Cooperative Mobility for
Competitive Megaregions

Utilize Crowd-Sourced Data and Machine Learning Technology to Enhance Planning for Transportation Resilience to Flooding

Ming Zhang (PI) and Qisheng Pan (Co-PI)

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16. Abstract Urban flooding has emerged as a critical challenge for cities worldwide, exacerbated by rapid urbanization and climate change. However, this review brings a ray of hope as it examines the current state of urban flood management, focusing on innovative modeling approaches, data collection methods, and planning strategies. We analyze the evolution of flood modeling techniques, from simple 1D models to complex 2D and coupled 1D-2D models, and explore the potential of crowdsourced data and machine learning in enhancing flood prediction and response. The review highlights the importance of integrated approaches that combine advanced modeling with sustainable urban planning, emphasizing the crucial need for adaptive strategies in the face of changing environmental conditions. We conclude by identifying key research priorities and practical implications for urban planners and policymakers in developing more flood-resilient cities.

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Part I: Urban Flooding - Challenges and Innovative Approaches in Planning and Management

Abstract

Urban flooding has emerged as a critical challenge for cities worldwide, exacerbated by rapid urbanization and climate change. However, this review brings a ray of hope as it examines the current state of urban flood management, focusing on innovative modeling approaches, data collection methods, and planning strategies. We analyze the evolution of flood modeling techniques, from simple 1D models to complex 2D and coupled 1D-2D models, and explore the potential of crowdsourced data and machine learning in enhancing flood prediction and response. The review highlights the importance of integrated approaches that combine advanced modeling with sustainable urban planning, emphasizing the crucial need for adaptive strategies in the face of changing environmental conditions. We conclude by identifying key research priorities and practical implications for urban planners and policymakers in developing more flood-resilient cities.

1. Introduction

Urban flooding has become one of the most urgent challenges facing cities in the 21st century, driven by the dual forces of climate change and rapid urbanization (Qi et al., 2021). The scale of this issue is starkly illustrated by statistics from 1995 to 2015, which show that floods accounted for nearly half of all climate disaster-related deaths, claiming an average of 30,000 lives annually (Gran Castro & Ramos De Robles, 2019). This crisis is a natural phenomenon and a complex interplay of environmental and human factors.

Urban flooding, distinct from traditional riverine or coastal flooding, is a phenomenon that occurs in developed areas when rainfall overwhelms existing drainage systems. Unlike flooding caused by overflowing bodies of water, urban flooding can happen anywhere in cities, often outside mapped floodplains, and results from inadequate or deteriorated stormwater infrastructure unable to handle excessive runoff. This issue is exacerbated by increased urbanization, which creates more impervious surfaces and is expected to worsen with climate change, bringing more frequent heavy precipitation events (Weber, 2019).

The Federal Emergency Management Agency (FEMA) defines urban flooding as inundation in built environments caused by rain overwhelming drainage systems, highlighting its unique nature. This distinction is crucial, as urban flooding requires solutions different from traditional flood management focused on floodplains. Understanding urban flooding as a separate issue is essential for developing effective mitigation and adaptation strategies in cities and addressing its environmental and social justice implications.

The United Nations projects that the global urban population will increase from 3.6 billion in 2011 to 6.3 billion by 2050, representing a shift from 51% to 68% of the world's population living in cities. This urbanization converts green spaces into impervious surfaces, increasing runoff and flood exposure, particularly in vulnerable areas like floodplains and low-lying coastal regions. Simultaneously, climate change is expected to intensify extreme rainfall events, although projections carry uncertainties and vary across temporal and spatial scales (Hammond et al., 2015).

These converging factors of urbanization and climate change present a complex challenge for urban planners and policymakers, necessitating comprehensive strategies to enhance flood resilience and adapt city infrastructure to changing environmental conditions. This review aims to examine the current state of urban flood management, focusing on innovative modeling approaches, data collection methods, and planning strategies that can help cities better prepare for and respond to urban flooding events.

2. Causes and Impacts of Urban Flooding:

Urban flooding is a complex issue that arises from the intersection of various environmental and human-driven factors. As cities grow and develop, the natural landscape is transformed, replacing green spaces with impervious surfaces such as roads, buildings, and parking lots. This urbanization process significantly increases surface runoff and heightens flood risk, as demonstrated (Hammond et al., 2015).

Climate change further exacerbates the problem, with projections indicating a trend towards more frequent and intense rainfall events. However, it is essential to note that these predictions come with inherent uncertainties and can vary considerably across different time frames and geographical areas (Field et al., 2012).

Another critical factor contributing to urban flooding is the state of infrastructure in many cities. Aging and inadequate stormwater management systems often struggle to cope with the increased water volume during heavy rainfall events. This issue was emphasized in a 2018 report by the University of Maryland and Texas A&M University, which pointed out the widespread challenges cities face in maintaining and upgrading their drainage infrastructure.

The same report highlights a less visible but equally important factor: uncoordinated watershed management. Many urban areas suffer from fragmented responsibilities at the governmental level, leading to disjointed and ineffective flood management strategies. This lack of coordination can result in piecemeal solutions that fail to address the broader, systemic nature of urban flooding.

Addressing urban flooding requires a comprehensive approach that considers all these interconnected factors. This may involve updating infrastructure, implementing green solutions to increase water absorption, improving intergovernmental coordination, and developing adaptive strategies to deal with the uncertainties of climate change.

The impacts of urban flooding extend far beyond the immediate inundation of streets and buildings, affecting communities in profound and long-lasting ways. These consequences are particularly severe for vulnerable populations, highlighting the uneven distribution of flood-related risks in urban areas.

Economic losses form a significant portion of flood impacts. Hammond et al. (2013) noted that these losses encompass direct and indirect costs. Direct damages include the destruction of property and infrastructure, while indirect losses stem from business interruptions and economic slowdowns in flood-affected areas. These financial burdens can be substantial, affecting individuals, businesses, and entire communities for years after flooding.

The social disruption caused by urban flooding is equally severe. According to the 2018 report by the University of Maryland and Texas A&M University, flooding often leads to the displacement of residents, sometimes for extended periods. Essential services such as healthcare, education, and public transportation can be severely disrupted, impacting daily life and community cohesion. Moreover, the psychological toll of experiencing a flood and its aftermath can have long-term effects on mental health and well-being.

Environmental damage is another critical consequence of urban flooding. Upreti et al. (2024) highlighted how floodwaters can carry pollutants and contaminants, spreading them throughout urban areas and into natural water bodies. This pollution can harm urban ecosystems, affecting flora and fauna and potentially impacting human health through contaminated water sources.

Perhaps most concerning is how urban flooding can exacerbate existing social inequalities. Low-income and minority neighborhoods often bear a disproportionate burden of flood impacts. These communities may be located in more flood-prone areas, have less resilient infrastructure, and possess fewer resources to prepare for and recover from flood events. This disparity underscores the need for equitable flood management strategies that prioritize vulnerable populations (University of Maryland & Texas A&M University, 2018).

Addressing these multifaceted impacts requires a holistic approach to urban flood management. This approach should focus on physical infrastructure improvements and consider social equity, environmental protection, and long-term community resilience. By understanding and addressing the full spectrum of flood impacts, cities can work towards creating more sustainable and equitable urban environments for all residents.

3. Evolution of Urban Flood Modeling

3.1 From 1D to 2D: Advancements in Hydraulic Modeling

The field of urban flood modeling has seen significant advancements in recent years, moving from simple one-dimensional (1D) models to more complex two-dimensional (2D) and coupled 1D-2D models. This evolution reflects the need for more accurate representations of the complex urban environment and its impact on flood dynamics.

One-dimensional models, such as HEC-RAS 1D and EPA-SWMM, have long been used for simulating riverine flooding and drainage networks. These models are computationally efficient but have limitations in capturing the complex surface processes involved in urban flooding (Garcia et al., 2020). They are particularly challenged when representing floodplain flows and the interaction between surface runoff and drainage systems.

Two-dimensional models, including HEC-RAS 2D and Infoworks ICM, offer improved capabilities in simulating pluvial flooding and interbasin transfers. These models can better represent the spatial variability of urban landscapes and provide more detailed flood extent and depth information. However, they are more computationally intensive, which can limit their application for real-time forecasting or large-scale assessments (Garcia et al., 2020).

The most advanced approach currently used in practice is the coupling of 1D and 2D models. These coupled models combine the efficiency of 1D models for representing drainage networks with the spatial detail of 2D models for surface flooding. Eldho et al. (2018) demonstrated the effectiveness of this approach through case studies in Mumbai, where coupled models were used to generate detailed flood inundation maps and hazard assessments for different return period storms.

3.2 Integrated Flood Assessment Models

In response to the complex nature of urban flooding, researchers have developed integrated flood assessment models that combine multiple components of the urban water cycle. For example, the Integrated Flood Assessment Model (IFAM) developed at IIT Bombay combines one-dimensional overland and channel flow models with a two-dimensional floodplain model (Kulkarni et al., 2014a, 2014b). This approach offers a comprehensive simulation of urban flooding scenarios, accounting for the interactions between various hydrological processes in the urban environment.

Integrating these models with Geographic Information Systems (GIS) has further enhanced their utility for urban planning and flood management. GIS integration allows for a more accurate representation of the urban landscape, including topography, land use, and drainage networks. This integration has become increasingly common, with over 80% of urban flood modeling approaches utilizing GIS (Salvadore et al., 2015).

3.3 Challenges and Future Directions

Despite these advancements, several challenges remain in urban flood modeling. Balancing model accuracy, stability, and computational efficiency is crucial, particularly for real-time applications. Data availability and quality, especially in developing countries, significantly constrain model development and validation (Eldho et al., 2018).

Future directions in urban flood modeling include the development of more efficient computational methods, such as GPU-based technologies and cloud computing, to improve the feasibility of complex models for large-scale applications (Hu & Song, 2018). There is also a growing trend towards multi-objective optimization algorithms for designing and evaluating flood mitigation strategies, allowing for more nuanced decision-making in complex urban environments (Zhou et al., 2019).

4. Innovative Data Collection Methods

4.1 Crowdsourcing and Social Media

The advent of smartphones and social media platforms has opened up new possibilities for urban flood monitoring and data collection. Crowdsourced data from public webcams, social media platforms, and citizen science projects can supplement traditional flood monitoring systems in urban areas (Helmrich et al., 2021).

Social media platforms like Twitter have been explored as sources of real-time flood information. Wang et al. (2018) demonstrated the use of Twitter data and crowdsourced photos for high-resolution urban flood monitoring. Their study employed natural language processing techniques to extract flood-related information from tweets and used computer vision to classify flood images. While the approach showed promise, challenges remain regarding data quality, relevance, and geolocation accuracy.

Citizen science projects have also emerged as valuable sources of flood data. These projects can provide high-quality, localized information but often suffer from limited coverage and irregular participation (Le Coz et al., 2016). Integrating data from multiple crowdsourced streams has been proposed to overcome individual sources' limitations (Helmrich et al., 2021).

4.2 Remote Sensing and Earth Observation

Advancements in remote sensing technologies have significantly enhanced our ability to monitor and map urban flooding. High-resolution satellite imagery and LiDAR data have become invaluable tools for creating detailed digital elevation models and land use maps, which are crucial inputs for flood modeling (Upreti et al., 2024).

Earth observation techniques have shown particular promise in addressing urban challenges such as slum mapping, air quality assessment, and disaster risk reduction. For instance, high-resolution satellite imagery combined with machine learning techniques has been used to identify and monitor informal settlements, which are often highly vulnerable to flooding (Kohli et al., 2013; Kuffer et al., 2016).

4.3 Challenges in Data Integration

While these innovative data collection methods offer new opportunities, they also present challenges regarding data quality, consistency, and integration. Songchon et al. (2021) developed methods for assessing the quality of crowdsourced social media data for urban flood management using binary logistic regression and fuzzy logic approaches. Their work highlights the potential of these methods but also underscores the need for robust quality assessment frameworks when dealing with non-traditional data sources.

Integrating diverse data streams - from traditional hydrological measurements to crowdsourced reports and satellite imagery - remains a significant challenge. Ren et al. (2022) identified the need for better data integration frameworks, such as ontology-based approaches, to enable more effective use of heterogeneous data in urban flood management.

5. Planning Strategies for Urban Flood Resilience

5.1 Green Infrastructure and Nature-Based Solutions

In recent years, there has been growing recognition of the potential of green infrastructure and nature-based solutions in mitigating urban flooding. These approaches aim to mimic natural hydrological processes and increase urban areas' capacity to absorb and store water.

Green infrastructure solutions, such as rain gardens, bioswales, and permeable pavements, can help reduce runoff and alleviate pressure on traditional drainage systems. Hou et al. (2020) demonstrated the effectiveness of rain gardens in regulating runoff using a 2D hydrodynamic model. Their study showed that properly designed rain gardens could significantly reduce peak flow rates and total runoff volumes.

Nature-based solutions extend beyond individual green infrastructure elements to encompass larger-scale ecosystem-based approaches. Dhyani et al. (2018) highlighted the importance of ecosystem-based disaster risk reduction strategies in urban planning, emphasizing their potential to enhance both flood resilience and overall urban sustainability.

5.2 Adaptive Urban Planning

Given the uncertainties associated with climate change and urban development, adaptive urban planning approaches have gained prominence in flood management strategies. These approaches emphasize flexibility and the ability to adjust strategies based on changing conditions and new information.

Ahern (2011) proposed a shift from "fail-safe" to "safe-to-fail" urbanism, emphasizing the need for urban systems that can adapt to and learn from disturbances like flooding. This approach involves designing urban landscapes that can absorb shocks and recover quickly rather than trying to prevent flooding entirely.

Integrated water management strategies considering the entire urban water cycle have also been advocated. These strategies aim to balance flood protection with other urban water management goals, such as water supply and environmental conservation (Eldho et al., 2018).

5.3 Real-Time Control and Smart City Technologies

Advancements in sensor technologies and data analytics have enabled more sophisticated approaches to urban flood management. Real-time control (RTC) operations have shown significant potential in improving the performance of flood mitigation measures compared to static operations.

Bilodeau et al. (2018) demonstrated the effectiveness of RTC strategies for stormwater detention basins in reducing flood risks. Similarly, Jafari et al. (2018) showed that optimization-based RTC approaches outperform rule-based approaches in managing urban drainage systems during flood events.

The concept of "smart cities" has further expanded the possibilities for urban flood management. Internet of Things (IoT) technologies, combined with big data analytics and artificial intelligence, offer new opportunities for real-time monitoring, prediction, and response to urban flooding (Voda & Radu, 2019).

5.4 Conclusion and Future Research Directions

Urban flooding represents a complex and growing challenge for cities worldwide, requiring innovative planning, modeling, and management approaches. This review has highlighted the significant advancements in urban flood modeling, from developing sophisticated hydraulic models to integrating diverse data sources. We have also explored emerging urban planning and technology strategies that show promise in enhancing flood resilience.

This review highlights several critical research priorities in the field of urban flood management, emphasizing the need for interdisciplinary approaches and innovative technologies. A primary focus is enhancing stormwater infrastructure integration in urban flood models. As Leandro et al. (2016) pointed out, current models often struggle to accurately represent the complexities of urban drainage systems, limiting their effectiveness in flood prediction and management.

Data collection and accessibility remain significant challenges, particularly in developing countries. Wing et al. (2020) emphasized the importance of addressing this data scarcity to improve model validation and assess flood risk reduction strategies. This priority underscores the need for global cooperation and knowledge sharing in urban flood research.

Understanding the intricate interactions between climate, land use, and hydrology in urban environments is crucial for predicting and mitigating future flood risks. This research priority recognizes the dynamic nature of urban systems and the need to adapt flood management strategies to changing environmental conditions.

The potential of crowdsourced data and artificial intelligence in flood management is an exciting area for further exploration. Researchers are called to develop more robust methods for integrating diverse data sources and to explore the applications of machine learning in real-time flood forecasting and response, particularly within the context of emerging smart city technologies.

Green infrastructure and nature-based solutions have gained attention as sustainable flood mitigation strategies. However, as highlighted by Zhou et al. (2019), there is a need for long-term studies to evaluate the effectiveness and sustainability of these approaches across different urban contexts.

The social and economic dimensions of urban flooding, including environmental justice issues, require further investigation. This priority acknowledges that flood impacts are not uniformly distributed and calls for research to address the disproportionate effects on vulnerable communities.

Rosenzweig et al. (2021) emphasized the importance of rigorous validation and testing, particularly for novel approaches such as crowdsourcing and social media-based methods. This priority ensures that new technologies and methodologies are reliable and effective before widespread implementation.

Wang et al. (2018) highlighted the need for automated data processing methods and sensitivity analyses across diverse urban settings. This research direction aims to improve the efficiency and applicability of flood management approaches in various urban environments.

Helmrich et al. (2021) advocated integrating multiple data sources and technologies to develop comprehensive flood management strategies. This holistic approach recognizes the complexity of urban flooding and the need for multifaceted solutions. Addressing implementation challenges is crucial to enhancing new approaches' practical value for urban planners and policymakers. As Upreti et al. (2024) noted, bridging the gap between research and practice is essential for effective urban flood management.

These research priorities collectively aim to advance our understanding of urban flooding, improve prediction and management strategies, and ultimately enhance the resilience of urban communities to flood risks. By addressing these key areas, researchers can contribute to developing more effective, equitable, and sustainable urban flood management practices.

6. Conclusion

Urban flooding has emerged as a critical challenge for cities worldwide, driven by the intertwined forces of rapid urbanization and climate change. This review has examined the current state of urban flood management, focusing on innovative modeling approaches, data collection methods, and planning strategies.

In conclusion, addressing urban flooding requires a comprehensive, adaptive, and interdisciplinary approach. As cities continue to grow and climate patterns shift, the importance of innovative flood management strategies will only increase. By combining advanced modeling techniques, diverse data sources, and sustainable planning strategies, we can work towards creating more flood-resilient urban environments. Future research and practice should focus on developing integrated solutions that not only mitigate flood risks but also contribute to our cities' overall sustainability and livability.

The challenges of urban flooding are complex and multifaceted, requiring interdisciplinary approaches that bridge the gaps between urban planning, hydrology, data science, and social sciences. As we progress, fostering collaboration between researchers, practitioners, and policymakers will be crucial to translate these findings into practical solutions for creating flood-resilient cities.

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Part II: A Review of Literature on Urban Flooding

1. Introduction

This report highlights urban flooding as a significant and growing challenge across the United States, causing substantial economic losses, social disruption, and housing inequality. Unlike riverine and coastal flooding, urban flooding is often overlooked despite its widespread impacts (University of Maryland & Texas A&M University, 2018). The causes are multifaceted, including aging and inadequate infrastructure, increased development leading to more impervious surfaces, more intense rainfall events, and uncoordinated watershed management.

A key finding is that many communities lack the necessary resources to effectively manage urban flooding. Low-income and minority neighborhoods are frequently disproportionately impacted, exacerbating existing social inequalities (University of Maryland & Texas A&M University, 2018). The report also highlights a significant governance issue: there is no single federal agency responsible for urban flood management, with responsibilities fragmented across federal, state, and local levels.

The study emphasizes the need for better data collection, risk mapping, and public communication about urban flood risks. Many flood-prone urban areas are not identified on FEMA flood maps, leaving residents unaware of their vulnerability (University of Maryland & Texas A&M University, 2018). Climate change and increasing extreme rainfall events are expected to worsen urban flooding unless mitigation steps are taken, underscoring the urgency of addressing this issue.

The report offers several recommendations to address these challenges. These include reviewing and clarifying responsibilities across levels of government, developing a national strategy for urban flood mitigation, improving infrastructure funding and upgrades, enhancing risk identification, mapping and communication, and supporting further research on urban flooding issues (University of Maryland, & Texas A&M University, 2018). While local-level solutions tailored to each community are important, the report stresses that federal and state support and coordination are also crucial to address this national challenge.

In conclusion, the report emphasizes that urban flooding is an overlooked but significant and growing problem requiring more attention and coordinated action across all levels of government. Better data, funding, public awareness, and mitigation strategies are needed to reduce urban flood risks and impacts, highlighting the complex and multifaceted nature of this issue (University of Maryland & Texas A&M University, 2018).

Urban flooding has emerged as one of the most pressing challenges facing cities globally in the 21st century, driven by the dual forces of climate change and rapid urbanization (Qi et al., 2021). The scale of this issue is starkly illustrated by statistics from 1995 to 2015, which show that floods accounted for nearly half of all climate disaster-related deaths, claiming an average of 30,000 lives annually (Gran Castro & Ramos De Robles, 2019). This crisis is a natural phenomenon and a complex interplay of environmental and human factors.

Urban flooding is considered a distinct phenomenon from traditional riverine or coastal flooding, occurring in developed areas when rainfall overwhelms existing drainage systems. Unlike flooding caused by overflowing bodies of water, urban flooding can happen anywhere in cities, often outside mapped floodplains, and results from inadequate or deteriorated stormwater infrastructure unable to handle excessive runoff. This issue is exacerbated by increased urbanization, which creates more impervious surfaces and is expected to worsen with climate change, bringing more frequent heavy precipitation events (Weber, 2019). The scale of urban flooding can range from significant disasters to routine problems like wet basements and sewer backups, often disproportionately affecting impoverished or neglected communities. Its complexity stems from sitting at the intersection of **climate change**, **urbanization**, and **infrastructure challenges**.

The Federal Emergency Management Agency (FEMA) defines urban flooding as inundation in built environments caused by rain overwhelming drainage systems, highlighting its unique nature. This distinction is crucial, as urban flooding requires solutions different from traditional flood management focused on floodplains. Understanding urban flooding as a separate issue is essential for developing effective mitigation and adaptation strategies in cities addressing its environmental and social justice implications.

Urban flooding poses a growing threat to cities worldwide, which serve as vital social hubs reliant on essential services such as energy, water, transport, housing, education, and employment. Recent examples in Brisbane, Bangkok, and Beijing underscore the disruptive potential of urban floods. The United Nations projects that the global urban population will increase from 3.6 billion in 2011 to 6.3 billion by 2050, representing a shift from 51% to 68% of the world's population living in cities. This urbanization converts green spaces into impervious surfaces, increasing runoff and flood exposure, particularly in vulnerable areas like floodplains and low-lying coastal regions. Simultaneously, climate change is expected to intensify extreme rainfall events, although projections carry uncertainties and vary across temporal and spatial scales. Studies have shown significant trends in extreme rainfall over the past century in regions like Denmark and North America (Hammond et al., 2015). The Intergovernmental Panel on Climate Change predicts an increased frequency of heavy precipitation globally in the 21st century despite acknowledged uncertainties and model biases. These converging factors of urbanization and climate change present a complex challenge for urban planners and policymakers, necessitating comprehensive strategies to enhance flood resilience and adapt city infrastructure to changing environmental conditions (Field et al., 2012).

2. Literature Review

The report reviews the state-of-the-art on urban flooding in the following pages, explicitly focusing on flood mapping, forecasting, risk assessment, and mitigation over the last ten years. Hammond et al. (2013) provide a comprehensive review of urban flood impact assessment methods, categorizing flood impacts into four main types: direct tangible, business interruption and indirect tangible, infrastructure impacts, and intangible impacts. The authors note that while direct tangible impacts are well-studied, other categories often receive less attention despite their significance. For direct tangible damage assessment, depth-damage functions are commonly used to relate flood characteristics to expected damage. This approach requires classifying assets at risk and estimating their value, with functions derived either from empirical data or synthetic analysis. However, a significant limitation is the lack of high-quality damage data for model validation. Business interruption and indirect impacts are more challenging to assess. Methods range from applying a fixed percentage of direct costs to more complex economic models like Input-Output and Computable General Equilibrium models. The authors highlight difficulties in estimating disruption duration and obtaining necessary economic data. Traffic disruption costs, while potentially significant, are often overlooked. Infrastructure impacts emerge as a particularly understudied area due to system complexity and data sensitivity. Direct damage is typically estimated using depth-damage functions, but indirect effects through infrastructure interdependencies are poorly understood. The review mentions emerging network analysis approaches aimed at capturing cascading failures in interconnected systems.

Intangible impacts, including health effects and environmental damage, present unique quantification challenges. Various models have been developed for assessing risk to life based on flood characteristics and population exposure. The authors note complex relationships between flooding and disease outbreaks, as well as significant but difficult-to-quantify mental health impacts like PTSD. Methods for valuing intangible impacts include metrics like DALYs/QALYs and willingness-to-pay approaches. Most flood impact studies focus primarily on direct tangible damages, with few attempts at integrating multiple impact categories. The authors discuss challenges in such integration due to different metrics, noting some studies that use common monetary metrics or multi-criteria techniques. Expected Annual Damage is highlighted as a method to integrate impacts from events of different probabilities. Key challenges identified include the lack of quality flood impact data for model development and validation, limited understanding of infrastructure vulnerabilities and interdependencies, difficulties in quantifying intangible impacts, and the need for improved methods to assess indirect economic impacts at the city scale. The authors emphasize the importance of accounting for future climate and socioeconomic changes in impact assessments. The review underscores the relevance of comprehensive flood impact assessment to building urban flood resilience. While understanding impacts is crucial for informing mitigation decisions, challenges remain in translating assessments into operational resilience metrics. The authors call for more comprehensive and integrated impact assessments to fully capture urban flooding consequences and support effective resilience strategies.

The study by Hammond et al. (2015) provides a comprehensive review of urban flood impact assessment methodologies, offering valuable insights into the state of the field. The authors employ a systematic literature review approach, categorizing flood impacts and analyzing various assessment methods. Their findings reveal significant gaps in current practices, particularly in assessing indirect and intangible impacts, with most existing methods focusing primarily on direct tangible impacts. The study also highlights a lack of standardization in assessment approaches, which hinders comparative analysis across different studies and regions. While the paper identifies emerging trends, such as the use of GIS and remote sensing technologies, it has several limitations. These include potential geographical bias towards developed countries, temporal limitations given its 2015 publication date, and a lack of empirical testing of the methods discussed. The study's scope may not capture the most recent advancements in the field, and it provides limited discussion on implementing improvements in practice. Despite these limitations, the paper offers a valuable framework for understanding and advancing urban flood impact assessment. However, it should be viewed as a foundation rather than a definitive guide, given the dynamic nature of the field. To gain a current understanding of state-of-the-art practices, this review should be supplemented with more recent literature and empirical studies. The identification of gaps in assessing indirect and intangible impacts, along with the need for standardization, highlights crucial areas for future research and methodological development in urban flood impact assessment.

While widely used for their simplicity and efficiency, hydrological models show limitations in detailed urban settings. Hydrodynamic models, particularly those based on shallow water equations, offer more accurate simulations but at the cost of higher computational demands (Leandro et al., 2011; Su et al., 2019). To bridge this gap, simplified models have emerged, providing a balance between accuracy and computational efficiency, especially useful for large-scale assessments (Teng et al., 2017).

Two main approaches to flood forecasting systems were identified: pre-simulated systems and real-time forecasting systems (Henonin et al., 2013). Real-time systems, while more adaptive, face challenges in balancing model complexity with operational requirements. The effectiveness of these systems is heavily dependent on the quality of rainfall data and forecasts, highlighting the critical role of data in urban flood management (Roodsari et al., 2019).

The design of flood mitigation strategies varies across scales. At the microscale, both gray infrastructure (e.g., drainage systems) and green infrastructure (e.g., rain gardens) are modeled for effectiveness (Hou et al., 2020). Mesoscale strategies often involve coupling urban flood models with optimization algorithms to find optimal combinations of measures (Bakhshipour et al., 2019). At the macro level, the focus shifts towards sustainable stormwater management frameworks and the concept of resilient cities, emphasizing a more holistic approach to urban flood management (Ahern, 2011).

Real-time control (RTC) operations have shown significant potential in improving the performance of flood mitigation measures compared to static operations. Successfully applied to drainage systems, detention ponds, and pumping stations, RTC strategies, particularly those based on optimization methods, generally outperform rule-based approaches (Bilodeau et al., 2018; Jafari et al., 2018). This finding underscores the importance of adaptive management in urban flood mitigation.

There is a growing trend towards model integration and optimization. Coupled models (e.g., 1D/2D) are increasingly used for more comprehensive urban flood simulation (W. Chen et al., 2018). Multi-objective optimization algorithms are increasingly employed to design and evaluate flood mitigation strategies, allowing for more nuanced decision-making in complex urban environments (Zhou et al., 2019).

Despite these advancements, several challenges remain. Balancing model accuracy, stability, and computational efficiency remains a crucial issue. Data availability and quality, particularly in developing countries, pose significant constraints. The review identifies a critical need for better-integrating flood models with decision-support tools to enhance their practical application. Additionally, more methodologies are needed for quantifying the sustainability of flood mitigation measures, an area that requires further research.

Technological advancements are crucial in addressing some of these challenges. GPU-based technologies and cloud computing are emerging as solutions to improve computational efficiency (Hu & Song, 2018). GIS technologies have become integral to model coupling and spatial analysis, with over 80% of urban flood modeling approaches now utilizing GIS (Salvadore et al., 2015). These technological trends suggest a future where more sophisticated, data-driven, and computationally efficient models will become increasingly accessible for urban flood management.

Wang et al. (2018) explore the use of social media (Twitter) data and crowdsourced photos to monitor urban flooding at high resolution. The study employs two main methodological approaches: natural language processing (NLP) for Twitter data analysis and computer vision techniques for crowdsourced photo classification.

For Twitter analysis, the authors retrained the Stanford NER model on Twitter data to improve location extraction, addressing a common challenge in social media analysis (Lingad et al., 2013). They then geocoded the extracted locations and used regular expressions to identify flood depth information. This approach allows for hyper-resolution flood monitoring, potentially addressing limitations in traditional remote sensing methods (Marcus & Fonstad, 2008).

The crowdsourced photo analysis utilized convolutional neural networks (CNN) via the Clarifai API to automatically classify photos and detect floods. This method builds on previous work using social media images for disaster assessment (R. Chen & Sakamoto, 2013; Nguyen et al., 2017). The authors manually validated a sample of 80 photos, finding an accuracy of 65% comparable to previous studies but indicating room for improvement. Key findings from the study include a weak correlation between Twitter volume and precipitation patterns (correlation coefficients 0.17-0.41) and clustering of Twitter posts at urban area length scales (~190 km). The CNN flood detection in crowdsourced photos matched road closure data in 2 of 4 validated locations. These results suggest the potential for using these data sources for urban flood monitoring but also highlight their accuracy and representativeness limitations.

Several limitations impact the robustness of the study's findings. The reliance on keyword filtering for Twitter data may miss relevant tweets, and the low geotagging rate (~1%) limits spatial coverage, a common issue in social media studies (Middleton et al., 2014). Urban areas appear over-represented in Twitter data compared to precipitation patterns, potentially skewing results. The CNN misclassified some flood photos, especially those with reflections or semi-submerged vegetation, indicating challenges in applying computer vision to varied real-world imagery.

Methodological limitations include the small sample size for manual validation of CNN results (only 80 photos) and limited direct comparison between Twitter and crowdsourced data. The study also lacks a quantitative assessment of flood depth extraction from tweets, which could provide valuable validation of the NLP approach. Additionally, there may be sampling bias in the crowdsourced photos based on app user distribution, a common concern in citizen science projects (Wiggins & Crowston, 2011).

Despite these limitations, the study provides a valuable foundation for further research on using social media and crowdsourcing for urban flood monitoring. The authors acknowledge many of the limitations and offer thoughtful suggestions for future improvements, including better photo-shooting guidance for crowdsourcers and data fusion schemes to integrate multiple data sources (Liggins et al., 2017). More rigorous validation against authoritative data sources and direct comparisons between the two data streams would strengthen future work in this area.

In conclusion, while the study demonstrates the potential of social media and crowdsourcing for high-resolution urban flood monitoring, it also highlights the challenges of using these data sources. Future research building on this work could significantly enhance our ability to monitor and respond to urban flooding events in real-time.

This study by Wang et al. (2018) presents a holistic framework for integrating multiple data sources and approaches in high-resolution urban flood modeling. The methodology incorporates several innovative elements, including the use of social media and photo data to reconstruct flood scenarios for model calibration and validation, comparison of different approaches for representing infiltration and drainage capacity, and investigation of terrain data processing impacts on model results. The use of a confusion matrix method for quantitative model assessment adds rigor to the evaluation process. However, the study's focus on a single small case study area limits the generalizability of its findings (Teng et al., 2017).

The key findings of the study provide valuable insights for urban flood modeling practices. The authors demonstrate that social media and photo data can be useful for reconstructing flood scenarios when direct measurements are unavailable, aligning with recent trends in utilizing crowdsourced data for flood modeling (Yu et al., 2016). They also found that a constant infiltration approach better represents flood recession processes compared to a rainfall reduction approach, which has implications for how drainage capacity is modeled in urban areas (Leandro et al., 2016). The significant impact of urban micro-features like buildings and underpasses on flood modeling results underscores the importance of high-resolution terrain data in urban flood modeling (Chen et al., 2012).

However, the study has several limitations that should be considered. The reliance on manual processing of social media data, while innovative, is time-consuming and may introduce biases. Future research could explore automated methods for extracting flood information from social media and photos (Fohringer et al., 2015). The lack of actual flow measurements for direct model validation is a significant limitation, as it leaves uncertainty about the absolute accuracy of the model predictions (Bates et al., 2010). Additionally, the study's limited exploration of parameter sensitivity and uncertainty leaves questions about the robustness of the findings across different conditions.

The authors' finding that raising building heights by 5m in DEMs produced more realistic results than 0.3m raises challenges some existing practices in flood modeling (Environment Agency, 2013). However, this result should be validated across a range of urban settings before being widely adopted. The suggestion that drainage capacity in the EA study may have been underestimated based on model comparisons is intriguing but requires further investigation and validation.

In conclusion, while this study presents a novel framework for integrating multiple data sources in urban flood modeling, its findings are limited by the focus on a single case study area and lack of direct flow measurements for validation. The proposed approach shows promise but requires further testing and refinement to demonstrate broad applicability and feasibility for large-scale implementation. Future work should focus on automating data processing, conducting sensitivity analyses, and comparing results to more complex model types across diverse urban settings (Salvadore et al., 2015). Additionally, the economic feasibility of implementing such high-resolution modeling approaches at larger scales needs to be addressed to ensure practical applicability.

This study on crowdsourcing for urban flood monitoring employs a comprehensive methodology, including an extensive literature review covering public webcams, social media, and citizen science projects (Helmrich et al., 2021). The researchers analyze existing databases and platforms to assess real-world capabilities and develop quantitative metrics to evaluate data sources systematically. A case study of Norfolk, VA, is also included to examine practical implementation. However, the methodology has some limitations, primarily focusing on databases and projects in Arizona, which may limit generalizability. The study also relies heavily on secondary data analysis rather than direct testing of crowdsourcing approaches or primary data collection.

The findings of the study highlight both the potential and challenges of different crowdsourcing methods for flood monitoring. Public webcams are found to provide reliable real-time data but are limited by fixed locations and viewing angles (Bothmann et al., 2017; Castelletti et al., 2016). Social media offers many observations but suffers from low relevance and poor geolocation accuracy (de Bruijn et al., 2017; Smith et al., 2015). Citizen science projects provide high-quality data but have limited coverage and frequency (Le Coz et al., 2016; Lowry & Fienen, 2013). A key strength of the study is its quantification of these capabilities using consistent metrics across data sources. The researchers also emphasize the potential for integrating multiple crowdsourced data types to overcome individual limitations.

However, the study has several important limitations. The findings on accuracy and precision are limited due to the lack of experimental validation. Conclusions about the integration of data sources remain largely speculative without practical testing. The study also provides a limited analysis of how crowdsourced data compares to traditional monitoring methods in terms of effectiveness and cost-efficiency. Furthermore, the focus on one geographic region (Arizona) limits the generalizability of the findings.

The research is also constrained by minimal examination of data quality, reliability, and representativeness issues that are crucial in crowdsourcing applications. Technical challenges in data integration and processing have not been explored in depth. Additionally, the proposed concept of an integrated flood observation network is not tested or validated in real-world conditions.

In conclusion, while this study provides a thorough review of the crowdsourcing potential for urban flood monitoring and highlights promising avenues, it is limited by its reliance on secondary data analysis rather than experimental testing. The research lays a strong foundation, but further studies with primary data collection and rigorous validation would be needed to conclusively demonstrate the feasibility and effectiveness of the proposed crowdsourcing approaches for urban flood monitoring (Rosenzweig et al., 2021; Wang et al., 2018).

Another research by (Li et al., 2023) presented a novel approach for automatically detecting actual water depth from social media images during urban floods using computer vision techniques (Li et al., 2023). The method involves three main steps: data acquisition and processing, training an object detection model using YOLOv5 to detect four human body parts (crus, thigh, shoulder, head), and automatic estimation of water depth based on the detected body parts and their average lengths. The object detection model achieved a mean Average Precision (mAP) of 0.967 on the test dataset, with an average detection speed of 0.0122 seconds per image. Validation of the water depth estimation showed 95.9% accuracy when comparing manually estimated versus automatically detected depth ranges. For actual measured depths, the accuracy was 39% within ±5cm error and 80% within ±10cm error, with a Mean Absolute Error (MAE) of 10.22 cm and a Mean Relative Error (MRE) of 0.33. The method was applied to map the 2016 flooding in Wuhan as a case study, analyzing 31 geotagged social media images to generate a flood depth map rapidly. The proposed approach offers several advantages, including the use of humans as a common reference scale in flood images, the estimation of actual water depth values rather than just severity categories, and a balance between accuracy and computational cost. This method improves upon previous studies that only classified flood severity into discrete levels (Feng et al., 2020; Pereira et al., 2019). However, limitations exist, such as errors due to using average body part lengths and detection issues with certain body poses or incomplete images. Future improvements could include distinguishing gender, using more advanced detection models, and better image filtering. Overall, this automated method shows promise for enhancing rapid flood mapping and emergency response efforts, providing a foundation for intelligent disaster reduction in the future.

This chapter by Upreti et al. (2024) provides a comprehensive overview of major challenges in urbanizing areas and the role of earth observations in addressing these issues. The study employs a literature review approach, synthesizing information from numerous sources to provide an overview of urban challenges and earth observation applications. The authors utilize case studies and examples from various cities globally to illustrate key points, integrating information across multiple disciplines, including urban planning, environmental science, remote sensing, and disaster management.

The study identifies major urban challenges, including waste management, slum proliferation, traffic congestion, environmental pollution, urban heat islands, and vulnerability to natural disasters (Upreti et al., 2024). It highlights the potential of earth observation techniques in addressing these challenges, particularly in areas like urban flood monitoring, slum mapping, air quality assessment, and disaster risk reduction. For instance, the authors discuss the use of high-resolution satellite imagery and machine-learning techniques for slum identification and monitoring (Kohli et al., 2013; Kuffer et al., 2016).

The authors emphasize the importance of ecosystem-based disaster risk reduction strategies and the role of green infrastructure in mitigating urban environmental issues (Dhyani et al., 2018; Strosser et al., 2014). They also underscore the need for integrated approaches combining earth observation with other technologies and on-ground data collection for effective urban management (Gerasopoulos et al., 2022).

However, the study has several limitations. It relies heavily on secondary sources without presenting any original research or data analysis, limiting the ability to draw new insights or validate existing findings. While the chapter provides numerous examples, it lacks rigorous quantitative analysis to support its claims about the effectiveness of various approaches. Although the study attempts to provide a global perspective, there seems to be a focus on certain regions (e.g., Asia) while others are underrepresented.

Furthermore, the chapter could benefit from a more detailed discussion of future trends and emerging technologies in earth observation for urban applications. While it touches on some emerging areas, like the use of artificial intelligence and machine learning in urban planning (Voda & Radu, 2019), a more in-depth exploration of these topics would enhance its value for forward-looking urban planners and policymakers.

In conclusion, while the chapter provides a comprehensive overview of urban challenges and the potential of earth observation, it would benefit from more critical analysis, original research, and a balanced discussion of the proposed approaches' potential and limitations. Integrating more diverse case studies and a stronger focus on implementation challenges would enhance its practical value for urban planners and policymakers. Despite these limitations, the study is a valuable starting point for understanding the intersection of urban challenges and earth observation technologies.

Urban flooding is one of the most common and damaging natural hazards, particularly in cities where risks to life and property are concentrated (Framing the Challenge of Urban Flooding in the United States, 2019). Despite the potential for major consequences, urban flooding remains difficult to forecast, largely due to a lack of data availability at fine spatial scales and associated predictive capabilities (Rosenzweig et al., 2021). This study explores the potential of crowdsourced data from public webcams, social media, and citizen science projects to supplement traditional flood monitoring systems in urban areas.

The authors evaluate three main crowdsourced data sources: public webcams, social media platforms (e.g., Twitter, Facebook), and citizen science projects. These sources are assessed based on 12 metrics including accessibility, quantity, frequency, relevance, spatial density, urban applicability, location precision, durability, real-time capability, and nighttime data availability. The assessment was conducted through a comprehensive literature review and analysis of existing databases for each data source (Bothmann et al., 2017; de Bruijn et al., 2017; Le Coz et al., 2016).

Public webcams were found to provide real-time data but at low spatial densities. Challenges include poor positioning and image quality issues, while opportunities include large spatial coverage and potential for automated processing (Castelletti et al., 2016; Morris et al., 2013). Social media platforms offer a high quantity of posts but with low relevance to flood monitoring. Major challenges include lack of precise location data and data quality issues, but these platforms provide opportunities for real-time data collection and wide spatial coverage (Jongman et al., n.d.; Smith et al., 2015).

Citizen science projects were found to provide highly relevant data but in lower quantities compared to other sources. Challenges include low or irregular participation and data quality concerns, while opportunities include detailed local data and community engagement (Lowry et al., 2019; Sadler et al., 2018). The study also highlighted a case study in Norfolk, Virginia, demonstrating the integration of citizen science data with public safety systems for urban flood monitoring (Loftis et al., 2019).

The paper concludes that each data source has unique strengths and weaknesses for urban flood monitoring. Integration of multiple crowdsourced data types with traditional monitoring could enhance urban flood data collection and forecasting capabilities. However, significant challenges still need to be solved in data quality, consistency, and integration. The authors recommend further research on data fusion methods and incorporation of crowdsourced data into flood models (Wang et al., 2018).

In summary, while crowdsourced data shows promise for augmenting urban flood monitoring capabilities, significant work is still needed to leverage these new data sources effectively. To improve urban flood monitoring and forecasting, an integrated approach combining multiple crowdsourced and traditional data streams is recommended (Uusitalo et al., 2015).

This study by Songchon et al. (2021) addresses the challenge of assessing the quality of crowdsourced social media data for urban flood management. The researchers developed and compared two methods for evaluating the quality of flood-related Twitter data: binary logistic regression and fuzzy logic. Using Twitter data collected during three consecutive years of flooding (2016-2018) in Phetchaburi City, Thailand as a case study, they demonstrated the potential of these approaches for quality assessment of crowdsourced information in disaster contexts.

Both models incorporated four predictor variables: retweet ratio, spatiotemporal index, distance to nearest neighbor, and flood risk zone. The researchers trained the models on data from the 2016 and 2018 floods, and tested them using data from the 2017 flood event. Results showed that both models performed well, with the fuzzy logic approach slightly outperforming the logistic regression. The logistic regression model achieved 85.42% accuracy and a 91.72% F1-score, while the fuzzy logic model reached 86.46% accuracy and a 92.49% F1-score (Songchon et al., 2021).

The study found that the fuzzy logic model was better at handling isolated tweets, which could be particularly useful in the early stages of a flood event when fewer reports are available. However, the authors noted that implementing the fuzzy logic approach involved more subjectivity in defining rules and membership functions. As part of their methodology, Songchon et al. (2021) also developed a procedure for automatically approximating tweet geolocation by matching location keywords to GIS databases, which helps to minimize manual interventions and reduce computational runtime.

The research demonstrates the potential for assessing the quality of crowdsourced social media data for flood monitoring and management. By enabling the estimation of uncertainties associated with such data, these methods could allow crowdsourced information to supplement or integrate with traditional data collection methods. This could be particularly valuable in data-scarce regions where conventional water level gauging stations are limited, but social media use is relatively high (Songchon et al., 2021).

Looking to the future, the authors suggest that further research could focus on increasing the data sample size by incorporating information from alternative crowdsourcing platforms and integrating social media data with different data types. They also propose that the general approaches presented could potentially be adapted for different types of hazards beyond flooding, such as tsunamis and cyclones. Overall, this study contributes to ongoing efforts to leverage crowdsourced data for improved disaster management and response (Songchon et al., 2021).

The article reviews the status of urban flood monitoring and forecasting in the Typhoon Committee (TC) region, which includes parts of Asia and the Pacific. Urban flooding has become a major hazard risk in recent decades due to rapid urbanization and climate change, especially in this densely populated region with uneven economic development (Liu et al., 2022).

The authors note that rainfall patterns in urban areas of the TC region have changed significantly, with increases in heavy rainfall events and total precipitation in many cities. For example, in Seoul, the number of days with over 80 mm of precipitation increased 1.3 times from the 1970s to present (Liu et al., 2022). These changes, coupled with increased impervious surfaces from urbanization, have led to greater flood risks. The paper cites examples of catastrophic urban floods in recent years, including a 2021 event in Zhengzhou, China that killed over 300 people (Liu et al., 2022).

To address these risks, TC members have made efforts to improve urban flood monitoring and forecasting systems. This includes increasing the density of hydrological telemetry stations and improving temporal resolution of observations. For example, Kuala Lumpur has expanded from 5 stations in the 1990s to over 27 currently, with plans for over 90 stations (DID Malaysia, 2021). Advanced technologies like weather radar, satellites, and image-based monitoring are being utilized for rainfall and water level observations (Liu et al., 2018).

For urban flood forecasting, the authors highlight the need to consider impermeable surfaces and complex drainage systems unique to urban areas. Coupling quantitative precipitation estimation/forecasting (QPE/QPF) products with hydrological models is crucial for accuracy and lead time (Liu, 2012). However, challenges remain in configuring and simplifying sewer networks for real-time modeling.

The authors identify several areas for future enhancement, including: 1) Improving the spatial and temporal resolution of QPE/QPF products for urban-scale forecasting; 2) Advancing image-based automated monitoring using Internet of Things (IoT) technologies; 3) Integrating real-time citizen geographic information into flood mapping; and 4) Applying big data and artificial intelligence techniques to handle the complexities of urban systems (Liu et al., 2022).

In conclusion, the paper emphasizes that improving urban flood monitoring and forecasting capabilities will be a long-term task for TC members given the increasing urbanization and flood risks in the region. The authors recommend further technological exchange and cooperation among members, as well as continued development of operational systems that can integrate various data sources and emerging technologies (Liu et al., 2022).

This article examines how heterogeneous data are used to tackle urban flooding issues. The authors reviewed 69 peer-reviewed articles on data-driven approaches for urban flood management, categorizing the tasks and data involved as well as identifying links between them (Ren et al., 2022).

The review identified eight main categories of tasks related to urban flood management: inundation simulation and prediction, risk analysis, flood monitoring, response and evacuation planning, trend analysis, cause analysis, conceptual modeling, and policy analysis. The most studied tasks were inundation simulation/prediction, risk analysis, and cause analysis, which inform tasks like response planning (Ren et al., 2022).

Eight main categories of data were also identified: hydrological data, topographic data, urban planning data, traffic data, disaster damage data, census data, human perception and behavior data, and parameter data. The most frequently used were urban planning, hydrological, and topographic data. Data sources included curated sources, aerial/radar images, physical sensors, social media, open web datasets, web news, and surveys (Ren et al., 2022).

The review found complex many-to-many relationships between tasks and data categories, with one data category often supporting multiple tasks and vice versa. However, there was a lack of consensus on methodological approaches and data usage across studies addressing the same tasks. This heterogeneity makes comparison and evaluation of different approaches challenging (Ren et al., 2022).

The authors identified several research opportunities, including: 1) Moving towards greater data integration and standardization to enable system interoperability; 2) Exploring recovery-related topics which have received less attention; 3) Leveraging new data types like IoT sensors and social media for real-time decision making; and 4) Incorporating more social factors and human behavioral data (Ren et al., 2022).

Key recommendations for future research include developing data integration frameworks (e.g. ontology-based), exploring recovery and resilience topics using big data, utilizing IoT and social media data for dynamic monitoring and response, adopting open data standards, and conducting more comparative studies on the impact of different data and analytics approaches (Ren et al., 2022).

The review provides a foundation for researchers to gain an overview of this domain and informs the development of data-driven approaches to urban flood management. However, limitations include not covering the entire literature and a potential bias towards recent studies from developing countries, particularly China (Ren et al., 2022).

Urban flooding in coastal regions presents a complex challenge that requires sophisticated modeling approaches to manage and mitigate risks effectively. Eldho et al. (2018) provide a comprehensive overview of integrated flood simulation techniques that combine numerical models with geographic information systems (GIS) and remote sensing data. This approach allows for a more holistic assessment of flood dynamics in coastal urban areas, where multiple factors such as heavy rainfall, inadequate drainage, channel overtopping, and tidal influences contribute to flooding events.

The authors present two main modeling approaches: the Integrated Flood Assessment Model (IFAM) developed at IIT Bombay, and the integration of HEC-HMS and HEC-RAS models with GIS tools. The IFAM combines one-dimensional overland and channel flow models with a two-dimensional floodplain model, offering a comprehensive simulation of urban flooding scenarios (Kulkarni et al., 2014a, 2014b). This model was demonstrated through a case study of the Vashi watershed in Navi Mumbai, simulating an extreme rainfall event from 2005. The results provided detailed flood extent maps and hydrographs, illustrating the model's capability to capture the complex dynamics of urban flooding in coastal areas.

The second approach, utilizing HEC-HMS for hydrologic modeling and HEC-RAS for hydraulic modeling, was applied to the Dahisar River catchment in Mumbai (Zope, 2016). This integration allowed for the generation of flood inundation maps and hazard assessments for different return period storms. Zope et al. (2015, 2016a) demonstrated how these tools can be used to evaluate the impacts of urbanization and land-use changes on flooding, providing valuable insights for urban planning and flood management strategies.

One of the key advantages of these integrated modeling approaches is their ability to incorporate spatial data through GIS integration. This allows for a more accurate representation of the urban landscape, including topography, land use, and drainage networks. Moreover, the models can generate detailed flood maps and hazard assessments that are crucial for flood mitigation planning, evacuation strategies, and overall disaster management in coastal urban areas (Eldho et al., 2018).

However, it's important to note that these advanced modeling techniques come with certain limitations. They require extensive data inputs, including high-resolution digital elevation models, land use maps, and detailed hydrological data. The computational demands can be significant, especially for large urban areas or long-term simulations. Additionally, there are inherent simplifications in the 1D/2D modeling approaches that may not capture all the complexities of urban flood dynamics (Eldho et al., 2018).

Despite these challenges, the integrated use of numerical models, GIS, and remote sensing offers powerful capabilities for flood assessment and management planning in complex urban environments. As demonstrated by the case studies in Mumbai, these tools can provide valuable insights into flood behavior under various scenarios, helping urban planners and disaster management authorities to develop more effective strategies for flood mitigation and response (Zope et al., 2016b).

In conclusion, the work presented by Eldho et al. (2018) highlights the importance of advanced, integrated modeling approaches in addressing the complex challenge of urban flooding in coastal regions. By combining hydrodynamic models with geospatial technologies, these methods offer a more comprehensive understanding of flood risks and potential mitigation strategies. As coastal cities continue to grow and face increasing threats from climate change, such tools will become increasingly vital for sustainable urban development and effective disaster management.

The article provides an overview of hydrodynamic models used in urban flood studies, categorizing them as 1D, 2D, or 3D based on their numerical solution to the Navier-Stokes equations. One-dimensional models like HEC-RAS 1D and EPA-SWMM are useful for riverine flooding but limited in capturing complex surface processes. Two-dimensional models such as HEC-RAS 2D and Infoworks ICM can better represent pluvial flooding and interbasin transfers but are more computationally intensive (Garcia et al., 2020). Three-dimensional models are rarely used in flood hazard mapping due to their high computational requirements (Sebastian et al., 2022).

Advances in computing have enabled the uptake of more complex flood hazard models in practice. However, their widespread application is still limited by the availability of resources, validation data, and scale (Courty et al., 2017). As a result, data-driven and machine learning approaches are increasingly used to estimate flood extent and impacts, leveraging alternative data sources like rescue requests, insurance claims, and social media (Knighton et al., 2020; Mobley et al., 2019; See, 2019).

The article identifies several key research priorities for improving urban flood resilience. These include enhancing tools to model flood hazards in the built environment at regional scales, advancing understanding of climate-land use-hydrology interactions, and increasing capacity to assess and manage urban flood risks under current and future conditions. There is a particular need for better integration of stormwater infrastructure in models (Leandro et al., 2016) and improved data collection and accessibility for model validation and flood risk reduction strategy assessment (Wing et al., 2020).

In conclusion, the article emphasizes the growing importance of urban flood modeling, particularly for pluvial flooding. It highlights the various types of models used, current challenges in the field, and future research directions. As urban areas continue to expand and climate change impacts intensify, improving our ability to model and manage urban flood risks will become increasingly crucial for community resilience.

Urban flooding, particularly pluvial flooding caused by extreme rainfall, has become a growing concern due to factors such as urbanization and climate change (Henonin et al., 2013). To address this issue, various modeling approaches and real-time flood forecasting systems have been developed. The article provides a comprehensive overview of these approaches and systems, highlighting their strengths and limitations.

Different types of models can be used for urban flood modeling, each with its own advantages and drawbacks. Rainfall-runoff models estimate runoff based on catchment characteristics (Henonin et al., 2013). One-dimensional (1D) models simulate flow in drainage networks but have limitations in representing surface flooding (Mark et al., 2004). Two-dimensional (2D) models can simulate surface flooding but may not capture drainage network effects (Fewtrell et al., 2011). More advanced approaches include 1D-1D models, which couple drainage network and surface flow models (Djordjević et al., 1999), and 1D-2D models, which couple drainage network and 2D surface models. The latter are considered the most realistic but are computationally intensive (Mark & Djordjević, 2006; Schmitt et al., 2004).

The authors propose a classification of real-time urban flood forecast systems based on the use of hydraulic models: empirical scenario-based systems (no hydraulic model, based on historical events and expert knowledge), pre-simulated scenario-based systems (using a catalog of pre-simulated hydraulic scenarios), and real-time simulation-based systems (using online hydraulic models in real-time).

Challenges remain in the field, particularly in terms of computational speed for real-time 2D and 1D-2D simulations. However, promising developments are occurring, such as the use of GPU acceleration (Crossley et al., 2009) and multi-layered coarse grid modeling (Chen et al., 2012), which may make these more complex models feasible for real-time applications in the future.

The authors emphasize that the choice of model and system should be based on data availability, flood context, and forecast needs rather than simply using the most advanced technology available (Henonin et al., 2013). This pragmatic approach recognizes the diverse challenges faced in different urban environments and the need for tailored solutions. As urban areas continue to grow and climate change impacts intensify, the development and refinement of these flood forecasting and modeling approaches will play a crucial role in enhancing urban resilience to flooding.

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