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Research article

Riverbank erosion vulnerability assessment and coping strategies: A case study of the riparian communities in the Mekong River Basin in Cambodia

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ABSTRACT

Riverbank erosion is a major hazard for riparian communities in the Mekong River Basin. This study aims to (1) assess the livelihood vulnerability of two communities residing along the Mekong River, namely, Kaoh Soutin (KS) and Ruessei Srok (RS), by using the livelihood vulnerability index framed within the Intergovernmental Panel on Climate Change vulnerability framework (LVI-IPCC) and (2) identify the coping strategies of the communities based on semi-structured interviews. The results show that KS is slightly more vulnerable to riverbank erosion than RS, as indicated by LVI-IPCC values of 0.49 and 0.46 for KS and RS, respectively. RS exhibits high adaptive capacity and low sensitivity, but its exposure level is relatively high. Majority of the respondents in KS (62 %) and RS (93 %) were affected by riverbank erosion. In KS, approximately 48 % of the respondents experienced displacement, and 39 % of them relocated once. Meanwhile, in RS, 81 % of the respondents experienced displacement, with 46 % displaced at least three times. The affected households have coped with riverbank erosion by reducing expenses, diversifying their income sources, seeking support from others, and receiving assistance from local authorities, NGOs, and government interventions. Despite such efforts to mitigate the effects of riverbank erosion, the high level of exposure and external factors, such as high living costs and low profits from agriculture, have weakened the ability of the people in both communities to cope with disasters. Moreover, the social ties among households, especially in KS, have declined, thereby making low-income households highly vulnerable to riverbank erosion.

1. Introduction

Disasters have immense effects on the social development of many countries. In addition, climate change has driven extreme climatic events that result in the occurrence of intense and frequent natural hazards [1]. According to the World Bank [2], disasters resulting from extreme natural hazards cost approximately $520 billion annually, pushing around 26 million people into poverty each year. Low-income countries are disproportionally affected by disasters because they experience high mortality rates and significant

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economic loss relative to their GDP [3]. At the local level, people with low socioeconomic status are likely to suffer from disasters [4,5]. The combined effects of climate change and disasters have exacerbated the current poverty issues and slowed down global efforts to eradicate poverty by 2030 [6]. Disasters can sometimes reverse years of social and economic growth, create political instability, and cause long-lasting damage to the environment [3]. Since the 1990s, many international conferences and global frameworks have focused on disaster risk reduction [7]. In 2015, the Sendai Framework for Disaster Risk Reduction (2015–2030) was adopted by UN member states [8]. This first major agreement of the post-2015 development agenda provides its member states with distinct actions to safeguard development gains from disaster risks.

Cambodia is one of the most disaster-prone countries in Asia. Approximately 86 % of the country lies within the Lower Mekong River Basin. According to the ASEAN Coordinating Center for Humanitarian Assistance on Disaster Management, Cambodia is the most vulnerable country to disaster and has the lowest capacity to cope with disasters among ASEAN countries [9]. Floods and drought are the primary natural hazards in this country. Other natural hazards include riverbank erosion, heavy storms, typhoons, and lightning strikes. The average annual cost of disasters in Cambodia was estimated to be $72.4 million or equivalent to 0.7 % of its GDP [10]. The Royal Government of Cambodia considers disaster management a key component of its social and economic planning [11]. Effective disaster management would strongly contribute to its poverty reduction drive.

Cambodia experiences recurrent floods because of its climate and geography. Flood is one of the main drivers that cause riverbank erosion along the Mekong River [12,13]. Human activities, such as sand extraction, may also contribute to riverbank erosion [14,15]. In this study, the term "riverbank erosion" specifically refers to lateral channel migration. This phenomenon frequently occurs along fluvial rivers, especially during and after the flood season. In contrast to flooding, riverbank erosion has a long-term effect on communities in Cambodia. Even though this disaster has a low mortality rate, it has seriously affected people's livelihoods, especially in the floodplain region, owing to the high cost of relocation and loss of valuable property and agricultural land. This effect has resulted in job losses and forced migration, thereby adding stress to people's financial resources and their ability to prepare for disasters. Given that the riverbank segments in rural areas are often left unprotected, rural communities may be at a high risk of riverbank erosion. People are left with no option but to adapt to this problem by utilizing available resources and coping strategies within their community.

The concept of vulnerability has become increasingly essential as a means to understand, measure, and evaluate the effects of disasters on people, although it remains a subject of debate and discussion [16]. The Sendai framework highlights the importance of understanding all aspects of disaster risk, including vulnerability, capacity, exposure of individuals and assets, hazard characteristics, and the environment [8]. This goal is a key priority for policies and practices in disaster risk reduction. A vulnerability assessment can help identify areas most vulnerable to a specific hazard and the particular indicators that mainly affect vulnerability [17]. In addition, the indicator values can help assess the effectiveness of policies or programs in reducing household or community vulnerability [18]. Studies on vulnerability to natural hazards and climate change have mainly depended on the concept of vulnerability from the Intergovernmental Panel on Climate Change (IPCC), which defines vulnerability as a function of exposure, sensitivity, and adaptive capacity [19]. Several methods have been developed for assessing vulnerability based on the context and level of analysis [20]. Indicator-based methods [21,22], expert-based approaches [23,24], participatory approaches [25,26], and GIS mapping [27,28] are commonly used in hazard vulnerability assessment. Researchers widely adopt index-based methods because they offer valuable tools for identifying and monitoring vulnerability across time and space [29].

Hahn et al. [22] developed a livelihood vulnerability index (LVI), which was built upon the sustainable livelihood approach (SLA). The SLA [30] acknowledges that the livelihood of rural communities depends on a range of assets, encompassing natural, physical, financial, social, and human resources. The SLA approach is valuable for assessing the ability of households to withstand shocks such as epidemics or civil conflict, but it only partly addresses the issues related to sensitivity and adaptive capacity to climate change [22]. Given the increasing complexity of household livelihood security due to climate change and disaster, a more comprehensive vulnerability assessment approach is needed. To overcome this limitation, the LVI incorporates climate and hazard exposure and considers household adaptation practices and sensitivity to provide a comprehensive evaluation of livelihood risks arising from climate change and disaster. The LVI uses a set of indicators that aggregate into seven major components, namely, natural disasters and climate variability, sociodemographic profile, livelihood strategies, social networks, health, food, and water. It can be calculated as a composite of these seven major components. The major components used in the LVI can be categorized into exposure, sensitivity, and adaptive capacity, aligning with the IPCC vulnerability concept. The resulting overall LVI can be calculated and referred to as LVI framed within the IPCC vulnerability framework (LVI-IPCC). The LVI-IPCC, calculated by the multiplication form of equation [LVI-IPCC = (Exposure Index − Adaptive Capacity Index) × Sensitivity Index], has been applied in several studies [18,31–36] for assessing livelihood vulnerabilities to riverbank erosion. It is a suitable tool for subcommunity- and community-scale analyses of climate vulnerability because it enables direct household surveys [37].

According to the literature, only a limited number of studies [38–43] have assessed the vulnerability of livelihoods to natural disasters and the corresponding human responses in Cambodia. This shortfall might be due to limited data availability, continuous time series data gaps, and a predominant focus on immediate disaster response rather than long-term vulnerability assessment. Moreover, most of these studies did not focus on riverbank erosion. Recent studies on vulnerability to riverbank erosion and coping strategies have mainly been concentrated in disaster-prone countries, such as Bangladesh and India [18,31–34,44–50]. Extending these studies to other regions, such as the Mekong, enables the acquisition of additional knowledge from local people with different cultural backgrounds in addressing riverbank erosion. For this reason, this study aims to assess the livelihood vulnerability of two communities along the Mekong River using LVI-IPCC and investigate the coping strategies practiced by the local people and authorities in both communes. The indicators and sub-components of LVI-IPCC, as outlined in Hahn et al. [22], have been adapted to align with the specific context and type of hazard being examined. Moreover, the aggregation method for the vulnerability index has been changed to an additive form.

This study provides insights into the vulnerability of people to riverbank erosion and identifies the aspects that lead to such vulnerability. Furthermore, it aids in comprehending the local people's perception of riverbank erosion, their coping strategies, and the factors that limit their coping capacity. Local knowledge is valuable and can be integrated with scientific knowledge to mitigate disaster risk. This study outlines the challenges associated with managing riverbank erosion and provides recommendations for the further development of risk management and policies related to riverbank erosion. The current study is part of a research project that aims to identify riverbank erosion hotspots, investigate the drivers of riverbank erosion through numerical modeling and local knowledge, assess livelihood vulnerability, and explore local coping strategies along the Mekong River in Cambodia. The study area in this research encompasses two communes, namely, Kaoh Soutin (KS) and Ruessei Srok (RS), which are selected based on the riverbank erosion hotspot map developed by Tha et al. [12] using satellite images and remote sensing techniques. Interviews conducted with community members and authorities have confirmed that riverbank erosion is a critical issue that must be addressed in these areas.

2. Study sites

This study focuses on two communes, namely, KS and RS, which are located along the Mekong River in Kampong Cham Province (Fig. 1). These communes were selected owing to their high riverbank erosion rate and high exposure to this hazard. In comparison with those in other rural communities, the roads, schools, and other key infrastructure in both communes are under greater threat of riverbank erosion. As reported by Tha et al. [12], these two communes experienced more than 1 km of lateral erosion between the years 1990 and 2020. KS and RS are located at the river bend, and the river segment in both communes has undergone remarkable morphological changes. Flood is a common natural hazard in these two communes during the rainy season, particularly from August to October, due to the overflow of the Mekong River. Floods have also been regarded as major drivers of riverbank erosion in KS and RS.

2.1. Kaoh Soutin commune

The KS commune covers an area of 2586 ha and has a population of 11,800, distributed among 2759 families [51]. Most families in KS have been residing in the area since before the Khmer Rouge Regime. They fled from their community during the Khmer Rouge Regime in 1976 and returned when the regime ended in early 1979. Approximately 61 % of the population in KS are farmers. However, according to local people, agriculture has not been able to ensure a stable income for their families in recent years, especially from small-scale farming. This instance is attributed to high production costs, lack of water access, and fluctuating or decreasing prices of agricultural products. Furthermore, disasters, specifically those resulting from riverbank erosion, have placed significant strain on many families due to the reduction or complete loss of farmland and the expenses associated with relocation. In KS, the worst riverbank erosion incident occurred in the year 2000 when the area was hit by two floods during the rainy season. In that year, the entire village of Ti Prampi was relocated to a safer area. The year 2018 marked another period of severe riverbank erosion, which led to the

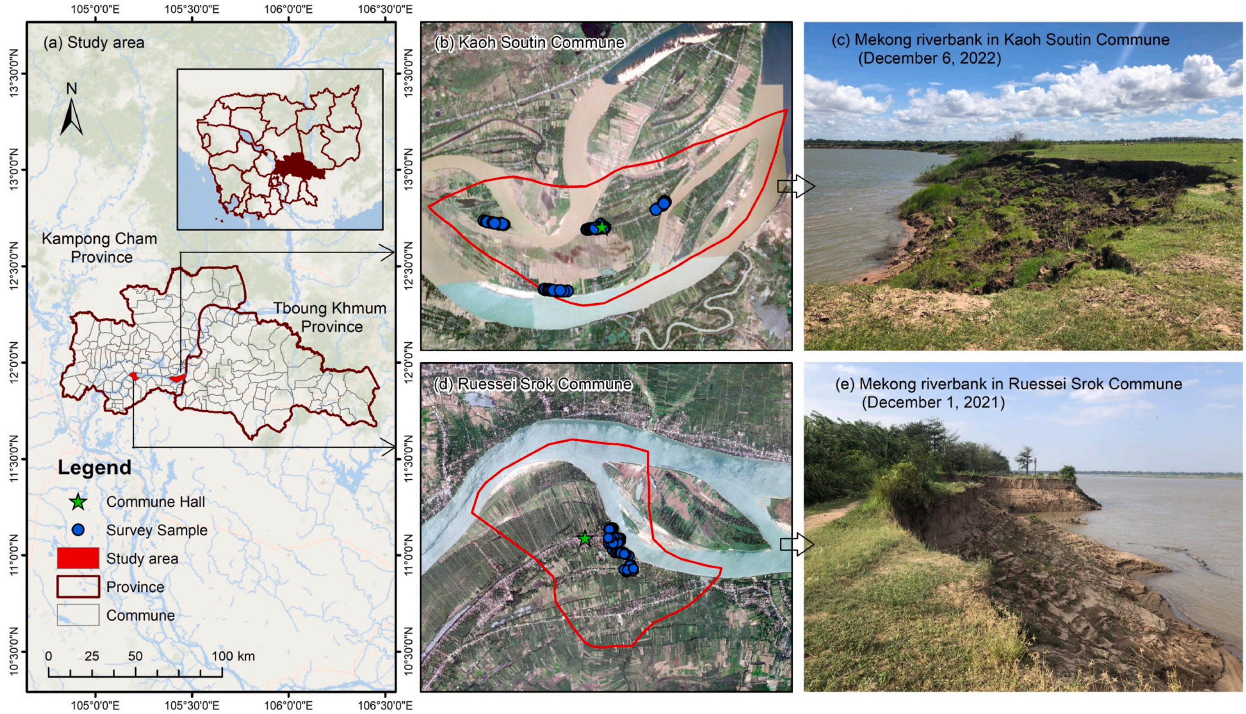

Fig. 1. Map of selected communes for case studies on vulnerability assessment and community coping strategies.

relocation of many families in the Ti Prammuoy Village. Given the unstable income from agriculture and the effect of riverbank erosion, people are transitioning towards non-agricultural occupations within or outside their community. Young adults are seeking employment in factories, private companies, businesses, and the public sectors with some people migrating to cities or even other countries in pursuit of job opportunities. The survey findings indicate that most of the people who continue to reside in the community are elderly adults involved in agriculture, livestock farming, and child-rearing. These individuals are highly vulnerable to riverbank erosion given their limited capacity to cope with this type of disaster.

2.2. *Ruessei Srok commune*

The RS commune covers an area of 1624 ha and has a population of approximately 7500, distributed among 1352 families [51]. The families residing along the Mekong River in RS comprise a mix of RS residents and those who migrated from the nearby Kaoh Toch village due to severe riverbank erosion. RS shares a similar demographic profile to KS, and its residents have the same way of living. However, RS has a more concentrated population than KS, where villages are spread far apart. Approximately 79 % of the population are farmers. People cultivate various crops and raise livestock. In RS, people experienced the worst riverbank erosion in 2011. The unexpected rate of riverbank erosion poses a substantial threat to the livelihoods of the residents in RS. In addition, riverbank erosion and deposition have led to conflicts between those who lose and gain land due to this natural process. The head of the RS commune reported that such conflict has arisen between RS residents who have lost their land and another community in Kong Meas District that has gained more land through deposition. Additional demographic data on both communes can be accessed from the Commune Database Online, as published by NCDD [51].

3. Methodology

3.1. *Data collection*

The livelihood vulnerability assessment utilized quantitative data obtained through household-level questionnaire surveys, spatial analysis using satellite images, and existing sociodemographic data from the commune database of Cambodia. The questionnaire surveys were conducted by the author and four enumerators in the KS and RS communes during 2022. Prior to data collection, the enumerators underwent briefings on the research purpose, data collection process, research ethics, and questionnaire content. During data collection, the researchers assisted the respondents in reading and answering the questionnaire items (Tables S1 and S2). Household heads residing in areas prone to riverbank erosion were randomly selected as respondents and informed about the research objective before providing their verbal consent.

The coping strategies employed by the local community were analyzed using qualitative data gathered during the fieldwork in 2022. Semi-structured interviews were conducted with affected households and the head of the communes. A semi-structured interview involves collecting data by asking questions based on predetermined themes while allowing researchers to explore relevant ideas that may arise during the interview process [52]. The household head or a member with a good understanding of the riverbank erosion hazard, regardless of age and gender, was interviewed. The interviews covered demographic and household information, loss of property, perception of riverbank erosion, coping strategies, factors limiting their coping capacity, living conditions, and government support (Table S3). The interview with the commune head focused mainly on community-support activities, government interventions, and challenges related to riverbank erosion risk management (Table S4). The snowball sampling method was used to select interviewees, starting with the individuals affected by the problem, as suggested by the head of each commune. A total of 20 interviews were conducted with hazard-affected people, and two interviews were performed with the community heads. Each interview lasted approximately 30 min. The interviews were recorded and transcribed in Khmer and subsequently translated into English. The NVivo program developed by QSR International [53] was used to organize and analyze the data.

3.2. *Sample size design*

The sample size for the questionnaire survey in each commune was calculated based on the methods of Cochran [54] and Israel [55] with respect to (i) population size, (ii) the proportion for the different variables of investigation ($p = 0.5$), and (iii) a 10 % margin of error at a 95 % confidence level.

The sample size for a large population size is computed as follows:

$$n_0 = \frac{z^2 pq}{e^2} \tag{1}$$

where n_0 is the sample size, z is measured in terms of standard deviation from the mean (determined using the statistical table), e is the desired level of precision, p is the estimated proportion of an attribute present in the population, and q is $1 - p$.

In a small population, the sample can be reduced using the following equation:

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}} \tag{2}$$

where n is the adjusted sample size, and N is the population size.

The estimated sample sizes for the questionnaire survey for KS and RS were 93 and 90 households, respectively. The actual samples collected from the survey were 94 households for KS and 100 households for RS.

3.3. Vulnerability assessment

3.3.1. IPCC vulnerability framework

In accordance with the fourth assessment report of the IPCC [19], the term vulnerability is defined as "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes." The IPCC concept defines vulnerability as a function of exposure, sensitivity, and adaptive capacity. Exposure pertains to the extent to which a specific system or community is exposed to a particular hazard [56,57]. Hazard exposure can be measured by considering the presence of people and economic assets, and the intensity of the hazard, which includes factors, such as frequency, magnitude, duration, and spatial extent of the hazard. Sensitivity reflects the degree to which a system is affected by hazard exposure [19,56,57]. The sensitivity

Table 1
Selected indicators for vulnerability assessment.

Vulnerability components	Subcomponents	Indicators	Unit	Functional relationship
Exposure	Severity of riverbank erosion hazard	Total eroded area (1990–2020)	ha	Exposure ↑ as eroded area ↑
		Average annual lateral erosion rate (1990–2020)	m	Exposure ↑ as erosion rate ↑
	Human exposure	HHs affected by riverbank erosion in the past	%	Exposure ↑ as affected HH ↑
		HHs experienced displacement	%	Exposure ↑ as displacement ↑
		HHs whose member(s) were injured/died due to riverbank erosion	%	Exposure ↑ as injury/death ↑
	Land/structure exposure	HHs experienced land loss due to riverbank erosion	%	Exposure ↑ as land loss ↑
		Housing units built in the area prone to riverbank erosion	%	Exposure ↑ as the housing unit ↑
		Length of road in the area prone to riverbank erosion	m	Exposure ↑ as road length at risk ↑
Sensitivity	Health sensitivity	HHs reported at least one chronically ill member	%	Sensitivity ↑ as illness ↑
		HHs reported at least one member with a mental/physical disability	%	Sensitivity ↑ as disability ↑
		The average distance to the nearest health center/hospital	m	Sensitivity ↑ as distance to the health center ↑
		HHs not having toilet	%	Sensitivity ↑ as the number of toilets ↓
		HHs with no access to clean drinking water	%	Sensitivity ↑ as access to clean water ↓
		HHs that could not afford health care	%	Sensitivity ↑ as affordable healthcare ↓
		HHs that do not have insurance	%	Sensitivity ↑ as owning insurance ↓
	Food and agriculture sensitivity	HHs experiencing insufficient food	%	Sensitivity ↑ as insufficient food ↑
		HHs experiencing a decrease in food production	%	Sensitivity ↑ as the decrease in production ↑
		HHs growing a single crop (among farmers)	%	Sensitivity ↑ as dependence on a single crop ↑
		HHs not raising livestock	%	Sensitivity ↑ as raising livestock ↓
	Demographic sensitivity	HHs with more members <15 years plus >65 years (dependency ratio)	%	Sensitivity ↑ as the dependency ratio ↑
		Female-headed HHs	%	Sensitivity ↑ as female-headed HHs ↑
Adaptive capacity	Economic status	HHs dependent solely on agriculture as an income source	%	Adaptive capacity ↑ as the dependency ↓
		HHs with a loan burden	%	Adaptive capacity ↑ as the burden of loan ↓
		HHs with an income of 10,000 KHR or less per working person	%	Adaptive capacity ↑ as poverty ↓
		HHs experiencing joblessness during riverbank erosion	%	Adaptive capacity ↑ as unemployment ↓
	Social network and communication	HHs who have received support from neighbors/relatives during the riverbank erosion	%	Adaptive capacity ↑ as receiving support ↑
		HHs who provided help to others	%	Adaptive capacity ↑ as providing support ↑
		HHs where a family member is affiliated with an organization	%	Adaptive capacity ↑ as affiliation ↑
		HHs who have received a warning about riverbank erosion	%	Adaptive capacity ↑ as access to warning ↑
		HHs with communicative devices (TV, radio, mobile phone) at home	%	Adaptive capacity ↑ as a communication mean ↑
	Education and skill	HHs head with an education (literacy rate)	%	Adaptive capacity ↑ as literacy rate ↑
		HHs with members having any formal or informal skill	%	Adaptive capacity ↑ as the skill ↑

of a community may be influenced by demographic, social, economic, cultural, and environmental factors. Adaptive capacity refers to the ability of a system to absorb the effects of potential hazards and to prepare for and recover from them [58]. Adaptive capacity can be influenced by financial resources, knowledge, awareness, institutions, and governance.

3.3.2. Vulnerability assessment indicators

A total of 32 indicators correspond to each component and subcomponent of vulnerability. Notably, some indicators are closely connected and may influence one another. Quantitative indicators play an important role in enhancing efforts to understand and reduce disaster vulnerability, despite potential design and contextual limitations [17]. Table 1 shows the indicators selected based on previous vulnerability studies [18,32,34] and the newly defined indicators suitable for riverbank erosion hazards. These indicators were categorized into nine sub-components of vulnerability. These sub-components were further grouped into vulnerability components including exposure, sensitivity, and adaptive capacity.

3.3.3. LVI-IPCC

No single best method exists for assessing vulnerability. This study uses the LVI-IPCC, which was developed by Hahn et al. [22]. The LVI-IPCC has recently been used in several studies [18,31–36] to assess the vulnerability of livelihoods to riverbank erosion.

To calculate the LVI-IPCC, the initial step involves normalizing all indicator values to a common scale. For binary indicators with two possible responses (“yes” or “no”), a value of 0 was assigned to “no,” and a value of 1 to “yes.” For continuous indicators, the values were normalized to a range of [0,1], with specific minimum and maximum values determined based on each indicator. The normalized values can be calculated using the following equation:

$$Index\ X_{ij} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \tag{3}$$

where X_{ij} is the value of indicator i for sample j; and X_{min} and X_{max} are the minimum and maximum values of indicator i, respectively.

Secondly, the mean value of each indicator from all samples was calculated as follows:

$$XA_i = \frac{\sum_{j=1}^{n} Index\ \mathrm{X}_{ij}}{n} \tag{4}$$

where XA_i is the mean standardized value for indicator i, and n is the sample size. For sensitive questions, specifically those related to health and income, respondents can opt not to answer. In such cases, the mean value is calculated in relation to the sample of respondents who have answered the question. In this survey, all respondents answered sensitive questions related to health, and most of them answered questions related to income and the burden of loans. Thirdly, the value of each subcomponent of vulnerability was calculated as follows:

$$M_k = \frac{\sum_{i=1}^{n} W_{XA_i} XA_i}{\sum_{i=1}^{n} W_{XA_i}} \tag{5}$$

where M_k is the subcomponent k, XA_i is the mean standardized value for indicator i, W_{XAi} is the weight of indicator i, and n is the number of indicators contributing to vulnerability subcomponent k. This study uses the equal-weight method, which assumes that each indicator contributes equally to vulnerability. The equal-weight method is simple and straightforward, and has been used in many studies [31–34] for the assessment of vulnerability to riverbank erosion. It also avoids subjective biases in weighting the indicator from personal judgment or expert opinion. However, this method may not reflect the actual importance of each indicator because some may be more critical than others. Therefore, the relevant indicators must be carefully selected based on the context of the study when using the equal-weight method to ensure that the results are meaningful.

Fourthly, the scores of each contributing vulnerability component, such as exposure, sensitivity, and adaptive capacity, were computed using the following equation:

$$\boldsymbol{EI} = \frac{\sum_{k=1}^{n} W_{M_k} M_k}{\sum_{k=1}^{n} W_{M_k}} \tag{6}$$

where EI is the exposure index, M_k is the subcomponent k that contributes to EI, W_{Mk} is the weight of subcomponent k, and n is the number of subcomponents that contribute to EI. Each subcomponent was also given an equal weight. Similarly, the sensitivity index (SI) and adaptive capacity index (AI) can be calculated in the same way by aggregating the corresponding subcomponents.

Finally, after computing the value of each contributing component of vulnerability (exposure, sensitivity, and adaptive capacity), the vulnerability index can be calculated as follows:

$$LVI\text{-}IPCC = EI + SI - AI \tag{7}$$

where *EI* is the exposure index, *SI* is the sensitivity index, and *AI* is the adaptability index. The additive form of the vulnerability index is used in this study. The vulnerability index calculated by the multiplication form of equation [LVI-IPCC = (EI – AI) × SI] is negative when the adaptive capacity index is higher than the exposure index. Moreover, an increased sensitivity would paradoxically result in a lower vulnerability score, thereby contradicting the expected relationship between sensitivity and vulnerability. In this study, the additive form was used to represent the degree of vulnerability based on the exposure, sensitivity, and adaptability of IPCC. The LVI-IPCC ranges from −1 to 2. The larger the LVI-IPCC, the higher the vulnerability of the commune.

The Chi-square (χ^2) test is employed to assess statistically the differences in each vulnerability indicator between the two communes, namely, KS and RS. The Chi-squared test is selected because the indicators collected during the survey are primarily categorical. This test is used to compare the distribution of categorical variables under the null hypothesis, which assumes that the mean of each indicator between the two communes shows no statistically significant difference using a significance level of 0.05. Each test has one degree of freedom, and the critical value for a significance level of 0.05 is 3.84, according to the Chi-square distribution table. If the calculated χ^2 value exceeds 3.84 or the P-value is less than 0.05, then the null hypothesis is rejected. This rejection indicates that the variables are dependent on the communes, suggesting a statistically significant difference between the two communes for these variables. Conversely, if the computed χ^2 value is less than or equal to 3.84 or if the P-value is greater than or equal to 0.05, then the null hypothesis is accepted. This acceptance suggests that no significant differences were observed in the variables between the two communes.

3.4. Perception of riverbank erosion and coping strategies

In this study, local people's experiences and perceptions of riverbank erosion and their coping strategies during the three phases of the disaster were analyzed using the qualitative method. The disaster responses from the local authority were also addressed. Qualitative data were collected through semi-structured interviews. The criteria for data sampling and the data collection process are detailed in Section 3.1. Thematic analysis, as outlined by Ref. [59], was used to interpret the data. Initially, interviews were recorded, transcribed in Khmer, and subsequently translated into English. The transcriptions were organized within the NVivo software developed by QSR International [53]. The relevant information from the responses to each question was then grouped systematically through coding, and the coded data were analyzed to identify different themes for addressing the research question.

The terms "coping strategies" and "coping mechanisms," which refer to short-term responses (usually taking the form of emergency responses) to disasters or situations that threaten livelihoods, have been used interchangeably [48,60]. While coping refers to "a feedback process that is directly linked to hazard impacts," adaptation is defined by "medium- and long-term adjustments and reorganization processes that correspond with the notion of change" [61]. With regard to spatial scale, coping strategies tend to emerge at a smaller scale (individual and household level). Adaptive strategies, on the contrary, link to factors such as cultural values, which slowly change and are more likely to emerge at larger spatial scales [60].

4. Results

4.1. Livelihood vulnerability assessment

The livelihood vulnerability assessment based on LVI-IPCC shows that KS is slightly more vulnerable to riverbank erosion than RS, as indicated by LVI-IPCC values of 0.49 and 0.46 for KS and RS, respectively. The LVI-IPCC ranges between −1 and 2. This result

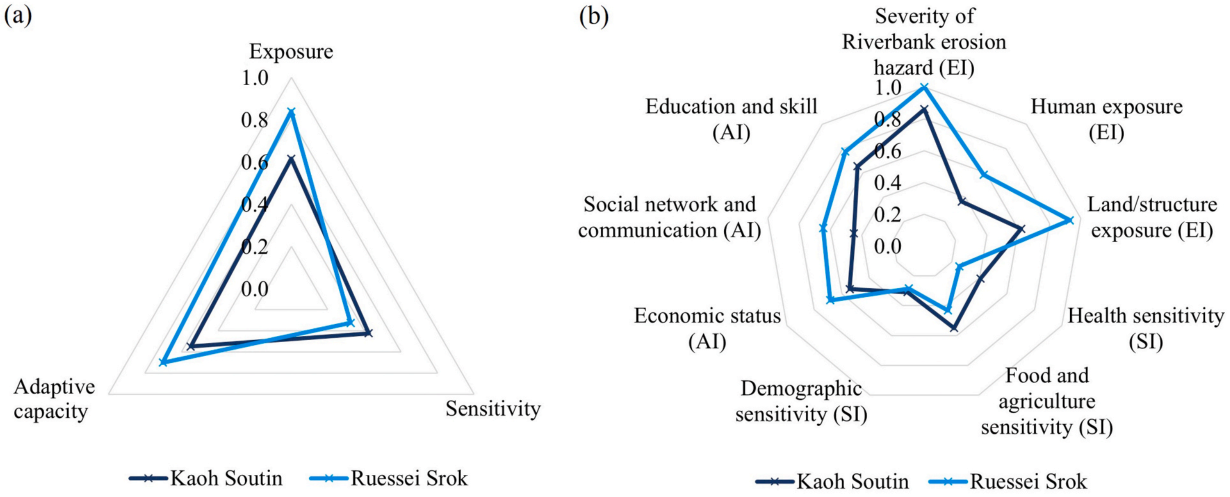

Fig. 2. Comparison of the scores of vulnerability (a) components and (b) subcomponents (ranging from 0 to 1) for both communes.

suggests that the communities are vulnerable to adverse effects, which could harm their livelihoods. RS exhibited high adaptive capacity and low sensitivity, but its exposure level was relatively high (Fig. 2a). Specifically, the exposure scores for KS and RS were 0.61 and 0.84, respectively, indicating that RS experiences a higher level of exposure to riverbank erosion than KS. Meanwhile, the sensitivity scores for KS and RS were 0.42 and 0.32, respectively, with the former being more sensitive to riverbank erosion than the latter. In terms of adaptability, KS had an adaptive capacity score of 0.55, whereas RS had a higher score of 0.70, indicating its greater ability to adapt to the challenges posed by riverbank erosion. Fig. 2b shows a detailed comparison of scores of vulnerability subcomponents. The hypothesis testing results of the difference in each applicable indicator mean between the two communities are summarized in Table 2.

In this study, exposure is composed of three main components: the severity of riverbank erosion, exposure of humans, and exposure of land and infrastructure. The scores for RS are higher than KS for all three exposure components (Fig. 2b). Respondents reported severe riverbank erosion incidents in KS during 2000 and 2018 and in RS during 2011. The estimated total eroded area between the years 1990 and 2020 was similar in both communes, with KS and RS experiencing 247 and 253 ha of erosion, respectively. However, the maximum average annual lateral erosion rate was significantly higher in RS (43 m/year) than in KS (32 m/year) [12]. According to the survey results in this study, a higher percentage of people residing along the Mekong River in RS (93 %) have been affected by riverbank erosion compared with KS (61 %). Moreover, the frequency of displacement (Fig. 3) and the land loss experienced by respondents (Table S5) in RS were also higher than those of KS. The differences between these indicators were statistically significant at the 95 % confidence interval (Table 2). Nonetheless, the number of people injured by the riverbank erosion was considerably small, with no significant differences exhibited between the two communes. In terms of risk to infrastructure, the number of housing units constructed in areas prone to riverbank erosion was higher in RS (435 units) than KS (266 units). These results suggest that RS is under a greater threat of riverbank erosion than KS. According to locals, floods, river flow direction, and deposition are the primary causes of riverbank erosion. They also mentioned the effects of waves caused by speed boats and wind, as well as poor soil strength and sand mining, but to a lesser extent. Riverbank erosion may affect a smaller population compared to floods and droughts. However, it causes extensive damage to individuals. Moreover, recovering from the effects of riverbank erosion is challenging, and the losses incurred are often irreversible.

Despite its greater exposure, RS exhibits less sensitivity to riverbank erosion compared with KS, particularly when considering health, food and agriculture, and demographic sensitivity. Among health indicators, access to clean drinking water and the ability to afford healthcare are statistically different between the two communes. More households in KS (29 %) cannot afford healthcare compared with RS (7 %). Moreover, almost all households in KS do not have access to clean drinking water. People in KS have recently been using water that is directly distributed from the river. RS is also less sensitive than KS to food and agriculture production. Approximately 53 % and 39 % of households in KS and RS experience food shortages, respectively. These food shortages consistently occur during the flood season, which falls between August and October and before harvesting. The survey findings show that fewer

Table 2

Chi-square independent test for vulnerability indicators between the two communes.

Indicators	KS n (%)	RS n (%)	χ^2	P-value
HHs affected by riverbank erosion in the past	57 (61 %)	93 (93 %)	28.94	0.000*
HHs experienced displacement	45 (48 %)	81 (81 %)	23.36	0.000*
HHs whose member(s) were injured/died due to riverbank erosion	1 (1 %)	1 (1 %)	0.00	0.964
HHs experienced land loss due to riverbank erosion	42 (45 %)	79 (79 %)	24.32	0.000*
HHs reported at least one chronically ill member	30 (32 %)	31 (31 %)	0.02	0.887
HHs reported at least one member with a metal/physical disability	6 (6 %)	11 (11 %)	1.29	0.256
HHs not having toilet	12 (13 %)	12 (12 %)	0.03	0.862
HHs with no access to clean drinking water	92 (98 %)	9 (9 %)	153.34	0.000*
HHs that could not afford health care	27 (29 %)	7 (7 %)	15.82	0.000*
HHs that do not have insurance	91 (97 %)	99 (99 %)	1.15	0.283
HHs experiencing insufficient food	50 (53 %)	39 (39 %)	3.93	0.047*
HHs experiencing a decrease in food production	44 (47 %)	17 (17 %)	19.97	0.000*
HHs growing a single crop (among farmers)	35 (73 %)	22 (71 %)	0.04	0.841
HHs not raising livestock	44 (47 %)	46 (46 %)	0.01	0.920
HHs with more members <15 years old plus >65 years old	23 (26 %)	30 (33 %)	1.10	0.294
Female-headed HHs	34 (36 %)	24 (24 %)	3.42	0.064
HHs dependent solely on agriculture as an income source	54 (57 %)	71 (71 %)	3.88	0.048*
HHs with a loan burden	17 (18 %)	18 (18 %)	0.0002	0.988
HHs with an income of 10,000 KHR or less per working person	18 (26 %)	8 (13 %)	3.40	0.065
HHs experienced joblessness during riverbank erosion	76 (81 %)	24 (24 %)	62.70	0.000*
HHs who have received support from neighbors/relatives	30 (32 %)	69 (69 %)	26.67	0.000*
HHs who provided help to others	48 (51 %)	82 (82 %)	20.98	0.000*
HHs where a family member is affiliated with an organization	14 (15 %)	27 (27 %)	4.26	0.039*
HHs who have received a warning about riverbank erosion	30 (32 %)	46 (46 %)	4.03	0.044*
HHs with communicative devices at home	90 (96 %)	99 (99 %)	2.04	0.153
HHs head with an education (literacy rate)	88 (94 %)	96 (96 %)	0.56	0.454
HHs with members having any formal or informal skills	35 (37 %)	59 (59 %)	9.19	0.002*

* Groups are significantly different ($P < 0.05$).

The degree of freedom for each test is 1.

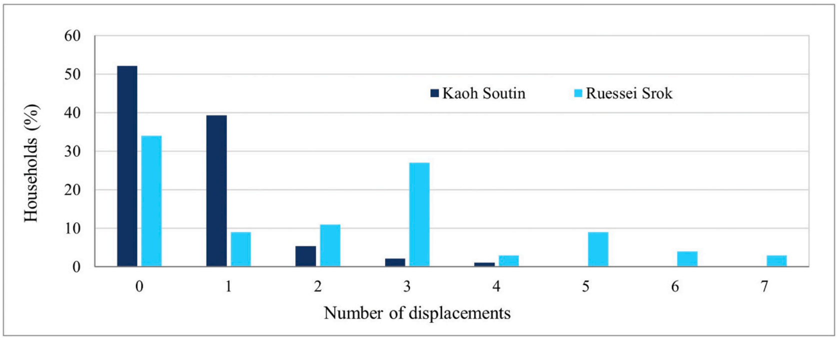

Fig. 3. Displacement frequency of people living in areas prone to riverbank erosion.

households in RS (17 %) reported a decrease in food production in recent years, as opposed to 47 % in KS. Other indicators of food and agriculture sensitivity show no significant differences between both communes. Additionally, KS and RS share similar demographic characteristics in terms of dependency ratio and female-headed households. Approximately, 26 % and 33 % of households in KS and RS, respectively, have a higher number of nonworking members than working ones. Additionally, the proportion of female-headed households in KS and RS stands at 36 % and 24 %, respectively.

RS demonstrates a higher adaptive capacity than KS in dealing with riverbank erosion. The survey shows that the number of households who solely depend on agriculture as their primary income source is significantly higher in RS (71 %) than KS (57 %). However, riverbank erosion has resulted in joblessness for a significantly higher proportion of households in KS (81 %) than RS (24 %), thereby highlighting the greater economic vulnerability of households in KS to this issue. Households in RS have stronger social networks and communication than those in KS and are more likely to receive support from their community during times of crisis. Based on experience, up to 69 % of disaster-affected households in RS received support from their neighbors and relatives in the form of food, workforce, finance, and temporary shelter. By comparison, only approximately 32 % of households in KS received support during these hard times. The survey results indicate a high level of literacy among respondents in both communes (over 90 %). Literacy equips individuals with the ability to access additional information on disasters, which in turn helps them prepare for such events efficiently. In terms of working skills, more households in RS (59 %) reported that household members have skills other than agriculture compared with those in KS (37 %).

4.2. *Community coping strategies*

According to the interviews, local people in KS and RS have similar strategies for coping with riverbank erosion. When riverbank erosion occurs, affected households commonly sustain their livelihoods by reducing their expenses and food consumption, exploring additional income sources, and seeking support from their relatives and neighbors. Local people in KS and RS have considerable experience with riverbank erosion and understand the risk of this hazard. Consequently, injuries and fatalities from riverbank erosion are infrequent, and the likelihood of a house collapsing into the river is low. Fig. 4 summarizes the coping strategies used by the

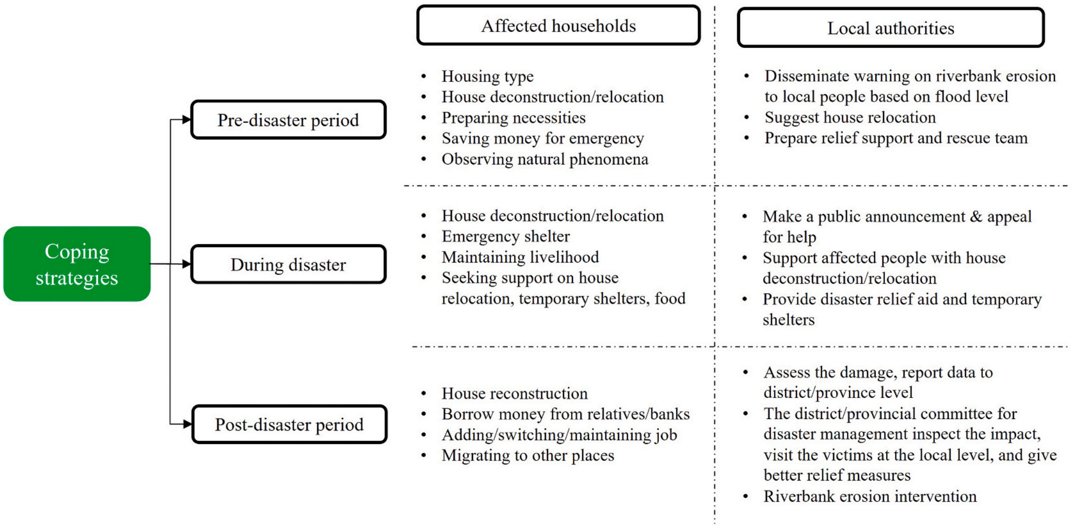

Fig. 4. Coping strategies employed by the communities of KS and RS.

affected households and the support they received from the local authorities in both communities. Further details are provided in the next sections.

4.2.1. Pre-disaster period

Typically, people prepare for riverbank erosion before the flood season. Families with good financial and physical resources can better prepare for riverbank erosion. However, some people may choose not to prepare for or respond to early risk warnings, not necessarily because of ignorance about the risk of riverbank erosion but rather because they are constrained by the available options for taking action. These limitations must be recognized and anticipated in disaster prevention and risk mitigation plans [62]. The following are ways in which people prepare for flood and riverbank erosion hazards:

- **Food and necessities:** Living with floods is considered a tradition for riparian communities. Prior to the three-month flood season, people prepare food, medicine, coal, boats for traveling, and other materials for daily needs.
- **House design:** In KS and RS, wooden stilt houses are the most common housing type because they can protect people from flooding. Moreover, wooden houses can be deconstructed and rebuilt in another place.
- **House relocation:** Households with enough resources can purchase land and relocate their house early, usually when it is between 50 and 100 m away from the riverbank. Meanwhile, low-income families remain near the riverbank until it comes remarkably close to their houses. Some respondents reported saving money for several years just for relocation.
- **Observation of riverbank and natural phenomena:** During flooding, people observe the presence of trees to locate the riverbank. Locals predict riverbank erosion by observing the bubbles and whirlpools in the river, cracks in the riverbank, flood level, and wind direction. The riverbank is likely to collapse in no more than a day if a bubble appears. If a whirlpool appears, then the riverbank could collapse after a day or two.

4.2.2. During disaster

Riverbank erosion mainly occurs during the flood season, spanning from August to October. Notably, the riverbank could collapse anytime during this period. The following practices indicate how people stay safe and deal with riverbank erosion and its effects during the flood season:

- **House relocation:** If the riverbank comes extremely close to their house, people will start moving immediately and collect whatever belongings they can. However, if they believe that their house will not collapse, they tend to wait until the flood season passes and relocate later. Sometimes, people begin moving their belongings to a safe place and leave their houses empty to minimize loss if they cannot relocate them in time. In KS, local people use boats to move their entire house without the need to deconstruct it first.
- **Emergency shelter:** Some displaced people request a temporary stay at a relative's house. Some of them build a temporary shelter in a safe place by using available wooden boards, tarps, or zinc roofing sheets. Those who do not own any land may ask for permission to build a temporary shelter on someone else's land.
- **Maintaining livelihood:** People reduce their expenses and food consumption to maintain their livelihoods during riverbank erosion. Moreover, affected family members do extra work to earn money to support their families. Some people borrow money from their relatives, neighbors, or banks to address their urgent needs.
- **Community support:** During an emergency, people ask for help with house relocation from their neighbors and local authorities. Some families also receive food, materials, and money for disaster relief.

4.2.3. Post-disaster period

People begin reconstructing their houses when the flood season ends, and the riverbank erosion situation improves. The reconstruction of their houses could take around two months. However, those lacking financial resources need more time to earn money to reconstruct their houses and rebuild the lost parts. It could take them years to rebuild their houses. In some cases, individuals resort to borrowing money from others or banks to fund their house reconstruction. After experiencing riverbank erosion, people who still have farmland continue with their agricultural activities or opt to sell their land. However, those who lost all their farmland need to seek alternative jobs or work for others. Some people lose their jobs and income entirely, causing them to depend on their family members who live and work outside the community. Most of the victims do not have concrete plans for dealing with riverbank erosion in the future. They could merely focus on solving the challenges at hand. Some individuals, especially elderly adults, may move to live with their children and be entirely dependent on them if they have to move again due to riverbank erosion.

4.2.4. Coping capacity and influencing factors

The ability to cope with natural hazards is increasingly recognized as a key component of vulnerability at the household or community level [63]. This study implies that coping with riverbank erosion is becoming more challenging with each passing year. As the riverbank continues to erode, people lose their agricultural land, which constitutes their primary income source. Moreover, house relocation costs a significant amount of money, thereby dragging people into poverty. In addition to dealing with riverbank erosion, the COVID-19 pandemic has severely affected people's livelihoods, not only in urban areas but also rural areas.

During the interviews with local people, four influencing factors of coping capacity, including financial and physical resources, social networks, health conditions, and awareness of riverbank erosion have been discussed. Most respondents regarded financial and physical resources as the most important factors in shaping their ability to cope with riverbank erosion.

Respondents may not perceive social networks as a significant factor in coping with riverbank erosion; however, these networks play a crucial role in enhancing coping capacity, particularly for low-income households. Unfortunately, the strength of relationships between families in these communities has loosened compared to the situation in the past. During the interviews, most participants mentioned that they now mainly depend on their own resources and are obliged to spend money, particularly for deconstructing and reconstructing their houses, unlike in the past when they received aid from neighbors without any financial responsibilities. Moreover, some people attempted to manage their response to the disaster individually out of a sense of indebtedness to others.

Health issues have also restricted the participants' coping capacity, especially for families with elderly members and older adults who rely on themselves to earn a living. Older adults may face physical limitations and have fewer income-generating options. They mainly depend on support from family members, and without this support, they can hardly deal with riverbank erosion.

Although knowledge of riverbank erosion is important, it is not the main challenge faced by local people. In many cases, they are already aware of the possibility of riverbank erosion even before receiving a warning from the local authority because they reside in close proximity to the disaster-prone area. Based on their observations, they can be cautious about incidents caused by riverbank erosion.

4.3. Disaster management and the responses from local authorities

The Government of Cambodia has exerted great efforts in disaster risk reduction by establishing the National Committee for Disaster Management (NCDM), which includes disaster management teams at all administrative levels. Moreover, Cambodia endorsed the Disaster Management Law in 2015, which serves to delineate the roles, responsibilities, and structure of NCDM, enhancing its capacity to manage disaster risk management effectively [42,64]. Cambodia has also entered into binding and nonbinding international and regional agreements on disaster risk reduction. However, implementing disaster risk reduction policies remains challenging due to the constraints related to the limited and unclear government budget. According to the World Bank [65], the general contingency budget of Cambodia is approximately US$115 million, with less than 10 % of this budget is used annually for disaster management. Notably, disaster risk management in Cambodia has focused more on emergency and post-disaster responses and less on investment in disaster risk reduction projects.

At the local level, the Commune Committee for Disaster Management (CCDM) is responsible for developing plans, carrying out disaster risk reduction and emergency preparedness and response activities, implementing disaster management policies and strategies, and coordinating disaster risk management and emergency responses between the District Committee for Disaster Management and the Village Disaster Management Group (VDMG) [42,66]. The main responsibilities of the VDMG are to strengthen disaster preparedness and response procedures by disseminating disaster information and warnings of forthcoming threats among local people and helping to evacuate them and their livestock during an emergency [66].

4.3.1. Riverbank erosion management in KS and RS

In KS and RS, CCDM and VDMG members work on a voluntary basis, with disaster management responsibilities integrated into their existing roles. Prior to the occurrence of riverbank erosion, warnings are issued based on the water level of the Mekong River as the primary indicator. Currently, water level information is disseminated to stakeholders by the Ministry of Water Resources and Meteorology and the Mekong River Commission. Local authorities are responsible for sharing this information with their constituents to ensure preparedness for flooding and riverbank erosion. Before the flood season, local authorities (commune and village levels), under the guidance of district and provincial disaster management committees, visit and inform people about the risk of riverbank erosion. They make recommendations concerning which residents should relocate their houses before the disaster. Additionally, they prepare relief support and organize the team in advance to support people during a disaster.

In the event of riverbank erosion, immediate responses are initiated by frontline actors, such as local authorities, local police, and volunteer groups. Their main goal is to assist the affected people with house deconstruction and relocation and evacuate them to safe areas. Moreover, disaster relief aid, such as necessities, including food, water, medicine, and tarps for temporary shelters, are provided. Other actors, such as monks, NGOs, and charitable individuals, also offer support. If the situation is difficult and urgent, then the local authority makes a public announcement to ask everyone in the community to help the affected people.

Once the emergency response and safety of all people are assured, the CCDM assesses the damage, reports data to the district/province committee, and requests aid and the necessary intervention. The district and provincial committees for disaster management will then access the affected communities to inspect the impact, visit the victims at the local level, and implement appropriate relief measures. So far, both communes have received various interventions from the government and charitable individuals. In KS, riverbank protection has not yet been considered. Nevertheless, some affected families received residential land in a safe place from charitable individuals and land from the pagoda abbot. The problem is that not all families benefited from these interventions. In RS, a government intervention has recently been implemented, involving the protection of the riverbank with sandbags because riverbank erosion poses a threat to key infrastructure. Even though the riverbank protection project is not fully completed as planned, it has temporarily stopped riverbank migration in some parts of the commune.

4.3.2. Riverbank erosion management challenges

Local disaster management in KS and RS faces several challenges. Firstly, some communes, such as KS, are geographically large, with villages located far apart, making it challenging to mobilize support to the affected people on time, especially during flood events. Secondly, the budget allocated for disaster risk reduction activities is insufficient, with the focus being mainly on emergency relief rather than long-term risk reduction measures. Thirdly, recent disaster risk reduction programs have primarily been government led, with the limited involvement of non-governmental agencies, especially in rural areas such as RS, owing to difficulties in accessing the area. Access to other funding sources is also limited, posing further challenges to effective disaster risk reduction efforts at the local level. These challenges highlight the need for improved resources, coordination, and support for local disaster management efforts in KS and RS to address the identified issues and effectively enhance community resilience to disasters.

5. Discussion

5.1. Livelihood vulnerability

This study aims to assess the livelihood vulnerability to riverbank erosion in KS and RS and determine the coping strategies employed by local people. KS and RS are vulnerable to riverbank erosion, with KS having a slightly higher LVI-IPCC value than RS. Despite their similar LVI-IPCC scores, the vulnerabilities in these communes stem from the remarkable differences in vulnerability components. In KS, vulnerability primarily results from high sensitivity and low adaptive capacity, whereas in RS, it is primarily attributed to high exposure. When examining the subcomponents of vulnerability in this case study, the primary factors that contribute to the IPCC vulnerability components of both communes are the high intensity of riverbank erosion for exposure, food and agriculture for sensitivity, and poor social network and communication for adaptive capacity. Previous studies on the vulnerability of riparian communities to riverbank erosion using LVI-IPCC identified several key drivers of vulnerability. Most studies [18,31,33–35] have suggested that the main influencing components of vulnerability include limited access to food, water, and healthcare. Some studies also found that livelihood strategies [33,34] and weak social networking [33,35,36] were crucial contributors to vulnerability. In the Mekong Region, Tri et al. [36] emphasized that beyond income and financial accessibility, factors, such as support from neighbors, substantially influenced the vulnerability and adaptive capacity of households in riparian communities in Vietnam. The study also underscored the importance of social networks in reducing vulnerability. The findings of this current study align with previous research on other regions and within the Mekong Region, emphasizing the importance of factors such as food access and social networks as primary drivers of vulnerability.

5.2. Coping strategies

The embeddedness of local people in their community has enabled them to generate well-grounded knowledge and practices to mitigate, prepare for, respond to, and recover from the effects of disaster [67]. Local knowledge has been recognized as an important element in disaster risk reduction [68]. Rahman and Gain [48] found that most affected people in Chromukha, Dakshin Bedkashi, and Ghorilal villages, Koyra Upazila, Khulna District, Bangladesh, adjusted to riverbank erosion by reducing their meal portions. However, Barua et al. [44] showed that the most practiced coping strategy employed by communities in the Banshkhali and Rangunia upazilas, Chittagong District, Bangladesh, was searching for social support, followed by decreasing meals. According to Rahman et al. [49], engaging in part-time work was the most effective coping strategy for riverbank erosion in the Kazipur Upazila of Sirajganj District, Bangladesh. The authors also noted that the possession of physical and financial resources was the most effective means of coping with riverbank erosion. Another study by Naher and Soron [47] in the Philipnagar and Maricha villages, Daulatpur Upazila, Kushtia District, Bangladesh suggested that maintaining pre-existing social networks may serve as a key resource of resilience in adapting to adverse events. Hutton and Haque [46] implied that displaced people in the Serajganj and Bogra districts of Bangladesh had adapted to the risk of riverbank erosion and did not perceive it as an immediate threat to their livelihoods. Similarly, Tri et al. [36] identified that riparian communities in Vietnam possessed an inherent capacity to cope with riverbank erosion. In KS and RS, people have managed to sustain their livelihoods by cutting down on expenses, limiting food consumption, seeking additional income opportunities, and reaching out to relatives and neighbors for help, especially with house relocation.

Local people in KS and RS have long been experiencing the effects of riverbank erosion and have been using available resources and techniques to cope with this disaster. They survive during difficult times; however, the recurrent riverbank erosion has caused severe damage to farmland and infrastructure and reduced people's income, thereby gradually decreasing their adaptive capacity. As a result, many people have left their communities in search of employment opportunities or new places to settle. Resettlement and migration due to riverbank erosion are also concerning issues in other communities in the Mekong Region [36]. Local authorities and the government have played an important role in supporting the affected people to cope with riverbank erosion, but most support is in terms of emergency relief. Interventions, including the provision of land for relocation and the protection of riverbanks with sandbags, are also being implemented. However, further actions must be taken to help people respond effectively to this hazard in the short and long term.

5.3. Recommendations

Improving the capacity of local people and authorities to cope with disasters is crucial, given that they are often the first to respond on the ground. Several recommendations are proposed based on the vulnerability assessment in this study for the short, medium, and long term for the two communes, local authorities, and the central government to enhance the management of risk from riverbank erosion at the local level. In the short term, households in areas at high risk of riverbank collapse are recommended to proactively prepare for future erosion and consider relocation despite the occurrence of low erosion in recent years. Local authorities should identify vulnerable populations within the community and address their specific needs during disastrous events, providing support for proactive relocation efforts, especially for low-income families. The central government should support the priority needs of local government and local people, facilitate collaboration among local governments, research institutions, and experts to develop mitigation strategies and ensure that local authorities have enough resources for mobilizing support during a disaster in the flood season. For example, local authorities in KS need boats.

In the medium term, it is crucial that local people diversify their income sources to reduce their reliance on agriculture. Local authorities should provide more job opportunities, and local people should be encouraged to learn new skills, enhance their social networks in KS, and maintain strong social networks in RS, and prepare relocation plans for severe riverbank erosion scenarios. Local authorities should diversify funding sources, measure and record damages from riverbank erosion, and promote income-generating activities. For RS, local authorities should also identify high-risk areas based on riverbank erosion patterns and inform people, improve early warning systems, and seek support for the riverbank protection project. The central government should prioritize intervention in areas with high potential impact, allocate sufficient funding and resources to support local authorities in implementing disaster risk reduction measures, and provide technical assistance and expertise to local authorities in conducting risk assessments, developing disaster management plans, and implementing mitigation measures.

In the long term, it is recommended that local communities at high risk consider relocating to a safer place within or outside the community. The local authority in KS should invest in improving drinking water to enhance the overall well-being of the population and reduce their livelihood vulnerability. The local authority in RS should aim to extend the current riverbank protection. The central government should invest in riverbank protection measures for river segments in the commune that experience high exposure.

6. Conclusion

This study assessed the livelihood vulnerability of people to riverbank erosion hazards in two communes, namely, KS and RS, along the Mekong River in Cambodia by using the LVI-IPCC. The coping strategies of the local communities were also examined through semi-structured interviews with affected people and local authorities. KS is slightly more vulnerable to riverbank erosion than RS, as indicated by the LVI-IPCC values of 0.49 and 0.46 for KS and RS, respectively. Despite the higher exposure levels in RS, people in this area have a greater adaptive capacity to deal with riverbank erosion. RS is also less sensitive to riverbank erosion. The findings of this study align with previous research on other regions and within the Mekong Region, emphasizing the importance of food access and social networks as primary drivers of vulnerability. In response to riverbank erosion, the local residents of KS and RS have adopted various strategies, such as reducing expenses and food, saving for potential relocation, and seeking support from relatives or neighbors. Some affected individuals have also received relief assistance from their local governments. However, these coping mechanisms mainly provide short-term relief. To offer enduring assistance to the local community, further long-term interventions are required. Based on the vulnerability assessment in this study for the short, medium, and long term for the two communes, the local authorities, and the central government, several recommendations are proposed to enhance the management of risk from riverbank erosion at the local level.

This study provides insight for decision-makers into the relevant institutions which support disaster risk reduction in rural communities. However, this study has some limitations. The use of vulnerability indicators with varying scales introduces a challenge in normalizing the values. The selection of boundary values for normalization becomes sensitive to the overall computed LVI-IPCC value, potentially affecting the interpretation and comparability of the results. Secondly, this study focuses on coping strategies at the community level within two specific communes, focusing on the perspectives and experiences of the affected local communities. This limitation suggests that further research is needed to gain a more comprehensive understanding of coping strategies, including the perspectives and actions of central-level authorities and organizations involved in disaster response. Further research should also explore the effects of multiple hazards on the livelihood vulnerability of local communities and the long-term effectiveness and sustainability of different coping strategies. Moreover, future studies should explore the role of local knowledge and traditional practices in disaster risk reduction and how they could be integrated with scientific knowledge to enhance disaster management efforts. By addressing these research gaps, decision-makers can appropriately support local communities in building their capacity to cope with the effects of riverbank erosion and other natural hazards.

Ethics declarations

This study was reviewed and approved by the Research Ethics Review Committee for Research Involving Human Subjects: The Second Allied Academic Group in Social Sciences, Humanities and Fine and Applied Arts at Chulalongkorn University, based on Declaration of Helsinki, the Belmont report, CIOMS guidelines and the principle of the international conference on harmonization – Good clinical practice (ICH-GCP), with the approval number: COA No. 191/65.

All participants provided informed consent to participate in the study.

All participants provided informed consent for the publication of their anonymized case details and images.

Data availability statement

Data will be made available on request.

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CRediT authorship contribution statement

Theara Tha: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Thanapon Piman:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Suthirat Kittipongvises:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation. **Piyatida Ruangrassamee:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25418.

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