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Elevating Pakistan's flood preparedness: a fuzzy multi-criteria decision making approach

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Abstract

In South Asia, Pakistan has a long and deadly history of floods that cause losses to various infrastructures, lives, and industries. This study aims to identify the most appropriate flood risk mitigation strategies that the government of Pakistan should adopt. The assessment of flood risk mitigation strategies in this study is based on certain criteria, which are analyzed using the fuzzy full consistency method. Moreover, flood risk mitigation strategies are evaluated by using the fuzzy weighted aggregated sum product assessment (WASPAS) method, considering previously prioritized criteria. According to the results, *lack of governance*, *lack of funding and resources*, and *lack of flood control infrastructure* are the most significant flood intensifying factors and act as major criteria for assessing flood risk mitigation strategies in Pakistan. *Adopting hard engineering strategies (e.g., dams, reservoirs, river straightening and dredging, embankments, and flood relief channels)*, *maintaining existing infrastructure*, and *adopting soft engineering strategies (flood plain zoning, comprehensive flood risk assessment, and sophisticated flood modeling)* are identified as the top three flood risk mitigation strategies by the fuzzy WASPAS method. The highest weight (0.98) was assigned to the adoption of hard engineering strategies to mitigate flood risks. The study introduces a novel dimension by analyzing the real-time impact of the unprecedented 2022 floods, during which approximately one-third of the nation was submerged. This focus on a recent and highly significant event enhances the study's relevance and contributes a unique perspective to the existing literature on flood risk management. The study recommends that the government of Pakistan should prioritize hard engineering strategies for effective flood risk mitigation. It also recommends that the government should incorporate these strategies in the national policy framework to reduce flood losses in the future.

Keywords: Flooding, Floods management in Pakistan, Structural and non-structural measures, Risk mitigation, Fuzzy set theory, FUCOM, Fuzzy WASPAS

Introduction

Natural disasters destroy lives, communities, and even an entire country. One of the most frequent natural catastrophes is flooding, which happens when excess water inundates normally dry land. In coastal locations, flooding is often caused by heavy rainfall, fast snowmelt, tropical cyclone storm surge, or tsunami. Floods can cause chaos among local people across a large area, ultimately leading to human casualties, property damage, and the destruction of vital public health infrastructure. Floods can reverse years of progress in terms of a country's poverty reduction and development. Floods have detrimental social, economic, and environmental effects on both individuals and communities (Kawasaki and Shimomura 2024). The impacts of floods heavily depend on the location, duration, depth, speed, extent, and vulnerability (Bertoli et al. 2024). Floods destroy communication lines and infrastructure, including power plants, roadways, and bridges, disrupting normal activities. From 1998 to 2017, floods affected over 2 billion people globally (WHO 2024). In 2021, there were 48% more global flood disasters than the previous years, resulting in 4393 fatalities. Approximately 1.81 billion people or 23% of the global population are now directly exposed to flood levels exceeding 0.15 m (Rentschler 2023). More than two-thirds of the world's population or 1.24 billion people who are in danger of floods live in South Asia. Natural catastrophes and flooding are constant threats in South Asia due to its geographical location (Ikram et al. 2024). The lack of resources, particularly coping and adaptive capacities, has left the nations in this area very vulnerable.

In South Asia, Pakistan has particularly experienced frequent floods because of climate change and mismanagement. The country has a long history of natural disasters (Raza 2022). As of 2020, the country had witnessed approximately 19 major flood disasters, resulting in a total of 594,700 km^2 of flooded land and 166,075 flooded communities (Ikram et al. 2024). Approximately 10,668 lives were lost as a direct impact of these disasters (Ikram et al. 2024). Further, economic losses were more than US $30 billion in direct costs. Figures 1 and 2 depict a condensed yet impactful summary of the substantial human, economic, and environmental toll inflicted by recurrent floods in Pakistan.

The floods of 2022 in Pakistan were more devastating than those of previous years, inflicting severe and widespread damage on communities, infrastructure, and the economy. These floods were due to intense rainfall, accompanied by riverine, urban, and flash flooding (United Nations 2023). Across the nation, numerous fatalities, animal deaths, and destruction to both public and private infrastructure were reported (OCHA 2022). Specifically, 32 districts in Baluchistan, 23 in Sindh, and 17 in Khyber Pakhtunkhwa were designated as "calamity afflicted" by the government of Pakistan (United Nations 2023). According to 2022 reports from the United Nations Satellite Center, approximately 75,000 km^2 of Pakistan was flooded (10%–12% of Pakistan)

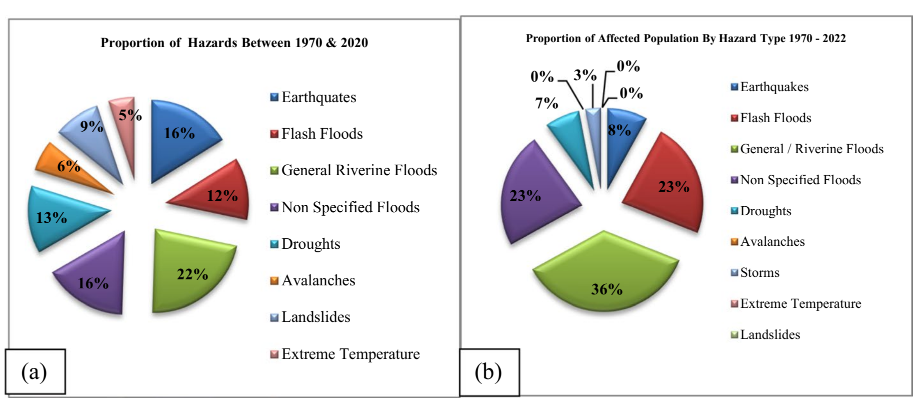

Fig. 1 **a** Proportion of hazards in Pakistan between years 1970—2020, **b** proportion of affected population by hazard type

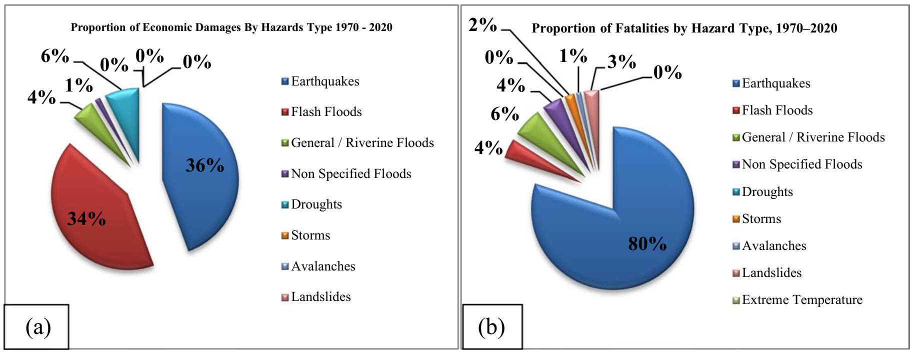

Fig. 2 **a** Proportion of economic damages in Pakistan by hazards type between 1970—2020, **b** proportion of fatalities by hazard type between 1970—2020

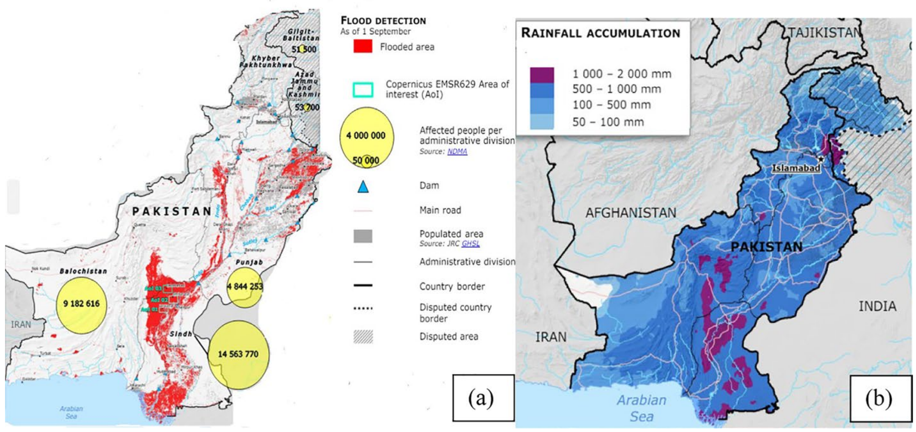

Fig. 3 **a** Pictorial view of flooded areas in Pakistan 2022, **b** pictorial view of rain accumulation in Pakistan 2022. Source: Emergency Response Coordination Center, European Commission (https://upload.wikimedia.org/wikipedia/commons/8/81/ECDM_20220902_SW_Pakistan.pdf)

(UNOSAT 2022). More than 33 million people were impacted by the excessive rains and floods, forcing at least 7.9 million to relocate (OCHA 2022). The National Disaster Management Authority (NDMA 2022) indicated that extreme rains and floods killed 1,717 people and injured 12,867, and at least 598,000 people resided in relief camps (WEP 2022).

The 2022 floods also caused extensive damage to crops and animals, including losing millions of tons of wheat stockpiled in warehouses (Qamer et al. 2022). All the main crops throughout the country were wiped off. Recent floods also ripped off rice and cotton fields, which are among the top five exports of Pakistan. Furthermore, the damage to agricultural land may be present in areas that are not inundated. Figure 3a and b depicts an overview of the flooded areas and total rain in Pakistan in 2022.

By implementing various mitigation strategies at the household and community levels, losses resulting from the negative effects of floods can be reduced. The development of efficient flood mitigation and adaptation policies and alternatives by the government can significantly contribute to lowering vulnerabilities and boosting local adaptive capacity.

It is necessary to have a thorough grasp of regional risks, adaptive capabilities, existing initiatives, and current requirements to build an effective flood mitigation strategy.

Numerous studies have been conducted on managing flood risks, and there are challenges associated with reducing and preparing for flood hazards in both developed and developing nations. However, most flood-related studies focus on the financial impacts of floods on local livelihoods or the agricultural sector and are theoretical. The diverse impact of climate change on flood risks demands further exploration, with an emphasis on understanding extreme weather events. Additionally, there is a need for research into the social dimensions of flood risk management, including community perceptions, behaviors, and the effectiveness of community-based strategies. Understanding how urban planning and infrastructure development can enhance resilience against floods, along with effective governance structures and policy frameworks, is a critical area that requires further investigation. Lastly, the importance of cross-border collaboration and governance mechanisms in managing transboundary flood risks is an emerging research frontier. These gaps underscore the need for comprehensive, interdisciplinary research to inform effective flood risk management strategies in a changing world. The results of this study can be utilized to build various instruments of a policy that strategically target particular places and can be used for additional research.

Based on the current research gaps and to better prepare Pakistan for future natural disasters, this study aims to develop a flood-resilient framework for the country. Specifically, it seeks to answer three research questions: (1) what are the most significant factors that play an important role in intensifying the impacts of floods in Pakistan? (2) What are the most viable flood risk mitigation strategies that can help in minimizing the impacts of floods in Pakistan? (3) How can flood risk mitigation strategies be adopted in the national policy framework?

This study adds to the current literature by developing a unique hybrid the fuzzy full consistency method (FUCOM)–fuzzy weighted aggregated sum product assessment (WASPAS) method to evaluate flood intensifying factors and flood risk mitigation measures. To the best of the author's knowledge, the application of these multi-criteria decision-making (MCDM) approaches for this purpose has not been done in the literature. Previous research has often relied on singular approaches; our hybrid method offers a comprehensive framework for assessing flood intensifying factors and mitigation strategies simultaneously. By combining the strengths of FUCOM in evaluating criteria consistency with the MCDM capabilities of WASPAS, our approach provides a robust and nuanced analysis of flood risk management strategies. This novel methodology offers a fresh perspective in the field and addresses the need for more holistic approaches to flood risk assessment.

The study further adds to the literature by examining the most significant flood intensifying factors and flood risk mitigation strategies by considering the circumstances of the most deadly 2022 floods in Pakistan's history. Furthermore, the study enriches the literature by offering more pragmatic and comprehensive methodologies for assessing the tangible impacts of floods in Pakistan. Finally, it concludes with policy recommendations for the government, the environmental protection agency, and disaster management authorities. The integration of MCDM methods, consideration of real-world events, and the development of practical policy recommendations contribute to a more holistic and comprehensive understanding of flood risk management, enriching the literature with a nuanced and practical perspective.

The findings of this study offer practical applications for other countries that are vulnerable to floods. The innovative methodology provides a transferable approach adaptable to diverse contexts. The common flood intensifying factors identified, such as governance issues and lack of resources, resonate globally. The top three mitigation strategies—hard and soft engineering approaches and infrastructure maintenance—offer practical references for countries seeking effective measures. The study's real-world contextualization, examining Pakistan's 2022 floods, enhances its applicability. The policy recommendations serve as a blueprint for governance in flood-prone regions everywhere.

The rest of the paper is organized as follows. "Literature review" section, which is the literature review, follows the introduction, discussing pertinent research papers. "Data collection and methodology" section focuses on data gathering and the study methodology. Fourth section presents the results and discussions. The conclusion, limitations, and future recommendations are covered in fifth section.

Literature review

Climate change, population growth, lack of industry financing choices, high production and transportation expenses, and a dependence on imported commodities are factors that negatively impact Pakistan's economy. In June 2022, the torrential monsoon caused the most devastating floods in Pakistan's history. The financial losses caused by these floods were almost twice as what were suffered in the floods of 2010 (Staff 2022). Agriculture was one of the highly impacted sectors, with 8.3 million hectares of crops destroyed (Staff 2022).

Considering the importance of climate change, numerous studies have examined the impacts of natural disasters, particularly floods, on people, properties, businesses, agriculture, and vital infrastructure. Pauline et al. (2022) used a framework to assess agricultural damages caused by floods as agriculture is a complex economic system that is particularly vulnerable to floods. Yildirim and Demir (2022) argued that floods commonly affect agricultural regions, resulting in economic losses and worldwide food shortages. Furthermore, they examined the seasonal changes in the agricultural flood risks across the state.

Anam et al. (2017) assessed the economic damages caused by floods on Pakistan's agricultural industry, concluding that the agriculture industry of Pakistan was significantly impacted by climate change, specifically floods. Additionally, they revealed that Pakistan's agricultural problems caused fluctuations in the country's gross domestic product (GDP) and slowed down economic growth. Fahd et al. (2020) performed a thorough literature review and concluded that Pakistan is among the nations that are most susceptible to climate change. They also discussed the strategies adopted by farmers and the government to counter the effects of climate change. Pozzi and Hillis analyzed the impacts of strong social networks on flood risk management. According to Pozzi and Hillis (2023), strong social networks can help communities to more effectively adapt to changing flood risk hazards.

Dottori et al. analyzed cost-effective flood risk mitigation strategies in Europe to reduce economic losses. According to Dottori et al. (2023), building-based flood proofing and relocation strategies can help reduce flood impacts in localized areas. Vafadarnikjoo et al. (2023) developed a decision-making model for flood risk management in Scotland. According to Vafadarnikjoo et al. (2023), flood forecasting and increasing awareness among local people are the top two strategies that can help reduce flood losses. Furthermore, these two strategies should be followed by emergency plans and responses, planning policies, maintenance, and self-help. Saqib et al. (2018) investigated factors that affect farmers' access to agricultural loans in flood-prone regions of Pakistan, finding that socioeconomic characteristics have a crucial effect on their ability to obtain agricultural credit. Therefore, there is a pressing need to develop a loan strategy to assist farmers in flood-prone regions of Pakistan.

Decisions involving several alternatives and evaluation criteria call for a method known as MCDM. MCDM methods evaluate potential alternatives by rating them on a set of criteria. Experts' or decision-makers' opinions are also considered when criteria and alternatives are weighed. The hybrid MCDM methods are gaining popularity in current scientific works. Separate methods are used to weigh criteria and alternatives in hybrid MCDM methods. This study utilizes FUCOM and fuzzy WASPAS analyses to examine and evaluate flood intensifying factors and food risk mitigation strategies.

Fuzzy full consistency method

Full consistency method (FUCOM) is a popular MCDM method and was developed by Pamučar et al. (2018). FUCOM can be applied in various fields, including engineering, environmental management, and public policy. Its flexibility allows for comprehensive evaluations of competing alternatives in complex decision-making processes, ranging from resource allocation to strategic planning (e.g., Pamučar et al. 2018). FUCOM has several advantages over alternative methods such as the analytic hierarchy process (AHP), best–worst method (BWM), and decision-making trial and evaluation laboratory (DEMATEL).

FUCOM provides a means to validate results, ensuring reliability in the decision-making process, while the DEMATEL method lacks consistency measure (Stević and Brković 2020). Moreover, FUCOM can manage complexity more effectively than AHP, which struggles with numerous pairwise comparisons, potentially simplifying the model without sacrificing accuracy (e.g., Khan et al. 2023). Unlike the BWM, which may introduce significant subjectivity due to consistency ranges, FUCOM can produce more objective outcomes, offering a more dependable basis for decision-making (e.g., Fazeli and Peng 2021). These attributes position FUCOM as a promising method for addressing decision-making challenges across various contexts.

FUCOM is used in the study to evaluate factors that play a significant role in intensifying flood impacts in Pakistan. To lessen the inherent ambiguity and fuzziness in expert opinions, the fuzzy set theory is also integrated with the MCDM methods (e.g., Biswas et al. 2023; Wang et al. 2023).

Numerous researchers have used FUCOM in their studies to solve complex problems in different areas. Sadeghi et al. (2023) used an integrated FUCOM–Geographic Information System approach to assess the vulnerability of Iran to subsidence hazards.

Groundwater potential recharge zones were identified by Akbari et al. (2021) by using hybrid techniques such as FUCOM, best worst method, analytical hierarchy process. Alam et al. (2023) analyzed the impacts of the Turkey earthquake disaster on the real estate industry by using a hybrid input–output model and FUCOM. Stević and Brković (2020) evaluated the importance of human resource assessment criteria using FUCOM. Using FUCOM, sustainability performance indicators were evaluated by Badi et al. (2022). Ahmad et al. (2022) proposed a simpler and more efficient model for evaluating healthcare establishments by using FUCOM and measurement of alternatives and ranking according to the compromise solution techniques.

Fuzzy weighted aggregated sum product assessment

WASPAS is another widely used MCDM method for evaluating and ranking alternatives. The WASPAS method was proposed by Zavadskas et al. (2012). WASPAS has been employed effectively in various sectors to solve issues of varying complexity. WASPAS is a novel combination of the weighted product model (WPM) and the weighted sum model (WSM). Its widespread use may be attributed to the fact that it is both mathematically straightforward and more precise than the WSM and WPM techniques (Chakraborty et al. 2015).

The WASPAS model can be applied across diverse fields such as project selection, supplier evaluation, resource allocation, and performance evaluation. Its flexibility allows decision-makers to customize the weighting of criteria based on the context of a decision problem. The main advantages of WASPAS over other decision-making techniques include computational easiness, consistency of results, and strong resistance against rank reversal of alternatives (Zavadskas et al. 2014). Furthermore, WASPAS can handle qualitative and quantitative criteria and provides transparent results that are easy to interpret (Khalilzadeh et al. 2024). Decision-makers can clearly understand how each alternative performs relative to others based on the weighted criteria, facilitating transparency and accountability in the decision-making process (Ozcalici 2022).

Chakraborty et al. (2015) studied the applicability of the WASPAS method. They validated the applicability by applying the WASPAS method to five real-time problems, concluding that the rankings obtained through the WASPAS method closely align with those reported by previous researchers across all examined problems. Its foundation in simple yet rigorous mathematics, coupled with its comprehensive nature, makes it suitable for successful application to various decision-making problems.

WASPAS has been applied by numerous researchers to many decision-making problems. Zavadskas et al. (2014) devised an integrated WASPAS–entropy approach for the selection of ocean water ports in Klaipeda. Ighravwe and Oke (2020) used the WASPAS method to evaluate maintenance performance systems. Yazdani (2018) conducted a suitability analysis by using the WASPAS method to determine the best location for wind farms. Dağıstanlı and Kurtay (2024) applied the WASPAS model to spatial analysis. Moreover, Wang et al. (2024) applied the WASPAS method to evaluate the investment decision of a community group buying platform, while Bouraima et al. (2024) implemented the WASPAS method to manage climate change risks. Numerous studies have integrated AHP and WASPAS to calculate criteria weights and choose alternatives (Emovon 2023).

By carefully examining the literature over the last 8 years, which includes research articles and official reports that provide data associated with floods in Pakistan, the study initially determined 25 flood intensifying factors and 20 flood risk mitigation strategies. With the help of planning and development professionals in the country, these intensifying factors and strategies were narrowed down in the context of the deadliest 2022 flood that occurred in Pakistan. Finally, the study adopted 11 flood intensifying factors and 10 resilient strategies, as presented in Tables 1 and 2, respectively.

This study focuses on the identification of the most resilient strategies that can reduce the negative impacts of natural disasters, specifically floods, in Pakistan. The approach and practical implications of this study are innovative. This is a novel study to use both the FUCOM and fuzzy WASPAS methods to evaluate flood intensifying factors and

Table 1 List of flood intensifying factors

Sr. no	Flood-intensifying factors	Description	Literature references
(1)	Ineffective governance practices	Governance structures and processes that fail to effectively address flood risk management and response	Dashab and Punia (2019) and Habibullah et al. (2022)
(2)	Insufficient financial and resource allocation	Limited allocation of funds and resources for implementing flood risk mitigation measures	Habibullah et al. (2022)
(3)	Forest degradation	The degradation or loss of forest cover, which exacerbates flood risk by reducing natural water retention and infiltration	Yana et al. (2022) and Abdulkareem et al. (2018)
(4)	Urban expansion/urbanization pressure	Rapid urban development and expansion contributing to increased vulnerability to floods	Zhou et al. (2019) and Ekmekcioğlua et al. (2022)
(5)	Absence of flood emergency procedures and early warning systems	Lack of established protocols and systems for effectively managing flood emergencies and providing early warnings to at-risk communities	Perera et al. (2020) and Trogrlić et al. (2023)
(6)	Inadequate flood control infrastructure	Insufficient infrastructure such as dams, levees, and drainage systems to mitigate flood impacts	Sohn et al. (2021) and Hamel and Tan (2022)
(7)	Deficient flood risk communication framework	Ineffective communication systems for disseminating flood risk information and raising public awareness	Mark et al. (2019) and Sawangnate et al. (2022)
(8)	Technological deficiency	Lack of access to and utilization of advanced technologies for flood monitoring, prediction, and response	Mercado et al. (2020) and Jin et al. (2023)
(9)	Outdated flood control systems	Flood control systems and mechanisms that are obsolete or no longer effective in addressing current flood challenges	Santoro et al. (2022) and Suriya et al. (2022)
(10)	Shortage of expertise	Insufficient availability of trained professionals and experts in flood risk management and response	Fekete et al. (2021) and Raškaa et al. (2023)
(11)	Limited attention to climate change impacts	Inadequate consideration of the role of climate change in exacerbating flood risks and the need for adaptation measures	Din et al. (2022)

Table 2 List of resilient strategies to mitigate flood impacts

Flood mitigation strategies	Description	Literature references
Adopting-hard-engineering strategies (dams, reservoirs, river straightening and dredging, embankments and flood relief channels)	Implementation of physical structures and modifications to watercourses to manage floodwaters and reduce flood risk	Ghare et al. (2021) and Li et al. (2022)
Adopting-soft-engineering-strategies (floodplain zoning, comprehensive flood-risk-assessment, sophisticated flood modelling)	Utilization of non-structural measures and planning techniques to mitigate flood impacts through improved land use and flood risk assessment	Kundzewicz et al. (2023) and YuChen (2022)
Maintaining-existing infrastructure	Ensuring the upkeep and resilience of current infrastructure to withstand flood events and minimize damage	Mastroianni et al. (2021) and Sumi et al. (2022)
Increasing the natural space along riverbanks and flood plains to enable safer riverine flooding	Creating buffer zones and preserving natural floodplains to absorb floodwaters and reduce the risk of inundation in populated areas	Krishnamurti et al. (2022)
Deploying advance information and warning systems	Implementation of advanced technologies and systems to provide timely and accurate flood warnings to at-risk communities	Oguz1 et al. (2019) and Gohar et al. (2023)
Efficient planning for land use	Strategic planning and management of land development to minimize exposure to flood hazards and protect vulnerable areas	Shun Chan et al. (2018) and Newman et al. (2022)
Regular-property-survey	Conducting periodic surveys to assess flood vulnerability and ensure proper land use planning and development regulations	Dillenardt et al. (2022) and Khairul et al. (2023)
Improving-traffic-access	Enhancing transportation infrastructure to facilitate safe evacuation and emergency response during flood events	Karthikeyan and Usha (2022) and Bucar and Hayeri (2022)
Flood water diversion and storage	Developing systems and structures to divert and temporarily store excess floodwater, reducing the risk of inundation in downstream areas	Wang et al. (2021) and Gopalan et al. (2022)
Increasing awareness among local people	Educating communities about flood risks, preparedness measures, and evacuation procedures to enhance resilience and reduce vulnerability	Islam et al. (2018) and Tolulope et al. (2023)

flood risk mitigation strategies in the context of Pakistan. Prior studies that examined the impacts of climate change in Pakistan are purely theoretical and did not provide any policy recommendations to stakeholders to reduce flood losses. In the context of Pakistan, there has been an absence of research that examines and evaluates flood resilience methods. Moreover, the methodology and outcomes of this study will be beneficial to the developing world as a whole.

Data collection and methodology

The flow diagram in Fig. 4 provides an overview of the data collection procedure and research methodology. The first step in the data collection is performing a thorough literature review to determine the essential flood intensifying factors and their mitigating

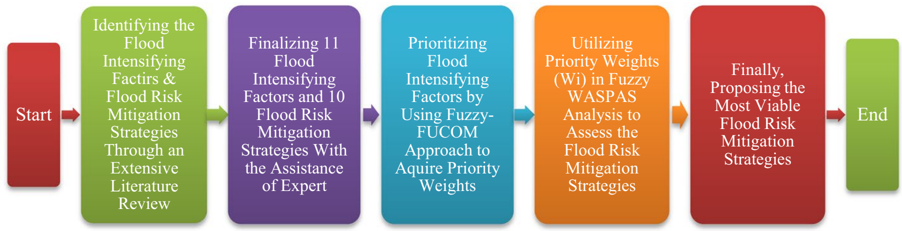

Fig. 4 Schematic representation data collection and methodology (author own constructed)

Table 3 Relation of linguistic terms and fuzzy sets

Linguistic variables	Attribute grade	Fuzzy numbers in triangular form
Very low	1	(0.0, 0.1, 0.3)
Low	2	(0.1, 0.3, 0.5)
Moderate	3	(0.3, 0.5, 0.7)
High	4	(0.5, 0.7, 0.9)
Very high	5	(0.7, 0.9, 1.0)

Source: Eric (2014)

strategies. The finalized list of 11 factors and 10 resilient strategies, compiled with the assistance of planning and development professionals, are presented in Tables 1 and 2, respectively. FUCOM was used to examine and analyze flood intensifying factors. The result of FUCOM was in the form of priority weights (WI), which were further utilized to analyze flood risk mitigation strategies by conducting fuzzy WASPAS analysis.

For the hybrid FUCOM–fuzzy WASPAS analysis, the primary data were collected by circulating questionnaires among professionals in the following institutions: Disaster Management Authority, Agriculture Department, Environmental Protection Agency, and Statistics and Information Department (Alam 2022; Alam 2023a, b). The experts used the five-point rating scale presented in Table 3 to express their opinion. The experts assigned "very low" to a flood risk factor and mitigation strategy that is least important, and "very high" was assigned to the most important. Detailed information about the experts is presented in the Appendix (Tables 9, 10). To reduce the uncertainty and ambiguity in the data collected from the experts, a fuzzy set theory was also used with FUCOM and the fuzzy WASPAS method. The fuzzy set theory, FUCOM, and fuzzy WASPAS method are explained in detail in Sections 3.1, 3.2, and 3.3, respectively.

Fuzzy set theory

Zadeh (1965) is widely recognized as the originator of the fuzzy set theory. Since its introduction, it has been frequently implemented to deal with ambiguity. The fuzzy set theory is mostly used in qualitative decision-making, which relies on decision-makers' qualitative perceptions (Narang et al. 2023). As experts' opinions are gathered as linguistic variables, their judgments are inherently fuzzy (Marinkovic et al. 2023). The fuzzy set theory, which emphasizes relative rather than absolute values for the attributes, may be used to eliminate this fuzziness.

Numerous researchers have integrated the fuzzy set theory with quantitative techniques to reduce uncertainty. Kou et al. (2024a) developed a comprehensive guide for making sustainable investment decisions in renewable energy, utilizing a novel hybrid facial expression-based fuzzy decision-making approach. Kou et al. (2024b) evaluated the multidimensional carbon neutrality policies in transportation using a novel quantum picture fuzzy rough modeling. Kou et al. (2024c) performed a comparative examination of the q-rung orthopair fuzzy sets (q-ROFs) DEMATEL model by applying fuzzy sets in renewable energy investments. Kou et al. (2024d) proposed a novel hybrid fuzzy decision-making model using bipolar q-ROFSs and multistepwise weight assessment ratio analysis for weighting QFD stages to select optimal omnichannel strategies for financial services.

In this study, fuzzy numbers in triangular form, as presented in Table 3, were used to fuzzify the data collected from the experts. When an expert ranks flood risk factor or mitigation strategy "very high," the opinion is converted into a fuzzy triangular number to reduce uncertainty in the data. All the data received from the experts were converted into fuzzy triangular numbers. The fuzzy triangular numbers were further utilized in the FUCOM and WASPAS method.

Fuzzy full consistency method

In this study, FUCOM was used to analyze flood intensifying factors. FUCOM has the benefit of requiring fewer pairwise comparisons than alternative approaches. This enables the results to be confirmed by determining the maximum deviation from consistency of comparison. Furthermore, it appreciates the transitivity in the pairwise comparisons of criteria (Pamučar et al. 2018). FUCOM addresses the problem of repeated pairwise comparisons of criteria that is present in other MCDM methods when computing the weights of criteria.

The primary data were collected by circulating the questionnaires among professionals (Alam 2022). The survey participants included 18 specialists from the agricultural sector, Disaster Management Authority, Environmental Protection Agency, and Statistics and Information Department. The experts used the rating scale presented in Table 3 to present their opinion. Detailed information about these experts is presented in "Appendix Table 9", which includes details about their organization, experience, and education level. After the evaluation of flood intensifying factors by the experts, their responses were converted into a pairwise comparison matrix, and a novel MCDM FUCOM was applied. Additional steps of the FUCOM analysis are presented below. The final weights of the FUCOM analysis are utilized in the fuzzy WASPAS method to rank flood risk mitigation strategies.

The following steps are associated with the technique:

Step 1 The method begins with the examination of pairwise comparisons of the experts' criteria.

Step 2 After a review of the criteria by the experts, the mean of all responses is determined. The average is then graded based on the weight of the criteria. The criterion with the highest weight coefficient is placed first in the ranking, while the criterion with the lowest weight coefficient is placed last. The obtained rankings are displayed in descending order, as follows:

$$C_{1(1)}^{(a)} > C_{1(2)}^{(a)} > \cdots > C_{1(n)}^{(a)} \tag{1}$$

where *C* is the criterion for assessing flood risk mitigation strategies; *a* is the number of participating experts; and *n* reflects each criterion's rating.

Step 3 The comparisons of the ranked criteria are carried out and the comparative priority of the evaluation criteria is also determined. The priority of the evaluation criteria is mathematically defined as follows:

$$\phi_{\frac{l}{l+1}} \tag{2}$$

where $l = 1, 2, 3\ldots n$ is the rank of the criteria.

The comparative priority of the evaluation criteria is an advantage of criterion $C_{1(n)}$ rank as compared with criterion $C_{1(n+1)}$ rank. The priority of all the evaluation criteria can be calculated by using Eq. (2).

Step 4 The weight coefficients $(W_1, W_2, W_3, \ldots\ldots\ldots..)^T$ of the evaluation criteria are calculated. The weight coefficients should satisfy the following two conditions.

The initial condition stipulates that the weight coefficient of the criterion should be equal to the relative importance of the observed criteria, and the condition is expressed mathematically as follows:

$$\frac{\boldsymbol{W_l}}{\boldsymbol{W_{l+1}}} = \boldsymbol{\Phi}_{\frac{l}{l+1}} \tag{3}$$

where *W* represents the weight coefficient of the factor, and $\boldsymbol{\Phi}_{\frac{l}{l+1}}$ represents the comparative priority of the evaluation criteria. After applying the first condition, the numerical values obtained are presented in Table 4.

The second condition states that the weight coefficient values must fulfill the mathematical transitivity (a = b, b = c, a = c), which is expressed mathematically as follows:

$$\boldsymbol{\Phi}_{\frac{l}{(l+1)}} \mathrm{X}\, \boldsymbol{\Phi}_{\frac{(l+1)}{(l+2)}} = \boldsymbol{\Phi}_{\frac{l}{(l+1)}} \tag{4}$$

where $\boldsymbol{\Phi}_{\frac{l}{(l+1)}}$ represents the priority of the evaluation criteria, and l is taken as $l+1$. The numerical values obtained by applying this condition are presented in Table 5.

Step 4 When all the conditions in Step 3 are met, a mathematical model based on the nonlinear programming is constructed by using Eqs. (5)–(8). The requirement of maximum consistency that is, DFC $x = 0$, for the obtained values of the weight coefficients should be fulfilled by minimizing the value of *x*. The obtained nonlinear model is solved by using LINGO software. After that, we then compute the final weight coefficients of the criterion:

Min *x*

$$\left| \frac{\boldsymbol{W_l}}{\boldsymbol{W_{(l+1)}}} - \boldsymbol{\Phi}_{\frac{l}{(l+1)}} \right| \leq \boldsymbol{x}, \forall \boldsymbol{j} \tag{5}$$

$$\left| \frac{\boldsymbol{W_l}}{\boldsymbol{W_{(l+1)}}} - \boldsymbol{\Phi}_{\frac{l}{(l+1)}} \mathbf{x} \boldsymbol{\Phi}_{\frac{(l+1)}{(l+1)}} \right| \leq \mathbf{x}, \forall \mathbf{j} \tag{6}$$

Table 4 First condition of fuzzy FUCOM analysis

CONDITION 1	F1/F9	F9/F5	F5/F4	F4/F3	F3/F7	F7/C2	F2/C8	F8/C6	F6/F11	F11/F10
	1.09570	1.06656	1.12106	1.059753	1.14486	1.050739	1.079908	1.0605326	1.1072386	1.5162601

F = Flood intensifying factors

Table 5 Second condition of fuzzy WASPAS analysis

Condition 2	F1/F9 * F9/F5	F9/F5 * F5/F4	F5/F4 * F4/F3	F4/F3 * F3/F7	F3/F7 * F7/F2	F7/F2 * F2/F8	F2/F8 * F8/F6	F8/F6 * F6/F11	F6/F11* F11/F10
	1.168	1.195	1.188	1.213	1.202	1.131	1.145	1.174	1.678

F = Flood intensifying factors

$$\sum_{\mathbf{j=1}}^{\mathbf{n}} \boldsymbol{W_j} = 1, \forall \boldsymbol{j} \tag{7}$$

$$\boldsymbol{W_j} \geq 0, \forall \boldsymbol{j} \tag{8}$$

where all the weights of the criteria cannot be negative values. The highest value of the criteria can be 1.

Step 5 Solving the mathematical model yields the following values for the weight coefficient of the criteria: $\left(W_1^{(a)}, W_2^{(a)}, \ldots\ldots., W_n^{(a)}\right)^T$. The resulting weights are then sorted in descending order, as presented in Table 7. The criterion with the highest weight appears first in the ranking, while the one with the least weight appears last. After acquiring the final weights from FUCOM, they are then utilized in the fuzzy WASPAS analysis to determine the most optimal alternative.

Fuzzy weighted aggregated sum product assessment

The fuzzy WASPAS method is used in this study to determine the most optimal strategy for minimizing flood risks. The primary data for this analysis are collected by circulating questionnaires among professionals. The effects of every flood risk mitigation strategy are seen in all flood intensifying factors. A total of 18 professionals working in the agriculture sector, Disaster Management Authority, Environment Protection Agency, and Statistics and Information Department were involved in this part of the survey. The experts employed the rating scale reported in Table 3 to present their opinions. Detailed information about these experts can be seen in "Appendix Table 10", which includes details about their organization, experience, and education level. After analyzing the relationship between flood risk mitigation strategies and flood intensifying factors by the experts, their responses were converted into a pairwise comparison matrix for further evaluation. The fuzzy WASPAS method was used to rank all the alternatives that is, flood risk mitigation strategies.

WASPAS is a novel combination of two well-known MCDM methods that is, WSM and WPM. The initial step in using WASPAS is to create a decision or evaluation matrix, denoted by $X=[x_{ij}]_{mxn}$, in which x_{ij} is the performance of the i^{th} alternative regarding the j^{th} criterion; m is the number of alternatives; and n is the number of criteria. All components of the decision matrix are normalized by using Eqs. (9)–(10) to make performance metrics comparable and dimensionally neutral:

$$\overline{\mathrm{x}}_{\mathrm{ij}} = \frac{x_{ij}}{max_i x_{ij}} \, for \ beneficil \ criteria \tag{9}$$

$$\overline{x}_{ij} = \frac{min_i x_{ij}}{x_{ij}} for\ non-beneficil\ criteria \tag{10}$$

For beneficial criteria, the value of factor x_{ij} is divided by the maximum available value in the column of that pairwise comparison matrix. For nonbeneficial criteria, the minimum value in the column of the pairwise comparison matrix is divided by the x_{ij} considered factor. Finally, $\overline{x}_{ij}$ is the normalized value of x_{ij}.

The WASPAS approach uses a combination of three criteria for success, the third of which is a joint criterion. The first optimality criteria are quite close to the WSM approach—it is the criterion of a mean weighted success. WSM is a prevalent and widely acknowledged MCDM method for evaluating a number of alternatives in relation to a set of decision criteria. Based on the WSM method, the total relative importance of the i^{th} alternative is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x}_{ij} w_{ij} \tag{11}$$

where w_{ij} is the weight (relative importance) of the j^{th} criterion and is multiplied by the normalized matrix. According to the WPM method, the total relative importance of the i^{th} alternative is evaluated as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} (\overline{x}_{ij})^{w_j} \tag{12}$$

A joint generalized criterion of weighted aggregation of additive and multiplicative methods is then proposed by using the following equation:

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} = 0.5\sum_{j=1}^{n} \overline{x}_{ij} w_{ij} + 0.5\prod_{j=1}^{n} (\overline{x}_{ij})^{w_j} \tag{13}$$

The numerical values obtained after the combination of WSM and WPM methods are presented in Table 6.

Table 6 Final weightages of fuzzy WASPAS analysis

Alternatives	WSM	WPM	WASPAS
S1	0.962	1	0.981
S2	0.276	0.254	0.265
S3	0.531	0.469	0.500
S4	0.004	0.004	0.004
S5	0.011	0.015	0.013
S6	0.021	0.027	0.024
S7	0.039	0.046	0.042
S8	0.143	0.145	0.144
S9	0.071	0.080	0.075
S10	0.007	0.010	0.009

WSM Weighted sum model, *WPM* weighted product model

To improve the precision and efficiency of the ranking, the WASPAS method builds a more generic expression to assess the relative importance of the i^{th} option as follows:

$$Q_{ij} = \lambda Q_i^{(1)} + (1-\lambda)Q_i^{(2)} = \lambda \sum_{j=1}^{n} \overline{x}_{ij} w_{ij} + (1-\lambda) \prod_{j=1}^{n} \left(\overline{x}_{ij}\right)^{w_j}, \lambda = 0{,}0.1, \ldots\ldots\ldots 1 \tag{14}$$

Now, the potential choices are sorted by their Q values. The most desirable alternative has the greatest Q value, while the least desirable alternative has the lowest Q value. In Eq. 13, when λ equals zero, the WASPAS method is transformed into the WPM method, and when λ equals one; it is transformed into the WSM method. WASPAS is used in MCDM problems to rank alternatives. It is a popular method due to its capacity to achieve the highest estimate precision.

Results and discussion

There are two distinct parts of the results and discussion section. The first part discusses the findings of the FUCOM analysis, which was performed to evaluate the significant flood intensifying factors. The findings of the fuzzy WASPAS analysis, which was performed to evaluate flood risk mitigation strategies, are presented in the second part.

Results of the FUCOM analysis

In the last step of the FUCOM analysis, the final weights after simulating the nonlinear model in LINGO software are arranged in descending order and presented in Table 7. The range of the final weights of the flood intensifying factors falls between 0.0424 and 0.1362, indicating a spectrum of influence on exacerbating flood impacts in Pakistan. The mean of this range, which is 0.09, serves as a pivotal point for assessing the relative significance of each factor. Factors surpassing this mean, such as ineffective governance practices (0.1362), insufficient financial and resource allocation (0.1243), and inadequate flood control infrastructure (0.1166), are pivotal contributors to heightened flood risks. Conversely, factors falling below this mean play a comparatively lesser role in amplifying

Table 7 Final weightages of fuzzy FUCOM analysis

Prioritized flood intensifying factors	Final weightages	
F1	Ineffective governance practices	0.1362
F9	Insufficient financial and resource allocation	0.1243
F5	Inadequate flood control infrastructure	0.1166
F4	Absence of flood emergency procedures and early warning systems	0.1040
F3	Urban expansion/urbanization pressure	0.0981
F7	Technological deficiency	0.0857
F2	Forest degradation	0.0816
F8	Outdated flood control systems	0.0755
F6	Deficient flood risk communication framework	0.0712
F11	Insignificance given to climate change	0.0643
F10	Shortage of expertise	0.0424
Sum		1

flood impacts. This quantitative analysis underscores the criticality of addressing key factors above the mean to effectively mitigate flood risks in Pakistan.

The results depicted in Figure 5 reveal that ***ineffective governance practices*** were given the greatest priority by the experts, with a weight of ***0.1362***. *Ineffective governance practices* are the highest flood intensifying factor, deserving the greatest attention. The framework highlights political commitment and strong organizations as a vital success ingredient for successful and sustained catastrophe risk reduction.

Increased attention to disaster preparedness on the part of policymakers, adequate funding, mandatory implementation of disaster prevention measures, and clear attribution of blame for any lapses in these efforts are hallmarks of effective governance (United Nations 2024). The results of several studies are consistent with the results of the current study. Tahir and Maham advocated that Pakistan has experienced several difficulties since 1947, such as a lack of stability, poor judicial performance, a precarious democratic system, and corruption. These problems have served as barriers to a smooth and sustainable government (Tahir 2021). According to Kugelman (2022a, b), the devastating repercussions may have been minimized if Pakistani administrations had intervened in a few regions. Ishaque and Bushra highlighted that poor governance has weakened sustainable development, exacerbated the effects of disaster risk, and made the fight against climate change more difficult in Pakistan. Water specialists have long criticized the state's neglect of water infrastructure, which has reduced its ability to resist abrupt spikes in river flows.

Insufficient financial and resource allocation is the second-leading cause of flood intensification in Pakistan, with a weight of *0.1243*. More than $30 billion in damages and economic losses were incurred because of flooding in Pakistan (World Bank 2022). Iqbal et al. (2023) advocated that the country's economy has been in poor shape over the past few years due to a number of factors, including sluggish GDP growth, rising global inflation due to the Russia–Ukraine conflict, a falling currency that makes imports expensive, and a decline in foreign reserves. Therefore, Pakistan is incapable of dealing with flood damages owing to the lack of funds (Mukhtar 2022).

To address these problems, Pakistan got billions of dollars in assistance from the World Bank, the European Union, and the Asian Development Bank (Ainsworth 2022).

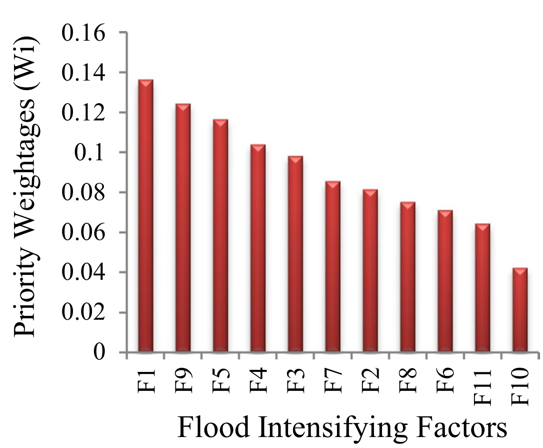

Fig. 5 Graphical results of fuzzy FUCOM analysis

Arshad et al. (2023) concluded that there is a dearth of rescue equipment in Pakistan; therefore, catastrophe sites pose numerous occupational, health, and safety hazards. Thus, funding and resources are essential to ensure the continuous availability of crucial medical supplies and food and to carry out rescue operations (OCHA 2022).

The third most important factor is *inadequate flood control infrastructure*, with a weight of *0.1166*. Ashraf et al. (2023) advocated that the government of Pakistan does not acknowledge the significance of flood control initiatives, resulting in inadequate infrastructure for flood control. The state's water infrastructure has been neglected for a long time, which according to the experts has significantly reduced the system's resilience to sudden spikes in water flow (Kugelman 2022a, b). According to Zia et al. (2023), the damage caused by floods may be greatly reduced if more money is allocated to large-scale infrastructure projects around the nation. Gray infrastructure initiatives are the most common means of preventing flood damage. Dams, reservoirs, altered channels, floodwalls, and levees are examples of gray infrastructure used for flood control (Dauer 2020).

Good governance, sufficient funding and resources, and effective flood control infrastructure contribute to minimizing loss of life, infrastructure damage, economic losses, displacement of people, environmental degradation, and social disruption associated with floods.

The experts assigned the lowest weight that is, *0.042* to *lack of experts.* The government of Pakistan has established many public sector institutions to combat natural catastrophes, and these institutions are staffed with professionals who can devise mitigation strategies for natural catastrophes (NDMA 2022).

After identifying the most significant flood intensifying factors, the next step is to point out the most viable and practical flood risk mitigation strategies in the context of Pakistan. To achieve this, the fuzzy WASPAS methodology is employed. Based on the prioritized flood intensifying factors, the analysis further evaluates and identifies the most effective flood risk mitigation strategies.

Results of the fuzzy WASPAS analysis

To counter the flood intensifying factors in Pakistan, flood risk mitigation strategies are identified and examined using the fuzzy WASPAS analysis. The final weights of the FUCOM analysis are utilized to assess the mitigation strategies. After the implementation of the fuzzy WASPAS method, the final weights are presented in Table 8. The final results of the fuzzy WASPAS analysis are depicted in Fig. 6. The findings indicate that *hard engineering strategies (dams, reservoirs, river straightening and dredging, embankments, and flood relief channels)* are the most essential resilient approach for flood risk reduction in Pakistan. The hard methods mitigate the effects of climate change by using tangible technology and steps that need the utilization of fixed assets.

The results of the study are consistent with the findings of numerous researchers. Shah et al. (2023) highlighted that the main flood protection system in Pakistan comprises 1,410 spurs and 6,807 km of flood protection embankments. They further advocated that due to insufficient maintenance, the structures are in bad condition. The embankment's design has not changed since its construction. Aslam (2018) stated that the standard operating procedures utilized at dam sites, barrages, bridges, and other infrastructures

Table 8 Final weightages of fuzzy FUCOM analysis

	Flood risk mitigation strategies	Weightages	Ranking
S1	Adopting-hard-engineering strategies (dams, reservoirs, river straightening and dredging, Embankments and flood relief channels)	0.9814	1
S3	Maintaining-existing infrastructure	0.5005	2
S2	Adopting-Soft-engineering-strategies (floodplain zoning, comprehensive flood-risk-assessment, sophisticated flood modeling)	0.2652	3
S8	Improving-traffic-access	0.1445	4
S9	Flood water diversion and storage	0.0756	5
S7	Regular-property-survey	0.0430	6
S6	Efficient planning for land use	0.0242	7
S5	Deploying advance Information and warning systems	0.0136	8
S10	Increasing awareness among local people	0.0093	9
S4	Increasing the natural space along riverbanks and flood plains to enable safer riverine flooding	0.0045	10

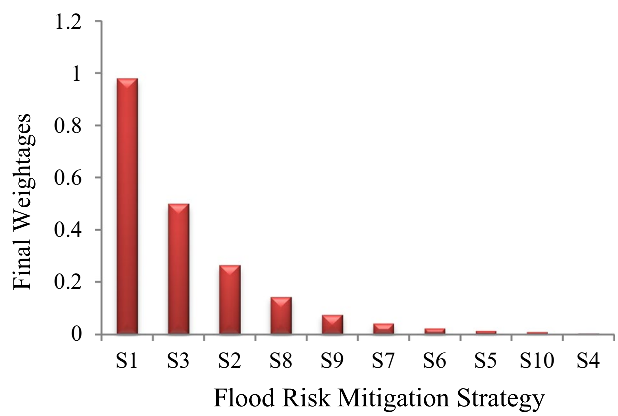

Fig. 6 Results of fuzzy WASPAS analysis

during flooding are not adequately directed toward reducing devastating flood effects. Awais and Zhang stated that the water storage reservoirs in Pakistan significantly prevent short-term flooding, although their effectiveness is impeded during catastrophic flooding. Emami (2015) stated that in Pakistan, hydel power production and irrigation are the two main uses of dams and reservoirs. These reservoirs' ability to handle flooding is the least considered. Furthermore, according to Jones et al. (2012), a significant number of executives in local and national governments, international agencies, and corporations prioritize planning and financing hard engineering strategies.

The second-ranked flood risk mitigation strategy is *maintaining existing infrastructure.* A good maintenance culture will avoid the degradation of hard structures, lengthen their lifespan, and considerably reduce the probability of their collapse. In November 2016, the Indus River system. According to Islam (2016), Chairman Indus River System Authority Rao Irshad Ali Khan stated that due to poor maintenance, the capacity of Tarbela Dam had decreased by 35% owing to reservoir sedimentation as the dam was originally planned to retain 9.6 million acre feet (MAF) but could now only contain 6.33 MAF, adding that the storage capacity of Mangla Dam and Chashma Dam had dropped by 16% and 61%, respectively. The people of Pakistan have also criticized the government for neglecting the reconstruction and maintenance of wrecked dams and reservoirs. As the disintegrating flood control infrastructures are unable to contain water (Khan 2021), in October 2022, due to extreme rains and flash floods, around 10 dams and reservoirs were broken in different regions of Baluchistan province (Shahid 2022).

Soft engineering strategies were ranked third by the experts. Soft approaches do not entail the construction of man-made structures but instead adopt a more sustainable and natural approach to mitigating the risk of floods (GCSE 2024). Generally, soft approaches emphasize information, policy, capacity development, and institutional function. According to Anees (2022), adopting soft approaches in Pakistan will promote behavioral adjustments to prevent possible losses from climate risks. According to Serm (2020), the viable soft engineering strategies for Pakistan include flood warning and preparation, flood plain zoning, vegetation, and river restoration. In Pakistan, many towns and villages are settled in flood prone regions. The government has issued clear warnings and instructions to the locals, but there is no practical implementation. The planning and development authority approves construction plans in flood prone regions by accepting bribes. The current government has initiated different projects for vegetation and river restoration.

Adopting hard and soft engineering approaches, alongside maintaining existing infrastructure, plays a vital role in mitigating the impacts of floods. These strategies aim to reduce infrastructure damage, protect humans, minimize economic losses, preserve environmental integrity, and alleviate social disruption caused by floods. By implementing measures such as dams, levees, flood plain restoration, and wetland preservation, communities can effectively manage flood risk and enhance resilience to future disasters.

Conclusion and policy recommendations

Pakistan's unique geo-climatic circumstances and limited ability for adaptation have made it susceptible to floods in the past few decades. Climate hazards, such as floods, have an enormous influence on Pakistan's economy as they result in severe losses to livelihoods, houses, infrastructure, property services, and physical and psychological health. Therefore, it is crucial to implement suitable adaptation strategies at the national level to reduce flood risks. This study first identified the most significant flood intensifying factors and then flood risk mitigation strategies through an extensive literature review and interviews with experts. Afterward, hybrid FUCOM and fuzzy WASPAS method were used to examine and analyze the intensifying factors and mitigation strategies.

The findings revealed that in the context of Pakistan, *lack of governance, lack of funding and resources, and lack of flood control infrastructure* are the most significant flood intensifying factors. The reason behind this is instability as no government in Pakistan has completed its five-year tenure. The instability further results in poor law and order situation, low production and exports, and low funding or investments from foreign countries. Although the country's early independence-era flood control systems are still operational, they are not enough to address current climate change conditions. Therefore, effective governance, ample funding and resources, and robust flood control infrastructure would collectively help mitigate the toll of floods, encompassing reduced loss of life, infrastructure damage, economic setbacks, displacement of people, environmental harm, and social upheaval.

The study also highlighted the top three strategies—*adopting hard engineering strategies, maintaining existing infrastructure, and adopting soft engineering strategies*—that should be adopted by the government to control and reduce flood losses in the future. To combat the effects of climate change, particularly flooding, it is essential to construct massive structures in flood prone areas as a part of the hard engineering approach. These strategies aim to limit infrastructure damage, safeguard lives, minimize economic losses, protect the environment, and mitigate social disruption during floods. Implementing measures such as dams, levees, and flood plain restoration enhances community resilience to future disasters. The government and the people may work together to accomplish the following key goals to minimize the impacts of floods in Pakistan. The government should invest in the construction and maintenance of flood control infrastructure every year. The government can also use the more ecologically sound, long-lasting, aesthetically pleasing, and budget-friendly preexisting processes.

Based on the findings, the following strategies should be included in the national policy framework:

- Massive construction of new infrastructure requires substantial resources. Therefore, the government should allocate funds for hard engineering projects every year.
- In the provinces of Baluchistan and Sindh, ten dams were broken because of the 2022 floods. Therefore, the government should invest in the maintenance of the current flood control infrastructure every year and produce annual reports containing all the relevant facts.
- To implement soft engineering strategies, the government should invest in cutting-edge flood monitoring and forecasting technologies to increase the effectiveness of early warning systems, such as weather radars, river level monitors, and rain gauges.
- As a part of soft engineering strategies, the government should create and implement thorough land-use planning guidelines that forbid building in flood prone areas.
- Furthermore, the government should implement zoning regulations and building standards that emphasize flood resistance and guarantee the secure relocation of communities residing in high-risk areas.
- As a part of soft engineering strategies, the government should increase cooperation between pertinent authorities, hold frequent exercises, and give emergency responders specialized training.
- The government should create and spread concise procedures for effective evacuation, rescue efforts, and the distribution of aid during floods.

- The government should work together with local, national, and international organizations to exchange leading practices, technical know-how, and flood control resources.

The study has considered the real-time situation of the highly devastating 2022 floods in Pakistan and has identified and analyzed the relevant flood risk factors and flood risk mitigation strategies. Future research can explore the long-term effectiveness and sustainability of the identified flood risk mitigation strategies implemented in response to the 2022 floods in Pakistan. Additionally, there is scope for investigating the integration of emerging technologies, such as remote sensing and artificial intelligence, in enhancing flood risk assessment and management practices. Furthermore, comparative studies across different regions or countries facing similar flood challenges can provide valuable insights into the transferability and adaptability of flood risk mitigation strategies. More research can be done in this area by employing other MCDM methods, such as AHP, the technique for order of preference by similarity to ideal solution, DEMATEL, and VIKOR (VIekriterijumsko KOmpromisno Rangiranje).

Appendix

See Tables 9 and 10.

Table 9 Experts' details

Expert id	Organization	Education	Experience
1	Rescue 1122	BS	5
2	PDMA	BS	3
3	Disaster Management Authority	BS	10
4	Agriculture Department	M.Phill	11
5	Environment Protection Agency	MS	9
6	Agriculture Sector	MS	5
7	Disaster Management Authority	BS	9
8	Environment Protection Agency	MS	7
9	Disaster Management Authority	BS	8
10	Agriculture Sector	BS	8
11	Statistics information	PHD	1
12	Agriculture Sector	MS	6
13	Environment Protection Agency	BS	9
14	Disaster Management Authority	MS	5
15	Disaster Management Authority	BS	7
16	Disaster Management Authority	MS	10
17	Agriculture Sector	MS	7
18	UET Peshawar	PHD	6

Table 10 Experts' details

Expert id	Organization	Education	Experience
1	Disaster Management Authority	MS	7
2	Disaster Management Authority	MS	10
3	Environment Protection Agency	BS	7
4	Agriculture Department	BS	11
5	University	PHD	4
6	University	MS	2
7	Statistics and Information Department	PHD	7
8	Agriculture Department	PHD	3
9	Agriculture Department	MS	6
10	Disaster Management Authority	BS	5
11	Environment Protection Agency	PHD	7
12	Disaster Management Authority	BS	6
13	Environment Protection Agency	BS	8
14	Disaster Management Authority	MS	9
15	Disaster Management Authority	MS	7
16	Agriculture Department	MS	4
17	Statistics and Information Department	BS	3

Abbreviations

FUCOM	Fuzzy full consistency method
WASPAS	Weighted aggregated sum product assessment
F-WASPAS	Fuzzy weighted aggregated sum product assessment
MCDM	Multi criteria DECISION making
MARCOS	Measurement of alternatives and ranking according to the compromise solution
WSM	Weighted sum model
WPM	Weighted product model
GOP	Government of Pakistan
SOPs	Standard operating procedures

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Availability of data and materials
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Author contributions
Zeshan Alam: Investigation; Data curation; Methodology; Writing—original draft; Writing—review and editing. Yousaf Ali: Investigation; Methodology; Data curation; Writing—original draft; Writing—review and editing. Dragan Pamucar: Writing—review and editing. All author(s) read and approved the final manuscript.

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