

# FLOOD RISK DETERMINANTS IN GIS-BASED STUDIES: A SYSTEMATIC REVIEW USING AHP AND MCDA

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**Abstract.** This systematic review synthesizes flood risk determinants and methodological approaches in GIS-based studies, with emphasis on Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP). Guided by PRISMA principles, the review analyzed 22 peer-reviewed studies published between 2015 and 2025, retrieved from five major academic databases. The results indicate that GIS-integrated AHP and MCDA methods are the most commonly applied approaches in flood risk mapping, particularly in Asian regions, with a noticeable increase in publications after 2023. Physical factors such as elevation, slope, rainfall, and land use/land cover are consistently identified as key determinants of flood risk. However, social and economic variables remain underrepresented despite their importance in assessing vulnerability. Many studies also rely on static datasets, with limited consideration of temporal variability such as seasonal rainfall and land-use change. Key gaps identified include the need for improved model validation using historical flood records, integration of dynamic environmental variables, and more balanced incorporation of hazard, exposure, and vulnerability components. A conceptual framework is proposed to support future research in developing more accurate, context-specific, and integrated flood risk maps for disaster risk reduction, sustainable urban planning, and climate change adaptation.

**Keywords:** *flood risk, GIS, AHP, systematic review, risk determinants*

## Introduction

Flood events constitute a major global natural hazard, repeatedly affecting large populations and generating substantial social, economic, and environmental impacts (Kundzewicz et al., 2014; Schanze et al., 2006). The severity and frequency of floods have been exacerbated by rapid urbanization, land-use changes, and climate variability, which intensify the vulnerability of both urban and rural communities (Feng et al., 2021; Pelling, 2003). Managing flood risk effectively depends on understanding how flood hazards interact with exposed elements and their associated vulnerabilities to produce adverse impacts (Dimitrova and Snair, 2024). Within this framework, hazard relates to the likelihood and magnitude of flooding, exposure denotes the spatial presence of populations and assets in flood-prone areas, and vulnerability reflects the degree to which these elements are susceptible to damage (Saad et al., 2024). Advances in spatial technologies, particularly Geographic Information Systems (GIS), have provided powerful tools for flood risk assessment and mapping. GIS enables the integration of multi-dimensional spatial data, including topography, hydrology, forestry, land use, and socio-economic indicators, facilitating the identification of flood-prone areas and the prioritization of mitigation measures (Ahmad et al., 2026; Amilin and Jamru, 2025; Buaya et al., 2025; Jamru et al., 2023a; Jamru et al., 2023b; Jamru et al., 2024a; Jamru et al., 2024b; Jamru et al., 2022; Linda Roziani et al., 2013; Alaghmand et al., 2010). Furthermore, the integration of multi-criteria decision analysis (MCDA) techniques such as the Analytical Hierarchy Process (AHP) allows for the systematic

weighting of multiple hazard, exposure, and vulnerability factors, supporting more objective and evidence-based flood risk mapping (Nkonu et al., 2023; Büchele et al., 2006). Although widely applied, GIS-based AHP approaches frequently emphasise hazard or susceptibility analysis, while giving comparatively limited attention to exposure patterns and socio-economic vulnerability. This fragmented focus limits the ability of flood risk maps to fully support risk-informed planning and disaster management decisions.

### *Literature review*

Flood hazard describes the probability and potential severity of flooding within a specific spatial context. It is primarily governed by hydrological and geomorphological characteristics, including rainfall patterns, river discharge, soil infiltration capacity, topography, and drainage network density (Breinl et al., 2021). Intense rainfall occurring over areas with limited infiltration capacity and low-relief terrain commonly promotes surface water accumulation, thereby elevating flood hazard levels (Cutter et al., 2012). Mapping hazard is critical not only for predicting flood extents but also for informing early warning systems, evacuation planning, and infrastructure design. The quantification of flood hazard using GIS has been widely adopted, often integrating topographic indices, hydrological parameters, and satellite-derived datasets to produce high-resolution flood susceptibility maps (Ali et al., 2025; Mabahwi et al., 2025). Exposure refers to the spatial coincidence of populations, assets, and critical infrastructure with areas susceptible to flooding (De Bono and Mora, 2014). High exposure implies that more elements at risk coincide with areas of potential flooding. Factors such as population density, urban expansion, land-use patterns, proximity to rivers, and critical infrastructure increase exposure levels (Dong et al., 2025; Tierney et al., 2000). Understanding exposure patterns is essential for effective disaster risk reduction, as it allows policymakers to prioritize interventions for highly exposed communities and infrastructure (Wen et al., 2025). GIS-based exposure mapping facilitates the spatial representation of vulnerable populations and urban infrastructure, helping authorities identify hotspots that require targeted flood mitigation measures.

Vulnerability indicates how social, economic, and environmental systems respond to and are affected by flood events (Tascón-González et al., 2020). It is influenced by social, economic, and physical factors, such as income levels, literacy, building quality, accessibility to essential services, and environmental resilience (Rasool et al., 2024; Cutter et al., 2012). Highly vulnerable populations often experience disproportionately severe impacts even under moderate flooding conditions (Lee et al., 2021). Integrating vulnerability assessment into flood risk mapping allows for the identification of communities and assets that require targeted adaptation strategies and risk reduction measures. Multi-dimensional approaches combining social, economic, and physical indicators are increasingly recommended for a holistic understanding of flood vulnerability (Rasool et al., 2024). Nevertheless, the practical implementation of such multidimensional vulnerability frameworks within GIS–AHP models remains inconsistent, with many studies relying on limited or proxy socio-economic indicators due to data availability and methodological constraints. While numerous studies have examined flood hazard, exposure, and vulnerability using GIS-based approaches, the determinants of flood risk remain fragmented across different geographical and socio-economic contexts (Nkonu et al., 2023). A systematic synthesis is therefore required to identify the most frequently applied and influential factors, as well as to evaluate

methodological patterns in GIS–AHP/MCDA-based flood risk mapping. Such a review can enhance methodological consistency, support evidence-based flood risk management, and inform the development of integrated, spatially explicit flood risk maps for sustainable urban planning, disaster preparedness, and climate adaptation (Islam et al., 2025; Chan et al., 2022).

## **Materials and Methods**

### ***Review protocol: PRISMA***

This review adopted PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) as a guiding framework to ensure transparent and systematic reporting of the literature selection and synthesis process. PRISMA offers a set of internationally recognised reporting standards that enhance the transparency, completeness, and reproducibility of systematic reviews and meta-analyses (Moher et al., 2009). Although PRISMA does not prescribe specific methodological procedures, it provides essential guidance for transparent reporting. The review process comprised the development of research questions, systematic database searching, application of predefined inclusion and exclusion criteria, assessment of study eligibility, and synthesis of the selected literature.

### ***Formulation of research questions***

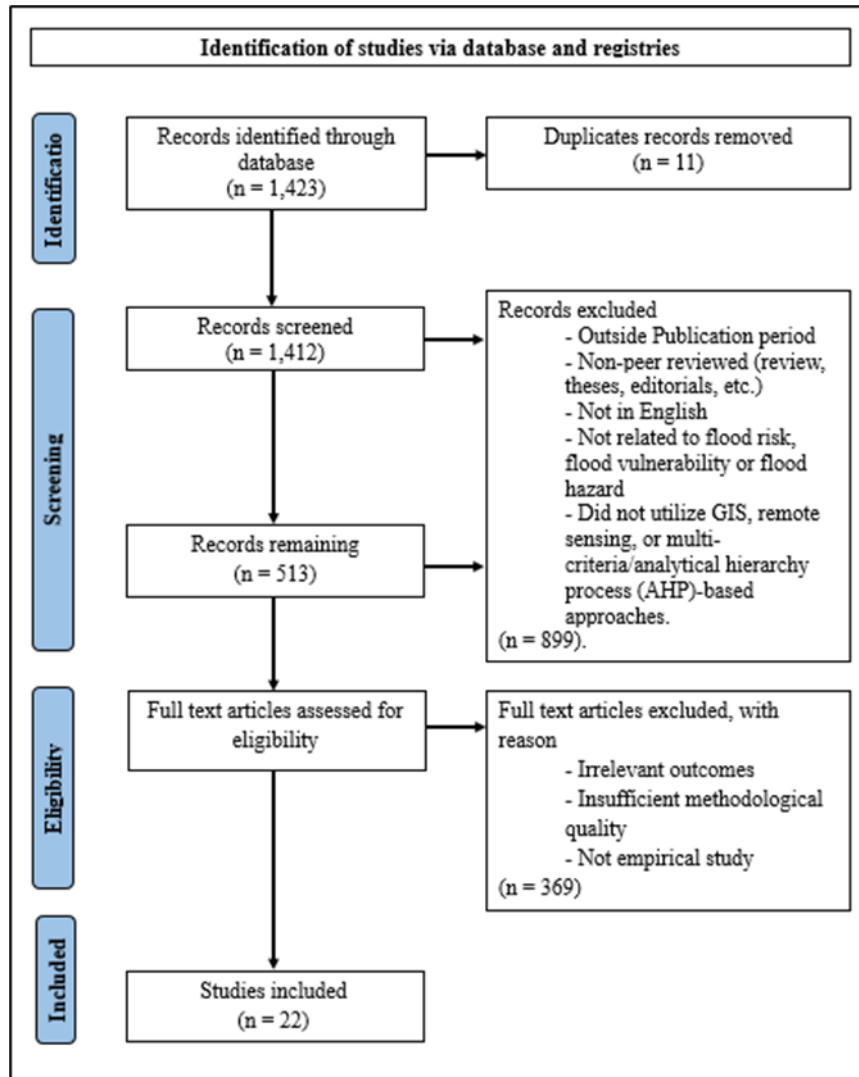
The research questions guiding this systematic review were developed to ensure consistency with the analytical focus of the study, particularly the synthesis of methodological patterns, commonly applied factors, and implications for future research in GIS–AHP-based flood risk assessment. Accordingly, this review seeks to address the following questions: (1) What are the key methodological characteristics of previous studies that applied GIS and AHP in flood hazard, exposure, vulnerability, and risk mapping? (2) What factors are most used across the hazard, exposure, and vulnerability components in GIS–AHP-based flood risk assessments? (3) What key gaps, limitations, and future research directions can be identified from existing studies to strengthen the development of flood risk mapping approaches?

### ***Data sources***

Relevant studies were identified through systematic searches of five electronic databases: Scopus, Springer, Wiley Online Library, ScienceDirect and Google Scholar. These databases were chosen because they provide broad access to peer-reviewed research in environmental science, hydrology, and GIS-related disciplines, as well as their frequent use in systematic reviews on flood risk assessment, vulnerability mapping and MCDA applications (Page et al., 2021).

### ***Systematic search strategy***

The systematic literature search was conducted through four sequential stages, namely identification, screening, eligibility assessment and final inclusion, as illustrated in *Figure 1*.



**Figure 1.** PRISMA flow diagram of the study selection process (adapted from PRISMA 2020).

### Identification

The identification stage involved developing synonyms, related terms, and variations of the study's core keywords, namely flood risk, flood hazard, vulnerability, and GIS/AHP. This approach was intended to maximise the retrieval of relevant literature across databases. Keyword development was guided by frameworks for systematic reviews in environmental and geospatial studies (Page et al., 2021; Moher et al., 2009) and supported by terms from previous flood risk and GIS-AHP studies. The primary literature search was conducted using Scopus, Springer, and Wiley Online Library due to their advanced search functionalities, multidisciplinary coverage, and rigorous indexing, which are particularly suitable for research in hydrology, disaster management, and geospatial analysis (Tingsanchali, 2012; Merz et al., 2010). Search strategies were constructed using Boolean operators, phrase searching, truncation, wildcards, and quotation marks to ensure consistency and reproducibility (Table 1). In addition, ScienceDirect and Google Scholar was included as a supplementary database to broaden the scope of the search, in line with recommendations for comprehensive environmental literature retrieval (Kitchenham and Charters, 2007). The comprehensive

search across all databases yielded a total of 1,423 records, as illustrated in *Figure 1*. The identification process was conducted in accordance with the PRISMA 2020 reporting guidelines (Page et al., 2021).

**Table 1.** *The search string.*

Database	Search string
Scopus	TITLE-ABS-KEY (("flood risk" OR "flood hazard" OR "flood vulnerability") AND ("GIS" OR "Geographic Information System" OR "geospatial") AND ("AHP" OR "Analytic Hierarchy Process" OR "multi-criteria decision analysis" OR "MCDA"))
Springer	("flood risk" OR "flood hazard" OR "flood vulnerability") AND ("GIS" OR "Geographic Information System" OR "geospatial") AND ("AHP" OR "Analytic Hierarchy Process" OR "multi-criteria decision analysis" OR "MCDA")
Wiley online library	("flood risk" OR "flood hazard" OR "flood vulnerability") AND ("GIS" OR "Geographic Information System" OR "geospatial") AND ("AHP" OR "Analytic Hierarchy Process" OR "multi-criteria decision analysis" OR "MCDA")

### Screening

Following the identification process, 11 duplicate records were removed, resulting in 1,412 records for screening. The remaining records were screened based on their titles and abstracts using predefined inclusion and exclusion criteria (*Table 2*). These criteria were developed in accordance with the PRISMA guidelines to ensure that only studies relevant to the research objectives (Kitchenham and Charters, 2007), namely flood risk mapping using GIS, Hazard×Exposure×Vulnerability factors, and AHP/MCDA approaches were retained. Consistent with standard systematic review practices, a publication period filter was applied to enhance feasibility and relevance (Okoli, 2015). Only studies published between 2015 and 2025 were considered, under the assumption that relevant evidence would be reported within this timeframe (Higgins and Green, 2011). During the title and abstract screening stage, 899 records were excluded for not meeting the inclusion criteria. This left 513 records for further consideration. Of these, 391 full-text articles were successfully retrieved and assessed for eligibility.

**Table 2.** *The inclusion and exclusion criteria.*

Criteria	Inclusion	Exclusion
Timeline	2015-2025	Articles published outside this period
Framework	Study incorporating hazard, exposure, and/or vulnerability factors	Studies without risk related factors or purely descriptive studies
Study focus	Flood risk, flood susceptibility, flood hazard or flood vulnerability using GIS based analysis	Studies not related to flood risk or not employing GIS approaches
Document type	Journal articles reporting empirical findings	Reviews, conference papers, reports, theses, book chapters, editorials
Methodology	GIS based spatial analysis, mapping or modelling	Non spatial, theoretical or conceptual studies
Language	English	Non-English

## ***Eligibility***

At the eligibility stage, the full-text versions of 391 articles were examined in detail to ensure full compliance with the inclusion criteria. Articles were excluded if they did not focus on flood risk, did not involve GIS-based analysis, lacked consideration of hazard, exposure, or vulnerability factors, or did not apply multi-criteria decision-making methods such as AHP/MCDA. Following this assessment, 369 full-text articles were excluded, resulting in a final sample of 22 studies that met all eligibility requirements and were included in the systematic review. Although no formal quality scoring system was applied, methodological robustness was implicitly considered during eligibility assessment, particularly regarding the use of validation techniques, transparency of factor selection, and clarity of GIS–AHP implementation.

## ***Studies included***

Demographic and bibliographic information of the included studies was exported from Mendeley into a structured Microsoft Excel database. Extracted information included study title, authors, journal, year of publication, study location, and type of flood risk analysis. Full-text articles were reviewed in detail to extract data relevant to the research questions, including study objectives, spatial and methodological characteristics, hazard and vulnerability factors considered, and key findings related to flood risk assessment. Data extraction was conducted systematically using a predefined extraction framework to ensure consistency across studies. The extracted data were analysed using frequency analysis to identify commonly applied GIS methods, H×E×V factors, and decision-making approaches. Additionally, thematic analysis was applied to synthesise recurring patterns, methodological frameworks, and best practices in flood risk assessment. This approach enabled a comprehensive and structured synthesis of existing evidence on GIS-based flood risk mapping and H×E×V evaluation.

## **Results and Discussion**

### ***Descriptive analysis of included studies***

The geographical distribution of the selected studies shows a strong concentration in Asia (77%), followed by Africa (23%) and Europe (5%) (*Figure 2*). This pattern reflects the high vulnerability of developing regions, particularly South and Southeast Asia, to flood hazards and the increasing reliance on GIS-based AHP approaches for flood risk assessment in these regions. The temporal distribution of the included studies indicates a clear increasing trend in the application of GIS–AHP approaches for flood risk assessment in recent years. *Figure 3* shows only one study was published in 2017 and 2018 respectively, followed by a gradual increase in 2021 and 2022 (two studies each). Publication activity accelerated from 2023 onwards, with eight studies published in 2024 and six studies in 2025. This pattern suggests a growing research interest and wider acceptance of GIS-based multi-criteria decision analysis techniques in flood-related studies.

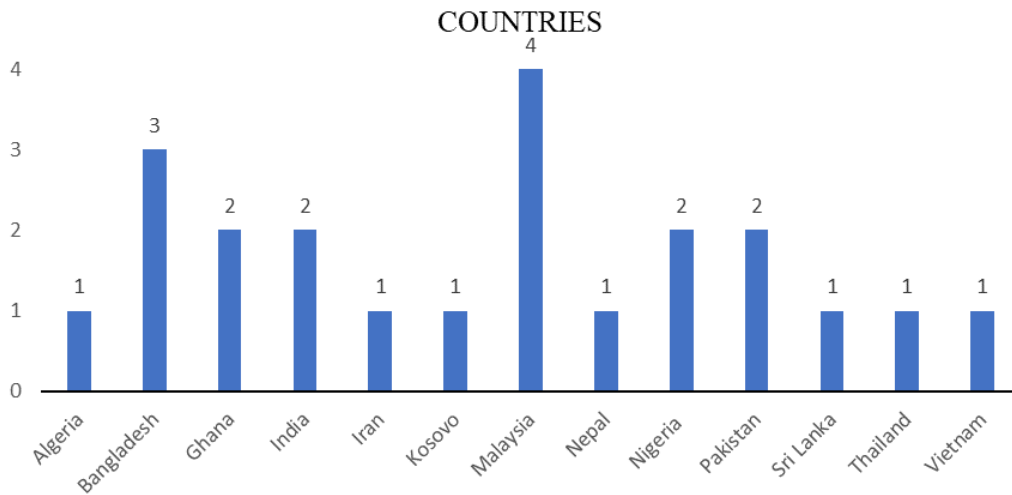


Figure 2. Geographical and quantitative distribution of articles selected research.

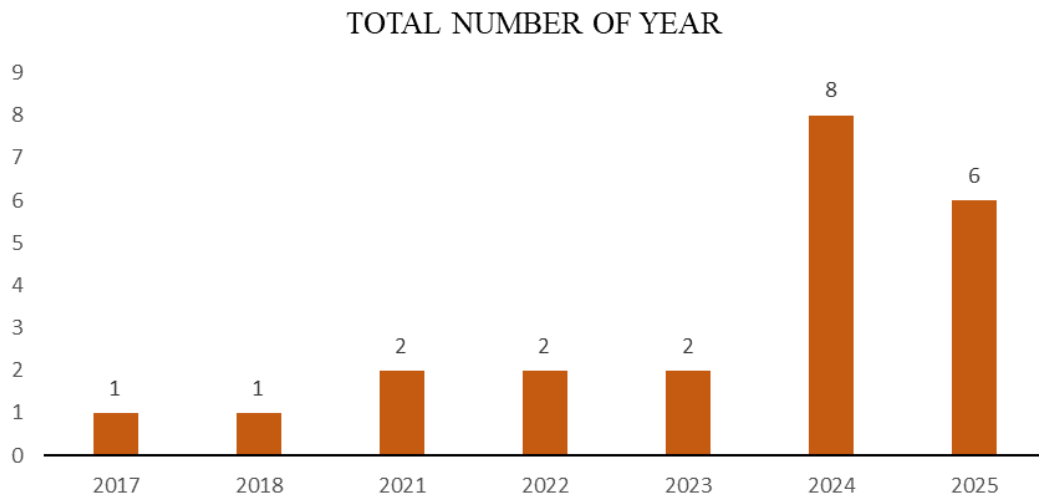
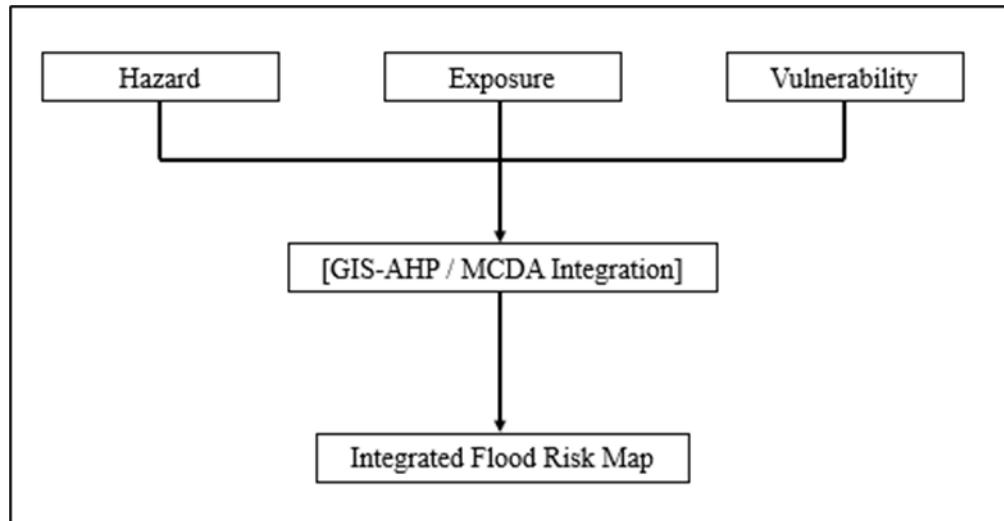


Figure 3. Distribution of selected articles by publication year.

### ***Proposed conceptual framework for integrated flood risk mapping***

The methodological characteristics of the 22 included studies reveal a strong dominance of GIS-based multi-criteria decision-making approaches, particularly the AHP, in flood related spatial assessments. Most studies applied the conventional GIS–AHP framework either as a standalone method for flood susceptibility or hazard mapping or integrated with additional analytical components to enhance model robustness (Ashfaq et al., 2025; Kabenla et al., 2024). Several studies strengthened their methodological reliability through validation techniques such as ROC/AUC, RMSE, and historical flood comparison, indicating an increasing emphasis on model verification within recent flood research (Nkonu et al., 2023; Sharir et al., 2022), hybrid methodological frameworks were also increasingly adopted by combining AHP with approaches such as frequency ratio, fuzzy logic, morphometric analysis, hydrological modelling, and runoff estimation (Ramdani et al., 2024; Chukwu et al., 2023; Ngo et al., 2022). The focus of the studies ranged from flood susceptibility and hazard mapping to vulnerability and comprehensive flood risk assessment, with relatively few studies

explicitly adopting an integrated hazard–exposure–vulnerability (HxExV) framework (Chaudhary et al., 2024; Ramkar and Yadav, 2021). All reviewed studies utilized GIS as the primary platform, often enhanced with remote sensing and advanced elevation datasets (Imani et al., 2025; Jariwala and Agnihotri, 2025). To synthesise these methodological patterns and common factors, a conceptual framework for GIS–AHP-based flood risk assessment is proposed (*Figure 4*) (Ashfaq et al., 2025; Kabenla et al., 2024; Seejata et al., 2018). The framework is structured around three interrelated components of flood risk: hazard, exposure, and vulnerability.



**Figure 4.** *Conceptual Framework for Integrated Flood Risk Assessment based on GIS-AHP and MCDA approaches, synthesised from the reviewed studies.*

The hazard component represents the physical and hydrometeorological drivers of flooding and is informed by factors most frequently applied across flood susceptibility and hazard mapping studies. These include rainfall, elevation, slope, drainage density, flow accumulation, Topographic Wetness Index (TWI), Stream Power Index (SPI), soil characteristics, and geomorphological parameters (Imani et al., 2025; Jariwala and Agnihotri, 2025; Seejata et al., 2018). The exposure component captures the spatial coincidence of populations, land use, and critical assets within flood-prone areas. Exposure-related factors commonly include land use/land cover, proximity to rivers, built-up areas, infrastructure distribution, and population density (Kader et al., 2024; Nkonu et al., 2023; Hadi et al., 2017). The vulnerability component represents the susceptibility of exposed elements to flood damage and is informed by socio-economic and demographic indicators. Indicators reported in the reviewed studies include literacy rate, income/economic condition, housing quality, infrastructure accessibility, and composite social vulnerability indices (Efraimidou and Spiliotis, 2025; Sharkar et al., 2025; Chaudhary et al., 2024). At the core of the framework is the GIS–AHP/MCDA analytical engine, which enables systematic weighting, standardisation, and spatial integration of hazard, exposure, and vulnerability factors. Within this framework, hazard, exposure, and vulnerability components are standardised and weighted independently prior to spatial integration, allowing flexibility in adapting the model to local data availability and decision-making priorities. AHP remains the dominant weighting technique, often enhanced through hybrid approaches such as fuzzy logic, frequency ratio, morphometric analysis, or hydrological modelling. However, heavy

reliance on expert judgement for AHP weighting, often without sensitivity analysis, raises concerns regarding subjectivity, reproducibility, and inter-study comparability across different geographical contexts. Validation techniques, including ROC/AUC, RMSE, and historical flood comparison, are incorporated to improve model robustness and credibility (Ashfaq et al., 2025; Sharir et al., 2022). The final output of the framework is an integrated flood risk map, providing spatially explicit decision-support information for flood mitigation, land-use planning, disaster preparedness, and climate adaptation strategies. By synthesising the most consistently applied determinants and methodological practices identified in the literature, the proposed framework offers a transferable and evidence-based structure for future GIS–AHP flood risk studies, while directly addressing the identified gap in holistic hazard–exposure–vulnerability integration (Chaudhary et al., 2024; Ramkar and Yadav, 2021; Seejata et al., 2018).

### ***Methodological characteristics of included studies***

The methodological characteristics of the 22 included studies reveal a strong dominance of GIS-based multi-criteria decision-making approaches, particularly AHP, in flood-related spatial assessments. Most studies applied the conventional GIS–AHP framework either as a standalone method for flood susceptibility or hazard mapping (Kabenla et al., 2024; Kader et al., 2024; Nizamani et al., 2024; Seejata et al., 2018), integrated with additional analytical components to enhance model robustness. Several studies strengthened their methodological reliability through the inclusion of validation techniques such as ROC/AUC, RMSE, and historical flood comparison (Ashfaq et al., 2025; Nkonu et al., 2023; Sharir et al., 2022), indicating an increasing emphasis on model verification within recent flood research. In addition, a growing number of studies adopted hybrid methodological frameworks by combining AHP with other analytical approaches such as frequency ratio, fuzzy logic, morphometric analysis, hydrological modelling, and runoff estimation. For example, Ashfaq et al. (2025) integrated GIS–AHP with frequency ratio and ROC/AUC, while Ngo et al. (2022) employed a combination of GIS–AHP and fuzzy overlay techniques. Other studies incorporated hydrological components such as the SCS–CN model (Chukwu et al., 2023) and morphometric parameters (Ramdani et al., 2024), a methodological evolution toward more comprehensive and interdisciplinary flood assessment models.

In terms of assessment focus, most studies primarily addressed flood susceptibility and hazard mapping (Agaj, 2025; Jariwala and Agnihotri, 2025; Ogundolie et al., 2024; Seejata et al., 2018), whereas a smaller subset extended their analyses to include flood vulnerability (Sharker et al., 2025; Nkonu et al., 2023) and comprehensive flood risk assessment (Chaudhary et al., 2024; Ramdani et al., 2024). Few studies have explicitly applied an integrated hazard–exposure–vulnerability (HxExV) framework (Chaudhary et al., 2024), suggesting that holistic flood risk modelling remains underrepresented in the existing literature. This trend indicates a prevailing emphasis on physical susceptibility mapping rather than comprehensive risk assessment, potentially limiting the practical usefulness of such studies for integrated flood risk management. This methodological gap further supports the relevance of adopting an integrated risk-based framework in the present study. Regarding spatial platforms, all reviewed studies utilized GIS environments as the primary operational platform for spatial analysis and modelling. Several studies enhanced their spatial datasets using remote sensing products and advanced elevation data, such as IFSAR-derived layers (Imani et al., 2025) and satellite-based environmental indices including NDVI, TWI, and SPI (Jariwala and

Agnihotri, 2025; Nizamani et al., 2024). This consistently demonstrates the central role of GIS as a flexible platform for integrating multi-source spatial data and supporting flood-related decision-making. Across the reviewed literature, the most frequently employed flood conditioning factors include elevation, slope, rainfall, distance to river, drainage density, land use/land cover, and soil characteristics (Ashfaq et al., 2025; Kader et al., 2024; Seejata et al., 2018). Several studies further expanded their analysis by incorporating vegetation indices (NDVI), hydrological indices (TWI), and flow accumulation parameters (Imani et al., 2025; Jariwala and Agnihotri, 2025). In studies focusing on vulnerability and risk, socio-economic indicators such as population density, literacy rate, infrastructure, and economic conditions were also included (Chaudhary et al., 2024; Ramkar and Yadav, 2021; Hadi et al., 2017). The consistency of these factors across different geographical contexts reinforces their scientific relevance and justifies their integration within the conceptual framework of the present study.

### *Common factors used*

An examination of the selected studies indicates a clear consistency in the selection of flood conditioning factors across different geographical contexts. Among the most frequently applied physical factors are elevation and slope, which are widely recognized as fundamental topographic controls influencing surface runoff behaviour and flood accumulation. These variables were consistently incorporated in numerous studies focusing on flood susceptibility and hazard mapping (Ashfaq et al., 2025; Kader et al., 2024; Seejata et al., 2018). Lower elevation areas and gentle slopes are commonly associated with higher flood susceptibility due to reduced drainage efficiency and increased water retention. Rainfall also emerged as one of the most dominant hydrometeorological factors in flood-related assessments. Several studies explicitly highlighted precipitation as a key driver in determining flood-prone zones, particularly in monsoon-affected regions such as South and Southeast Asia (Jariwala and Agnihotri, 2025; Nizamani et al., 2024; Seejata et al., 2018). The inclusion of rainfall as a core parameter reflects its direct influence on runoff generation and flood occurrence. Another commonly utilized factor is distance to river and drainage density, which represent hydrological connectivity and exposure to fluvial flooding. Studies have shown that areas located closer to river channels or with high drainage density tend to experience greater flood susceptibility (Ashfaq et al., 2025; Kader et al., 2024). This relationship supports the theoretical understanding that proximity to water bodies significantly increases flood risk due to overflow potential during extreme discharge events.

LULC was also consistently employed across most studies, reflecting the role of anthropogenic activities in influencing flood dynamics. Urban expansion, deforestation, and agricultural modification have been linked to increased surface runoff and reduced infiltration capacity (Ramdani et al., 2024; Nkonu et al., 2023; Seejata et al., 2018). The frequent inclusion of LULC confirms its importance in both physical and vulnerability-based flood assessments. In addition to these core factors, several studies incorporated soil characteristics such as soil type and permeability, which affect infiltration rates and water retention capacity (Kader et al., 2024; Perera, 2021). Similarly, advanced hydrological indices including TWI, NDVI, flow accumulation, and SPI were increasingly adopted in more recent studies, demonstrating a methodological shift toward more data-driven and process-oriented flood modelling approaches (Imani et al.,

2025; Jariwala and Agnihotri, 2025; Nizamani et al., 2024). For studies extending beyond hazard and susceptibility toward vulnerability and risk assessment, the inclusion of socio-economic and demographic indicators became more evident. Indicators such as population density, literacy rate, infrastructure accessibility, and economic conditions were used to capture the human dimension of flood impacts (Chaudhary et al., 2024; Ramkar and Yadav, 2021; Hadi et al., 2017). This highlights the growing recognition that flood risk is not solely controlled by physical processes but also shaped by societal vulnerability. Overall, the consistency of these commonly used factors across diverse regions strengthens their scientific credibility and supports their relevance for application in the present study. The selected factors in this research are therefore grounded in established methodological practices and supported by a broad body of recent empirical evidence.

### ***Implications for future research***

The synthesis of the reviewed studies demonstrates that the integration of GIS with AHP and related multi-criteria decision-making (MCDA) techniques has become a dominant methodological framework for flood susceptibility, hazard, vulnerability, and risk assessment across diverse geographical contexts (Kabenla et al., 2024; Kader et al., 2024; Sharir et al., 2022). However, most studies rely on a relatively similar set of physical conditioning factors, such as elevation, slope, land use/land cover, distance to river, and rainfall. While these variables are scientifically justified, their repeated use may limit the ability of models to capture the full complexity and spatial heterogeneity of flood risk, particularly at the local scale (Agaj, 2025; Nizamani et al., 2024). Future research should therefore explore the inclusion of more context-specific variables, such as dynamic land-use change, localized climate variability, and socio-economic characteristics, to enhance the sensitivity and realism of flood risk models (Efraimidou and Spiliotis, 2025; Chaudhary et al., 2024). Another important implication concerns model validation practices. Although several studies have incorporated validation techniques such as ROC/AUC, RMSE, or comparison with historical flood events, comprehensive validation remains inconsistently applied across the literature (Ashfaq et al., 2025; Imani et al., 2025; Nkonu et al., 2023). This indicates a critical need for future studies to strengthen the validation component by systematically integrating empirical flood records, post-event satellite imagery, or long-term hydrological datasets. Strengthening model validation would improve the credibility, robustness, and practical applicability of flood risk maps for real-world disaster management and planning.

Furthermore, the review reveals a methodological gap in the holistic integration of risk components. A substantial number of studies focus primarily on flood susceptibility or vulnerability as isolated outcomes, without fully integrating hazard, exposure, and vulnerability into a comprehensive flood risk framework (Ogundolie et al., 2024; Shadmaan and Hassan, 2024; Perera, 2021). Future research is therefore encouraged to adopt more comprehensive risk frameworks that explicitly combine these three components. Such an integrated approach would be more consistent with contemporary disaster risk theory and would provide more meaningful and actionable insights for policymakers, planners, and local authorities in designing effective flood mitigation and adaptation strategies. Future GIS–AHP flood risk studies should therefore move beyond static representations by incorporating temporal land-use change, climate variability, and scenario-based analyses to better reflect evolving flood risk conditions.

## Conclusion

This systematic review highlights the effectiveness of integrating GIS with AHP and related multi-criteria decision-making approaches for flood risk assessment. The proposed conceptual framework provides a structured and evidence-based approach for integrating hazard, exposure, and vulnerability components, enabling the production of spatially explicit flood risk maps to support urban planning, disaster mitigation, and climate adaptation. Nevertheless, limitations persist, including inconsistent representation of socio-economic vulnerability indicators, potential regional specificity of conditioning variables, and reliance on available spatial datasets, which may affect the transferability of the framework across different contexts. The framework demonstrates practical value in identifying high-risk areas, prioritising mitigation measures, and informing policy development. Future research should therefore incorporate dynamic land-use changes, localised climate variability, improved validation strategies, and broader socio-economic indicators to enhance model robustness and contextual relevance. In the context of increasing flood risks driven by rapid urbanisation and climate change, the proposed GIS–AHP-based framework offers a timely and practical decision-support tool, particularly for data-scarce regions requiring integrated and evidence-based flood risk management and governance.

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## Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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