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A Review of Urban Flooding Management Approaches: Predictive Modeling for Stormwater Catch Basins

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Abstract. Urban flooding has become a major global problem that is caused by the fast growth of cities, climate change, and the lack of proper infrastructure to cope with the increased stormwater runoff. Therefore, an effective stormwater management system is necessary to alleviate flooding by gathering and rerouting rainwater to the drainage systems. Predictive modeling has turned into an important tool for stormwater management simulation, as it can demonstrate runoff behavior and the impact of catch basins. Different hydrologic and hydraulic modeling software each have their own features for studies related to stormwater, watershed, and floodplains. The EPA SWMM integrates green solutions, such as rainwater harvesting, bio-retention systems, permeable pavements, floodplains, and infiltration trenches. The PCSWMM makes it possible to predict floods in real time and design detention systems making it appropriate for large and multiple uses watersheds at the same time. HEC-HMS provides a solid base for event-based and watershed simulations that require a lot of data sources and different runoff diversion methods. Meanwhile, InfraWorks and XPSWMM are dedicated to integrated hydrologic-hydraulic modeling. Moreover, MIKE+ and OpenFlows FLOOD provide high resolution detailed flood simulations and sophisticated unified platforms. Nevertheless, there is not a single modeling platform that completely solves the problem of hydrological, hydraulic and urban variability. The review applied Latent Dirichlet Allocation (LDA) to select relevant papers from various databases and identify the research issues in the simulation software for urban flooding management, which in turn led to the future research and policy making in flood control systems. The research shows that existing modeling tools can only partially connect real-time monitoring information with climate changes and machine learning methods to create complete prediction systems. The research results give new understanding about creating adaptive data-driven flood modeling methods which will help improve stormwater management techniques and upcoming flood management policies for urban areas at risk of flooding.

Introduction

Urban flooding is a major problem in cities across the globe, particularly in regions experiencing rapid urbanization due to inadequate stormwater drainage systems, an increase in impermeable land areas, and climate change [1,2,3]. The current drainage systems might be unable to cater the significant runoff from urbanization. Extreme rainfall events have the potential to exceed conventional stormwater management systems, resulting in flooded streets, surface runoff, and substantial property damage [2,4,5]. Scholars have found that as the impervious surface ratio raised by 90%, the flooding volume increased by 108% [3,6]. Moreover, the surface run-off

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increased by 9326.9 x10^3 m^3 as the pervious surface was transformed to 60% impermeable [3]. Due to the growing frequency of urban flooding in recent years, flood-risk management has been recognized as a global concern which emphasizes the need for sustainable flood-mitigation measures [1].

Stormwater management includes integrated system that concentrate on infiltration, run-off reduction, retention, and improving water quality [3,7,8]. The conventional strategy is to accumulate surface runoff thru drainage systems and convey it to subsurface infiltration trenches or ponds [9]. This technique efficiently lowers surface runoff volumes while allowing groundwater recharge. In contrast, enlarging open pervious surfaces and improving infiltration rates of the surface using permeable pavement or porous materials, however, the implementation is often constrained in highly developed areas [10,11,12]. Moreover, there are large-volume catch basins at the receptor points that serve to control the directed and mixed water from the entire drainage system which often need pumping due to the flat area. One of the latest design innovations is setting aside the low places that are to be used as both temporary storage during the rains and public parks during the hot months, thus enhancing drainage and urban life [13,14].

The stormwater regulation systems are necessary to avoid water-logging in cities [8,15]. The changes in climatic patterns and the increase of mean sea level have made it progressively difficult to deal with stormwater problems, and thus the use of standard flood management methods has become useless [8,16]. Researchers have focused on innovative stream techniques that can delay runoff discharge and subsequently cause a reduction in peak flow during the heavy rainfall period thereby mitigating urban flooding. The influence of artificial intelligence (AI) and machine learning (ML) on stormwater management by way of developing more accurate and advanced predictive models has recently become a topic of interest [8,17]. Stormwater predictive modeling is the method of forecasting future runoff and flooding events using the help of artificial intelligence based on land use, rainfall intensity, and stormwater infrastructure capacity [17,18]. By using predictive models which incorporate real-time data, geographical stations, and satellites, the urban planners and engineers can foresee possible flooding and accordingly take preventive measures so as to be able to control urban runoff more easily and effectively [17,19]. The continuous development of comprehensive modeling tools presents an opportunity of a long-term flood risk management approach that can assist communities in becoming more resilient to both temporal weather variations and permanent environmental changes [2,8,17]. This study has investigated sustainable drainage systems together with machine learning methods. The research about predictive modeling tools which assess large stormwater catch basins and detention systems remains insufficient according to existing studies. This study overcomes that restriction through its systematic review which assesses urban flooding management predictive modeling tools by using Latent Dirichlet Allocation (LDA) to examine current research and discover vital study areas and technical deficiencies. The results offer guidance for creating adaptive data-driven predictive system modeling which enhance stormwater catch basin efficiency and urban flood control in areas with low elevation like the Philippines.

Methodology

The research has utilized the Latent Dirichlet Allocation (LDA) for topic modeling and MATLAB to analyze large datasets of published articles from 2020 – 2025 to identify research gaps in urban flooding management. The keywords used are “Stormwater Management”, “Urban Flooding”, and “Predictive Modeling”. The methodology extracted relevant topics from a dataset of 206 Elsevier articles which provide valuable insights into the development of stormwater systems and the predictive modeling which help in the design of more resilient urban flood control systems. LDA revealed (refer with: Fig 1) top topics such as “Stormwater Management”, “Flood Control Systems”, “Rainwater Run-off” and “Predictive Modeling”.



Figure 1. Topic Modelling using Matlab

A total of 206 articles were initially identified through the Scopus database. After removing duplicate and irrelevant records, 54 articles remained for screening. Following a comprehensive screening process, 29 articles were determined to be relevant and were included in this review. (Refer with: Fig 2)

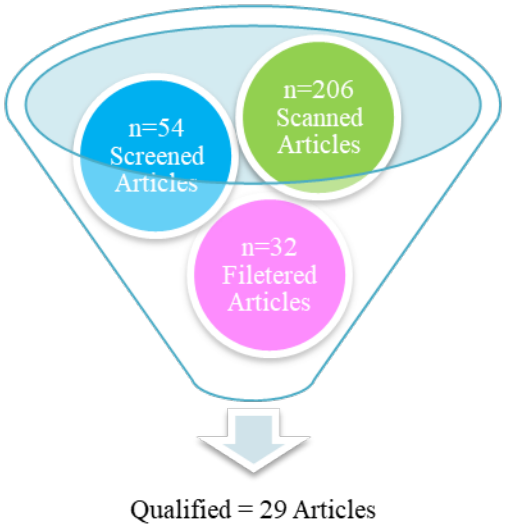


Figure 2: Literature Identification, Screening, and Inclusion

Urban Stormwater Management Systems and Contemporary Flooding Challenges

Urbanization drastically impacts the hydrologic behavior of catchments by expanding impermeable areas such as streets, roofs, and highways [20,21]. The growing frequency of intense rainfall events, rising urbanization, and climate change have all led to changes in urban stormwater management. Modern approaches generally use a systems-oriented framework that takes consideration for the generation, distribution, storage, and release of run-off throughout the whole urban catchment. The three (3) major approaches are: restoration, modification and engineering solutions, each offering distinct hydraulic and environmental benefits. However, several issues must be resolved to make sustainable stormwater management [21,22].

Restore: Reforestation and Subsurface Infiltration. Flood mitigation has come to rely on reforestation as the major technique. The latter is the method adopted in environmental conservation by the application of vegetation layering, mainly in the form of trees and plants [23]. The method is supported by safeguarding coasts with mangroves and increasing the water holding

capacity of flood-prone areas by using vegetation blocks. This technique is indeed a very effective means to protect humans from floods while at the same time protecting nature [23,24].

The aim of the technology is to capture rainwater through the surface drainage and direct it to underground infiltration systems where it can be absorbed by the soil. This process helps to keep the surface runoff at very low rates and at the same time increases the groundwater level. Nevertheless, the application is limited by geological and hydrogeological factors in the area. Thus, poor soil permeability, high groundwater levels, or the risk of contamination of soil or groundwater could all cause a significant drop in infiltration rate. Moreover, underground systems must be designed in such a way that clogging and loss of capacity over time are prevented, which in turn requires regular maintenance and monitoring [25].

Modification. Embedding changes in ecological features strengthens the control of flooding. The enlarging of the area, in particular, the making of riverbanks more solid, and the creation of trenches and swales, as well as the provision of these features, will all lead to a significant increase in the capability of the river to slow down and to hold excess water [24].

The use of permeable pavements for paving, doing soil vegetatively, and using porous materials have all been mentioned as methods for increasing infiltration rates. The system offers a very simple but effective method which is infiltration at or very close around the point of rainfall. This method is known to minimize surface run-off. The challenges it poses to the structural design project, the requirement for durable permeable materials, and the difficulty of maintenance due to sediment blockage are some of the issues this method encounters. Consequently, although it is efficient in areas of low to medium density, sometimes the method is not feasible in densely populated areas due to the restriction on its scalability [26,27].

The scheme of modifying manages to reduce runoff while at the same time providing temporary water storage and treating the water by natural biological processes [28]. Nonetheless, the mentioned challenges are related to the operation of the project and include among others: guaranteeing sufficient surface area, integrating with the existing infrastructure, and winning public acceptance of open reservoirs. In addition to that, seasonal variations, silt build-up, and maintenance of the plants are factors that affect the functioning of the scheme and need to be managed through adaptive design and management measures [22].

Engineering Solutions. Engineered interventions such as floodwalls, embankments, and storage reservoirs are applied when natural restoration or modification approaches are inefficient. Structures are carefully built to prevent extreme flooding in metropolitan areas [29].

Retaining stormwater addresses the flooding in low-lying areas downstream where significant amounts of runoff converge [29]. Retention facilities are often large-scale installations designed temporarily hold rainfall and discharge controllably. The system frequently requiring pumping mechanism due to geographical limits [24,30] Although engineering scheme is very effective at lowering the risk of downstream flooding, they have presented significant challenges and could be vulnerable to power outages or catastrophic incidents that exceeded design capacity [14,31]. To address these issues, recent strategies include sacrificial low-ground areas that act as both public areas during dry conditions and flood storage during storms. However, safety, accessibility, and social acceptability must all be carefully considered when designing the water retention facility [13,14,29,31].

Meanwhile, the so-called "flood control tunnel" in Burgos Circle, Bonifacio Global City (BGC), Taguig, Metro Manila, Philippines (Refer with: Fig. 3 and Fig. 4), can manage pluvial rain. Indeed, the tunnel is an underground retarding basin built beneath Burgos Circle, which functions as temporary storing excess stormwater area during periods of intense rainfall [32]. The facility serves as a subterranean reservoir that collects and controls run-off to prevent the overwhelming

surface run-off. The holding tank can accommodate approximately 22,000 m³ of water [33]. The water cannot flow out of the basin during the heavy storm but is released step by step into the nearby rivers after the rain has stopped, thus lowering the peak discharge and flood risk [24,34]. This method has proved the efficiency of retention facility in the metro area by marking a significant drop in flooding both within and outside the city [8,34]. The detention basin is an exemplary model of a modern metropolis flood-resistant design that has opened the door to the installation of similar systems in Metro Manila as a long-term solution to flooding [24,34].



Figure 3. Burgos Circle, BGC, Philippines, "Flood Control Tunnel" (Aerial View) [33]

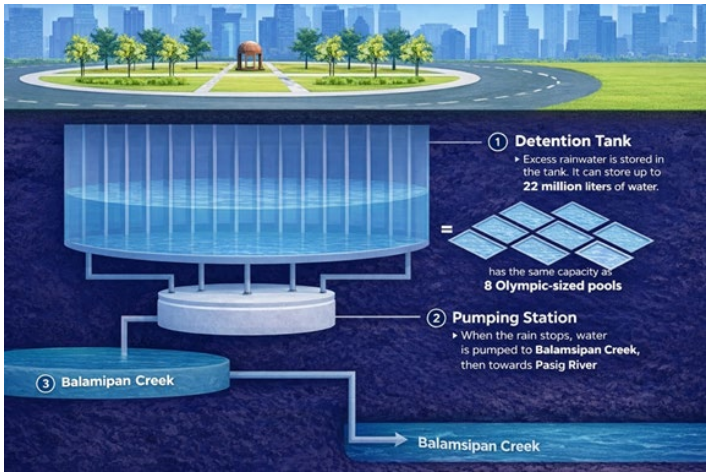


Figure 4. Underground Retention Basin Beneath Burgos Circle, BGC, Philippines (Cross-sectional detail) [33].

However, the climate variability significantly disrupt natural hydrologic processes, putting stormwater systems under unprecedented demand [17,35]. High-intensity rainfall events have become more frequent and intense, surpassing the design capacity of traditional drainage systems. Urban growth also shortens catchment reaction times, decreases infiltration, and speeds up runoff generation by substituting impermeable materials for permeable surfaces [36]. Indeed, Nature-Based Solutions (NBS) have shown that the development of predictive urban planning tools that incorporate GIS-based spatial planning, complex assessment frameworks, and geospatial simulation could help with the implementation and optimal positioning of NBS in stormwater management [37]. Furthermore, a transition from conventional hydrological modeling to intelligent and dynamic systems has also been advocated [17]. (Refer with: Table 1) shows some applications and challenges of NBS in stormwater management.

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Table 1. The following projects utilized the NBS in stormwater management.

Location / Project	Types	Scale / Capacity	Performance / Outcomes	Applicability of predictive modeling	Ref. No.
Water Sensitive Urban Design - WSUD (Barcelona)	Application of swales and park vegetations for water retention.	Catchment Area (as shown)	Improved interception efficiency and reduced surface flooding and island heat effect	Most predictive models rely on static or simplified inlet efficiency parameters and have limited capability to dynamically simulate water accumulation leading to potential overestimation of interception and percolation efficiency in real storm events.	[38]
Chicago, USA	Deep tunnel and underground stormwater storage system (TARP)	Regional mega-infrastructure; deep tunnels and reservoirs (multi-million m^3 storage)	Long-term reduction in urban flooding and combined sewer overflow frequency	Large-scale predictive models require extensive calibration and long-term datasets; accurate simulation of pressurized flow, transient surcharge, and operational controls increases numerical complexity and uncertainty in extreme-event forecasting	[39]
Rotterdam, Netherlands (Benthemplein Water Square)	Water plaza with integrated stormwater detention via surface inlets	Local site-scale detention ($\approx 10^3$ m^3 order of magnitude)	Short-term detention and peak attenuation during cloudburst events	Model performance is highly sensitive to high-resolution surface topography, rainfall spatial variability, and outlet control assumptions; simplified boundary conditions may underestimate localized ponding or overflow behavior	[40]
South Korea (urban flood-prone cities)	Deep stormwater drainage tunnels and underground conveyance-storage facilities	City-scale infrastructure	Reduction in flood depth and duration shown in design and optimization studies	Predictive modelling accuracy depends on 1D–2D coupling strategies and assumed tunnel roughness; simplified representations may not fully capture inlet–tunnel interactions and transient storage behavior under extreme rainfall	[41]

Indeed, NBSs are crucial for managing surface runoff and mitigating flooding in urban areas [42]. The systems typically include catch basin inlets, subsurface pipe conveyance, and outfalls to manage runoff during rainfall. Contemporary predictive modeling studies using Storm Water Management Model (SWMM) and related software consistently demonstrated that a gradual rise in surface imperviousness ratio results a significant increase in surface rainfall volumes and flooded junctions that exceeded the surface drainage systems' capacity [43], [44].

Studies using predictive modeling revealed that the geographical extent and duration of surface ponding are underestimated the inlet capacity, clogged mechanisms, and surface–substructure interactions, even though such an approach has the benefit and capacity to evaluate systems from a wide perspective [45]. Therefore, when considering flood risk management simulations of urbanized catchments, explicit acknowledgment of inlet capacities and maintenance parameters is crucial [46].

Technical Challenges in Flood Management Approaches

The existing methods which have been created to control urban flooding face numerous execution difficulties which remain unsolved. Restoration and infiltration-based approaches face limitations because of soil permeability and groundwater conditions and the gradual clogging of their infiltration systems [56]. The hydraulic performance of permeable pavements and vegetated swales and infiltration trenches will decrease because their maintenance requires ongoing efforts which will result in sediment buildup [57,59]. The engineered flood control measures which include detention tanks and underground reservoirs, and pump-assisted drainage systems enable better runoff management, but their operation depends on mechanical systems and power sources which face risks during extreme rainfall events [56,57,58]. The systems' performance prediction remains challenging because of three main factors which include rainfall variability and inlet capacity and surface-to-subsurface flow patterns.

Stormwater Predictive Modelling Software Key Components and Challenges

The integration of predictive modeling in designing stormwater catch basin and urban flooding management represents a significant advancement in the effort to address the unresolve challenges of urban flooding. Recent studies have made significant effort in utilizing the software for predicting stormwater runoff (Refer with Table 2).

Table 2. Predictive Modelling Software Key Components and Challenges

Software	Type / Primary Use	Key Components	Challenges	Ref.
EPA SWMM (Storm Water Management Model)	Drainage, Water Detention facility and Hydrologic-Hydraulic Model	√ Run-off Simulations √ Spatial Variability √ Drainage system modeling √ Sizing Detention Facility √ Free Software	√ Hydrometeorological estimates of inflows √ Complex tunnel geometry √ Mixed flows	[47,48]
PCSWMM	Drainage, Watershed, sewer over flow mitigation,	√ Stand-alone GIS for water management	√ Data modeling complexity √ Model Calibration	[49,50]

Software	Type / Primary Use	Key Components	Challenges	Ref.
	floodplain delineation and integrated catchment analysis	√ Time series management and analysis √ Hydraulic and hydrologic modeling √ Evaluates Green infrastructure and water quality modeling √ Ease of configuration of detention pond	√ Inherent Software constraints √ Limited accessibilty √ Cost	
HEC-HMS	Watershed Hydrological Model	√ Open channel Simulations √ Synthetic Precipitation √ Hydrologic simulations √ Model Optimization √ Simulated Watershed response √ Sediment and water quality √ Stream Flow Forecasting √ GIS Connection	√ Complexity in handling large data √ Software integration compatibility √ Display issue using high-resolution images √ Calibration Complexity	[51]
InfoWorks ICM	Integrated Catchment Model (Autodesk)	√ Catchment runoff modeling √ Advanced calibration √ Seamless software integration √ Water quality	√ Simulation stability √ Date integration between complex detailed models √ Modeling urban environments variability √ Cost	[52]

Software	Type / Primary Use	Key Components	Challenges	Ref.
XPSWMM	Stormwater, wastewater and flood modelling	√ Hydrodynamics Modeling √ Simulate rainfall run-off √ Analyze Water Quality	√ Simulation stability √ Date integration between complex detailed models √ Modeling urban environments variability √ Cost	[52]
MIKE URBAN / MIKE FLOOD	Urban Water & Flood Modelling	√ Dynamic water distribution modelling √ Stormwater and waste water analyses √ River modelling √ Predicts the impact of flood event √ Evaluate flood mitigation measures	√ Software transition and integration √ Complex model coupling √ Calibration and Validation	[53,54]
OpenFlows FLOOD	Flood & Hydraulics Modelling	√ Analyze and mitigate flood risks in urban, riverine, and coastal areas √ Simulate hydrological and hydraulic processes √ Flood Forecasting √ Water quality issues	√ Computational intensity √ Data Interoperability √ Integration Complexity √ Model Stability	[55]

The U.S. Environmental and Protection Agency model (EPA SWMM) can simulate general green infrastructure measures designed to reduce runoff volume, delay peak flows, and improve infiltration and evapotranspiration at the source. These practices include bio-retention cells or bioswales, infiltration, and evaporation; continuous permeable pavement systems, and green roofs, which incorporate soil and vegetation above a drainage layer to retain and evapotranspiration roof

runoff. The SWMM also includes infiltration trenches, which are gravel-filled narrow excavations that intercept runoff and promote infiltration [47]. However, the unpredictability of hydrometeorological data estimation, the difficulty of hydraulic calculations for tunnel geometry and related structures, and the existence of rapidly varying flow conditions during storms are some of the primary challenges. Furthermore, although realistic simulation of mixed-flow and two-phase flow regimes are currently unrealistic for use at large, system-scale modeling levels due to methodological and technical restrictions [48].

Further, the PCSWMM offers a thorough modeling framework that incorporates catchment and watershed-scale analysis, water quality modeling, low impact development (LID), and green infrastructure evaluation. The software includes sanitary sewer systems with sophisticated control and calibration tools, dual drainage systems that combine surface and subsurface flows. In addition, the platform provides real-time flood forecasts for both immediate and long-term planning, as well as stormwater management and sewer rehabilitation to reduce floods, overflows, and infiltration problems. Planners can assess future hydrologic impacts and create adaptive strategies for resilient, regulation-compliant urban water systems to advanced features that enable floodplain mapping and risk analysis, dynamic storm simulation using high-resolution radar rainfall, and climate change resilience assessments [50]. The software was able to accurately simulate larger multi-purpose watersheds [49]. However, data restrictions, model complexity, and innate software limitations are primarily constraints to adopting PCSWMM for floodplain modeling. Model validation and calibration might prove challenging due to these problems, especially in large and complicated research subject areas [49].

The Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) integrates the modern computational tools, meteorologic processes, and actual basin representation. The software provides an all-inclusive method to the simulation of watershed hydrology. The entire process for discharge modeling is carried out with the help of different techniques for infiltration, ground water flow, and channels routing which can be applied to live data and ongoing events at the same time. Moreover, the HEC-HMS accurate modeling a climatic variability which made possible by the comprehensive meteorologic inputs, such as historical and synthetic precipitation, and evapotranspiration. Flexible temporal specifications are used to govern hydrologic simulations to produce comprehensive tabular and graphical results. Moreover, integrated optimization tools of HEC-HMS can easily be calibrated for modeling parameters against the actual datasets [51].

InfraWorks creates accurate simulation of rivers, sewer networks, surface runoff, and floodplains by combining hydrologic and hydraulic components. The software facilitates the simulation of important aspects of water quality, including temperature fluctuation, sediment behavior, and pollution transport. Additionally, InfraWorks easily integrates with other Autodesk platforms, such as Civil 3D and InfoDrainage, allowing for the ease of integration of other designs. Further, XPSWMM software also provide thorough stream and floodplain simulation model and combines hydrologic and hydraulic assessments. To assess stormwater, sanitary, and sewage systems together. The XPSWMM allows for a thorough modeling of runoff, drainage patterns, and pollutant transfer. The software also opens up the possibility of doing scenario-based analysis just easier, since it compares the performance of green infrastructure, and storm occurrences and also allows for the use of different software [52]. However, the software was met with criticism over its ability to represent temporal and spatial variability, data integration coming from complex and difficult models, and simulation permanence [52].

MIKE+ software which is the model manager acts as the main user interface for the stormwater model setup and the water distribution simulations which are carried out with great efficiency. The software is capable of dynamic hydrological and water quality modeling. Under this circumstance, the system allows for the management of pumps and valves, leak minimization, network segmentation organization, flow volume assessment, and water source tracking. Further, the

software simulate river current and enable detailed analysis of flows, hydrologic changes, and pollutant transport quality to guide in disaster mitigation and water quality improvement, while the 2D overland module offers sophisticated flood simulation features to predict risks of failure, and assess mitigation strategies for climate adaptation and disaster preparation [53]

OpenFlows FLOOD uses spatially distributed numerical analysis in modeling hydrologic and hydraulic processes within river basins. The software can be integrated with OpenFlows SewerGEMS to link surface flow with runoff and sewage network behavior, as well as to simulate coastal flooding produced by storm surges. OpenFlows models realistic predictions of flood occurrences, the platform uses real-world digital context and enhanced visualization, as well as ContextCapture 3D reality meshes. The software presents built-in real-time management to compare various mitigation techniques, delineates flood prone area and enhances emergency preparation [55].

The review of predictive modeling software for managing stormwater catch basins and urban floods has brought some important challenges that need to be solved in order to improve urban flood control systems and promote sustainable stormwater management. The key challenges are as follows.

1. Most existing stormwater models fail to capture the complexities of rapidly evolving urban environments, indicating a need for more advanced predictive tools that can integrate the increasing land used and terrain [2,19].
2. Lack of integration of climate predictability in stormwater models, which is crucial for simulating extreme weather and preparing cities for future challenges. Studies have shown that modeling the spatial and temporal climate variability remains a challenge [4,15].
3. The application of machine learning and AI to flood predictions has shown potential, but it is still not extensively developed especially in stormwater catch basin management. Furthermore, there are difficulties in working with large datasets and performing high-number analysis, together with limitations in the use of high-resolution images [8].
4. One of the challenges in software transition and integration is the software compatibility issue, the data interoperability constraint, and the complex model coupling. In addition to that, the high complexity in calibrating and validating models across different scales and datasets still poses a challenge.
5. One of the most significant challenges facing the water forecasting system is the high costs associated with software licensing and model development and maintenance.
6. The last point is that the integration of green infrastructure into predictive models and the scalability of smart technologies in large urban areas still needs to undergo research [17].

Conclusion.

The use of predictive modeling in the management of stormwater catch basin and urban flooding simulations is indeed a great progress to solve the unresolved problems associated with the old methods. There are several hydrologic and hydraulic simulation tools available, and each has its own strengths. The EPA SWMM is particularly adept at modeling the green infrastructure methods such as bioretention systems, permeable pavements, rooftop gardens, infiltration trenches, and stormwater harvesting, which are all aimed at reducing runoff, delaying peak flows, and enhancing infiltration. The PCSWMM extends the capabilities of SWMM by adding watershed-scale estimation, water quality simulation, LID evaluation, real-time flood forecasting, climate change assessment, and detention and sewer system design; hence, it becomes suitable for large, multi-purpose watersheds.

In addition, HEC-HMS provides a powerful and adaptable scenario for watershed hydrology based on meteorologic inputs, with complex runoff and routing algorithms, and time-integrated optimization tools in real-time simulations. On the other hand, InfraWorks and XPSWMM focus on the integrated hydrologic-hydraulic modeling, floodplain visualization, and pollutant transport

analysis. In the same way, MIKE+ does offer advanced simulations of water distribution, collection systems, river modeling, and 2D overland flooding but OpenFlows FLOOD is more into fully distributed flood simulation, urban-coastal integration, and providing high-quality visualization in real-world digital environments.

The research shows that existing modeling platforms enable hydrologic and hydraulic simulations, yet no single tool can solve the complexities of urban variability and hydraulic and hydrological modeling requirements. The study demonstrated its importance through existing technological deficiencies in predictive flood modeling tools and demonstrated the urgent requirement for synchronized modeling systems that utilize current monitoring systems and weather changes and research-based insights.

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