

A systematic literature review of digital elevation models and hydrological models integration for advanced flood risk management

Raheel Ahmad , Khairul Nizam Abdul Maulud , Umair Bin Zamir , Siti Fatin Mohd Razali , Zaher Mundher Yaseen , Biswajeet Pradhan , Mohd Nazish Khan & Bekzod Eshquvvatov

To cite this article: Raheel Ahmad , Khairul Nizam Abdul Maulud , Umair Bin Zamir , Siti Fatin Mohd Razali , Zaher Mundher Yaseen , Biswajeet Pradhan , Mohd Nazish Khan & Bekzod Eshquvvatov (2025) A systematic literature review of digital elevation models and hydrological models integration for advanced flood risk management, *Geomatics, Natural Hazards and Risk*, 16:1, 2549487, DOI: [10.1080/19475705.2025.2549487](https://doi.org/10.1080/19475705.2025.2549487)

To link to this article: <https://doi.org/10.1080/19475705.2025.2549487>



© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 21 Aug 2025.



Submit your article to this journal [↗](#)



Article views: 622



View related articles [↗](#)



View Crossmark data [↗](#)

A systematic literature review of digital elevation models and hydrological models integration for advanced flood risk management

Raheel Ahmad^a, Khairul Nizam Abdul Maulud^{a,b}, Umair Bin Zamir^c, Siti Fatin Mohd Razali^b, Zaher Mundher Yaseen^d, Biswajeet Pradhan^e, Mohd Nazish Khan^f and Bekzod Eshquvvatov^f

^aEarth Observation Centre, Institute of Climate Change, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia; ^bDepartment of Civil Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia; ^cSindh Education and Literacy Department, Government of Sindh, Karachi, Pakistan; ^dCivil and Environmental Engineering Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia; ^eCentre for Advanced Modelling and Geospatial Information Systems (CAMGIS), Faculty of Engineering and Information Technology, School of Civil and Environmental Engineering, University of Technology Sydney, Ultimo, New South Wales, Australia; ^fDepartment of Geography and Natural Resources, Sharof Rashidov Samarkand State University, Samarkand, Uzbekistan

ABSTRACT

Floods are one of the most prevalent natural disasters, and advancements in geospatial technologies have revolutionized flood management, particularly the use of Digital Elevation Models (DEMs) in hydrological modelling. However, a comprehensive analysis DEMs integration in flood risk management is lacking. This study addresses this gap through a thorough Systematic Literature Review focusing on the combined application of DEMs and hydrological models in flood mitigation and risk management. The SLR scrutinized 21 articles, revealing eight key themes: DEM data sources and characteristics, DEM integration with hydrological models, flood hazard mapping applications, terrain impact assessment, model performance evaluation, machine learning in flood management, ecosystem services and resilience, and policy and governance implications. These findings emphasize the importance of precise DEM selection and correction for successful flood modelling, highlighting Advanced Land Observing Satellite as the most effective freely available DEM for use with the HEC-RAS unsteady flood model. This integration significantly enhances flood mitigation efforts and strengthens management strategies. Finally, this study underscores the pivotal role of DEM integration in crafting effective flood mitigation strategies, especially in addressing climate change challenges and bolstering community and ecosystem resilience.

ARTICLE HISTORY

Received 13 May 2025
Accepted 10 August 2025

KEYWORDS

Floods; hydrological cycle; climate change; risk management; climate resilience

1. Introduction

Floods are the most pervasive and calamitous natural disaster globally (Avila-Aceves et al. 2023). Hence, there is a need to develop comprehensive strategies for mapping and modelling. In this regard, geospatial technologies are widely being used for flood mapping, mitigation and risk assessment (Taloor et al. 2024; Yang 2024). Flood inundation mapping is typically performed using remote sensing datasets (Bhattacharya et al. 2019; Islam and Ahamed 2023). Taloor et al. (2025) is convinced that SAR and optical remote sensing data integration provided the better flood hazard evaluations and hence quick post-flood management measures can be achieved. Flood modelling and simulation are integral parts of flood studies (Xu et al. 2022). The geospatial technologies have been exploited for glacial lake studies particularly in the term of flash floods modelling and mapping (Taloor et al. 2022). It is necessary to discuss the differences between the hydrological, hydraulic and hydrodynamic modelling because the models are slightly different from each other, while they overlap as well. The integration of hydrological and hydraulic models is widely acknowledged as an important method for flood mapping (Teng et al. 2017). Moreover, it is also being utilized for the improvement of hydrodynamic models,

CONTACT Khairul Nizam Abdul Maulud  knam@ukm.edu.my

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

specifically in urban flood modelling in 2D using Shallow Water Equations (Guo et al. 2023). However, the utilization of Digital Elevation Models (DEM) for flood modelling and simulation is inevitable because of the instant, near actual, and detailed availability of the terrain information (Xu et al. 2021).

The mapping of flood inundations using remote sensing involves different techniques (Munasinghe et al. 2018; Sajjad et al. 2023). These flood inundations were used to assess the accuracy of flood models and simulations. The data can be compared to the ground based DEM and laser altimetry even in riverbed mapping, which is integral for analysis of flood inundations (Bures et al. 2019). However, the use of ground surveys and laser altimetry-based DEMs is costly and requires an enormous amount of time and effort (Roub et al. 2012). Therefore, the its use in conjunction with commercially available DEMs has emerged over the past decade (Azizian and Brocca 2020). The quality of the topographic characteristics of the flood plain in the model largely depend on the DEM spatial resolution, that is, for a higher spatial resolution, better representation of the topography (Bhuyian and Kalyanapu 2018). The evaluation for the accuracy of DEMs is largely carried out using a number of criteria that also differentiate their usability in different applications (Khal et al. 2020). In this regard, the vertical accuracy of some of the freely available DEMs has been assessed, and it has been suggested that resolution and both relative and absolute errors should be considered in the application to a flood model (Muench et al. 2022; Meadows et al. 2024).

In this study, the author would have focused on hydrological modelling in the context with floods and had some overlaps with hydraulic and hydrodynamic modelling. Many hydrological models have been developed over time and are widely utilized for flood simulation and control (Zhai et al. 2021; Zhai et al. 2021; Icyimpaye et al. 2022). A number of software have been utilized for conducting flood modelling worldwide, such as HEC-RAS (Azizian and Brocca 2020; Khojeh et al. 2022), MIKE (Parvaze et al. 2022), LISFLOOD (Cantoni et al. 2022), TUFLOW (Jamali et al. 2019) and others that work on the criteria of different models, such as 1D, 2D, and hybrid hydrological models. Data preparation for flood models can be developed using different techniques and software solutions. Similarly, satellite-based precipitation products can provide better results for HEC-HMS (Belayneh et al. 2020). Global hydrological models can provide daily flow data, even in data-scarce regions, allowing the development of global stochastic flood models. These models use simulated discharge to derive the spatial dependency of flood events, thus overcoming the limitations of historical record availability. Stochastic flood models can simulate realistic flood events by incorporating spatial dependence, which has a significant impact on monetary loss calculations (Olcese et al. 2022). The semi-distributed hydrological model, GRSD, can perform better to simulating flood peaks during flash floods (Peredo et al. 2022). Flood mitigation and planning based on the model results are integral for better flood management. Afreen et al. (2022) emphasized the importance of organized land use planning and flood zonation in the study area to manage floods effectively. This highlights the need to implement effective land use management strategies based on scientifically determined vulnerable areas to mitigate the impacts of floods. Furthermore, it emphasizes the significance of utilizing statistical models and satellite remote sensing data *via* Geographic Information System (GIS) platforms to develop effective strategies for managing the negative consequences of flood threats.

Flood models and DEM are integral to each other for flood mitigation and risk assessment. Although plenty of work has been carried out in the past, such as Sanders (2007), the correlation between DEM and flood inundation modelling using different available datasets. Yan et al. (2015) discussed low-cost space-borne DEM datasets and explored their potential for determining different flood parameters. Musa et al. (2015) highlighted the applications of DEM and other datasets for surface water modelling. Grimaldi et al. (2016) assessed not only DEM but also other remote sensing datasets to examine the uncertainty of hydraulic flood models. Hawker et al. (2018) discussed the errors generated over a period of time using Shuttle Radar Topographic Mission and its derived datasets. This study aimed to review the integrated role of flood models and DEMs in flood mitigation and risk assessment. This study further elaborates on the already carried out work and aims to fill the gap by performing a systematic literature review on the different available DEMs and their characteristics, particularly in the context of different flood models and software, as well as its integrated role in flood risk management and mitigation. The review extracted articles from reputed databases, such as Tylor Francis, Science Direct, Sage Journal, Web of Science, Scopus, and Emerald.

This research was carried out using an integrated method, a quantitative and qualitative approach, which aims to provide a detailed understanding of the integration of DEM and flood modelling and to contribute valuable additions to the currently available research in this context.

2. Analytical framework

Considering the increasing frequency of floods worldwide, mainly due to global climate change, there is a deficiency in the comprehensive examination and recognition of patterns in current research pertaining to flood modelling and mapping. Conventional approaches to literature review may inadvertently introduce biases and transparency challenges, thereby complicating the ability of succeeding researchers to reproduce or comprehensively analyze the referenced studies. Therefore, most authors select systematic reviews as a means to distinguish scientific breakthroughs and trends (O'Hagan et al. 2018). To fill this void, the present study utilized a Systematic Literature Review (SLR) approach, with particular emphasis on the significance of DEM and flood modelling in support of better flood management and mitigation. The analytical framework delineated in Figure 1 serves as a roadmap for the review procedure, allowing the authors to pinpoint research gaps and offer insights for prospective investigations.

The main research question that may guide this review is as follows: How can the DEM and hydrological models relate to each other for flood analysis and mitigation? This study highlights the crucial

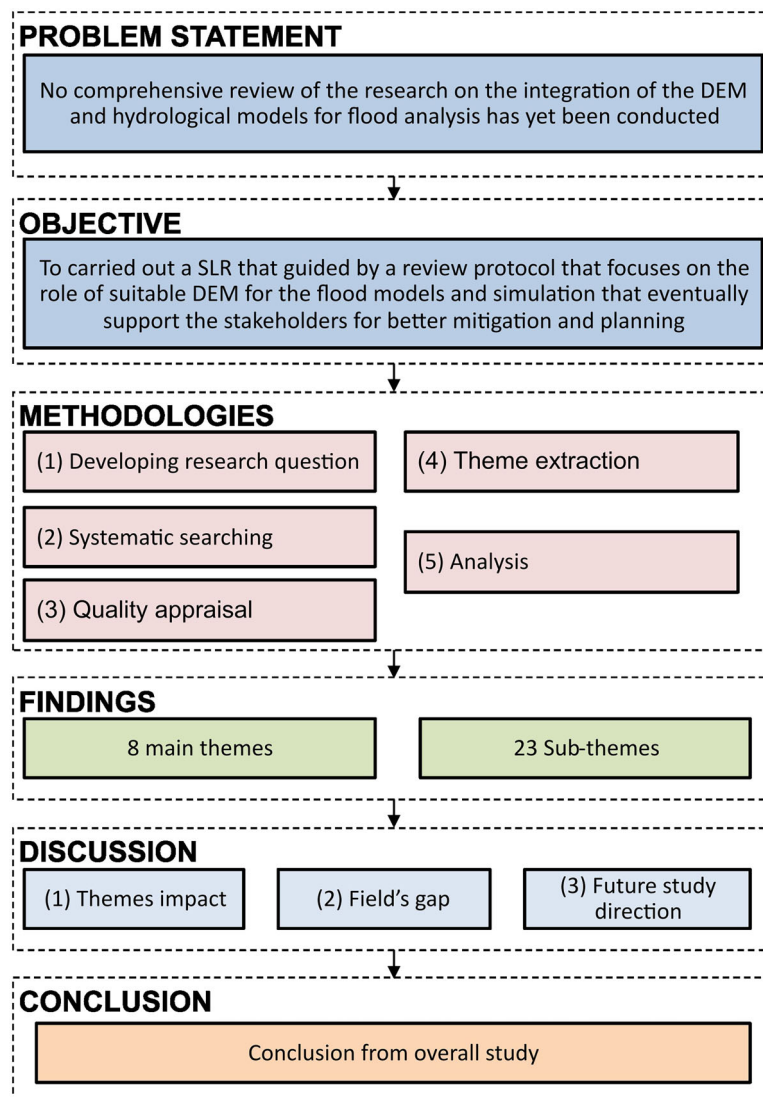


Figure 1. Workflow structure of this research.

linkage between DEM and hydrological models and their impact on flood risk assessment and mitigation. By carrying out SLR, this research aims to reveal the challenges in the use of different DEMs and their effects on hydrological models that eventually lead to the setting of a baseline for flood risk assessment and mitigation strategies. This information will contribute to further enhancement of the field and provide guidance for future research.

3. Methodology

This study's current methodology was guided by a review protocol named ROSES. ROSES (The Reporting on the Systematic Evidence Syntheses) is a set of procedures for SLR and investigations in natural sciences (Haddaway et al. 2018; Pant et al. 2023). ROSES aims to incentivize researchers to provide pertinent information with optimal details. In instances where applicable, the authors contemplated alternative propositions suggested in the review to ensure that the review procedure aligns with the intended objectives.

3.1. Developing the research question

The research question was formulated by utilizing two different sources: First, ideas derived from the earlier studies, such as Xu et al. (2021), Khojeh et al. (2022) and Arash and Yasi (2023). Each article was related to the DEM and Flood modelling, and simulations. Secondly, the acronym PICO, which is 'P' for "Patient or Problem", 'I' for "Intervention", 'C' for "Context" and 'O' for "Outcome" (Cooke et al. 2012) and utilized in many studies for rapid reviews (Rathbone et al. 2017).

Based on this understanding, the reviewers provided three main elements in this review: integration of the DEM and Hydrological models (problem), contribution (intervention), and application in flood management and mitigation planning (Context/Outcome). Therefore, it allows the reviewers to formulate the core research question of the review: How does integrating different types of DEMs impact the accuracy of hydrological model and flood mitigation outcomes across various terrains?

3.2. Systematic searching techniques

To obtain pertinent articles, three systematic search strategies, that is, identification, screening, and eligibility, were implemented, as suggested by Mohamed Shaffril, Samsuddin, and Abu Samah et al. (2021). These procedures empowered the reviewers to find and amalgamate the study findings in a clear and organized way to conduct an SLR transparently.

3.2.1. Identification

- a. This process was carried out in order to delineate relevant articles for the evaluation.
- b. The reviewers examined alternate variations, related concepts, and synonyms of the principal keywords.
- c. Five main keywords were determined by the study question: DEM, Floods, integration, modelling, and mitigation.
- d. These keywords were refined after consultation with experts, adaptation of previous studies, and use of online sources.
- e. Keywords include DEM, Floods, remote sensing, hydrological modelling, and mitigation.
- f. Search techniques: identifying specific phrases, employing wildcards, truncations, Boolean operators, and applying field-code queries in the WoS and Scopus datasets (refer to Table 1). Additionally, a manual procedure was carried out in Sage Journals, Science Direct, Taylor Francis, Springer Link, and Emerald.
- g. Specification of the context of Article: (1) The integration of DEM and Flood modelling requires different parameters, and (2) the review focuses on the consequences of flood simulations and risk assessment of mitigation strategies.
- h. The number of possible articles identified: 12,887.

Table 1. Strings used for searching.

Dataset	Query of Searching
Scopus	TITLE-ABS-KEY ((flood* OR coastal* OR river* OR runoff*) AND (hydro*gical* OR model* OR hec*) AND (DEM* OR DTM OR DSM*) AND (remote AND sensing* OR gis* OR geospatial*) AND (mitigation* OR disaster* OR management*))
Web of Science	TS= (("FLOOD*" OR "coastal*" OR "river*" OR "runoff*") AND ("Hydro*gical*" OR "model*" OR "HEC*") AND ("DEM*" OR "DTM" OR "DSM*") AND ("remote sensing*" OR "GIS*" OR "geospatial*") AND ("mitigation*" OR "disaster*" OR "management*"))

Table 2. Criteria for the searching.

Technique	What is included?	What is excluded?
Timeline	2018–2024	2017 and before
Document type	Research papers only	Conference papers, books or chapters and Review articles
Language	English	Other languages
Subject area	Natural Sciences (Earth Sciences, Geography, Environmental, water resources)	non-physical science studies, health studies, medical sciences, social science and engineering

3.2.2. Screening

- a. The screening process involved a set of dataset searches and manual assessment by the reviewers, adhering to predefined criteria. (see [Table 2](#)).
- b. The emphasis given during the screening procedure for articles issued from 2018 to 2024 is aligned with the policy of relevant and advanced development in research highlighted by García-Peñalvo (2022). This period was selected because of the availability of a sufficient number of published papers, ensuring a comprehensive and inclusive review strategy.
- c. Research papers with facts and carrying major relevant data were considered for this purpose.
- d. The study was restricted to papers published in English to mitigate potential misunderstandings.
- e. To boost the interdisciplinary approach to investigate geographical and hydrological studies, research articles from natural sciences were added as standards to explore new and pertinent publications.
- f. 9,970 number of research papers were discarded in this method as they didn't meet the criteria.
- g. This resulted in the qualification of 2,917 articles, and after the removal of duplications overlaps, the final 2,851 articles were selected for evaluation in the next round.

3.2.3. Eligibility

- a. This procedure was performed to screen titles, abstracts, and substances related to the applied themes of the research and to determine which of the articles met the inclusion criteria.
- b. Screening of the titles results the exclusion of 2,370 articles.
- c. Whereas, the screening of the abstract results the exclusion of further 385 articles
- d. Owing to the non-application of the contents of the selected articles, 69 were rejected.
- e. Six papers were excluded because of the lack of emphasis on the DEM datasets and their relevance to flood modelling and disaster management.
- f. Finally, 21 studies were approved for the quality evaluation stage (see [Figure 2](#)).

3.3. Quality appraisal

Quality appraisal was based on a qualitative, mixed, and quantitative design; therefore, the chosen research papers used the Mixed Method Appraisal Tool (MMAT) version 2018 by Hong et al. (2018) (see [Table 3](#)). The same method has been applied comprehensively in many studies (Abu Samah et al. 2021; Mohamed Shaffril, Samsuddin, and Abu Samah et al. (2021); Rahman et al. 2024). However, this tool has not been extensively utilized for flood modelling and mapping studies, particularly in the context of disaster mitigation and management. For this purpose, two reviewers were assigned the task of evaluating the quality of the papers according to several factors, including details that could answer the research questions, confidence in assessing these questions, adequacy of sampling and data collection methods, and suitability of statistical analyses conducted to achieve the study's objectives.

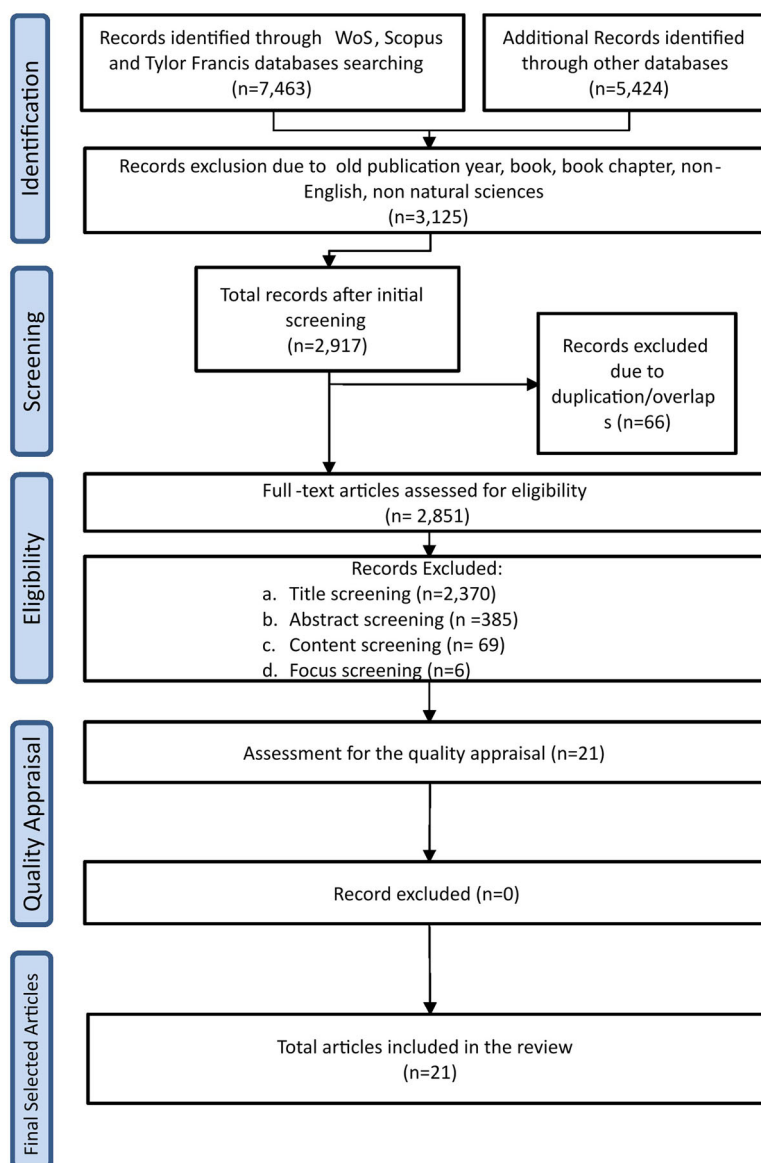


Figure 2. The flowchart of the systematic search work.

Additionally, the reviewers evaluated the interpretation of data, presentation of results, depth of discussion, and conclusion of each article. The assessment of quality followed the guidelines outlined in the Mixed Methods Appraisal Tool (MMAT), which categorized articles as low-quality (25%), average (50%), above-average (75%), or high-quality (100%) based on their findings and qualifications of questions (see Table 4).

3.4. Data retrieval and evaluation

The reviewers applied diverse strategies to expose and discern the significant patterns and associations in this study. Following the framework delineated by Noyes et al. (2019), which distinguishes between quantitative and qualitative syntheses, the reviewers explained the adaptation of the mixed-method reviews.

Thematic analysis, guided by Lochmiller (2021), has been utilized to identify patterns in existing research. The reviewers commenced their analyses by engaging in a comprehensive review and comprehension of the entire dataset, thereby acquiring valuable insights. The reviewers then structured the data into wide-ranging codes, and pertinent details about the research questions were extracted.

Table 3. The criteria used for the evaluation of selected articles (Hong et al. 2018).

Method for the research	Evaluation standards
Qualitative	QA1—The methodology suitable for addressing the study question? QA2—Is the research question sufficiently addressed by the qualitative data gathering procedures? QA3—Do the findings accurately derived from the data? QA4—Interpretation of outcomes adequately supported by data? QA5—Consistency between collection, interpretation, analysis, qualitative data sources, collection, analysis, and interpretation?
Quantitative (descriptive)	QA1—Is the sample technique appropriate for addressing the theme? QA2—Reflection of the characteristics of the concerned population in the sample is accurate? QA3—Measurements are suitable? QA4—Is the low probability of risk of non-response bias? QA5—Does the statistical analysis adequately address the research question?
Mixed methods	QA1—Does the research question have a sufficient justification for utilising a mixed methods design? QA2—Is the integration of the many components in study successful? QA3—Interpretations of the integration of the two components are satisfactory or not? QA4—Discrepancies and incongruities in findings are sufficiently countered? QA5—Various parts of the study conform to standards of respective methodological tradition?

Table 4. Quality assessment results.

Study	Research design	QA1	QA2	QA3	QA4	QA5	No of criteria fulfil	Accepted for review
(Ahmad et al. 2022)	MM	✓	✓	✓	✓	✓	5/5	✓
(Arash and Yasi 2023)	QN	✓	✓	✓	✓	✓	5/5	✓
(Avand et al. 2022)	MM	✓	✓	✓	✓	✓	5/5	✓
(Azizian and Brocca 2020)	QN	✓	✓	✓	✓	✓	5/5	✓
(Barman et al. 2023)	QN	✓	✓	✓	✓	✓	5/5	✓
(Farooq et al. 2019)	QN	✓	✓	✓	✓	✓	5/5	✓
(Fereshtehpour et al. 2024)	MM	✓	✓	✓	✓	✓	5/5	✓
(Hawker, Bates, et al. 2018)	QL	✓	✓	✓	✓	✓	5/5	✓
(Hou et al. 2021)	QN	✓	✓	✓	✓	✓	5/5	✓
(Khojeh et al. 2022)	QN	✓	✓	✓	✓	✓	5/5	✓
(Li et al. 2023)	MM	✓	✓	✓	✓	✓	5/5	✓
(Lim and Brandt 2019)	MM	✓	✓	✓	✓	✓	5/5	✓
(Liu et al. 2023)	MM	✓	✓	✓	✓	✓	5/5	✓
(Meadows et al. 2024)	QN	✓	✓	✓	✓	✓	5/5	✓
(Mubialiwo et al. 2022)	QN	✓	✓	✓	✓	×	4/5	✓
(Muench et al. 2022)	MM	✓	✓	✓	✓	✓	5/5	✓
(Pandya et al. 2024)	MM	✓	✓	✓	✓	✓	5/5	✓
(Parizi et al. 2022)	MM	✓	✓	✓	✓	✓	5/5	✓
(Rangari et al. 2019)	QN	✓	✓	✓	✓	×	4/5	✓
(Xu et al. 2021)	QN	✓	✓	✓	✓	✓	5/5	✓
(Zhu and Chen 2024)	MM	✓	✓	✓	✓	✓	5/5	✓

Note: QA = quality assessment; QN = quantitative; QL = qualitative; MM = mixed-method; U = Unclear.

This process led to the discovery of eight major themes, each of which was explored to uncover a total of 23 potential subthemes. To ensure the accuracy of their results, the authors sought the input of specialists in qualitative synthesis and disaster management who confirmed the authenticity of the developed themes and sub-themes (see Table 5). This systematic analysis provides a detailed understanding of how DEM and hydrological models provide a baseline for flood mitigation and modelling. Moreover, it provides full comprehension of the relationships and patterns within the data.

4. Results

4.1. Descriptive analysis

The 21 selected articles focused on studies in different geographic jurisdictions. A total of five research articles (Azizian and Brocca 2020; Avand et al. 2022; Khojeh et al. 2022; Parizi et al. 2022; Arash and Yasi 2023) focused their studies in Iran, whereas three articles each in China (Hou et al. 2021; Xu et al. 2021; Zhu and Chen 2024) and India (Rangari et al. 2019; Barman et al. 2023; Pandya et al. 2024), two articles selected from the study area of Pakistan (Farooq et al. 2019; Ahmad et al. 2022), one article each selected from the study area of Niger (Muench et al. 2022), Finland (Liu et al. 2023), Sweden (Lim and Brandt 2019), Madagascar (Li et al. 2023), Uganda (Mubialiwo et al. 2022). One article focused on the two study areas in the United Kingdom and Pakistan, while two of the selected articles focus on the global study region; it is depicted in Figure 3.

Table 5. Findings of the designated themes and sub-themes.

Author / Theme	DEM data sources and characteristics		Integration - DEMs and Hydrological Models		Appl. in Flood Hazard Mapping		Terrain Ch. Impact		Model Performance Evaluation			ML for Flood Management			Ecosystem Services and Resilience			Policy and Governance					
	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
(Ahmad et al. 2022)	✓		✓	✓	✓	✓	✓	✓	✓						✓						✓		
(Arash and Yasi 2023)	✓		✓	✓	✓	✓	✓	✓	✓						✓						✓		
(Avand et al. 2022)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Azizian and Brocca 2020)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Barman et al. 2019)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Farooq et al. 2019)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Fereshtehpour et al. 2024)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Hawker, Bates, et al. 2018)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Hou et al. 2021)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Khojeh et al. 2022)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Li et al. 2023)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Lim and Brandt 2019)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Liu et al. 2023)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Meadows et al. 2024)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Mubiallwo et al. 2022)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Muench et al. 2022)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Pandya et al. 2024)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Parizi et al. 2022)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Rangari et al. 2019)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Xu et al. 2021)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
(Zhu and Chen 2024)	✓		✓	✓	✓	✓	✓	✓	✓	✓					✓						✓		
DEM data sources and characteristics	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT <td>MTI</td> <td>CA</td> <td>REA</td> <td>ERS</td> <td>EV</td> <td>FRM</td> <td>CR</td> <td>PI</td>	MTI	CA	REA	ERS	EV	FRM	CR	PI
Integration of DEMs and Hydrological Models	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
Applications in Flood Hazard Mapping	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
Terrain Characteristics Impact	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
Model Performance Evaluation	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
ML for Flood Management	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
Ecosystem Services and Resilience	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI
Policy and Governance	SDM	UAS	EAA	RMT	VMT	IMF	FDM	FDT	AAF	TI	LC	SVF	C	V	SRT	MTI	CA	REA	ERS	EV	FRM	CR	PI

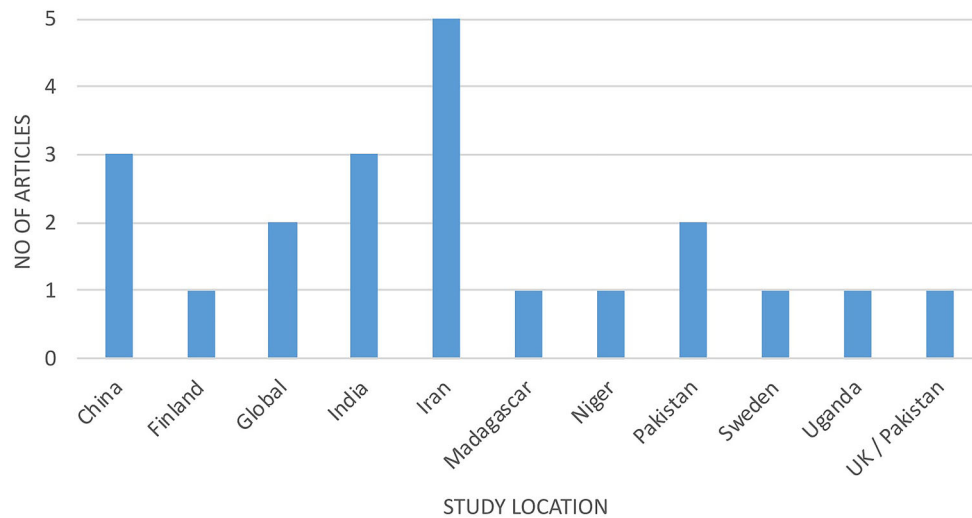


Figure 3. Study areas used in selected papers.

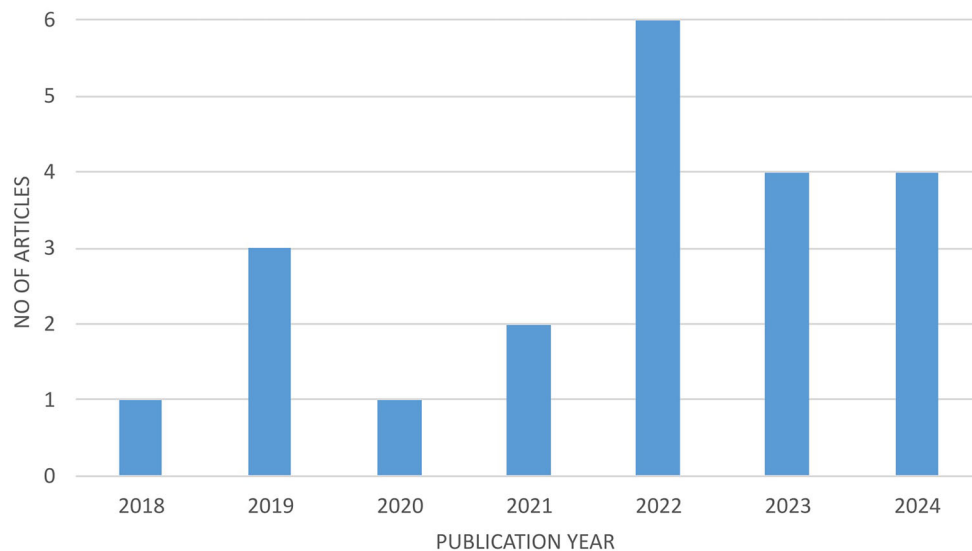


Figure 4. Years of publication of selected articles.

As far as the publication period is concerned, single paper was issued in 2018, three articles were published in 2019 (Farooq et al. 2019; Lim and Brandt 2019; Rangari et al. 2019), one article was published in 2020 (Azizian and Brocca 2020), two papers were printed in 2021 (Hou et al. 2021; Xu et al. 2021), six research studies were published in 2022 (Ahmad et al. 2022; Avand et al. 2022; Khojeh et al. 2022; Mubialiwo et al. 2022; Muench et al. 2022; Parizi et al. 2022), four articles published in 2023 (Arash and Yasi 2023; Barman et al. 2023; Li et al. 2023; Liu et al. 2023) and four articles were published in 2024 (Fereshtehpour et al. 2024; Meadows et al. 2024; Pandya et al. 2024; Zhu and Chen 2024) as shown in Figure 4.

It was discovered that two articles each were published in the Natural Hazards (Farooq et al. 2019 Khojeh et al. 2022) and Remote Sensing (Ahmad et al. 2022; Zhu and Chen 2024), whereas all other articles were published in different journals i.e. Applied Geomatics (Pandya et al. 2024), Earth Science Informatics (Fereshtehpour et al. 2024), Earth Systems and Environment (Mubialiwo et al. 2022), Environmental Modelling & Software (Hou et al. 2021), Frontiers in Earth Science (Hawker, Bates, et al. 2018), Frontiers in Environmental Science (Muench et al. 2022), Geomatics Natural Hazards & Risk (Lim and Brandt 2019), Hydrology (Li et al. 2023), International Journal of Digital Earth (Meadows et al. 2024), International Journal of Disaster Risk Science (Xu et al. 2021), International Journal of Remote Sensing (Azizian and Brocca 2020), Iranian Journal of Science and Technology-

Table 6. The rankings of the chosen journals.

	Journal	No. of papers	Included in Scopus?	Scopus rating	Included in WoS?	WoS rating
1	Natural Hazards	2	YES	Q1	YES	Q2
2	Remote Sensing	2	YES	Q1	YES	Q1
3	Applied Geomatics	1	YES	Q2	YES	Q2
4	Earth Science Informatics	1	YES	Q2	YES	Q2
5	Earth Systems and Environment	1	YES	Q1	YES	Q1
6	Environmental Modelling & Software	1	YES	Q1	YES	Q1
7	Frontiers in Earth Science	1	YES	Q2	YES	Q2
8	Frontiers in Environmental Science	1	YES	Q2	YES	Q2
9	Geomatics Natural Hazards & Risk	1	YES	Q1	YES	Q1
10	Hydrology	1	YES	Q2	YES	Q2
11	Int. J. of Digital Earth	1	YES	Q1	YES	Q1
12	Int. J. of Disaster Risk Science	1	YES	Q1	YES	Q2
13	Int. J. of Remote Sensing	1	YES	Q1	YES	Q2
14	Iranian J. of Science and Technology	1	YES	Q2	YES	Q3
15	Journal of Environmental Management	1	YES	Q1	YES	Q1
16	Journal of Flood Risk Management	1	YES	Q2	YES	Q2
17	Journal of Hydro-Environment Research	1	YES	Q2	YES	Q2
18	Modeling Earth Systems and Environment	1	YES	Q3	YES	Q3
19	Natural Hazards and Earth System Sc.	1	YES	Q1	YES	Q1

Source: WoS (2023), Scopus (2023).

Transactions of Civil Engineering (Barman et al. 2023), Journal of Environmental Management (Parizi et al. 2022), Journal of Flood Risk Management (Arash and Yasi 2023), Journal of Hydro-Environment Research (Avand et al. 2022), Modeling Earth Systems and Environment (Rangari et al. 2019) and Natural Hazards and Earth System Sciences (Liu et al. 2023). The selected articles were of commendable quality and are indexed by WoS and Scopus databases. The majority of them were placed in Q1 or 2, as depicted by Table 6.

4.2. The developed themes

Eight primary themes were derived from thematic analysis of the 21 articles. These themes helped organize the review process and provide insights into the different aspects of the research question. (1) DEM data sources and characteristics, (2) Integration-DEMs and Hydrological Models, (3) Applications in Flood Hazard Mapping, (4) Terrain Characteristics Impact, (5) Model Performance Evaluation, (6) Machine Learning for Flood Management, (7) Ecosystem Services and Resilience, and (8) Policy and Governance (see Table 5).

4.2.1. DEM data sources and characteristics

The first and foremost theme that needs to be examined is the different DEM data sources and their characteristics to be utilized in the selected studies. The reviewers categorized the DEM sources as satellite derived DEMs, aerial and surveyed DEM and included the enhancements and accuracy assessments made by the authors of the selected articles.

4.2.1.1. Satellite derived DEMs. The satellite remote sensing data is the primary source of the Digital Elevation Model generation. Over the period of time, the technology has advanced, and the spatial resolutions of the remote sensing datasets have improved. Based on the importance in this review following are the main satellite derived DEMs that have been utilized.

4.2.1.2. SRTM. The Shuttle Radar Topography Mission (SRTM), conducted in 2000, has generated high-resolution digital elevation models (DEMs) using radar interferometry. It has been widely utilized across various disciplines and provides global coverage at spatial resolutions of 30 and 90 meters (Jing et al. 2014; Azizian and Brocca 2020). It has several benefits, such as free availability of global coverage and performance in terms of vertical accuracy (Carrera-Hernández 2021), and has been efficiently utilized in flood modelling and mapping in ten of the selected articles. Similar to Khojeh et al. (2022), the capability of SRTM-30 m was found to be higher in defining model geometry, simulating flood extent, and deriving peak discharge compared to the ASTER DEM. Moreover, Arash and Yasi (2023) believe

that it is helpful for accurately simulating river geometry and flood extent, particularly for wide-straight and braided rivers. Parizi et al. (2022) found that SRTM shows reduced errors in flow velocities compared with same-resolution UAV measurements. Even Root Mean Square Error (RMSE) for SRTM on average is 2.82 m lower than the LiDAR DEM used by Muench et al. (2022). It was also observed during DEM sensitivity analysis by Farooq et al. (2019) that the SRTM maximum simulated flood depth differed and was only 1 m higher than the WorldDEM, whereas other DEMs, such as Advanced Land Observing Satellite (ALOS) World3D and ASTER, were higher by 3 m and 25 m, respectively. SRTM is utilized efficiently along with flood inundation maps in automated surface water extraction using the newly cloud-based GIS tool Floodwater Depth Estimation Tool (FwDET), which facilitates the rapid estimation of floodwater extent and depth (Li et al. 2023). Furthermore, It was resampled to 150, 200, 300, 400 and 500 m resolutions to analyze its impact on the accuracy of the flood simulations (Zhu and Chen 2024). Zhu and Chen (2024) observed that SRTM is highly compatible with physical-based distributed hydrological models, such as Liuxihe model, and also found it reliable and effective in various hydrological contexts.

Despite these advantages, SRTM has limitations that need to be addressed when used for flood modelling and mapping. Similar corrections are needed for meandering patterns in floodplains and lowland rivers according to Arash and Yasi (2023) and Xu et al. (2021), which may have limitations in accurately representing coastal areas due to neglecting recent topographic changes. It is unsuitable for minor undulations (Barman et al. 2023). Hawker, Bates, et al. (2018) also observed that SRTM has wider error distributions in overall vertical accuracy compared to the recent products of TanDEM-X. Khojeh et al. (2022) suggested that the size of the map pixels can affect the estimated size of the flood area, with larger pixels leading to overestimation. SRTM also contains gaps and anomalies because of the radar side-view imaging limitation and that multiplied in the vegetated areas, which can be corrected using deep learning techniques such as those used by Sun et al. (2023). Another important limitation of SRTM is the shadow effects that may occur in urban areas, especially in urban flood modelling. Moreover, the coarser resolution of SRTM, that is, 30 m, would also make it difficult to accurately depict the urban area elevations, and it must be corrected through ground data or other high-resolution datasets, as performed by Kim et al. (2020).

4.2.1.3. ASTER. The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) provides a Digital Elevation Model (DEM) collaboratively by the Ministry of Japan and NASA. Initially, two versions were released, in 2009 and 2011. Meanwhile, the release of the latest version of the ASTER DEM in August 2019 highlights significant improvements in vertical and horizontal accuracy compared to the previous version, and it is available worldwide at a resolution of 30 m (Khojeh et al. 2022). Recently, it has been increasingly utilized in flood modelling owing to its high spatial resolution and global coverage. Arash and Yasi (2023) and Avand et al. (2022) utilized ASTER for flood inundation mapping and simulations, respectively. It can also be integrated with other datasets, such as rainfall data and land cover information, to enhance the accuracy of flood modelling predictions, as demonstrated by Barman et al. (2023). The ASTER GDEM v2 was used to simulate the flood propagation process and predict peak discharge after applying different interpolation methods successfully performed by Hou et al. (2021). Farooq et al. (2019) highlighted that the ASTER DEM resulted in a higher simulated flood depth than the WorldDEM, SRTM, and ALOS DEMs, but it provided the highest terrain errors. Moreover, it generally underestimates elevation values and is considered the weakest dataset in simulating inundated areas as compared to others (Azizian and Brocca 2020). Moreover, It had a root mean square error (RMSE) value of 1.77 m for flow depth, the highest calculated by Parizi et al. (2022) and RMSE value of 8.68 by Xu et al. (2021) and 4.2 m by Muench et al. (2022). According to Khojeh et al. (2022), and performs poorly in estimating the flood discharge. It also overestimates the elevation along riverbeds and underestimates the land surrounding the braided channel, and has the largest range of elevation differences compared to other DEMs (Muench et al. 2022).

4.2.1.4. ALOS. Advanced Land Observing Satellite (ALOS) DEM (Digital Elevation Model) is a global free dataset derived from satellite imagery collected by the ALOS satellite mission by the Japan

Aerospace Exploration Agency (JAXA) and includes three sensors: PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping), AVNIR-2 (Advanced Visible and Near Infrared Radiometer Type-2), and PALSAR (Phased Array type L-band Synthetic Aperture Radar) (Khojeh et al. 2022; JAXA 2024). It offers elevation data with spatial resolution of 12.5 and 30 m. Arash and Yasi (2023) recommended this as the most accurate choice for flood mapping and revealed that it provides realistic cross-sectional shapes owing to PRISM sensor accuracy. It provides similar results to the ground-based DEMs in the study by Azizian and Brocca (2020). ALOS also proved to be more accurate in the machine learning model of Random Forest compared to other models by Avand et al. (2022). The simulated flood velocity for the ALOS DEM was higher than those of the other DEMs by Farooq et al. (2019). It has the lowest RMSE of 1.19 m, the lowest among all in the study by Muench et al. (2022), and is also acknowledged by Pandya et al. (2024), who also found its RMSE least across various slope classes. ALOS-derived AW3D30 performs better in certain aspects such as water level deepening (Xu et al. 2021). It also aids in providing the necessary elevation data for the analysis of flood risk assessment and socio-economic impacts of floods in the study by Mubialiwo et al. (2022) and both the Mubialiwo et al. (2022) and Parizi et al. (2022) agrees that ALOS performed better at estimating flow velocity for all return periods compared to ASTER and SRTM. Although ALOS shows little to no error by aspect, Meadows et al. (2024) were not satisfied with its performance, as it was found to have the longest errors among the DEMs considered.

Some of the other satellite-derived DEMs, which are the by-products of the above-mentioned DEMs, have been used in a few studies, such as NASADEM, which takes advantage of improved SAR methods and newly available elevation data to fill voids in the original SRTM data (Hawker, Bates, et al. 2018). Barman et al. (2023) are convinced that CARTOSAT DEM outperforms ASTER DEM in 2D simulations, whereas Rangari et al. (2019) utilized linear data to develop the DTM of CARTOSAT to effectively perform flood simulations, particularly in urban areas. Parizi et al. (2022) revealed that TanDEM-X DEM, even after downsizing to 30 m, outperformed the modelling fluvial flood characteristics, making it the preferred choice in areas with limited high-resolution topographic data. Pandya et al. (2024) used the Copernicus Global Land Operations (GLO)-DEM as a reference DEM because of its high vertical accuracy in evaluating the performance of other DEMs. and found it to be the most suitable among all designated study areas. The complete list of DEMs utilized in this review, along with their spatial resolutions and other details, are depicted in Table 7.

4.2.1.5. Aerial and surveyed DEMs. This is the most effective and accurate medium for developing DEMs and has been efficiently utilized in some of the reviewed studies for comparison with satellite-derived DEMs. The five researchers Fereshtehpour et al. (2024), Hawker, Bates, et al. (2018), Lim and Brandt (2019), Liu et al. (2023), and Muench et al. (2022) utilized the LiDAR dataset for flood studies, particularly the accuracy assessments of the global satellite DEMs. The UAV DEM resolution significantly impacts flood characteristics, with changes in the inundation area, mean flow depth, and mean flow velocity, as discussed by Parizi et al. (2022).

4.2.1.6. Enhancement and accuracy assessments. Correcting DEMs is inevitable in flood simulations. Therefore, except for five studies (Farooq et al. 2019; Avand et al. 2022; Mubialiwo et al. 2022; Li et al. 2023; Fereshtehpour et al. 2024) all others carried out enhancements and corrections and performed some accuracy assessments in the DEMs. For example, Azizian and Brocca (2020) were convinced that they improved the efficiency of hydraulic models. In addition, DEMs must be corrected for meandering patterns in lowland rivers (Arash and Yasi 2023). Lim and Brandt (2019) also observed that lower DEM resolutions perform better but may lack accuracy. Moreover, using the Dixon criterion improves the accuracy of flood simulations and reduces errors in extreme water depths (Xu et al. 2021).

4.2.2. Integration of DEMs and hydrological models

Another important theme is to integrate DEMs with Hydrological Models for floods. The reviewers first looked for descriptions of the methods used to couple DEMs with hydrological models and the rationale behind the chosen integration approach. The reviewers identified sections in which the article

Table 7. List of the DEMs and its characteristics utilized in selected studies.

DEM / Data Source	Spatial Resolution (meters)	Vertical Accuracy (meters)	Source Data	Data Correction	Free	Pros	Cons	References
GMTED	250,500, 1000	~20–30	Various sources	None	Yes	<ul style="list-style-type: none"> • suitable for large-scale studies. 	<ul style="list-style-type: none"> • Low resolution, not suitable for detailed flood modelling. 	(Li et al. 2023)
MERIT DEM	~90	~2–3	Various sources	Multi-error removal algorithms	Yes	<ul style="list-style-type: none"> • High accuracy with multi-error removal 	<ul style="list-style-type: none"> • Medium resolution, may not capture fine terrain details. 	(Hawker, Bates, et al. 2018; Xu et al. 2021; Muench et al. 2022; Li et al. 2023)
NASADEM	~90	~1	SRTM, ASTER, and other datasets	Fill voids using advanced algorithms	Yes	<ul style="list-style-type: none"> • High vertical accuracy, suitable for global flood risk studies. 	<ul style="list-style-type: none"> • May not capture local features well, voids still present. 	(Xu et al. 2021; Meadows et al. 2024)
SRTM	30, 90	~10	Shuttle Radar Topography Mission (SRTM)	None	Yes	<ul style="list-style-type: none"> • Free, globally available, commonly used in flood models. 	<ul style="list-style-type: none"> • Lower accuracy in some areas, especially in rugged terrain. 	(Hawker, Bates, et al. 2018; Farooq et al. 2019; Azizian and Brocca 2020; Xu et al. 2021; Ahmad et al. 2022; Khojeh et al. 2022; Muench et al. 2022; Parizi et al. 2022; Arash and Yasi 2023; Li et al. 2023; Meadows et al. 2024; Pandya et al. 2024; Zhu and Chen 2024)
ASTER 30 m	30	~17	ASTER satellite data	Surveyed datasets, resampling using nearest neighbor method,	Yes	<ul style="list-style-type: none"> • Global coverage, good for medium-scale studies. 	<ul style="list-style-type: none"> • Lower vertical accuracy, resampling can reduce precision. 	(Farooq et al. 2019; Azizian and Brocca 2020; Hou et al. 2021; Xu et al. 2021; Avand et al. 2022; Khojeh et al. 2022; Muench et al. 2022; Parizi et al. 2022; Arash and Yasi 2023; Barman et al. 2023; Pandya et al. 2024; Zhu and Chen 2024)
ALOS	12.5, 30	~5	ALOS satellite data, AW3D30	Resampling, using river geometry acquired through GPS-RTK and other advanced algorithms	Yes	<ul style="list-style-type: none"> • High accuracy, suitable for coastal and riverine flood models. 	<ul style="list-style-type: none"> • Not always available for all regions. 	(Farooq et al. 2019; Azizian and Brocca 2020; Xu et al. 2021; Avand et al. 2022; Khojeh et al. 2022; Mubialiwo et al. 2022; Muench et al. 2022; Parizi et al. 2022; Arash and Yasi 2023; Li et al. 2023; Meadows et al. 2024; Pandya et al. 2024)
Coastal DEM	~30	~5–10	Various sources	Mean, Dixon criterion	Yes	<ul style="list-style-type: none"> • Ideal for coastal flood risk assessment 	<ul style="list-style-type: none"> • Lacks detailed features inland. 	(Xu et al. 2021)

(continued)

Table 7. Continued.

DEM / Data Source	Spatial Resolution (meters)	Vertical Accuracy (meters)	Source Data	Data Correction	Free	Pros	Cons	References
FABDEM	≤ 30	~ 2	Fusion of different data sources	vertical errors correction using RF	Yes	<ul style="list-style-type: none"> Relatively High resolution, ideal for urban and forested areas. 	<ul style="list-style-type: none"> Requires correction for forest and building data 	(Meadows, Jones, and Reinke et al. 2024)
Copernicus DEM	30	~ 1	Sentinel data and Tandem-X	Advanced algorithms	Yes	<ul style="list-style-type: none"> High vertical accuracy, advanced correction algorithms. 	<ul style="list-style-type: none"> Limited availability, some regions might be under represented. 	(Meadows et al. 2024; Pandya et al. 2024)
TanDEM-X	30 (actual 12)	$\sim 1-2$	TerraSAR-X and TanDEM-X satellite data	Radar interferometry	No	<ul style="list-style-type: none"> High precision, excellent for detailed flood 	<ul style="list-style-type: none"> Expensive 	(Parizi et al. 2022)
WorldDEM	12	$\sim 0.5-2$	TerraSAR-X and TanDEM-X satellite data	Radar technology	No			(Farooq et al. 2019)
Arctic DEM	10	$\sim 2-5$	original 2m created from stereo WV1,2,3 data	artefacts removal, morphological filters	Yes	<ul style="list-style-type: none"> High resolution, good for Arctic and remote flood modelling. 	<ul style="list-style-type: none"> Limited to specific regions 	(Liu et al. 2023)
CARTOSAT	10	$\sim 2-5$	Derived from 2.5 m CARTOSAT stereo satellite data	GCPs and tie point generations	Yes	<ul style="list-style-type: none"> High accuracy, suitable for urban flood risk management. 	<ul style="list-style-type: none"> Requires ground control points (GCPs), limited global coverage. 	(Rangari et al. 2019; Barman et al. 2023; Pandya et al. 2024)
LiDAR	1-30	$\sim 0.1-1$	Light Detection and Ranging (LiDAR) data	None	No	<ul style="list-style-type: none"> Extremely high accuracy, ideal for localized flood modelling. 	<ul style="list-style-type: none"> Very Expensive, limited geographic coverage. 	(Hawker, Bates, et al. 2018; Lim and Brandt 2019; Muench et al. 2022; Liu et al. 2023; Fereshtehpour et al. 2024)
UAS (Unmanned Aerial System)	1-30	$\sim 0.1-1$	UAV/UAS-derived imagery	None	No			(Parizi et al. 2022)

discusses how DEM data are integrated with hydrological models to simulate flood dynamics. This theme has been subdivided into raster or vector-based modelling techniques and integrated modelling frameworks, in which the type of model is discussed along with the results. Raster-based DEM integration uses grid-cell data and is the most common phenomenon applied in flood models that include corrected, hydro-enforced DEMs. In contrast, vector-based modelling approaches have been used by Hou et al. (2021) and Li et al. (2023). For an integrated modelling framework, several models can be used for flood modelling and simulations. Some studies utilized single techniques, whereas others adopted combined techniques, as depicted in Table 8. It has been observed that HEC-RAS has been largely utilized for flood simulations by Ahmad et al. (2022), Farooq et al. (2019), Mubialiwo et al. (2022), Parizi et al. (2022), and Rangari et al. (2019) in 2D, whereas Arash and Yasi (2023) used it in both 1D/2D. The HEC-RAS is an open-source, freely available hydraulic modelling software that has been effectively utilized in flood modelling and simulations. Rangari et al. (2019) explained in detail the procedure in which HEC-RAS works.

The other model that was found to perform better on plain topography and high-resolution datasets according to Moghim et al. (2023) is the LISFLOOD-FP, which was affectively utilized by Hawker et al. (2018), Lim and Brandt (2019), Liu et al. (2023), and Xu et al. (2021). LISFLOOD-FP is also freely available for non-commercial purposes. This model was utilized by Fereshtehpour et al. (2024) along with machine learning as a combined technique, and Li et al. (2023) used the open-source Python framework HYDRAfloods for automatic extraction of flood extents and other mapping algorithms. Shallow water areas are challenging to simulate. Hou et al. (2021) used the Shallow Water Equation (SWE)-based model for simulation and applied numerical methods and interpolations to examine changes. The HEC-RAS simulation was combined with a simplified Physical Response Curve (SPRC) for flood risk analysis by Khojeh et al. (2022). Barman et al. (2023) used a 2D hydrodynamic model with statistical parameters such as mean absolute error (MAE), RMSE, R2, and Nash–Sutcliffe efficiency (NSE). The physical-based Distributed Hydrological modelling system (PBDHMS), which includes physical parameters and uses inputs of soil and meteorological data along with land use/land cover and DEMs, such as the Liuxihe model integration, results in strong applicability in complex terrain areas even with coarser resolution SRTM DEM (Zhu and Chen 2024). In addition, some hydrogeomorphic methods have been used in different studies over the last two decades, such as Nardi et al. (2006), who devised the floodplain delineation method for investigating the scaling relation of floodplains. Moreover, an automated GIS-based procedure called GM3 was implemented by Manfreda et al. (2014) for flooded area delineation. Samela et al. (2017) applied geomorphic classifiers to flood-prone area delineation in data-scarce regions for large-scale applications. The consistent performance of hydrogeomorphic models in floodplain delineation, climate, and river basin morphology was highlighted by Annis et al. (2022).

4.2.3. Applications in flood hazard mapping

This theme has been subdivided into Floodplain delineation methods, Flood depth estimation techniques, and the most important accuracy assessment of flood hazard maps. Floodplain delineation methods were discussed and applied in five studies. Farooq et al. (2019) closely adjusted the DEM using satellite images to accurately show where the river is, ensuring that the flood simulation is as accurate as possible. Khojeh et al. (2022), Lim and Brandt (2019), and Mubialiwo et al. (2022) used hydraulic models to delineate the floodplain, while Hou et al. (2021) used interpolation techniques. However, the flood depth analysis was carried out in 13 studies, including the aforementioned authors. The accuracy assessment of the flood hazard maps was performed by Ahmad et al. (2022), Avand et al. (2022), Farooq et al. (2019), Mubialiwo et al. (2022), Rangari et al. (2019), and Xu et al. (2021), who compared maps in different scenarios.

4.2.4. Terrain characteristics impact

The impact of terrain characteristics on flood modelling and risk assessment must be assessed. This includes terrain impact, land cover role (which also includes land use), and spatial variability assessment of flood risk. Azizian and Brocca (2020) linked the accuracy assessment of DEMs with the terrain

Table 8. Models used in the simulation of floods.

Hydrological Model	Hydraulic Model	Hydro-dynamic	Machine Learning	Other Methods	References (cited papers)
Single Techniques HEC-RAS (1D/2D) HAND			1. Artificial Neural Network (ANN) 2. Generalized Linear Model (GLM) 3. Random Forest (RF)		(Arash and Yasi 2023) (Muench et al. 2022) (Avand et al. 2022)
Liuxihe Model (Physical-Based Distributed) HEC-RAS (2D)		2D Hydrodynamic model			(Barman et al. 2023) (Zhu and Chen 2024)
HEC-RAS (1D) Combined techniques		LISFLOOD-FP(2D)			(Farooq et al. 2019; Rangari et al. 2019; Ahmad et al. 2022; Mubialiwo et al. 2022; Parizi et al. 2022; Pandya et al. 2024) (Hawker, Bates, et al. 2018; Lim and Brandt 2019; Xu et al. 2021; Liu et al. 2023) (Azizian and Brocca 2020) (Fereshtehpour et al. 2024)
		LISFLOOD-FP(2D)	Cutting edge deep learning (DL) method Convolutional neural network (CNN) (1D)		
	Shallow Water Equation (SWE) based model			Numerical Methods: Finite volume method, Runge-Kutta Interpolation Methods: IDW, Kriging, Thin-Plate Spline (TPS), Topo to Raster, Trend Smoothing Method (TSM), Parametric Cubic Splines (PCs) Simplified Physical Response Curve (SPRC) Mapping algorithms: Edge Otsu, Bmax Otsu and Fuzzy Otsu	(Hou et al. 2021)
HEC-RAS (2D)					(Khojeh et al. 2022)
HYDRA-Floods					(Li et al. 2023)

impact of riverbeds and cross-sectional shapes, while Farooq et al. (2019) assessed land cover changes by incorporating Manning's value of the main channel, floodplain, agriculture, forest, orchards, and rangelands. Land use changes, such as turning forests into farms or cities, can significantly affect how much water runs off the land and how quickly floods can occur, as discussed by Avand et al. (2022). Pandya et al. (2024) examined the differences in terrain calculations among selected DEMs and observed over- and under-estimations. Lim and Brandt (2019), Liu et al. (2023), Meadows et al. (2024), Mubialiwo et al. (2022), Rangari et al. (2019), and Xu et al. (2021) also examined the importance of land use/land cover for flood modelling. The effectiveness of terrain characteristics, land use/land cover, and soil parameter inclusion results in an improvement in the accuracy of flood simulations (Zhu and Chen 2024). Spatial variability for flood risk refers to how different areas might experience different flood extents and depths based on their location, elevation, and other geographical features, as discussed by the authors like Lim and Brandt (2019), Liu et al. (2023), Mubialiwo et al. (2022), and Rangari et al. (2019). Hence, it is evident that this theme could impact the search for answers to the research questions.

4.2.5. Model performance evaluation

Flood model performance evaluation is of immense importance in flood modelling and risk assessment (Modi et al. 2022) and that is therefore, these themes are also included in this review. It is subdivided into model calibration, validation, and model sensitivity reliability tests. Some of the selected studies carried out calibration, such as Barman et al. (2023), used numerical procedures such as the correlation coefficient (R²), root mean square error (RMSE), Nash-Sutcliffe efficiency (NSE), and mean absolute error (MAE), and assessed model performance. NSE and R, along with the relative error of process (RE), relative error of flood peak (PE), and time difference of flood peak occurrence (PT), were used by Zhu and Chen (2024) in the Liuxike model and found an NSE above 0.75 throughout the study area. The Jaccard Index (JI) was found to be an effective tool for comparing watershed boundaries delineated using five different DEMs (Pandya et al. 2024). Farooq et al. (2019), Khojeh et al. (2022), Lim and Brandt (2019), Mubialiwo et al. (2022), and Parizi et al. (2022) utilized Manning's roughness coefficient for model calibration, and a few utilized real-world flood events for the validation of the model. Ahmad et al. (2022) evaluated the model performance using relatively coarser resolution satellite imagery of MODIS, as well as ground data collected through field visits. Arash and Yasi (2023) and Azizian and Brocca (2020) tested model sensitivity reliability using various DEMs and scenarios for flood map production. However, a sensitivity reliability test carried out by Farooq et al. (2019) revealed that terrain errors in DEMs, such as ASTER, can significantly affect the model's ability to accurately represent floodplain areas, affecting the simulated maximum flood depth and inundation extent, while Hawker, Bates, et al. (2018) found that the DEM errors were under-represented in the sensitivity analysis. Parizi et al. (2022) conducted a sensitivity test for Manning's coefficient and showed linear relationships with variables and maximum sensitivity values for the inundation area, flow depth, and calculated velocity. Xu et al. (2021) identified that sensitivity analysis showed significant differences in flood inundation results, and the impact of variation in different spatial resolutions clearly varied the results of the flooding simulations.

4.2.6. Machine learning for flood management

Machine learning is the latest emerging technology that is widely used in flood modelling and mapping (Jamali et al. 2021). Its integration into flood prediction models offers significant advantages over traditional methods by enabling the analysis of complex, nonlinear relationships between flood-related parameters. Therefore, this theme was included by the reviewers and subdivided into ML tool integration and comparative assessment. Avand et al. (2022) focused on assessing the influence of the Digital Elevation Model (DEM) spatial resolution using ML techniques on the precision of flood probability prediction. A generalized Linear Model, Random Forest and Artificial Neural Network were used to predict the flood probability based on 14 causative factors and 220 flood locations. It was found that only the resolution of the DEM did not influence the accuracy of the flood probability prediction, but other parameters such as distance from the river, rainfall, and elevations also influenced the floods in a

particular area. The Random Forest model showed higher accuracy in preparing Flood Probability Maps than the Artificial Neural Network and Generalized Linear Model.

Fereshtehpour et al. (2024) investigated the effectiveness of the cutting-edge deep learning method, namely 1D Convolutional Neural Network (CNN). CNN configure in two convolutional and three fully connected layers and provided the discharge values and LISFLOOD-FP generated flood depths as input features. The comparison between DTM and DSM in different resolutions was carried out in different DEM resolutions and it is concluded that coarse resolution may be considered as a viable option for rapid flood prediction. However, it tends to over predict flood depth and extent. ML models offer a rapid, cost-effective, and scalable alternative to traditional hydrodynamic simulations, which are often complex and require extensive input data. It has been studied that CNN and Random forest integration with remote sensing and DEM datasets significantly enhanced flood risk management strategies.

4.2.7. Ecosystem services and resilience

The vulnerable regional ecosystem can largely be affected by flooding, which needs to be incorporated into effective flood management. The theme has been subdivided into riparian ecosystem assessment, ecosystem-resilient solutions, and economic valuation. Mubialiwo et al. (2022) discussed these sub-themes in detail while studying the Ugandan River Malaba sub-catchment. The conditions and functions of the riparian zone were assessed to determine the areas of erosion, riverine forests, and ecosystems. Moreover, the economic valuation of the damage to agriculture and physical infrastructure has also been carried out in different flood return periods and flood risk adaptation measures that can be implemented in floodplains. Natural barriers to flood prevention need to be protected, while recreational opportunities should be explored to generate revenue and community resilience.

4.2.8. Policy and governance

Policy and governance play a vital role in the decision-making and implementation of disaster risk reduction controls. This theme is subdivided into flood risk management, community resilience, and policy implications. Avand et al. (2022) briefly discussed flood risk management for producing and evaluating flood-probability maps at different resolutions. The findings of Avand et al. (2022) can be useful for water managers and decision-makers in implementing effective mitigation strategies and adaptation procedures for probable floods. Li et al. (2023) highlighted the advantages and limitations of different flood-mapping algorithms and emphasized the importance of considering both satellite data and DEM-based methods for accurate and timely flood monitoring and mitigation. Ahmad et al. (2022) developed a multivariate flood hazard classification map for the study area, highlighting potentially vulnerable urban areas, villages, and road networks. Rangari et al. (2019) developed flood risk maps for this region and identified high-, medium-, and low-risk areas in an urban flood study area. Mubialiwo et al. (2022) estimated the socio-economic impact of floods in the region to discuss the potential damage to agriculture, humans, and infrastructure (health, education, religious places, roads) based on different flood scenarios. Mubialiwo et al. (2022) also highlighted the key factors for policy and governance, which include community sensitization to build trust in government initiatives and the importance of site-specific damage functions to eliminate bias in flood risk assessments. This would be helpful for regulatory decision-making and land use planning related to flood risk management. It assesses the integration of scientific evidence into policy frameworks, institutional arrangements, and governance mechanisms to enhance the resilience to floods and climate change.

5. Discussion

This study emphasizes on the role of different DEMs in flood modelling and its integration with different hydrological, hydraulic and hydrodynamic models that has been widely utilizing in flood inundation and extent modelling. Various sources of DEM data and their characteristics, including spatial resolution, accuracy, and availability has been examined. It also explores how different DEM datasets influence the outcomes of flood modelling and decision-making processes. It has been studied the different resolution DEMs have different applications particularly for flood modelling. Like Lim and Brandt (2019) reveals that the performance of the lower resolution DEMs were high but it lacks in

accuracy. Over the period of time, the resolution of the DEMs got better, however it raised other implications. Like the data availability issues and most importantly cost effectiveness. The high resolution DEMs are costly especially in developing countries, the aerial and surveyed DEMs are usually acquired on demand. Therefore, the flood modelling studies largely rely on global, freely available DEMs like Hou et al. (2021); Li et al. (2023); Pandya et al. (2024) and Xu et al. (2021) utilizes the freely available DEMs and examined their effect on flood models. Moreover, the satellite derived DEMs cannot be effectively utilize in flood modelling until it gets enhanced and corrected as agreed by Azizian and Brocca (2020) that this would enhanced the efficiency of the hydraulic models. The most important correction in this regard is hydro-correction of the river using satellite data and hydro-enforcement of the river geometry depth like carried out by Farooq et al. (2019). Moreover, it is also examined that the free DEMs alone cannot provide the best model results until there assessment be carried out by other high resolution DEMs, either surveyed or UAV/LiDAR based like Arash and Yasi (2023) utilize the direct surveyed data, while Muench et al. (2022) uses LiDAR dataset for the same. Moreover, UAV DEM applications in contrast with global DEMs are outstanding as discussed by Parizi et al. (2022) but the cost and other implications of the UAS are kept their usage very limited. After assessing the three most commonly utilized free DEMs, i.e. SRTM, ASTER and ALOS, it has been identified by the reviewers that ALOS performance in different flood modelling parameters is commendable and is highly recommended to perform quick and efficient flood modelling. Whereas, among the commercially available datasets, WorldDEM the latest product corrected through TanDEM-X satellite data and other sources has been performed well.

The DEM integration with flood models was an important task in search of answer to the research question. Two of the freely available hydraulic and hydrodynamic models namely HEC-RAS and LISFLOOD-FP were discussed in details to examined the utilization in different studies. However, majority of the selected studies found HEC-RAS efficient for the purpose of flood modelling. Like Khojeh et al. (2022) find out that the unsteady state of modelling in HEC-RAS provides accurate flood characteristics of mitigation. It can be simulated on the historic maximum flood events and provides the output including inundation depth, velocity and extents (Farooq et al. 2019). Arash and Yasi (2023) revealed that the 1D model is sufficiently fair for straight streams, whereas the 2D model is required for floodplain-meandering rivers. Physically based distributed hydrological models, such as Liuxihe, demonstrated the effectiveness of using meteorological parameters as well as land use, land cover, and soil datasets (Zhu and Chen 2024). The application in flood hazard mapping includes floodplain delineation and depth estimations, which are carried out using different procedures while performing DEM correction and hydraulic modelling. The resultant flood hazard maps were assessed in different situations in some of the selected studies. Moreover, the physical characteristics of vulnerable areas, including terrain, land use, land cover, and spatial variability, directly impact flood risk assessments. Therefore, the forest, agriculture, and the change of the natural landscape into farms and urban areas largely affect water flow and flooding. The integrated flood model performance evaluation demands certain calibration, validation, and model sensitivity testing using different parameters, such as statistical measures and other techniques, among which the most important is Manning's roughness coefficient, which has been widely used for model evaluation. It has been observed that the calibration using the past events enhances the reliability of the flood models. This review further assessed the involvement of machine learning techniques in flood management and studies ML-based random forests, artificial neural networks, generalized linear models, and convolutional neural networks at different DEM resolutions. These methods can be used for rapid flood predictions.

Recent climate change has affected ecosystems worldwide, including riverine ecosystems (Parasiewicz et al. 2019). Therefore, sustainable flood management and mitigation strategies include the preservation of natural habitats and landscapes, particularly floodplain ecosystems. A sustainable ecosystem would provide a natural barrier to slow down water flow and minimize floods with the help of natural wetlands, riverine forests, natural meandering, and oxbow lakes. Therefore, this review also incorporates the strategies for riparian ecosystem assessment, resilient solutions, and important viable and cost-effective solutions to be incorporated in flood management.

The acquired scientific results would not be worthwhile if they were not applied in proper flood risk management, policy making, and governing strategies. In this regard, the community resilience plays a

key role in flood risk management. Arash and Yasi (2023) confirmed that flood modelling enhances community resilience. Flood mitigation strategies are a priority for policymakers and stakeholders globally, according to Barman et al. (2023). Li et al. (2023) emphasized the implementation of a flood forecasting system for effective disaster management. Moreover, flood hazard assessment helps policymakers in planning and development procedures (Farooq et al. 2019). Hence, it is imperative that the integration of a Digital Elevation Model (DEM) with hydrological models significantly contributes to the development of flood mitigation and management strategies.

5.1. Limitations and biases

This SLR has some potential biases. For example, the articles were selected only from English language sources, which resulted in the exclusion of valuable information from research studies published in other languages. However, due to translation challenges and the difficulties in converting articles from other languages, the reviewers opted to focus solely on studies published in English. Moreover, the article selection based on ROSES in search of the core research question. The articles study area also kept in consideration by the reviewers to highlight the impact of different regional physiographic characteristics.

6. Enhancing flood modelling accuracy: DEM selection, data integration, and sustainable practices

As a result of this SLR, several research gaps have been identified, and it has been observed that flood modelling accuracy could be further enhanced by considering a few critical parameters such as DEM selection, correction, and data integration. The selection of DEM for flood modelling depends upon various factors, including topography of the area (for example, coastal areas, high gradient, local depressions, and drainage pattern), cost effect, DEM spatial resolution, river type (such as meandering and braided rivers), river morphology (such as channel cross-sections, erosions, and depositions), and data availability, which are often not considered by researchers. Therefore, the targeted datasets must be selected by considering the flood-prone areas as well as the factors highlighted. In this regard, pre-prepared DEMs products of vulnerable areas must be readily available for flood inundation and simulations. Moreover, the correction of the selected DEMs has often been neglected by many researchers, as it directly impacts the flood inundation estimates in the models if the necessary corrections are not applied to the DEM prior to being available for flood modelling. This can involve manual or systematic editing to reduce errors (Hawker, Bates, et al. 2018). Several corrections of DEM are discussed in this review, such as applying algorithms, ancillary information integration, hydro-corrections, speckle, and sink removal. In addition, the integration of topographical information from surveyed or aerial sources can significantly reduce the errors in DEMs. However, despite all the corrections, many DEMs have inherent limitations with respect to the base data. Therefore, the inherent characteristics of the DEM must be comprehensively studied and applied to specific scenarios prior to the flood model. Like (Xu et al. 2021) suggest for the DEM quality can be improved by reducing noise and systematic errors. Moreover, DEM integration with flood models largely depends on certain parameters, such as the boundary condition, threshold values, and flow hydrographs, which are often not critically analyzed and eventually show uncertainty in flood modelling results and require further exploration (Lim and Brandt 2019). Furthermore, DEM integration in addressing climate change challenges is essential, as it facilitates the evaluation of land-use changes, altered flood regimes, and altered hydrological patterns as a result of environmental stressors. The identification of vulnerable ecosystems such as riparian buffers and wetlands, which act as natural flood-mitigating agents, is facilitated by high-resolution DEMs. Sustainable flood management strategies can be developed by integrating the DEM data with hydrological models. These strategies can incorporate eco-based solutions such as adaptive land-use planning, wetland conservation, and reforestation to enhance climate resilience. Moreover, in flood model accuracy assessment and performance analysis, temporal variations and data collection duration must be considered (Meadows et al. 2024). Nash-Sutcliffe efficiency (NSE) and Correlation coefficient (R2) were found to be effective procedures for DEM accuracy assessment (Barman et al. 2023; Pandya et al. 2024;

Zhu and Chen 2024). It has been suggested that the entire accuracy assessment procedure should be documented to avoid misleading results (Muench et al. 2022). In the future, researchers should focus on improving flood simulation accuracy using different criteria, such as different return periods, improved flood management, and infrastructure data incorporation etc (Hou et al. 2021). In addition, the resultant products of flood simulations, such as flow velocity, can be significantly affected by the input DEM resolution, as highlighted by Parizi et al. (2022). Therefore, future research should also test the model with different DEM resolutions of the same DEM, as carried out by Fereshtehpour et al. (2024), or different DEMs products.

The reviewers also emphasized the importance of Machine Learning (ML) techniques in this field. However, it has been revealed that it largely depends on the datasets provided for model training, and because of the lack of availability of different types of datasets, software, and computational machines, ML accuracy is compromised. Therefore, the input data need to be enriched so that, in the future, ML utilization for error identification can yield accurate results, as recommended by Xu et al. (2021). As revealed by this review, Landuse/Landcover (LULC) utilization in model calibration has been an integral requirement, and it is recommended by Mubialiwo et al. (2022) for future studies that LULC data developed by high spatial resolution can provide high accuracy. However, it is strongly recommended for future researchers that LULC data preparation be consistent with the spatial resolution of the DEM. For example, a low spatial resolution DEM cannot calibrate the highly accurate LULC data correctly, which would directly deteriorate the model results. However, a higher DEM resolution can affect the watershed-extracted water system and river convergence calculations (Zhu and Chen 2024). Therefore, the threshold for the utilization of the correct DEM resolution is critical for accurate flood modelling. This review highlighted that sustainable practices have not been followed in studies on this topic. For instance, an important research gap identified is the lack of sustainable ecosystem studies, particularly in floodplains and vulnerable areas. Keeping in view the recent climatic changes, this part of the research needs to be addressed extensively by future researchers using different parameters, such as riparian ecosystem assessment, preserving natural habitat, and identification of the delayed water flow techniques that include strategies for diversion of flooded water in arid areas, tree plantations, flood protective embankments, etc. The continuous change in Earth's environmental dynamics demands sustainable practices, especially when formulating flood mitigation strategies. The key findings qualifying the developed research question are listed as Table 9.

Table 9. Key findings.

Parameter	Impact of DEM Integration	Flood Mitigation Outcomes	Key References
DEM Resolution & Accuracy	<ul style="list-style-type: none"> • HR improves accuracy • Cost and availability limitation 	<ul style="list-style-type: none"> • Enhanced accuracy improves flood prediction and mitigation. 	(Lim and Brandt 2019; Li et al. 2023)
DEM Integration with Hydrological Models	<ul style="list-style-type: none"> • ALOS with HEC-RAS improves flood predictions 	<ul style="list-style-type: none"> • Accurate integration improves mitigation strategies. 	(Farooq et al. 2019; Khojeh et al. 2022)
DEM Correction Techniques	<ul style="list-style-type: none"> • Enhanced DEM accuracy • Improved model results 	<ul style="list-style-type: none"> • Improve flood extent and depth estimates. 	(Azizian and Brocca 2020; Xu et al. 2021)
Free vs Commercial DEMs	<ul style="list-style-type: none"> • Free DEMs like ALOS, are suitable • Commercial DEMs offer higher precision. 	<ul style="list-style-type: none"> • Commercial DEMs provide better accuracy in flood risk mapping and mitigation strategies. 	(Parizi et al. 2022; Arash and Yasi 2023)
Machine Learning for DEM Improvement	<ul style="list-style-type: none"> • ML improve DEM quality, especially for complex terrains 	<ul style="list-style-type: none"> • ML-enhanced DEMs allow rapid flood mitigation planning. 	(Xu et al. 2021; Parizi et al. 2022)
Terrain Influence on DEM Performance	<ul style="list-style-type: none"> • Improves DEM in steep region 	<ul style="list-style-type: none"> • Terrain-adapted DEMs improve flood mitigation in challenging areas. 	(Muench et al. 2022; Zhu and Chen 2024)
Sustainable Flood Management	<ul style="list-style-type: none"> • Identify natural flood mitigation solutions (e.g. wetlands). 	<ul style="list-style-type: none"> • Integration of DEMs with ecosystems supports sustainable flood strategies. 	(Hou et al. 2021; Meadows et al. 2024)
Policy and Governance Role	<ul style="list-style-type: none"> • better policy-making for flood risk management. 	<ul style="list-style-type: none"> • more informed flood mitigation policies. 	(Barman et al. 2023; Li et al. 2023)
Research Gaps in DEM Integration	<ul style="list-style-type: none"> • Limited access to HR DEMs in some regions hinders the integration of accurate data. 	<ul style="list-style-type: none"> • More comprehensive data and better DEM integration are needed for effective flood mitigation in vulnerable areas. 	(Xu et al. 2021; Meadows et al. 2024)

In summary, future research should emphasize improved DEM selection criteria, enhanced integrated parameters of DEM and hydrological models, minimization of data limitations, and incorporation of riparian ecosystem assessment. Furthermore, as a need for time, studies should further suggest developing short-, mid-, and long-term strategies, particularly in the context of sustainable development, and devise tangible solutions (structural measures, channelization, etc.) as well as intangible solutions (developing community resilience, stakeholder engagement, climate change adaptations, etc.) to floods.

7. Conclusion

The lack of a comprehensive Systematic Literature Review (SLR) on the integrated role of DEM and hydrological models for flood mitigation and risk management led to the development of this study. Findings from numerous studies illuminate the implications of the selection and correction of DEMs, as well as their integrated use in different flood models for flood mitigation and management. This study extensively examines the role of different DEM products and their integration with flood models to support flood risk management. Eight key themes emerged from the SLR of the 21 selected studies: DEM data sources and characteristics, Integration of DEMs and Hydrological Models; Applications in Flood Hazard Mapping; Terrain Characteristics Impact; Model Performance Evaluation; Machine Learning for Flood Management; Ecosystem Services and Resilience; Policy and Governance.

The review findings highlight the selection of a suitable DEM and its applied correction to be integrated with flood models. After performing corrections, ALOS was found to be the best freely available DEM for performing quick and efficient flood modelling coupled with the HEC-RAS unsteady flood model. Moreover, different characteristics were examined to enhance the efficiency of the developed products and assess their application in flood mitigation and management strategies. This review highlights that DEM-based flood modelling is not only essential for flood risk assessment but also contributes to climate adaptation and sustainable ecosystem management. The ability to simulate terrain changes under different climate scenarios allows researchers and policymakers to anticipate flood risks, implement nature-based solutions, and design sustainable infrastructures. Ultimately, the key factors in policy making and governance have been identified, and it has been revealed that the integration of DEMs with hydrological models plays a vital role in developing flood mitigation and management strategies, addressing issues due to climate change, and ensuring the resilience of communities and ecosystems to flooding. Finally, the review contributes significantly to addressing the gap in the integrated role of DEMs and hydrological models in flood mitigation and management strategies. However, the review also identifies several research gaps, especially the lack of inclusion of climate change adaptations and sustainable ecosystem assessments that need to be focused on in the future.

Acknowledgements

The authors would like to thank the Valuation and Property Services Department (JPPH) (KK-2023-005) and Earth Observation Center, Institute of Climate Change, UKM.

Ethical approval

The authors confirm that no ethical approval was necessary for the subject matter or materials addressed in this manuscript. The authors affirm that the research discussed in this manuscript does not present any ethical concerns.

Author contributions

CRedit: **Raheel Ahmad**: Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing; **Khairul Nizam Abdul Maulud**: Conceptualization, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing; **Umair Bin Zamir**: Investigation, Methodology; **Siti Fatin Mohd Razali**: Investigation, Visualization; **Zaher Mundher Yaseen**: Investigation,

Validation; **Biswajeet Pradhan**: Investigation, Validation; **Mohd Nazish Khan**: Investigation, Validation; **Bekzod Eshkuvatov**: Investigation, Validation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author would like to thank the Valuation and Property Services Department (JPPH) for their financial support under research grant KK-2023-005.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

- Abu Samah A, Shaffril HAM, Fadzil MF, Ahmad N, Idris KA. 2021. Systematic review on adaptation practices in aquaculture towards climate change impacts. *Sustainability*. 13(20):11410. doi: [10.3390/su132011410](https://doi.org/10.3390/su132011410).
- Afreen M, Haq F, Mukhtar Z. 2022. Flood susceptibility analysis of the Panjkora Valley Northern Pakistan, using frequencyratio approach. *IJDRBE*. 13(5):601–614. doi: [10.1108/IJDRBE-09-2020-0104](https://doi.org/10.1108/IJDRBE-09-2020-0104).
- Ahmad I, Wang XQ, Waseem M, Zaman M, Aziz F, Khan RZN, Ashraf M. 2022. Flood management, characterization and vulnerability analysis using an integrated RS-GIS and 2D hydrodynamic modelling approach: the case of Deg Nullah, Pakistan. *Remote Sens*. 14(9):2138. doi: [10.3390/rs14092138](https://doi.org/10.3390/rs14092138).
- Annis A, Karpack M, Morrison RR, Nardi F. 2022. On the influence of river Basin morphology and climate on hydrogeomorphic floodplain delineations. *Adv Water Resour*. 159:104078. doi: [10.1016/j.advwatres.2021.104078](https://doi.org/10.1016/j.advwatres.2021.104078).
- Arash AM, Yasi M. 2023. The assessment for selection and correction of RS-based DEMs and 1D and 2D HEC-RAS models for flood mapping in different river types. *J Flood Risk Management*. 16(1):e12871. doi: [10.1111/jfr3.12871](https://doi.org/10.1111/jfr3.12871).
- Avand M, Kuriqi A, Khazaei M, Ghorbanzadeh O. 2022. DEM resolution effects on machine learning performance for flood probability mapping. *J Hydro-Environ Res*. 40:1–16. doi: [10.1016/j.jher.2021.10.002](https://doi.org/10.1016/j.jher.2021.10.002).
- Avila-Aceves E, Plata-Rocha W, Monjardin-Armenta SA, Rangel-Peraza JG. 2023. Geospatial modelling of floods: a literature review. *Stoch Environ Res Risk Assess*. 37(11):4109–4128. doi: [10.1007/s00477-023-02505-1](https://doi.org/10.1007/s00477-023-02505-1).
- Azizian A, Brocca L. 2020. Determining the best remotely sensed DEM for flood inundation mapping in data sparse regions. *Int J Remote Sens*. 41(5):1884–1906. doi: [10.1080/01431161.2019.1677968](https://doi.org/10.1080/01431161.2019.1677968).
- Barman D, Baruah A, Sarma AK, Aggarwal SP. 2023. Performance assessment of DEM vertical sensitivity on two-dimensional hydrodynamic simulation in an alluvial tributary floodplain of the Brahmaputra lower basin in India. *Iran J Sci Technol Trans Civ Eng*. 47(6):3935–3948. doi: [10.1007/s40996-023-01149-z](https://doi.org/10.1007/s40996-023-01149-z).
- Belayneh A, Sintayehu G, Gedam K, Muluken T. 2020. Evaluation of satellite precipitation products using HEC-HMS model. *Model Earth Syst Environ*. 6(4):2015–2032. doi: [10.1007/s40808-020-00792-z](https://doi.org/10.1007/s40808-020-00792-z).
- Bhattacharya B, Mazzoleni M, Ugay R. 2019. Flood inundation mapping of the sparsely gauged large-scale Brahmaputra basin using remote sensing products. *Remote Sens*. 11(5):501. doi: [10.3390/rs11050501](https://doi.org/10.3390/rs11050501).
- Bhuyian MNM, Kalyanapu A. 2018. Accounting digital elevation uncertainty for flood consequence assessment. *J Flood Risk Management*. 11(S2):S1051–S1062. doi: [10.1111/jfr3.12293](https://doi.org/10.1111/jfr3.12293).
- Bures L, Roub R, Sychova P, Gdulova K, Doubalova J. 2019. Comparison of bathymetric data sources used in hydraulic modelling of floods. *J Flood Risk Management*. 12(S1):e12495. doi: [10.1111/jfr3.12495](https://doi.org/10.1111/jfr3.12495).
- Cantoni E, Trambly Y, Grimaldi S, Salamon P, Dakhlaoui H, Dezetter A, Thiémig V. 2022. Hydrological performance of the ERA5 reanalysis for flood modeling in Tunisia with the LISFLOOD and GR4J models. *J Hydrol-Reg Stud*. 42:101169. doi: [10.1016/j.ejrh.2022.101169](https://doi.org/10.1016/j.ejrh.2022.101169).
- Carrera-Hernández JJ. 2021. Not all DEMs are equal: an evaluation of six globally available 30 m resolution DEMs with geodetic benchmarks and LiDAR in Mexico. *Remote Sens Environ*. 261:112474. doi: [10.1016/j.rse.2021.112474](https://doi.org/10.1016/j.rse.2021.112474).
- Cooke A, Smith D, Booth A. 2012. Beyond PICO: the SPIDER tool for qualitative evidence synthesis. *Qual Health Res*. 22(10):1435–1443. doi: [10.1177/1049732312452938](https://doi.org/10.1177/1049732312452938).
- Farooq M, Shafique M, Khattak MS. 2019. Flood hazard assessment and mapping of River Swat using HEC-RAS 2D model and high-resolution 12-m TanDEM-X DEM (WorldDEM). *Nat Hazards*. 97(2):477–492. doi: [10.1007/s11069-019-03638-9](https://doi.org/10.1007/s11069-019-03638-9).

- Fereshtehpour M, Esmailzadeh M, Alipour RS, Burian SJ. 2024. Impacts of DEM type and resolution on deep learning-based flood inundation mapping. *Earth Sci Inform.* 17(2):1125–1145. doi: [10.1007/s12145-024-01239-0](https://doi.org/10.1007/s12145-024-01239-0).
- García-Peñalvo FJ. 2022. Developing robust state-of-the-art reports: systematic literature reviews. *Educ Knowl Soc.* 23:e28600. doi: [10.14201/eks.28600](https://doi.org/10.14201/eks.28600).
- Grimaldi S, Li Y, Pauwels VRN, Walker JP. 2016. Remote sensing-derived water extent and level to constrain hydraulic flood forecasting models: opportunities and challenges. *Surv Geophys.* 37(5):977–1034. doi: [10.1007/s10712-016-9378-y](https://doi.org/10.1007/s10712-016-9378-y).
- Guo K, Guan M, Yan H, Xia X. 2023. A spatially distributed hydrodynamic model framework for urban flood hydrological and hydraulic processes involving drainage flow quantification. *J Hydrol.* 625:130135. doi: [10.1016/j.jhydrol.2023.130135](https://doi.org/10.1016/j.jhydrol.2023.130135).
- Haddaway NR, Macura B, Whaley P, Pullin AS. 2018. ROSES RepOrting standards for Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Environ Evid.* 7(1):7. doi: [10.1186/s13750-018-0121-7](https://doi.org/10.1186/s13750-018-0121-7).
- Hawker L, Bates P, Neal J, Rougier J. 2018. Perspectives on Digital Elevation Model (DEM) simulation for flood modeling in the absence of a high-accuracy open access global DEM. *Front Earth Sci.* 6:233. doi: [10.3389/feart.2018.00233](https://doi.org/10.3389/feart.2018.00233).
- Hawker L, Rougier J, Neal J, Bates P, Archer L, Yamazaki D. 2018. Implications of simulating global digital elevation models for flood inundation studies. *Water Resour Res.* 54(10):7910–7928. doi: [10.1029/2018WR023279](https://doi.org/10.1029/2018WR023279).
- Hong QN, Fàbregues S, Bartlett G, Boardman F, Cargo M, Dagenais P, Gagnon M-P, Griffiths F, Nicolau B, O’Cathain A, et al. 2018. The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *EFI.* 34(4):285–291. doi: [10.3233/EFI-180221](https://doi.org/10.3233/EFI-180221).
- Hou J, Ma Y, Wang T, Li B, Li X, Wang F, Jin S, Ma H. 2021. A river channel terrain reconstruction method for flood simulations based on coarse DEMs. *Environ Model Softw.* 140:105035. doi: [10.1016/j.envsoft.2021.105035](https://doi.org/10.1016/j.envsoft.2021.105035).
- Icyimpaye G, Abdelbaki C, Mourad KA. 2022. Hydrological and hydraulic model for flood forecasting in Rwanda. *Model Earth Syst Environ.* 8(1):1179–1189. doi: [10.1007/s40808-021-01146-z](https://doi.org/10.1007/s40808-021-01146-z).
- Islam MM, Ahamed T. 2023. Development of a near-infrared band derived water indices algorithm for rapid flash flood inundation mapping from sentinel-2 remote sensing datasets. *Asia-Pac J Reg Sci.* 7(2):615–640. doi: [10.1007/s41685-023-00288-5](https://doi.org/10.1007/s41685-023-00288-5).
- Jamali B, Bach PM, Cunningham L, Deletic A. 2019. A cellular automata fast flood evaluation (CA-ffe) model. *Water Resour Res.* 55(6):4936–4953. doi: [10.1029/2018WR023679](https://doi.org/10.1029/2018WR023679).
- Jamali B, Haghghat E, Ignjatovic A, Leitão JP, Deletic A. 2021. Machine learning for accelerating 2D flood models: potential and challenges. *Hydrol Process.* 35(4):e14064. doi: [10.1002/hyp.14064](https://doi.org/10.1002/hyp.14064).
- JAXA. 2024. Japan Aerospace Exploration Agency - ALOS @EORC homepage. [accessed]. https://www.eorc.jaxa.jp/ALOS/en/index_e.htm.
- Jing CW, Shortridge A, Lin SP, Wu JP. 2014. Comparison and validation of SRTM and ASTER GDEM for a subtropical landscape in Southeastern China. *Int J Digit Earth.* 7(12):969–992. doi: [10.1080/17538947.2013.807307](https://doi.org/10.1080/17538947.2013.807307).
- Khal M, Algouti A, Algouti A, Akdim N, Stankevich SA, Menenti M. 2020. Evaluation of open Digital Elevation Models: estimation of topographic indices relevant to erosion risk in the Wadi M’Goun watershed, Morocco. *AIMS Geosci.* 6(2):231–257. doi: [10.3934/geosci.2020014](https://doi.org/10.3934/geosci.2020014).
- Khojeh S, Ataie-Ashtiani B, Hosseini SM. 2022. Effect of DEM resolution in flood modeling: a case study of Gorganrood River, Northeastern Iran. *Nat Hazards.* 112(3):2673–2693. doi: [10.1007/s11069-022-05283-1](https://doi.org/10.1007/s11069-022-05283-1).
- Kim DE, Liang S-Y, Gourbesville P, Andres L, Liu J. 2020. Simple-yet-effective SRTM DEM improvement scheme for dense urban cities using ANN and remote sensing data: application to flood modeling. *Water.* 12(3):816. doi: [10.3390/w12030816](https://doi.org/10.3390/w12030816).
- Li WZ, Li DF, Fang ZN. 2023. Intercomparison of automated near-real-time flood mapping algorithms using satellite data and DEM-based methods: a case study of 2022 Madagascar flood. *Hydrology.* 10(1):17. doi: [10.3390/hydrology10010017](https://doi.org/10.3390/hydrology10010017).
- Lim NJ, Brandt SA. 2019. Flood map boundary sensitivity due to combined effects of DEM resolution and roughness in relation to model performance. *Geomat Nat Hazards Risk.* 10(1):1613–1647. doi: [10.1080/19475705.2019.1604573](https://doi.org/10.1080/19475705.2019.1604573).
- Liu YX, Bates PD, Neal JC. 2023. Bare-earth DEM generation from ArcticDEM and its use in flood simulation. *Nat Hazards Earth Syst Sci.* 23(1):375–391. doi: [10.5194/nhess-23-375-2023](https://doi.org/10.5194/nhess-23-375-2023).
- Lochmiller CR. 2021. Conducting thematic analysis with qualitative data. *TQR.* 26(6):2029–2044. doi: [10.46743/2160-3715/2021.5008](https://doi.org/10.46743/2160-3715/2021.5008).
- Manfreda S, Nardi F, Samela C, Grimaldi S, Taramasso AC, Roth G, Sole A. 2014. Investigation on the use of geomorphic approaches for the delineation of flood prone areas. *J Hydrol.* 517:863–876. doi: [10.1016/j.jhydrol.2014.06.009](https://doi.org/10.1016/j.jhydrol.2014.06.009).
- Meadows M, Jones S, Reinke K. 2024. Vertical accuracy assessment of freely available global DEMs (FABDEM, Copernicus DEM, NASADEM, AW3D30 and SRTM) in flood-prone environments. *Int J Digit Earth.* 17(1). doi: [10.1080/17538947.2024.2308734](https://doi.org/10.1080/17538947.2024.2308734).

- Modi P, Revel M, Yamazaki D. 2022. Multivariable integrated evaluation of hydrodynamic modeling: a comparison of performance considering different baseline topography data. *Water Resour Res.* 58(8):e2021WR031819. doi: [10.1029/2021WR031819](https://doi.org/10.1029/2021WR031819).
- Moghim S, Gharehtoragh MA, Safaie A. 2023. Performance of the flood models in different topographies. *J Hydrol.* 620:129446. doi: [10.1016/j.jhydrol.2023.129446](https://doi.org/10.1016/j.jhydrol.2023.129446).
- Mohamed Shaffril HA, Samsuddin SF, Abu Samah A. 2021. The ABC of systematic literature review: the basic methodological guidance for beginners. *Qual Quant.* 55(4):1319–1346. doi: [10.1007/s11135-020-01059-6](https://doi.org/10.1007/s11135-020-01059-6).
- Mubialiwo A, Abebe A, Kawo NS, Ekolu J, Nadarajah S, Onyutha C. 2022. Hydrodynamic modelling of floods and estimating socio-economic impacts of floods in Ugandan river Malaba sub-catchment. *Earth Syst Environ.* 6(1):45–67. doi: [10.1007/s41748-021-00283-w](https://doi.org/10.1007/s41748-021-00283-w).
- Muench R, Cherrington E, Griffin R, Mamane B. 2022. Assessment of open access global elevation model errors impact on flood extents in Southern Niger. *Front Environ Sci.* 10:880840. doi: [10.3389/fenvs.2022.880840](https://doi.org/10.3389/fenvs.2022.880840).
- Munasinghe D, Cohen S, Huang YF, Tsang YP, Zhang JQ, Fang Z. 2018. Intercomparison of satellite remote sensing-based flood inundation mapping techniques. *J Am Water Resour Assoc.* 54(4):834–846. doi: [10.1111/1752-1688.12626](https://doi.org/10.1111/1752-1688.12626).
- Musa ZN, Popescu I, Mynett A. 2015. A review of applications of satellite SAR, optical, altimetry and DEM data for surface water modelling, mapping and parameter estimation. *Hydrol Earth Syst Sci.* 19(9):3755–3769. doi: [10.5194/hess-19-3755-2015](https://doi.org/10.5194/hess-19-3755-2015).
- Nardi F, Vivoni ER, Grimaldi S. 2006. Investigating a floodplain scaling relation using a hydrogeomorphic delineation method. *Water Resour Res.* 42(9). doi: [10.1029/2005WR004155](https://doi.org/10.1029/2005WR004155).
- Noyes J, Booth A, Moore G, Flemming K, Tunçalp Ö, Shakibazadeh E. 2019. Synthesising quantitative and qualitative evidence to inform guidelines on complex interventions: clarifying the purposes, designs and outlining some methods. *BMJ Glob Health.* 4(Suppl 1):e000893. doi: [10.1136/bmjgh-2018-000893](https://doi.org/10.1136/bmjgh-2018-000893).
- O'Hagan EC, Matalon S, Riesenber LA. 2018. Systematic reviews of the literature: a better way of addressing basic science controversies. *Am J Physiol Lung Cell Mol Physiol.* 314(3):L439–L442. doi: [10.1152/ajplung.00544.2017](https://doi.org/10.1152/ajplung.00544.2017).
- Olcese G, Bates PD, Neal JC, Sampson CC, Wing OEJ, Quinn N, Beck HE. 2022. Use of hydrological models in global stochastic flood modeling. *Water Resour Res.* 58(12):e2022WR032743. doi: [10.1029/2022WR032743](https://doi.org/10.1029/2022WR032743).
- Pandya D, Rana VK, Suryanarayana TMV. 2024. Inter-comparison and assessment of digital elevation models for hydrological applications in the Upper Mahi River Basin. *Appl Geomat.* 16(1):191–214. doi: [10.1007/s12518-023-00547-2](https://doi.org/10.1007/s12518-023-00547-2).
- Pant DR, Techato K, Pradit S, Gyawali S, Baniya B. 2023. The wild mega-grazers maintaining vegetation assemblages in grassland ecosystems are under threats: a systematic review on grassland ecosystems across the globe. *Indian J Environ Prot.* 43(3):219–226.
- Parasiewicz P, King EL, Webb JA, Piniewski M, Comoglio C, Wolter C, Buijse AD, Bjerklie D, Vezza P, Melcher A, et al. 2019. The role of floods and droughts on riverine ecosystems under a changing climate. *Fisheries Management Eco.* 26(6):461–473. doi: [10.1111/fme.12388](https://doi.org/10.1111/fme.12388).
- Parizi E, Khojeh S, Hosseini SM, Moghadam YJ. 2022. Application of Unmanned Aerial Vehicle DEM in flood modeling and comparison with global DEMs: case study of Atrak River Basin, Iran. *J Environ Manage.* 317:115492. doi: [10.1016/j.jenvman.2022.115492](https://doi.org/10.1016/j.jenvman.2022.115492).
- Parvaze S, Khan JN, Kumar R, Allaie SP. 2022. Flood forecasting in Jhelum river basin using integrated hydrological and hydraulic modeling approach with a real-time updating procedure. *Clim Dyn.* 59(7–8):2231–2255. doi: [10.1007/s00382-022-06206-3](https://doi.org/10.1007/s00382-022-06206-3).
- Peredo D, Ramos MH, Andréassian V, Oudin L. 2022. Investigating hydrological model versatility to simulate extreme flood events. *Hydrol Sci J.* 67(4):628–645. doi: [10.1080/02626667.2022.2030864](https://doi.org/10.1080/02626667.2022.2030864).
- Rahman S, Maulud KNA, Ujang U, Jaafar W, Shaharuddin S, Ab Rahman AA. 2024. The digital landscape of smart cities and digital twins: a systematic literature review of digital terrain and 3D city models in enhancing decision-making. *SAGE Open.* 14(1):19. doi: [10.1177/21582440231220768](https://doi.org/10.1177/21582440231220768).
- Rangari VA, Umamahesh NV, Bhatt CM. 2019. Assessment of inundation risk in urban floods using HEC RAS 2D. *Model Earth Syst Environ.* 5(4):1839–1851. doi: [10.1007/s40808-019-00641-8](https://doi.org/10.1007/s40808-019-00641-8).
- Rathbone J, Albarqouni L, Bakhit M, Beller E, Byambasuren O, Hoffmann T, Scott AM, Glasziou P. 2017. Expediting citation screening using PICO-based title-only screening for identifying studies in scoping searches and rapid reviews. *Syst Rev.* 6(1):233. doi: [10.1186/s13643-017-0629-x](https://doi.org/10.1186/s13643-017-0629-x).
- Roub R, Hejduk T, Novák P. 2012. Automating the creation of channel cross section data from aerial laser scanning and hydrological surveying for modeling flood events. *J Hydrol Hydromech.* 60(4):227–241. doi: [10.2478/v10098-012-0020-5](https://doi.org/10.2478/v10098-012-0020-5).
- Sajjad A, Lu JZ, Chen XL, Chisenga C, Mazhar N. 2023. Rapid assessment of riverine flood inundation in Chenab floodplain using remote sensing techniques. *Geoenviron Disasters.* 10(1). doi: [10.1186/s40677-023-00236-7](https://doi.org/10.1186/s40677-023-00236-7).
- Samela C, Troy TJ, Manfreda S. 2017. Geomorphic classifiers for flood-prone areas delineation for data-scarce environments. *Adv Water Resour.* 102:13–28. doi: [10.1016/j.advwatres.2017.01.007](https://doi.org/10.1016/j.advwatres.2017.01.007).
- Sanders BF. 2007. Evaluation of on-line DEMs for flood inundation modeling. *Adv Water Resour.* 30(8):1831–1843. doi: [10.1016/j.advwatres.2007.02.005](https://doi.org/10.1016/j.advwatres.2007.02.005).

- Sun XP, Zhou C, Xie J, Ouyang ZD, Luo YF. 2023. SRTM DEM correction based on PSO-DBN model in vegetated mountain areas. *Forests*. 14(10):1985. doi: [10.3390/f14101985](https://doi.org/10.3390/f14101985).
- Taloor AK, Khajuria V, Sharma S, Parsad G, Sambyal S, Kothiyari GC, Sharma M, Mehta P. 2025. Integrated optical and SAR data analysis for the monsoonal flood hazard mapping in the Tawi Basin Northwest Himalaya. *Phys Chem Earth*. 139(:103948. doi: [10.1016/j.pce.2025.103948](https://doi.org/10.1016/j.pce.2025.103948).
- Taloor AK, Sharma S, Sharma D, Chib R, Jasrotia R, Gupta S, Kothiyari GC, Mehta P, Kale RV. 2024. Estimation of MFFPI for flood hazards assessment using geospatial technology in the Tawi Basin, India. *Geosyst Geoenviron*. 3(1):100233. doi: [10.1016/j.geogeo.2023.100233](https://doi.org/10.1016/j.geogeo.2023.100233).
- Taloor AK, Thapliyal A, Kimothi S, Kothiyari GC, Gupta S. 2022. Geospatial technology-based monitoring of HAGL in the context of flash flood: A case study of Rishi Ganga Basin, India. *Geosyst Geoenviron*. 1(3):100049. doi: [10.1016/j.geogeo.2022.100049](https://doi.org/10.1016/j.geogeo.2022.100049).
- Teng J, Jakeman AJ, Vaze J, Croke BFW, Dutta D, Kim S. 2017. Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. *Environ Model Softw*. 90:201–216. doi: [10.1016/j.envsoft.2017.01.006](https://doi.org/10.1016/j.envsoft.2017.01.006).
- Xu CW, Yang JS, Wang LY. 2022. Application of remote-sensing-based hydraulic model and hydrological model in flood simulation. *Sustainability*. 14(14):8576. doi: [10.3390/su14148576](https://doi.org/10.3390/su14148576).
- Xu KP, Fang JY, Fang YQ, Sun QK, Wu CB, Liu M. 2021. The importance of digital elevation model selection in flood simulation and a proposed method to reduce DEM errors: a case study in Shanghai. *Int J Disaster Risk Sci*. 12(6):890–902. doi: [10.1007/s13753-021-00377-z](https://doi.org/10.1007/s13753-021-00377-z).
- Yan K, Di Baldassarre G, Solomatine DP, Schumann GJP. 2015. A review of low-cost space-borne data for flood modelling: topography, flood extent and water level. *Hydrol Process*. 29(15):3368–3387. doi: [10.1002/hyp.10449](https://doi.org/10.1002/hyp.10449).
- Yang C. 2024. Application and assessment of GIS technology in flash flood risk management. *SE*. 9(1):p26. doi: [10.22158/se.v9n1p26](https://doi.org/10.22158/se.v9n1p26).
- Zhai XY, Guo L, Liu RH, Zhang YY, Zhang YQ. 2021. Comparing three hydrological models for flash flood simulations in 13 humid and semi-humid mountainous catchments. *Water Resour Manage*. 35(5):1547–1571. doi: [10.1007/s11269-021-02801-x](https://doi.org/10.1007/s11269-021-02801-x).
- Zhai XY, Guo L, Zhang YY. 2021. Flash flood type identification and simulation based on flash flood behavior indices in China. *Sci China Earth Sci*. 64(7):1140–1154. doi: [10.1007/s11430-020-9727-1](https://doi.org/10.1007/s11430-020-9727-1).
- Zhu H, Chen Y. 2024. A study of the effect of DEM spatial resolution on flood simulation in distributed hydrological modeling. *Remote Sens*. 16(16):3105. doi: [10.3390/rs16163105](https://doi.org/10.3390/rs16163105).