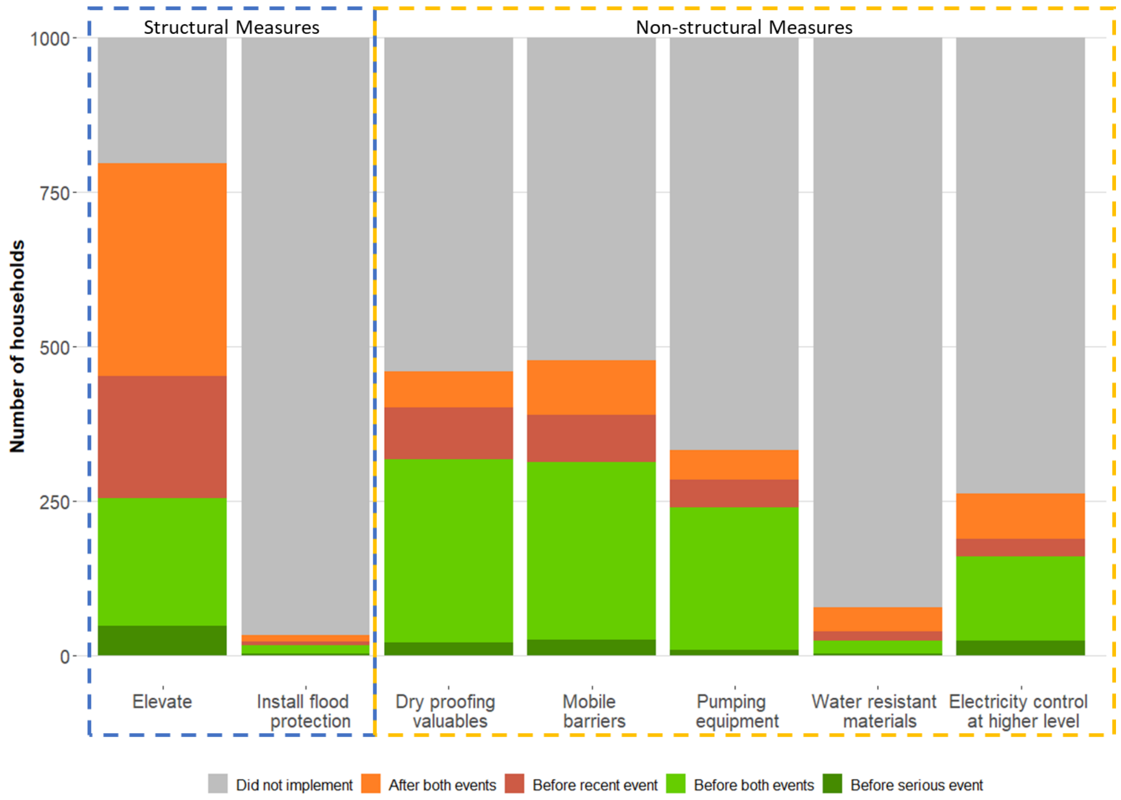
In summary, lasso and elastic net regression models are applied to the four household groups representing Structural-Proactive (SP), Non-Structural-Proactive (NSP), Structural-Reactive (SR), and Non-Structural-Reactive (NSR) households to identify the most important aspects of the PMT-TTM framework that influence risk reducing behavior. For each household group, the absolute variable coefficient values associated with the lowest deviance value are derived from lasso and elastic-net regression. Thereafter, weighted median is computed from normalized variable coefficients where the reciprocal of deviance acts as weights. Since the predictors used in the model correspond to the aspects of the PMT-TTM framework, the variable importance based on a weighted median value greater than 0.5 are considered to have an influence on the decision of a household to adopt structural or non-structural precautionary measures proactively or reactively.

4 Results and discussion

4.1 Implementation of private precautionary measures

Building elevation has the highest implementation rate: 54.2% of the households have reactively undertaken this measure (i.e., implementation after both events or before recent event) and 25.5% have adopted it proactively (i.e., implementation before both events or before serious event) (Figure 3).

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022



210 **Figure 3: Number of households that implemented private precautionary measures and the timeline of the implementation with respect to the most serious and the most recent event in the last 10 years.**

Although the average cost of elevating a building is 61 million VND (Figure 4) which is much higher than implementation costs of other precautionary measures.

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

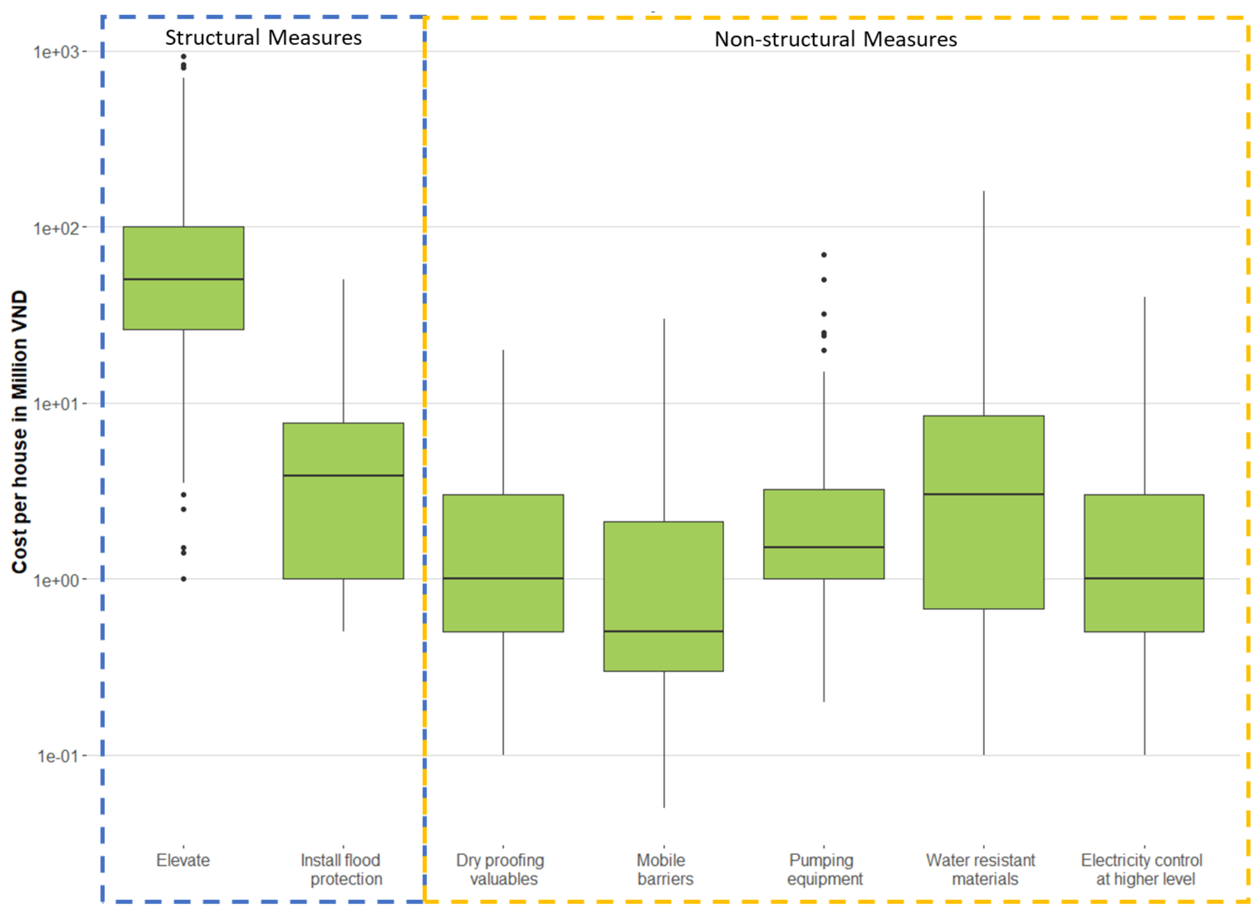


Figure 4: Implementation cost of the private precautionary measures represented using boxplots (the box - in green represents the 25th and 75th percentile; the black solid line in the middle of the box represents the median; the whiskers show the minimum and maximum values)

Second most implemented measure is mobile barrier, which is closely followed by dry proofing valuables with implementation ratio of 47.7% and 46% respectively. Furthermore, 33.3% have pumping equipment to pump out flood water and 26.2% have installed electricity control at higher level. Pumping equipment and mobile barriers endure average cost of implementation per house of 1 and 0.77 million VND respectively which is attributed to the purchasing cost of pumps and mobile water barriers. Average cost of dry proofing valuables, applying water resistant building materials and installing electricity control at higher level is 0.38, 0.53 VND and 0.54 million VND respectively. On the contrary, installation of flood protection systems and usage of water-resistant materials have the lowest implementation ratio of 3.3% and 7.7% respectively although their implementation cost is 0.28 and 0.53 million VND which is relatively low. Therefore, no correlation between implementation of precautionary measures and cost can be detected for HCMC.

Majority of the respondents in this study have exclusively only elevated their house. Buildings are often built elevated or are elevated during renovations. Other measures such as installation of flood protection systems and usage of water-resistant materials, though found effective in other regions, are not common in HCMC. This might be due to lack of knowledge or lack of support to increase responsibility among households to implement other private measures (Bubeck et al., 2012; Chinh et al., 2016). Barriers are convenient to implement without the need to make permanent structural changes to the building and yet they prevent flood water from entering the house. Dry proofing also prevents the contact of valuable items with flood water. However, these measures can be effectively implemented only when flood warning is given in advance. Highest number of respondents have elevated their houses only after experiencing serious and recent flood events (Figure 3) because the flooding is getting worse in HCMC (Paulo and Rivai, 2021). Elevation effectively prevents the floodwater from reaching the living area. Elevation process can be done to the entire building including the floor or only a new elevated floor can be constructed within the building (FEMA, 2007). However, this contradicts with the results of Koerth et al. (2013), which reports that in Denmark and Germany, structural measures are rarely implemented due to their high costs. Similar discrepancy can be observed in another study conducted in Germany and France by Bubeck et al. (2018), which reports the requirement of policies to encourage flood-proof rebuilding. Thus, the choice of private precautionary measures by households in HCMC starkly differs from the prevalent measures in western Europe. This difference might be due to socio-economic differences between the regions. Countries in the western Europe are often sparsely populated and have a developed economy. In contrast, HCMC is a densely populated metropolis with a rapidly growing economy. In addition, HCMC's mitigation choices are also driven by frequent floods, inundations occur almost during every rainy season, so that people learn to live with floods.

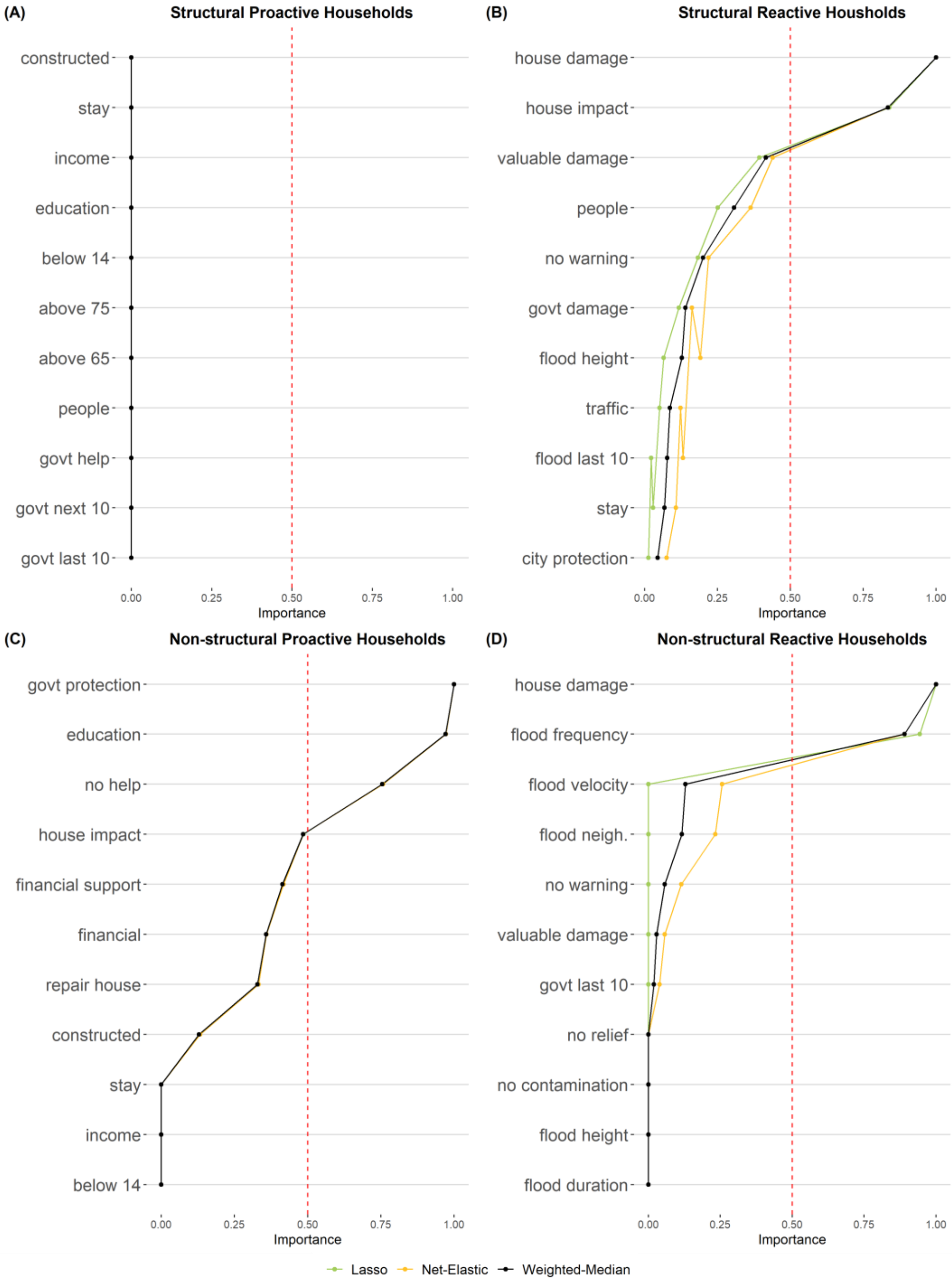
4.2 PMT-TTM drivers of private precautionary measures

Implementation of penalized regression analysis to the variables established by the PMT-TTM framework recognises a set of important variables for each household group, except for the structural measures proactive group. This section infers the selected variables which have importance greater than 0.5 since they are presumed to influence the decision of households to implement precautionary measures.

For households which undertook structural measures after they experienced a serious flood event the variables 'house damage' and 'house impact' are distinguished as significant with importance values of 1 and 0.83, respectively (Figure 5(b), Table 3). Average coefficient value of 'House damage' computed from lasso and elastic net regression is 1.09, which implies that the higher damage level to the building because of the serious flood event, increases the probability of the household adopting structural precautionary measures. On the other hand, 'House impact' variable with an average coefficient value of -0.91 has a negative sign indicating that households which strongly believe that their house will be more severely affected by flooding in the future are less likely to adopt structural precautionary measures. The 'House impact' variable is affiliated with the severity factor which belongs to threat appraisal (Appendix A). The finding that perceived increase of severe flood damage in the future discourages the implementation of structural measures is consistent with previous studies (Babcicky and Seebauer, 2019; Gebrehiwot and van der Veen, 2015; Grothmann and Reusswig, 2006). To avoid this counterproductive effect, it is suggested to not only communicate the severity of flood risks, which rather leads to non-protective behaviour, but

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

to convey information regarding the availability of efficient precautionary measures and how to implement these to increase the sense of responsibility and self-efficacy (Bubeck et al., 2018; Koerth et al., 2013).



265 **Figure 5: Drivers of private precautionary measures for (A) structural proactive households; (B) structural reactive households; (C) non-structural proactive households; and (D) non-structural reactive households (Variables on the y-axis correspond to variable names in Appendix A).**

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

Table 3: Variables influencing implementation of precautionary measures (Importance: 0 -> no importance; 1 -> high importance, Coefficients: positive -> encourages uptake of measures; negative -> discourages uptake of measures, Deviance: towards 0 -> good statistical model fit; towards ∞ -> poor statistical model fit)

Household group	Variable name (importance > 0.5)	Variable description	Coefficients		
			Lasso	Elastic net	Average
Structural Reactive households	*Deviance*		*1.272*	*1.271*	*1.271*
	House damage (1)	Level of house damage experienced due to previous flood events.	1.16	1.02	1.09
	House impact (0.83)	Degree of belief one's house will be more severely affected due to floods in the future.	-0.97	-0.85	-0.91
Non- Structural Proactive households	*Deviance*		*1.298*	*1.298*	*1.298*
	Government protection (1)	Degree of belief the government will implement effective flood protection measures.	0.40	0.40	0.40
	Education (0.97)	Level of education attained within a household	0.34	0.38	0.36
	No help (0.75)	Degree of belief one has to deal with the consequences of flooding by oneself.	0.24	0.29	0.26
Non-structural Reactive households	*Deviance*		*1.262*	*1.260*	*1.261*
	House damage (1)	Level of house damage experienced due to previous flood events.	0.37	0.26	0.31
	Flood frequency (0.89)	Number of previous flood events experienced since 2010.	0.36	0.23	0.29

For households that have proactively adopted non-structural precautionary measures, the important variables are 'Government protection', 'Education' and 'No help' with importance values of 1, 0.97 and 0.75 respectively (Figure 5(c), Table 3). Their corresponding average of regression coefficient values are 0.40, 0.36 and 0.26, respectively. 'Government protection' implies that households which strongly believe in the government to establish effective flood protection measures are motivated to adopt non-structural measures proactively. This result confirms another study conducted in the Netherlands (Bočkarjova et al., 2009). A study by Botzen, et al., (2019b) also found that high trust in the city's flood risk management approach was a driver for private building elevation (structural measure). However, it might have been more decisive that the building codes prompted building elevation and discouraged only dry proofing measures. 'Education' is the next important influencing variable indicating that households with higher levels of education are more likely to undertake non-structural precautionary measures prior to experiencing any serious flood event. It highlights the significance of education since educated households are more aware of the available flood precautionary measures. Therefore, education and training activities that teach people how to implement effective flood precautionary measures can greatly contribute towards reducing flood damage. A study conducted by Kumar Paul & Nazir Hossain (2013) in Bangladesh highlights the significance of developing awareness of suitable coping strategies to enhance the long-term resilience among the people. 'No help' is the third important variable expressing that households which recognize that they have to solely cope with the consequences of a flood event are more probable to adopt non-structural precautionary measures proactively to reduce flood damages. Botzen, et al. (2019b) and Gebrehiwot and van der Veen, (2015) have further indicated high belief in one's ability to protect themselves lead to proactive implementation of precautionary measures in their studies.

Finally, significant variables for households that have adopted non-structural flood precautionary measures after they experienced a serious flood event are 'House damage' and 'Flood frequency' with importance values of 1 and 0.89, respectively (Figure 5(d), Table 3). Average regression coefficient of 'House damage' is 0.31 and of 'Flood frequency' is 0.29. Similar to SR households, 'House damage' greatly influences the decision of implementing non-structural measures. The high damage levels experienced from previous flood events encouraged the reactive implementation of non-structural precautionary measures. Next 'Flood frequency' variable conveys that experiencing flood events multiple times has urged the households to undertake non-structural precautionary measures to reduce the damages from flood. This is in accordance with other studies that acknowledge past flood experiences to encourage protective attitude among households (Ansari, 2018; Bočkarjova et al., 2009). In addition to the important influencing variables identified here, age (Bubeck et al., 2018; Gebrehiwot and van der Veen, 2015), response cost (Gebrehiwot and van der Veen, 2015; Weyrich et al., 2020), intrinsic rewards (Gebrehiwot and van der Veen, 2015) and ownership (Bubeck et al., 2018; Oakley et al., 2020) were recognized as significant variables in previous studies.

The analysis of structural proactive household groups did not reveal any significant influencing variable as exhibited in Figure 5(a). One potential reason is that many proactive households that have implemented structural measures would have often implemented them while building the house or they might have bought the house with the measure already implemented. In both these cases, we are not able to ascertain whether the householder made a conscious choice to implement the measure.

Nevertheless, the long-term improvement in precautions taken by commune authorities and households appears as inseparable components of the integrated flood risk mitigation strategy (Nguyen, et al., 2021(b)). Findings in this study are especially relevant in many fast developing Asian cities due to their similar features regarding high population density, strong social network and spontaneous individual coping measures. At household level, certain indicators including education, income and place attachment can be empirically valid for taking active actions (Ji, et al., 2021). Both wet-proofing and dry-proofing measures are widely adopted as the most common precautionary measures (Lasage, et al., 2014), including ground elevation, foundation strengthening, using reinforced materials, precautionary savings, in various countries and cover coastal cities (Du, et al., 2020) as well as inland regions (Shah, et al., 2017). However, findings confirmed that the high level of uptake of precautionary measures was dependent on distance, household composition, income, occupation of

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

the household and social network type (Okayo, et al., 2015). In addition, households may be better aware of the limitation of public flood protection through their precautionary behavior, and thus found which measures can reduce most of the flood damages (Kuo, 2016). Therefore, it would be interesting to do a comprehensive analysis on the motivating factors that can be used to move reactive households to the proactive group. To further explore this specific theme, empirical data on the cost and benefits of flood precautionary measures would be paramount.

5 Conclusion

Behavioural analysis assists decision makers to develop effective policies and programmes to encourage citizens to participate in integrated flood risk management strategies. Integrated risk management is especially important in cities like HCMC which are frequently affected by compound floods, e.g., combined fluvial, pluvial and coastal flooding. An exploratory analysis of the precautionary measures implemented reveals that there is no correlation between the costs of implementation and the type of precautionary measure implemented, implying that costs do not restrict the implementation of precautionary measures in HCMC. The PMT-TTM framework applied to “Structural - Proactive”, “Structural - Reactive”, “Non-structural - Proactive” and “Non-structural - Reactive” household groups identified a set of important aspects that motivates the implementation of precautionary measures. The results exhibit that the perceived increase of severe flood damage in the future discouraged the reactive implementation of structural measures, implying the necessity for a pragmatic communication of flood risks to not discourage protective behaviour. The analysis further shows that high education levels along with the belief that the government is taking actions to reduce flood risk, but one has to deal with the consequences of flooding by oneself positively influenced the decision of proactive groups. Therefore, organizing flood awareness campaigns to constructively communicate about flood risks in HCMC, preventive measures undertaken by the government and how precautionary measures can be implemented by a household, can motivate proactive behaviour of households. This will also increase the sense of responsibility among households in HCMC to adopt private flood precautionary measures proactively. Since flood risk is predicted to increase in HCMC even more should be done to better adapt for the future.

6 Appendix A

This section gives a list of questions and their corresponding responses used in the household survey.

Factor	**Variable name**	**Question**	**Data type**	**Responses**
Risk Perception	Flood last 10	Did the flood change during the last 10 years?	Ordinal	1. Much increased 2. Increased 3. No change 4. Decreased

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

				5. Much decreased
	Flood next 10	Do you expect changes of flood in the next 10 years?	Ordinal	1. Much increased 2. Increased 3. No change 4. Decreased 5. Much decreased
	Economic loss	How likely would you have economic losses?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Severity	Traffic	Would traffic and road system be collapsed in your living/working area?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	House impact	My house will be more severely affected by floods in future	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Financial	Would you face a serious financial problem or even bankrupt?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Health	Would you or your family members be suffering health impacts?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Self-Efficacy	House economy future	What do you expect for your household economy in next 10 years for dealing with flooding?	Ordinal	1: Richer (e.g. for preparing and repairing your house) 2: Poorer 3: Same
	Change livelihood	How likely would you change your livelihood to another way of earning income?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Resist flood	Could your residential or shop house resist in such extreme flood scenario?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Repair house	Would you like to fortify and repair your houses?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Relocate	Would you move away (relocate residential)?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Financial support	Could you get financial support from any person or organizations?	Ordinal	Scale (1-5) 1: Unlikely

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

				5: extremely likely
Household Profile	People	How many people are living in your household?	Discrete	-
	Above 65	Out of these, how many are 65 years and older?	Discrete	-
	Above 75	How many are 75 years and older?	Discrete	-
	Below 14	How many are 0-14 years old?	Discrete	-
	Education	Which is the highest educational attainment in your household?	Ordinal	1. No member never went to school 2. primary school 3. secondary school 4. high school 5. university bachelor/Vocational training 6. master 7. PhD or higher
	Income	How high is the available income per month (million VND)?	Ordinal	1: less than 1m 2: 1m – 5m 3: 5m – 10m 4: 10m – 20m 5: 20m – 30m 6: 30m – 50m 7: 50m – 80m 8: 80m – 100m 9: >100m
	Stay	Since when have you been living in this location?	Discrete	-
	Constructed	When was the house constructed?	Discrete	-
Dependency on government	City protection	city provides a good protection against floods	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Flood warning	Flood warnings by the local government officials are helpful	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Government protection	The government will take care of good and effective flood protection measures.	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Government	Flood risk and damage have been	Ordinal	Scale (1-5)

https://doi.org/10.5194/egusphere-2022-171
Preprint. Discussion started: 17 May 2022

	damage	increasingly borne by government		1: strongly disagree 5: Strongly agree
	No help	Households or shops/firms are left alone to taking care of flood	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Flood neighborhood	You are generally satisfied with the flood management in your neighborhood	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Government last 10	What was the change of government support in dealing with floods in the last 10 years?	Ordinal	1: Maintained 2: Reduced 3: Increased
	Government next 10	What do you think the local government will do to deal with floods in the next 10 years?	Ordinal	1: Maintained 2: Reduced 3: Increased
	Government help	Would you expect help from government?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Past flood experien ce	Flood frequency	How many times have you been flooded since 2010 (i.e., flood water entering your house)?	Ordinal	1: 1-5 (less than once a year) 2: 6-10 (about once a year) 3: 11-20 (1-2 times a year) 4: 21-50 (2-5 times a year) 5: 51-100 (5-10 time a year) 6: over 100 (more than 10 time a year)
	Flood duration	Duration of inundation at the house (hours)	Continuous	-
	Flood height	Highest water point from your ground floor (cm)	Continuous	-
	No contamination	The flood water contained the following contaminants	Binary	1: No contamination 0: Contamination
	Flood velocity	flow velocity on the road/street	Ordinal	1: calm 5: torrential
	No warning	Type of warning	Binary	1: Did not receive warning

				0: Received Warning
	House damage	What was the damage to your house/business building because of the flood?	Ordinal	1: No damage; 2: Minor damages - Usable; 3: Moderate damages; 4: Major damages – needs repair; 5: Complete damage – needs replacement,
	Valuable damage	In the residential part of your house, what furniture, appliances, other contents were damaged and how much were the values?	Ordinal	1: No damage; 2: Minor damages - Usable; 3: Moderate damages; 4: Major damages – needs repair; 5: Complete damage – needs replacement,
	No relief	What kind of relief helps did you receive in the flood emergency?	Binary	1: Did not receive relief 0: Received Relief

7 Code availability

The code used for our analysis can be provided upon request.

8 Author contributions

Conceptualization/Research Design: T.V., N.S., H.K., M.G.; Data Analysis and model development: T.V., N.S.; Visualization: T.V.; Interpretation of results: T.V., N.S., H.K., L.E.Y; Writing - Original Draft: T.V.; Writing - review & editing: T.V., N.S., H.K. and L.E.Y; Supervision: N.S., H.K.

9 Competing interests

The authors have no competing interests to declare. Heidi Kreibich is an executive editor at Natural Hazards and Earth System Sciences (NHESS) journal.

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