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A REVIEW ON USE OF GIS TECHNOLOGY FOR MAPPING AND MODELLING URBAN FLOODS

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Abstract
Urban flooding is an old phenomenon with new dimensions such as rapid urban sprawls, deforestation, and diversion of natural streams of rivers and canals. Analysts have developed flood models to identify risk prone areas to better predict and manage urban floods. The two most important models to predict urban flooding is spatially distributed models and spatially lumped models. GIS data is used in these hydrological modelling to develop scenarios and conduct physical experiments. One of the most important tool in flood management is remote sensing that allows the analysts to efficiently manage torrential rainwater and ensure that water does not cause urban flooding by storing the water in dams, and for gardening. Some of the major indices that can assist in analyzing climate conditions include Normalized Difference of Water Index (NDWI), the Unmanned Aerial Vehicles (UAV), Normalized Difference of Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Digital elevation model are best suited to map the topography and enable the researchers and policymakers to develop robust disaster management plans in the event of urban flooding. In these models, the analysts use GIS-based conversion of rainfall to runoffs which help in mitigating the negative impact of urban flooding. This review article has discussed different aspects of urban flooding and various GIS-based models that can facilitate in managing urban floods.

Keywords: *Urban flooding, GIS-based models, flood modelling*

抽象的

城市洪水是一种古老的现象，具有新的维度，例如城市快速扩张、森林砍伐以及河流和运河的自然溪流改道。分析人员已经开发出洪水模型来识别风险易发区域，从而更好地预测和管理城市洪水。预测城市洪水的两个最重要的模型是空间分布模型和空间集总模型。在这些水文建模中使用 GIS **数据来开**发情景和进行物理实验。洪水管理中最重要的工具之一是遥感，它使分析人员能够有效地管理暴雨，并通过将水储存在水坝和园艺中来确保水不会导致城市洪水。有助于分析气候条件的一些主要指数包括归一化水指数差 (NDWI)、**无人机** (UAV)、

Received: November 18, 2021 / Revised: December 09, 2021 / Accepted: January 30, 2021 / Published: February 10, 2022
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归一化植被指数差 (NDVI) 和增强植被指数 (EVI)。数字高程模型最适合绘制地形图，使研究人员和政策制定者能够在发生城市洪水时制定稳健的灾害管理计划。在这些模型中，分析人员使用基于 GIS 的降雨转换为径流，这有助于减轻城市洪水的负面影响。这篇评论文章讨论了城市洪水的不同方面以及有助于管理城市洪水的各种基于 GIS 的模型。

关键词：城市洪水，基于 GIS 的模型，洪水建模

Introduction

Climate change around the world has forced extreme weather conditions and altered the hydrological cycle [43]. In the last four decades the severity and frequency of flooding disasters has increased significantly all over the world [45]. Every region of the world has faced floods which cost damage to property as well as human life [37]. In recent times, urban flooding has increased in major metropolitan centres. Researchers associate urban flooding with poorly planned urban sprawl along the river banks, alteration in the streams and deforestation [1, 3]. According to some studies, flood disasters has severely affected people as compared to that any other disaster [18].

The urban population is more vulnerable to extreme climate conditions [46]. These harsh climate conditions have compelled policymakers and researchers from various fields to analyze the problem and make urban centres more resilient [8]. In urban centers the term resilience deals with the capacity to bear the adverse climatic event and the ability to adapt to the disturbances [47]. Similarly, another researcher explained resilience as the capacity to adapt, absorb, resist and recover from harmful impact of a hazard and restoration of basic structures and functions [28]. In the disaster risk management, the policymakers assess the resilience of major urban centers to face adverse events. There is no single defined indicator for analyzing disaster resilience [27]. However, the research community has outlined the main facets of resilience that includes social, economic, natural, institutional, ecological and infrastructural components [35].

Developing flood models is critical for high magnitudes areas to predict floods. These models provide vital information for the city authorities, planners and public to effectively manage to flood and mitigate the risk of disaster. In the flood modelling two outputs are generated including flood inundation and hazard maps [26]. These two facilitate in visualizing depth, extent, and velocity, they help in identifying the potential risk areas during flooding. Moreover, these visual maps also form the basis for analyzing the cost and impact of floods. Therefore, in flood risk management, flood maps are of paramount importance [40]. According to Moel et al [30], flood modeling maps provide adequate time for the planners and policymakers to craft a robust emergency response.

The urban surface in inhomogenous which creates complexity in urban flooding [21]. Besides that, the dynamic nature of urban landscape also enhances the Spatio-temporal nature of flooding thus complicating the urban flooding [34]. Therefore, it is onerous to completely understand urban flooding and there is no effective remediation to mitigate the adverse impact of urban flooding without insightful understanding of the issue. There is a need to develop a comprehensive approach to comprehend unban flooding. Generally, the urban flood mapping is complex process. The two mostly developed hydrological models include spatially distributed models and spatially lumped models. According to a study, the distributed model has greater accuracy as compared to the lumped model to understand flooding in the urban watersheds [11]. Furthermore, there are more computationally intensive details in the distributed model than in the lumped models. There is multiple software available for hydrologic modelling such as HEC-HMS and SWAT etc. However, there are major limitations in this software such as their failure to delineate watershed areas and cannot perform modelling on the distributed scale. Thus, this software cannot conduct Spatio-temporal analysis of urban flooding. Moreover, the visual outputs are also not available in this software. Contrarily, Geographic Information System (GIS) is capable of visualize Spatio-temporal phenomenon [7]. Since urban flooding needs accurate assessment which is possible through a better understanding of flooding and GIS provides a suitable option to study urban flooding and visualise the outputs. Therefore, this review aims to analyze the GIS modelling to better understand urban flooding.

GIS in Environmental Modelling

Geographic Information System is a dynamic modelling system that can provide spatial analysis, visualization, data management and processing. The Table 1 below demonstrates the application of the Geographic Information System for data processing, generating output maps and spatial analysis.

Table 1 Various Applications of GIS Systems

Application Fields	**Specific Contents**	**GIS, Algorithm, Model, Sensor or Satellites**
Water resources mapping and management	Glaciers mapping	Landsat, ASTER GDEM, GIS, TIN 3D model.
	Soil moisture detection	GPR, CMP, FO, GIS spatial analysis
	Groundwater and subsidence analysis	GIS spatial analysis, GPS
	Irrigation planning	UAV, HTM for video image classification, GIS visualization
Rainfall measurements and design storm	Rainfall measurements	TRMM, GPM, GIS spatial analysis and visualization
	Design storm and urban	Huff curve, SWMM, GIS

	flood modeling	data preprocess and visualization
Rainfall runoff prediction and flood forecasting	Flood modeling	GSSHA model, GPM IMERG, GIS visualization
	Rainfall Runoff simulation	RCM, LSM, CoLM, CoLM+LF, GIS data preprocess
	Hood inundation forecast	ARX regressor, MOG A algorithm, GIS visualization
Water body and flood mapping	Flash flood detection	TMPA real time 3B2RT, CT, CDFs, J FI, GIS spatial analysis
	Urban water body mapping	ZY-3 images, AUWEM, GIS spatial analysis
	Hood inundation mapping	ENVISAT, ASAR, GIS spatial analysis

The huge bulk of data resources make it onerous to efficiently manage such a high risk management data particularly during a disaster management program, for instance during the Texas flooding event in 2016. One researcher suggested that it is imperative to proactively assimilate tools to analyze the data and unlock its potential in predicting and mitigating the adverse impact of urban flooding using various data [41]. One of the most commonly used GIS includes ArcGIS that can process remote sensing images and conduct spatial analysis, providing a map of output. The policymakers can effectively use GIS generated spatial analysis to predict urban flooding and develop robust conclusions [34].

Hydrologic modelling can use GIS data and remote sensing to create scenarios and perform physical experiments. These models enable the researchers and forecasters to view the full spectrum of the past and predict future outcomes. Furthermore, the simulations for a long time period also enable to robustly predict the low-probability events that are often ignored during ground observations [5]. These estimates are vital for hilly areas with no in-situ observations during stream flows and rainfall. In such areas, normally satellite-measured rainfall data is used in hydrological models to project flooding risks in the future [4].

Similar to other models, environmental modelling is also a simplification of reality [32, 6]. The reason for simplification is that the real-life events are based on numerous intertwined factors and it is practically not possible to simulate 100% similar factors in modelling. The modelling uses mathematical equations to simplify and explain the behaviour of various factors [31]. In these models, the mathematical equations are based on specific assumptions which potentially neglect key aspects to minimize complexities and reduce the computational costs. Thus, the modelling provides an overview of simplified environmental scenarios rather than complex real-life processes.

Both the remote sensing and Geographic Information System facilitate in the spatial aspect of environmental modelling. In environmental modelling, remote sensing provides vital data such as LIDAR data, Satellite imagery, aerial photographs to derive the topography and geologic data. Whereas, GIS facilitates storing, capturing, using and visualizing spatial data [42, 16]. However, there is a need for further processing to use the data from remote sensing and GIS in environmental systems. Added geometry and attributes are required in the datasets to identify the alterations in landscapes. Besides, there is also a need to transform some data to specific formats for use in modelling. GIS enable these datasets to be used as inputs in environmental modelling [16].

Moreover, GIS also enable analyzing and visualizing outputs from environmental modelling in addition to pre-processing. In the GIS, there are varied spatial modelling methods that expand its analytical capacity and provide insights into the evolving geographic trends. The visualization capability of GIS makes it the most suitable tool to display both spatial and non-spatial information [42].

Remote Sensing in Flood Management

According to Sarker [39], GIS when used in combination with remote sensing provides an efficient tool to analyze and identify flood zones and impacts on the flooded area. The application of remote sensing in flood modelling saves time and ensure efficient data analysis of geo-morphological data [15]. Furthermore, the GIS maps using remote sensing can also effectively manage rainwater in cities and ensure extended availability of water for gardening, emergency response and landscaping [44].

Furthermore, it has been reported that remote sensing plays a vital role in monitoring droughts and developing emergency responses to flooding. Multiple indices have been developed with the help of MODIS reflectance data to analyze the climate conditions, such as Normalized Difference of Water Index (NDWI), Enhanced Vegetation Index (EVI), and Normalized Difference of Vegetation Index (NDVI) [29]. Moreover, remote sensing in the Unmanned Aerial Vehicles (UAV) also offer a low-cost flexible platform to monitor soil moisture, vegetation growth, and flooding inundation mapping [48]. Effect flood mapping helps in develop improved disaster response for instance in 2015, the sustained flood in river basins in Oklahoma and Texas was monitored through UAVs using remote sensing and the airborne images helped in assessing daily variations in flood extents [41].

Flood Inundation Modelling

The inundation modelling is performed to analyze and predict the impact of flooding in a geographic region by simulating the flow properties of flood water. For predicting the movement and timing of flow in the channel, hydraulic models are used. In these models wave propagation is approximated which helps in determining the extent of flood, velocity of flood water and the depth which helps in developing the outputs of the models. The equations used to develop these models determine the complexity of the models regarding flows. Two major equations govern the hydraulic models. These include momentum equations and continuity equations. The momentum equation follows Newton's second law of motion which states that rate of change in momentum is equivalent to the applied forces on it [17]. Whereas, the continuity equation states that the inflows and outflows cause the net change in mass of control volume. In the momentum equation, the factors such as gravity, pressure, friction and inertia are considered in the flowing flood water. The hydraulic models use these equations differently to lower the complexity and stabilize the model. Therefore, these equations are used to develop assumptions about the flood.

Hydrological Modelling

GIS finds its application in hydrological modelling [23]. According to research, GIS in hydrological modelling helps in developing projections models in catchments [12]. Furthermore, it was also reported that GIS helps in inquiry of flood hazards, obtain topographical variables, flow-direction and stream networks [10]. GIS has been utilized in hydrological models to assess the qualitative and quantitative impacts of floods and drain off [13]. According to Devendran [14], simulation of hydrologic model is composed of three main components including sketches of given area and the databases table that provide mathematical explanation of models and the parameters included in it [14]. Besides, another researcher has developed various other hydrological models to accurately assess and predict about the flooding in an area. These models provide a logical understanding of watersheds to better cope with potential flooding.

Digital Elevation Model

Analysts must get accurate elevation data to map the topography of an area for better disaster mitigation and management. The GIS system provide an option for generating digital elevation model that provide information about flooding and variation in landform [20]. It has been reported that digital elevation models produced by geographical information systems aid in determining the patterns of drainage in an area, catchment area and the pathway for flows and runoffs [19]. The DEMs provide clear visualization of the topographical elements and serve as a data platform to fulfil the requirement of flood analysts. In the DEM the terrains are visually represented which helps in analyzing watersheds using GIS systems [36]. Furthermore, it can also be used to extract networks of drainage in an area based on runoff water, gravity and steepest descent. During the extraction of drainage networks, no interference is assumed [2].

Moreover, in the Digital Elevation Modelling, the boundaries of the watershed are displayed through morph graphic data [33]. A good DEM is not constrained by topographic attributes [9]. It was also reported that the quality of DEM resolution significantly affects the accuracy of the hydrology model [22]. Three different features of DEM determines the hydrology watershed. These include features of the selected area, channel network length and the elevation of the main channel which is viewed through different resolutions of DEM [38].

GIS-Based Watershed Delineation

Previous case studies have performed watershed delineation using DEM. Watershed delineation accuracy depends on DEM. Therefore, it is imperative that Digital Evaluation Modelling is free from error as much as possible to accurately delineate the watershed. A researcher established algorithms for eliminating errors from DEM-based GIS. It was reported that the catchment has large flat areas. The researcher fixed the horizontal area with the help of low-pass filtering on flat pixels. Furthermore, the depressions and ponds in the DEM were fixed to define the stream network. The developed algorithm was applied to delineate the outlet points of the depressions. In the modified DEM, the pond pixels were equal to the elevation shown in each exit cells. Thus, the use of low-pass filtering helped in removing errors in the DEM models using GIS tools [36]. In another study, a researcher demonstrated the ways to delineate watersheds. The researcher argued that filling of the DEM is needed to eliminate errors from the DEM models e.g., to produce a depression less model. Filling the DEM facilitated in identifying the flow direction which further helped in creating an accumulation raster. The figure below demonstrates the delineating watershed as proposed by Zhang et al. [49].

GIS-Based Conversion of Rainfall to Runoffs

In the GIS systems, Soil Conservation Service (SCS) Curve Number (CN) is applied to approximate the runoff from rainfall [24]. One another research investigated the effectiveness of the SCS CN method to estimate runoffs and it was found that this model accurately estimates runoffs for distributed modelling. However, this method is not applicable for the long-term evaluation of runoffs of a watershed. Some of the benefits of using the SCS CN method include the predictability, stability, reliance on a single parameter of Curve Number (CN) and it is well-established. However, there are some drawbacks of using this method, these include the limitation of this method to be applied in another geographic region as it was specifically developed for Midwestern US data. Besides, this method is only applicable at low base flow sites.

Conclusion

This review paper investigated the current literature on urban flooding and various modelling techniques available to predict the risk of urban flooding. Geographic Information System is the most dynamic modelling system available to visualize, manage, analyze and process the flooding data. Besides that, hydrological modelling can also utilize data generated from GIS and remote sensing to develop scenarios. These models help predict future outcomes. Furthermore, GIS is also used in capturing and storing data as well as generating environmental modelling. The review revealed various techniques that can be used to delineate watersheds and successfully convert rainfall into runoffs.

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