IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 2, February 2024

DOI: 10.17148/IARJSET.2024.11207

Flood Modeling: A Comprehensive Review on IDF Curves, HEC-HMS, HEC-RAS, and GIS Integration

Rajesh Kumar V[1,2]*, Guganesh S[1], Hussain Babu D[1] and Kumaresan P[1]

Irrigation, Industrial and Infrastructure SBG, WET IC, L&T Construction[1]

DSc Research Scholar, Manipur International University, India[2]

rajeeii@yahoo.com*

Abstract: Flood modeling is a critical aspect of managing the risks associated with flooding events, with recent advancements emphasizing an integrated approach. This extensive review examines the integration of Intensity-Duration-Frequency (IDF) curves, Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), Hydrologic Engineering Center-River Analysis System (HEC-RAS), and Geographic Information Systems (GIS). This review article contributes to the understanding of challenges, advancements, and practical implications associated with the application of IDF curves, capabilities and applications of HEC-HMS, HEC-RAS and GIS in flood risk assessment. By synthesizing these methodologies, the review aims to contribute to the understanding of flood modeling techniques, supporting informed decision-making and resilient infrastructure planning.

Keywords: Intensity-Duration-Frequency (IDF) curves, Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), Hydrologic Engineering Center-River Analysis System (HEC-RAS), and Geographic Information Systems (GIS), HEC-HMS, HEC-RAS and GIS.

I. INTRODUCTION

Floods, recognized as one of the most devastating natural disasters globally[1] pose a severe threat to both rural and urban areas. In regions heavily dependent on irrigation for agriculture, the vulnerability of irrigation infrastructure to flooding becomes a significant concern[2,3]. Flood-induced damage to irrigation systems leads to reduced agricultural productivity, economic losses, and food security challenges. Addressing this multifaceted issue necessitates a systematic and integrated approach to flood risk assessment and mitigation[4,5].

Flood modeling emerges as a crucial tool in planning and implementing irrigation projects. It offers insights into potential flooding extents and severity, facilitating effective flood control measures and optimized water resource management[6,7]. This approach is particularly pertinent in urban areas, where green infrastructure can aid in flood risk reduction. To comprehensively address the challenges posed by flooding to irrigation infrastructure, a methodology integrating Intensity-Duration-Frequency (IDF) curves, the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), the Hydrologic Engineering Center-River Analysis System (HEC-RAS), and Geographic Information Systems (GIS) technology is imperative.

There is a need for an integrated approach to flood risk assessment to address the specific vulnerabilities in irrigation-dependent regions. The increasing frequency and intensity of extreme weather events necessitate a sophisticated and integrated approach[8–10]. This review supports the gravity of the issue and provides a foundation for the subsequent exploration of IDF curves, HEC-HMS, HEC-RAS, GIS, and their integration in flood risk assessment. This comprehensive review explores the synergies among IDF curves, HEC-HMS, HEC-RAS, and ArcGIS.

II. INTENSITY-DURATION-FREQUENCY (IDF) CURVES

IDF curves, fundamental tools in flood modeling, serve as the cornerstone for rainfall estimation and characterization. The relationship between rainfall intensity, duration, and the probability of occurrence is intricate and critical for accurate hydrological modeling[11].

The significance of site-specific IDF curves, derived from local rainfall data, cannot be overstated, enabling precise estimates for hydrological modeling processes. Recent advancements in IDF curve research and their application in

DOI: 10.17148/IARJSET.2024.11207

predicting rainfall intensity for various return periods[12]. This review article emphasizes the importance of IDF curves in providing insights into extreme precipitation events, playing a crucial role in the accurate estimation of potential flooding scenarios and their incorporation into flood risk assessment models.

The development of IDF curves involves sophisticated statistical analyses and modeling techniques. A study by Sun Y et. al. (2019) underscores the global importance of refining IDF curves, acknowledging the dynamic nature of climate patterns and the necessity for robust tools to predict rainfall extremes [13]. These endeavors align with the broader context of climate change, where extreme weather events are becoming more frequent and intense[14]. Practical implications of IDF curves in flood modeling are evident in their role in designing resilient infrastructure and implementing effective flood control measures. The work of Galiatsatou P & Iliadis C (2022) emphasizes the importance of accurate IDF curves for hydrological design, contributing to the overall resilience of communities facing increasing flood risks[15].

Despite their utility, challenges in applying IDF curves persist. Localized and accurate rainfall data are prerequisites for constructing reliable IDF curves. The study by Wambua R (2019) highlights the importance of considering spatial and temporal variability in rainfall patterns when developing IDF curves[16]. These challenges underscore the need for ongoing research to refine methodologies and improve the accuracy of IDF curves, especially in the face of changing climate patterns.

As research in this field progresses, the limitations of traditional IDF curves are being addressed. Recent approaches incorporate climate projections and uncertainty analyses into IDF curve development[17]. This adaptation reflects the need to enhance the robustness of IDF curves in the context of evolving climate patterns and supports the broader goal of resilient flood risk assessment.

III. HYDROLOGIC ENGINEERING CENTER-HYDROLOGIC MODELING SYSTEM (HEC-HMS)

After establishing the importance of IDF curves in flood modeling, the focus shifts to the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS). HEC-HMS plays a pivotal role in simulating precipitation-runoff processes and estimating streamflow patterns across complex watersheds. Key studies underscore the adaptability and accuracy of HEC-HMS in various river basins [18,19]. These studies demonstrate the utility of HEC-HMS in predicting streamflow patterns, especially in regions with limited historical flood data. The model's ability to simulate complex hydrological processes provides valuable insights for flood risk assessment in diverse geographical settings.

In situations where historical data on flood events are limited, HEC-HMS proves invaluable. The model's capability to consider various hydrological parameters, including land use, soil properties, and topography[20], enhances its applicability in different contexts. The comprehensive approach of HEC-HMS ensures that the simulation and forecasting of peak flows are not solely reliant on historical data but are adaptable to changing environmental conditions. Furthermore, the calibration and testing of HEC-HMS in various river basins speaks to the model's reliability. Calibration processes ensure that the simulated hydrographs align with observed data, enhancing the accuracy of flood predictions. This iterative approach of testing and refining the model contributes to its effectiveness in diverse hydrological conditions[18].

As climate change introduces heightened uncertainty in precipitation patterns, HEC-HMS's role becomes even more critical. The model's ability to consider changing environmental conditions and predict streamflow patterns positions it as a valuable tool in adapting to evolving climate scenarios[21,22]. This aligns with the broader objective of developing flood risk assessment methodologies that can withstand the uncertainties associated with climate change.

IV. HYDROLOGIC ENGINEERING CENTER-RIVER ANALYSIS SYSTEM (HEC-RAS)

Building on the discussion of HEC-HMS, the next integral component of flood modeling is the Hydrologic Engineering Center-River Analysis System (HEC-RAS). HEC-RAS is a numerical modeling software developed by the United States Army Corps of Engineers. HEC-RAS is chosen for its advantages over other models, encompassing numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities. Its versatility in simulating floods and assessing potential impacts on infrastructure positions it as a valuable tool in flood risk assessment[23].

Hydraulic modeling using HEC-RAS involves the simulation of floods to assess their potential impacts on infrastructure, including irrigation projects. The rainfall data derived from IDF curves is input into HEC-HMS to estimate watershed runoff, generating hydrographs representing the flow into the river system. These hydrographs are then routed through

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁐ Peer-reviewed & Refereed journal ⁐ Vol. 11, Issue 2, February 2024

DOI: 10.17148/IARJSET.2024.11207

the river network using HEC-RAS for hydraulic modeling, assessing flood inundation and hydraulic behavior[24]. One of the notable advantages of HEC-RAS is its ability to consider various factors such as channel geometry, cross-sections, and hydraulic structures.
This comprehensive approach ensures a detailed representation of the river system, enabling accurate predictions of flood behavior. The software's graphical and reporting capabilities further facilitate the visualization and communication of flood scenarios to decision-makers and stakeholders.

The importance of HEC-RAS in hydraulic modeling is exemplified by its application in various studies[6,25,26]. These studies demonstrate the software's efficacy in simulating floods, estimating peak discharges, and assessing the potential impacts on critical infrastructure. The validation and calibration processes ensure that HEC-RAS aligns with observed data, enhancing its reliability in diverse hydrological conditions. The integration of HEC-HMS and HEC-RAS in flood modeling provides a comprehensive understanding of precipitation-runoff processes and hydraulic behavior[24,25]. This integrated approach is crucial for informing decision-makers and stakeholders involved in flood risk management for irrigation infrastructure.

V. GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic Information Systems (GIS) and, more specifically, ArcGIS, play a pivotal role in the integrated approach to flood risk assessment. GIS technology plays a crucial role in enhancing the spatial understanding of flood-prone areas and aiding decision-making processes. GIS enables the integration of diverse spatial data, including detailed topographic information, cross-sections, and channel geometry[27]. This spatial integration enhances the identification of vulnerable areas for irrigation infrastructure, providing valuable insights for risk assessment and decision-making.

The application of GIS in flood risk assessment involves the creation of detailed maps illustrating the spatial distribution of flood-prone areas. These maps, generated through the integration of topographic data and hydrological modeling results, contribute to a comprehensive visualization of potential flood scenarios. The ability to overlay different layers of information, such as land use and soil properties, further refines the analysis, assisting in the identification of critical areas that may be prone to flooding. ArcGIS, a widely used GIS software, offers advanced capabilities for spatial analysis and visualization. The utilization of ArcGIS in flood risk assessment enhances the precision of mapping and allows for the development of interactive tools for decision-makers[28].

This software's adaptability and user-friendly interface contribute to its widespread adoption in the field of hydrology and flood modeling. The spatial analyses conducted through GIS not only aid in identifying vulnerable areas but also support decision-makers in formulating effective risk assessment and management strategies. The visualization of flood scenarios, their potential impacts, and the identification of critical infrastructure at risk contribute to more informed decision-making[29]. As climate change continues to alter precipitation patterns and increase the frequency of extreme weather events[30] GIS becomes an indispensable tool for adapting flood risk assessment methodologies. The dynamic nature of GIS allows for the incorporation of updated climate data and the continuous monitoring of changing environmental conditions. This integration of GIS, particularly ArcGIS, into the flood risk assessment framework enhances spatial understanding and decision-making processes.

VI. SUMMARY

The integration of IDF curves, HEC-HMS, HEC-RAS and GIS components synergizes the information for decision-makers, stakeholders, and practitioners involved in flood risk management for irrigation infrastructure. The integration begins with the development of site-specific IDF curves using local rainfall data (Bhere & Reddy, 2022). These curves provide precise rainfall estimates for different return periods, such as the 2-, 5-, 10-, 50-, and 100-year return periods, establishing a fundamental basis for rainfall estimation and characterization. IDF curves play a pivotal role in flood modeling, drawing from a diverse range of studies and methodologies. The IDF curves, along with other relevant data such as land use, topography, and basin characteristics, serve as input for HEC-HMS. This hydrological model simulates the precipitation-runoff processes and estimates streamflow patterns across the complex watershed.

The adaptability of HEC-HMS is crucial, especially in regions with limited historical data on flood events (Ramachandran et al., 2019). The significance of HEC-HMS in flood modeling is its adaptability, reliability, and contribution to predicting streamflow patterns. The model is calibrated and tested to ensure accurate simulation and forecasting of peak flows. The next step involves hydraulic modeling using HEC-RAS. The rainfall data from IDF curves is input into HEC-HMS to estimate watershed runoff, generating hydrographs. These hydrographs represent the flow into the river system and are then routed through the river network using HEC-RAS. This hydraulic modeling assesses flood inundation and hydraulic

DOI: 10.17148/IARJSET.2024.11207

behavior, providing insights into potential impacts on irrigation projects. GIS technology, particularly ArcGIS, is concurrently employed throughout this process. GIS facilitates the integration of spatial data, including topographic information, cross-sections, and channel geometry.
Through GIS-based analyses, vulnerable areas for irrigation infrastructure are identified, aiding in decision-making and risk assessment. This integrated approach ensures a holistic understanding of potential risks and impacts, guiding decision-makers in developing effective flood mitigation strategies.

In conclusion, the integration of IDF curves, HEC-HMS, HEC-RAS, and GIS exemplifies the practical application of the proposed methodology. This review article contributes to a robust foundation for understanding the components and applications of this integrated approach in contemporary flood risk assessment.

REFERENCES

[1]. United Nations Office for Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future [Internet]. UN; 2022. Available from: https://books.google.co.in/books?id=LQB0EAAAQBAJ

[2]. Amaratunga D, Anzellini V, Guadagno L, Hagen JS, Komac B, Krausmann E, et al. Regional assessment report on disaster risk reduction 2023 Europe and Central Asia. 2023;Available from: https://epubl.ktu.edu/object/elaba:183253845/183253845.pdf

[3]. Sarkar S. Drought and flood dynamics of Godavari basin, India: A geospatial perspective. Arabian Journal of Geosciences [Internet] 2022;15(8):772. Available from: https://doi.org/10.1007/s12517-022-10041-5

[4]. Pörtner HO, Roberts DC, Poloczanska ES, Mintenbeck K, Tignor M, Alegría A, et al. IPCC, 2022: Summary for policymakers. 2022;Available from: https://edoc.unibas.ch/91322/

[5]. Reduction UNO for DR. Global assessment report on disaster risk reduction 2022: Our world at risk: Transforming governance for a resilient future. UN; 1901.

[6]. Green C, Dieperink C, Ek K, Hegger DLT, Pettersson M, Priest M, et al. Flood risk management in Europe: the flood problem and interventions. 2013;

[7]. Merga BB, Mamo FL, Moisa MB, Tiye FS, Gemeda DO. Assessment of flood risk by using geospatial techniques in Wabi Shebele River Sub-basin, West Hararghe Zone, southeastern Ethiopia. Appl Water Sci [Internet] 2023;13(11):214. Available from: https://doi.org/10.1007/s13201-023-02019-9

[8]. Schotten R, Bachmann D. Integrating Critical Infrastructure Networks into Flood Risk Management. Sustainability [Internet] 2023;15(6):5475. Available from: https://doi.org/10.3390/su15065475

[9]. Kiedrzyńska E, Kiedrzyński M, Zalewski M. Sustainable floodplain management for flood prevention and water quality improvement. Natural Hazards 2015;76:955–77.

[10]. Center ADR. Sendai framework for disaster risk reduction 2015–2030. United Nations Office for Disaster Risk Reduction: Geneva, Switzerland 2015;

[11]. Te Chow V, Maidment DR, Mays LW. Applied hydrology. 1988.

[12]. Lanciotti S, Ridolfi E, Russo F, Napolitano F. Intensity–Duration–Frequency Curves in a Data-Rich Era: A Review. Water (Basel) [Internet] 2022;14(22):3705. Available from: https://doi.org/10.3390/w14223705

[13]. Sun Y, Wendi D, Kim DE, Liong SY. Deriving intensity–duration–frequency (IDF) curves using downscaled in situ rainfall assimilated with remote sensing data. Geosci Lett 2019;6(1).

[14]. Ipcc CC. Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 2014;1132.

[15]. Galiatsatou P, Iliadis C. Intensity-Duration-Frequency Curves at Ungauged Sites in a Changing Climate for Sustainable Stormwater Networks. Sustainability (Switzerland) 2022;14(3).

[16]. Wambua RM. International Journal of Advanced Research and Publications Estimating Rainfall Intensity-Duration-Frequency (Idf) Curves for A Tropical River Basin. 2019;Available from: www.ijarp.org

[17]. Ewea HA, Elfeki AM, Al-Amri NS. Development of intensity–duration–frequency curves for the Kingdom of Saudi Arabia. Geomatics, Natural Hazards and Risk2017;8(2):570–84.

[18]. Sahu MK, Shwetha HR, Dwarakish GS. State-of-the-art hydrological models and application of the HEC-HMS model: a review. Model Earth Syst Environ [Internet] 2023;1–23. Available from: https://doi.org/10.1007/s40808-023-01704-7

[19]. de Andrade Cruz LG, de Andrade FO, de Araújo AN. Performance evaluation of HEC-HMS hydrological model applied to the Tibagi river watershed in the State of Paraná–Brazil. Ciência e Natura [Internet] 2022;44:e7–e7. Available from: https://doi.org/10.5902/2179460X68815

[20]. Engineers USACO. HEC-HMS: Hydrologic Modeling System–Technical reference manual. US Army Corps of Engineers Hydrologic Engineering Center, Davis, CA http://www hec usace army mil/software/hec-hms/documentation html 2000;
[21]. Hasan HH, Mohd Razali SF, Ahmad Zaki AZI, Mohamad Hamzah F. Integrated hydrological-hydraulic model for flood simulation in tropical urban catchment. Sustainability [Internet] 2019;11(23):6700. Available from: https://doi.org/10.3390/su11236700
[22]. Salvadore E, Bronders J, Batelaan O. Hydrological modelling of urbanized catchments: A review and future directions. J Hydrol (Amst) 2015;529:62–81.
[23]. Brunner GW. HEC-RAS River Analysis System: Hydraulic Reference Manual, Version 5.0. US Army Corps of Engineers–Hydrologic Engineering Center 2016;547.
[24]. Ghimire E, Sharma S, Lamichhane N. Evaluation of one-dimensional and two-dimensional HEC-RAS models to predict flood travel time and inundation area for flood warning system. ISH Journal of Hydraulic Engineering [Internet] 2022;28(1):110–26. Available from: https://doi.org/10.1080/09715010.2020.1824621
[25]. Ramachandran A, Palanivelu K, Mudgal B V, Jeganathan A, Guganesh S, Abinaya B, et al. Climate change impact on fluvial flooding in the Indian sub-basin: A case study on the Adyar sub-basin. PLoS One [Internet] 2019;14(5):e0216461. Available from: https://doi.org/10.1371/journal.pone.0216461
[26]. Shuaibu A, Hounkpè J, Bossa YA, Kalin RM. Flood risk assessment and mapping in the Hadejia River Basin, Nigeria, using hydro-geomorphic approach and multi-criterion decision-making method. Water (Basel) [Internet] 2022;14(22):3709. Available from: https://doi.org/10.3390/w14223709
[27]. Maidment DR. Arc Hydro: GIS for water resources. ESRI, Inc.; 2002.
[28]. Andimuthu R, Kandasamy P, Mudgal B V, Jeganathan A, Balu A, Sankar G. Performance of urban storm drainage network under changing climate scenarios: Flood mitigation in Indian coastal city. Sci Rep [Internet] 2019;9(1):7783. Available from: https://doi.org/10.1038/s41598-019-43859-3
[29]. Alam N, Saha S, Gupta S, Chakraborty S. Prediction modelling of riverine landscape dynamics in the context of sustainable management of floodplain: a Geospatial approach. Ann GIS [Internet] 2021;27(3):299–314. Available from: https://doi.org/10.1080/19475683.2020.1870558
[30]. Masson-Delmotte VP, Zhai P, Pirani SL, Connors C, Péan S, Berger N, et al. Ipcc, 2021: Summary for policymakers. in: Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change. 2021.