Chapter 4
Flood Hazard Mapping Using Hydraulic Models and GIS: A Review

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Abstract Floods are a natural event and are among the most frequent and destructive disasters, causing major infrastructure losses and disrupting livelihoods around the world. Floods are most often caused by extreme hydro-metrological and natural forces, but over the past decade, climate change and human response have added new dimensions. There is a wide array of flood risk management methods that can reduce this destruction, which requires estimating flood risks and their impacts. Preventive measures such as efficient land use planning, flood mapping, and implementation of other agronomical and engineering structures are essential in mitigating the hostile impacts of flood. Flood hazard estimation and mapping can be carried out using various methods depending on data, resources, and time availability. In contrast, flood assessment with the creation of the Geographic Information Systems (GIS) database for the flood zone and hydraulic modelling software such as HEC-RAS and HEC-HMS has proven to be useful for flood assessment. GIS can accurately predict the extent of flooding and produce flood maps, as well as flood damage estimation maps and flood hazard maps. Flood hazard maps can be analysed to provide advance warnings for general preparation and, if needed, evacuation. It is, therefore, one of the most significant tools for flood risk management.

Keywords Floods · GIS · HEC-RAS · HEC-HMS · Flood hazard maps

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4.1 Introduction

Flood, a natural catastrophe, affects several regions of the globe, both developed and developing countries. Any natural phenomenon can be defined as a hazardous event if it occurs with the likelihood of causing loss or damage settlements. Flood hazards are among the most common and destructive disasters, causing extensive damage and disrupting livelihoods worldwide. The impact of floods can vary worldwide due to geographical, agricultural, and economic reasons. Although flood calamities are primarily caused by natural events, their repercussions have been increased as a result of human activities. Urbanisation in developing countries and the rapid growth of the associated population lead to the increase of uncontrolled and unplanned development activities (Shah et al. 2020). The development activities involve floods, and flood in plain areas in the cities can potentially increase loss of life and damaging properties. Thus, to minimise the risk of flooding and associated hazards and losses, it is essential to disseminate accurate and reliable information to the public in the form of flood inundation maps. The primary purpose of flood risk assessment is to gain a good understanding of the likelihood of floods of a given intensity occurring over a long period of time. Through this approach, individuals can implement precautionary measures and actions to minimise the impact of floods.

The mixture of human vulnerability and physical exposures results in flood hazards. It is difficult to control floods, but we can take measures to minimise their impact. Identifying the right measures to deal with floods is a difficult task. The stages involved in flood disaster management include prediction, preparedness, prevention, reduction, and damage assessment. The flood peril areas can be identified by flood hazard assessment and mapping. It also improves flood risk management and disaster preparedness. The anticipated degree and depth of flooding in a particular site under different scenarios can be assessed through flood hazard assessments and mapping.

Changing land use planning, creating emergency response plans, implementing specific flood protection measures, etc. are measures that can improve flood management preparedness. Flood risk assessments can be broadened to assess specific risks, taking into account the socio-economic characteristics of exposure areas.

The generation of flood inundation map is greatly promoted from the development of modelling and remote sensing (RS) and geographic information system (GIS) techniques (Bera et al. 2012). The flood risk areas can be identified by combining hydrologic models with RS and GIS by using hydrological models such as Hydrologic Engineering Centres-River Analysis System (HEC-RAS) and Hydrologic Engineering Centres-Hydrologic Modelling System (HEC-HMS). Apart from the identification of areas under flood hazard, floods can also be predicted.

For flood hazard assessment and mapping, the key components required are digital elevation models (DEMs) for generating the topographical features of the region and hydrological models for simulating several flood events and its effects. Generating flood inundation maps is greatly influenced by the resolution of the DEM, as higher-resolution DEMs tend to produce more reliable and precise maps compared to lower-resolution DEMs (Ogania et al. 2019). Apart from DEM, various dataset such as land cover data, soil data, and meteorological data are also needed. GIS software such as ArcGIS, QGIS, and IGIS may be required for generation of maps. This software can also act as a visualisation tool.

Topographic data may be gathered (satellite data) or existing topographic datasets may be used. The use of GIS software enables the mapping of the depth and extent of flooding by measuring local land elevations in response to extreme water levels. Hydrological and historical data on floods, precipitation patterns, and climate data are required to simulate flood modelling, and these variables are used to estimate flooding depth and extent in various scenarios. This identification of high-risk flood zones allows planners to improve awareness and response. Integrated approaches that incorporate flood hazard assessments and associated maps can be implemented by land use and development planners to improve flood preparedness, enhance land developments, and increase community awareness.

This paper has presented the different case studies related to flood disaster management and successful implementation of GIS for mapping hazard maps. This work reflects the effectiveness and applicability of different flood hazard mapping methodologies. Successful implementation of flood hazard mapping will not only provide essential information on flood hazards but also enhance management and land use planning measures by limiting development in flood-prone areas.

4.2 Methodology

Flood hazard management is a critical task that involves identifying potential flood-prone areas and taking preventive measures to minimise flood risk. The following three phases can explain the methodology involved in developing a flood hazard map: (a) preparing/acquiring a DEM using ArcGIS, (b) simulating flood flows for various return periods using hydraulic models, and (c) producing flood risk maps by integrating the output from phase (a) and phase (b).

The initial phase is creating a flood hazard map (FHM) consisting of collecting and organising appropriate data. This involves acquiring data on the study region, topography, hydrology, land use, rainfall patterns, and climate data, from a range of sources, such as satellite imagery, ground surveys, and existing databases. The collected data is then processed and structured into an appropriate format for use in flood hazard modelling.

The second phase involves the utilising of the collected data to establish a flood hazard model. RS and GIS techniques are utilised to process the data and create a hydrological model that can forecast water behaviour in the area. The main objective of the model is to define and predict the higher-risk area of flooding.

The third phase incudes the generation of FHM based on the second phase which shows the areas at higher risk of flooding and the potential degree of the flood. The map can also be used to identify areas where flood mitigation measures are needed, such as constructing flood walls or implementing land use changes. The map can

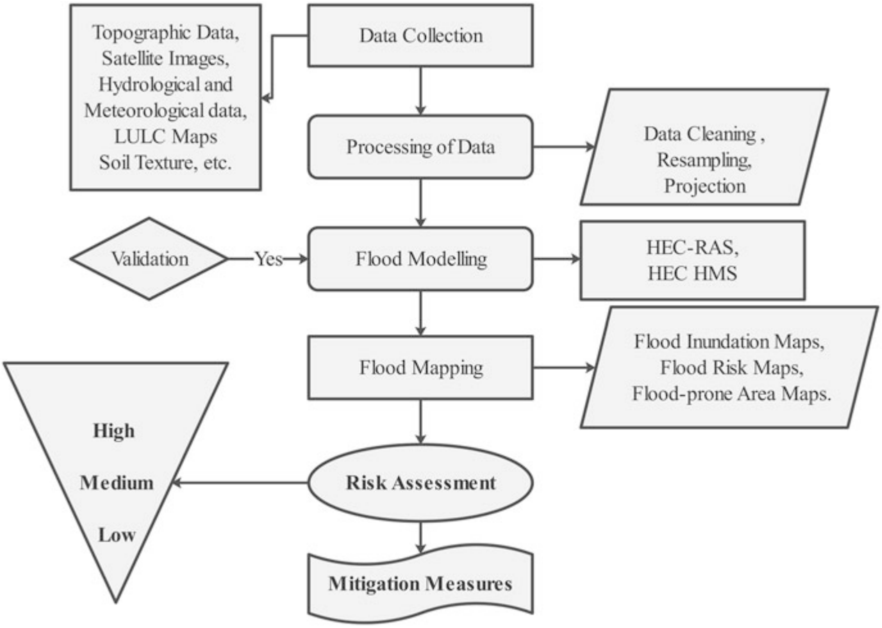

Fig. 4.1 Flowchart of flood hazard management

also be used for emergency planning and response, as it helps authorities to identify areas that are most at risk and to develop appropriate measures to mitigate the impact of flooding. The steps involved in flood hazard management using remote sensing (RS)-GIS and hydrological modelling are shown in Fig. 4.1.

4.3 HEC-RAS and HEC-HMS Model

The hydraulic model HEC-RAS, developed by the US Army Corps of Engineers (USACE), is commonly utilised to estimate the hydraulic characteristics of streams and rivers; this model allows the user to input data and obtain output on the screen and conduct further investigations. Besides the energy conservation equation, HEC-RAS needs data on river cross-sections and upstream flow rate to determine the depth and mean velocity of the river (Fan et al. 2009). By using GIS, the variation of water levels along the channel, which can be superimposed on a DEM of the region, can be computed by HEC-RAS to determine the extent and depth of flooding.

The hydraulic model of flood-prone areas using HEC-RAS in RS and GIS was created to generate the flood hazard maps for northern Thailand's Ping River Basin (Duan et al. 2012). The flood-inundated areas and flood depths of Chiang Mai province for the year 2005 were prepared by employing the HEC-RAS one-dimensional flood model. The accuracy of model was validated by cross-checking the model outputs with the RS image.

In another study carried out for Greece, the flood-inundated area maps were generated for different areas, where both the similarities and differences were showed (Panagoulia et al. 2013). The hydrologic processes for the given return period were simulated by using HEC-HMS software, and hydrographs were prepared. Several simulations related to the hydraulics of open channel flow were conducted using ArcGIS-compatible HEC-RAS software. They concluded that prioritising and planning flood protection measures in the early phase are vital in generating flood inundation maps.

HEC-RAS model along with GIS was used for the Mert River Basin, Turkey, to prepare the flood hazard maps (Demir and Kisi 2015). They employed ArcGIS software to digitise the topographical data and finally generate DEM. Using HEC-RAS software, simulation of flood values was performed. Their output was integrated to prepare the flood risk maps.

HEC-RAS was integrated with GIS to delineate flood depths and degrees for Nam Phong River in northeast Thailand (Nut and Plermkamon 2015). The steady flow simulated flood along 148 km of the river and floodplain mappings for different return periods were derived. The researchers concluded that incorporating hydraulic simulation with GIS could improve the efficiency and accuracy of floodplain mapping and management. Moreover, ArcGIS and HEC-RAS provide powerful tools for planners and decision-makers.

Romali et al. (2018) evaluated the competence of the HEC-HMS model in flood risk assessment by comparing the observed historic data with the simulated result for certain flood events of Segamat Town, Malaysia. Using Nash-Sutcliffe model efficiency as a performance indicator, both model calibration and validation were carried out. The calibration and validation periods were evaluated using Nash-Sutcliffe efficiency values of 0.90 and 0.76, respectively.

The one-dimensional HEC-RAS model in combination with GIS was also used to create FHM of Ajay River basin, where parts of Jharkhand and West Bengal contribute to the drainage basin (Chakraborty and Biswas 2020). They classified FHM in five distinct categories based on various return periods, that is, very low, low, moderate, high, and very high. The damage to land use and population was quantified in detail with the aid of the map produced based on distinct classifications.

Multispectral data from Landsat-8 OLI and Sentinel-2, as well as DEM data from Aster (30 m) and Cartosat (10 m), were used in HEC-RAS and RAS mapper to make flood inundation maps of the sub-watershed Imphal River Basin in Manipur (Bipinchandra et al. 2019). The study's results gave a good look at how floods affect the area where the study was done.

A framework was made to use GIS, HEC-HMS, and HEC-RAS to model floods on a regional scale in the Indian city of Hyderabad (Rangari et al. 2019). Flood inundation maps were made based on three floods that happened in the city: one in July 1989, one in August 2000, and one in August 2008. Flood inundation maps were made that showed both the areas at risk and the places where flooding was likely to happen.

HEC-RAS 5.0.7 and Global Flood Monitoring System (GFMS) tools were employed to identify flood risk zones and delineate flood extent in Prayagraj, India, at the conjunction of River Gange and Yamuna (Sangam) (Kumar et al. 2020). When compared, the estimated data was found to be in close proximity to the observed data indicating the applicability of HEC-RAS and GFMS data/tools together.

4.4 Other Methods

Flood risk maps for the Guwahati Municipal Corporation (GMC) Area, Assam, were prepared by performing field surveys and contacting several governmental bodies to collect information and identify the major causes of the flood (Barman and Goswami 2009). Using Erdas and ArcGIS, they generated the FHM by integrating the collected information and presented the flood-vulnerable areas of the study area.

Another study was carried out for Dikrong River Basin in Arunachal Pradesh where flood-prone areas were mapped using GIS (Bhadra et al. 2011). A comparison was made between the generated inundation maps with already published maps under Brahmaputra Board Master Plan for the study area. They observed a very low differences (<5%) between modelled and reported map inundation areas, indicating successful application. They also determined that using GIS techniques is a cost-effective and dependable approach for producing flood inundation maps in areas with undulating topography such as Dikrong.

In order to create composite flood hazard index for Ghana, an additive model was proposed where topographical, land cover, and demographic data were used (Forkuo 2011). A district-level map of flood-prone areas and maximum flood hazard zones were generated using GIS. The study further reconfirms the conclusion made by other researchers (Barman and Goswami 2009; Bhadra et al. 2011) on the applicability of GIS in flood hazard mapping.

Flood inundation maps were developed for the Dep River Basin, Nigeria, where flood occurs at different severities every year (Daffi et al. 2014). Using GIS software, they generated flood-inundated area maps based on different return periods for the river basin. They found that area under agriculture sector was affected the maximum (68.82–146.10 km^2 for return periods of 2–1000 years).

To create a high-resolution FHM, Giustarini et al. (2015) created a high-resolution hazard map by using a global inundation model from the European Centre for Medium-Range Weather Forecasts and a large collection of ENVISAT ASAR imagery. Their study showed that the combination of these methods was more beneficial than the conventional numerical modelling approach for producing high-resolution flood hazard maps.

As an advancement in the flood inundation mapping using Landsat-7 and Google Earth images along with extensive field survey, Ullah and Zhang (2020) delineated the inundated areas of the Panjkora River Basin, eastern Hindu Kush, Pakistan. The study involved locating 154 flood stations, where 70% of them were used for constructing the model and the remaining 30% for validation purposes. Flood-prone areas were identified based on eight parameters, including elevation, slope, drainage density, rainfall, normalised difference vegetation index (NDVI), land use, and topographic wetness index (TWI). The correlation between flood occurrences and each parameter was analysed, resulting in a reliable model with a success and prediction rate of more than 82%.

4.5 Conclusion

In the present study, different kinds of literature have been reviewed where different hydrological models and software have been used to identify flood-inundated areas and flood hazard mapping. Usage of hydrological models can explicitly account for the role of hydraulic structures and provide additional information, such as flow depth, velocity, and volume of flow which can be useful for other applications.

The increase in flood frequency throughout the world is a major concern. Identifying the flood-vulnerable areas is the preliminary step for comprehensive flood risk management. A better understanding of the return period and flood extent and the adoption of mitigation policies are necessary to minimise the risk. Lack of use of flood modelling techniques and faulty land use has worsened the flood situation in most parts of the world. Further, rapid urbanisation and deforestation vastly contribute to the increased flood hazards. A clear understanding and awareness of current and potential flood risks result in society mobilising local energies in building resilience. Therefore, knowledge of flood hazards is vital for taking preventive measures.

A careful, sustainable urban planning, redirection measures on flood risk management, and monitoring programmes are essential to improve flood preparedness and thereby enhance land developments and promote community awareness. While flood hazard mapping does not reduce the risk of flooding, it will certainly increase awareness to the community. Flood hazard mapping complements and reinforces other adaptive strategies including emergency planning, flood protection, and evacuation planning. For any flood control and mitigation measures, there is a need to take human behaviour into consideration to better respond to flood risk. A lack of understanding of the benefits of flood hazard mapping may also be an impediment to implementation. In addition, flood mitigation strategies cannot be restricted to the construction of infrastructure or the development of plans using a top-down approach. Local governments and policymakers need to adopt integrated risk management strategies that can be much more effective when local communities are involved.

References

Barman P, Goswami DC (2009) Flood Zone Mapping of Guwahati Municipal Corporation Area using GIS technology. 10th ESRI India User Conference. Geography in Action

Bera K, Pal M, Bandyopadhyay J (2012) A case study of Mongalkote Blocks, Burdwan, West Bengal, India. Int J Sci Res Publ 2(11):1–9

Bhadra A, Choudhury S, Kar D (2011) GIS in flood hazard mapping—a case study. World Acad Sci Eng Technol, International Journal of Geological and Environmental Engineering 5:861–866

Bipinchandra M, Romeji N, Loukrakpam C (2019) Flood hazard risk assessment an mapping of a sub-watershed of Imphal River Basin, Manipur, India: A Multi-resolution Approach. Part of Lecture Notes in Civil Engineering book series (LNCE), Vol. 33

Chakraborty S, Biswas S (2020) Application of Geographic Information System and HEC-RAS in Flood Risk Mapping of a Catchment. Part of the Lecture Notes in Civil Engineering book series (LNCE), Vol. 33

Daffi R, Otun J, Ismail A (2014) Flood hazard assessment of River Dep floodplains in North-Central Nigeria. Int J Water Resour Environ Eng. 6(2):67–72

Demir V, Kisi O (2015) Flood hazard mapping by using geographic information. Adv Meteorol 2016:9. Article ID 4891015

Duan M, Zhang J, Liu Z, Aekakkararungroj A (2012) Use of remote sensing and GIS for flood hazard mapping in Chiang Mai Province, Northern Thailand. p 203–208

Fan C, Ko CH, Wang WS (2009) An innovative modeling approach using Qual2K and HEC-RAS integration to assess the impact of tidal effect on River Water quality simulation. J Environ Manag 90:1824–1832

Forkuo EK (2011) Flood hazard mapping using aster image data with GIS. Int J Geomatics Geosci 1 (4):932–950

Giustarini L, Chini M, Hostache R, Pappenberger F, Matgen P (2015) Flood hazard mapping combining hydrodynamic modeling and multi annual remote sensing data. Remote Sens 7: 14200–14226

Kumar N, Kumar M, Sherring A, Suryavanshi S, Ahmad A, Lal D (2020) Applicability of HEC RAS 2D and GFMS for flood extent mapping: a case study of Sangam area, Prayagraj, India. Model Earth Syst Environ 6:397–405

Nut N, Plermkamon V (2015) Floodplain mapping using HEC-RAS and GIS. Int J Environ Rural Dev 6(1):153–158

Ogania JL, Puno GR, Alivio MBT, Taylaran JMG (2019) Effect of digital elevation model's resolution in producing flood hazard maps. Global J Environ Sci Manag 5(1):95–106

Panagoulia D, Mamassis N, Gkiokas A (2013) Deciphering the Floodplain Inundation Maps in Greece. 8th International Conference Water Resources Management in an Interdisciplinary and Changing Context. European Water Resources Association

Rangari VA, Sridhar V, Umamahesh NV, Patel AK (2019) Floodplain Mapping and Management of Urban Catchment Using HEC-RAS: A case study of Hyderabad city. The Institution of Engineers (India), p 49–63

Romali NS, Yusop Z, Ismail AZ (2018) Hydrological Modelling using HEC-HMS for Flood Risk: Assessment of Segamat Town, Malaysia. IOP Conf. Series: Materials Science and Engineering, 318: 012029. https://doi.org/10.1088/1757-899X/318/1/012029

Shah SMH, Mustaffa Z, Teo FY, Imam MAH, Yusof KW, Al-Qadami EHH (2020) A review of the flood hazard and risk management in the South Asian Region, particularly Pakistan. Scientific African, p 2468–2276

Ullah K, Zhang J (2020) GIS-based flood hazard mapping using relative frequency ratio method: a case study of Panjkora River Basin, eastern Hindu Kush, Pakistan. PLoS One 15(3). https://doi.org/10.1371/journal.pone.0229153