PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 5 No. 1 (2024) 585-593

https://publisher.uthm.edu.my/periodicals/index.php/peat

# Flood Warning Prediction Using HEC-HMS Software and GIS at Panchor Area

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DOI: https://doi.org/10.30880/peat.2024.05.01.063

**Article Info**

Received: 28 December 2023
Accepted: 15 January 2024
Available online: 15 June 2024

**Keywords**

HEC-HMS, GIS, coefficient of determination, subbasin, Panchor, calibration, validation, accuracy

**Abstract**

Flooding is a serious hazard to people's lives, infrastructure, and the environment. Flood warning systems that are effective are critical for disaster management and impact mitigation. This research proposes a comprehensive flood warning prediction approach for the Panchor area using the Hydrologic Modelling System (HEC-HMS) software and Geographic Information System (GIS) tools. Using historical data local hydrological characteristics, the HEC-HMS program model and estimates river flow in response to rainfall events. A rainfall-runoff model that accounts for multiple hydrological components is developed and verified. The flood prediction system incorporates GIS technology to increase forecast accuracy by analyzing and visualizing geographical data. The system continuously monitors rainfall data from meteorological stations in the Panchor catchment area, issues early flood warning based on predetermined river discharge and water level thresholds, and sends alerts authorities and communities for immediate evacuation disaster response. The efficacy of the system is determined by comparing projected flood events to historical flood records, as well as assessing the accuracy, lead time, and reliability of the warning signal of the system. Calibration findings, which illustrate simulated and observed flows, determine model accuracy. The Nash-Sutcliffe Efficiency (NFE) of 0.931 suggests a decent fit, while the validation summary findings for Built Environment and Ecosystems Engineering (BEE) reveal improved model performance with a NFE of 0.755. the complexity of the model has a substantial influence on model performance, with calibration guaranteeing accurate representation of real-world scenarios and parameter selection ensuring proper parameterization and enhanced $R^2$ values.

## 1. Introduction

Flooding is a global hazard induced by heavy rains and climate change that kills millions and affects 1.4 billion people. Engineers, researchers, and politicians have devised flood mitigation structures as well as non-structural approaches such as flood mapping and modeling to minimize this. Flood risk is divided into two categories: hazard and vulnerability, with vulnerability referring to the existence of people, livelihoods, environmental services, infrastructure, or economic, social, or cultural assets[14,15].

Monsoon seasons, rainstorms, inadequate drainage, and growing urbanization all contribute to flooding in Malaysia[17]. Flooding is caused by factors such as inadequate floodwater storage, persistent high rainfall, changes in land use, basin slope, drainage system, soil type, topography, climate change, and deforestation[16].

This article provides an overview of current research effort in ensemble flood forecasting, as well as discussion of knowledge gaps and future research opportunities[21]. Flood forecasting is critical in hydrology because it aids in the prevention of economic and human losses[19]. Because of its simplicity and open-source nature, the HEC-HMS software was used for this investigation. Hydraulic modeling is an essential component of any system that forecasts river water levels[3]. Hydrological processes and their spatial distribution may be studied and forecasted using HEC-HMS and GIS software.

Due to heavy rainfall, Malaysia sees regular floods and flash floods throughout the monsoon season. Rapid urbanization and hill terrain development have put several areas at risk of flooding. Flash floods killed 32 persons in Kuala Lumpur in 1971. Extreme rains in Kota Tinggi in 2006 and 2007 caused enormous property destruction and devastation, resulting in millions of dollars in losses[13]. The worst flood in Johor history struck in December 2006/2007, resulting in a total loss of 1.5 billion ringgits[1]. The government has been assisting victims, but money for flood victims and infrastructure should be prioritized[4]. The number of flood victims in Johor had topped 50,000 as of March 5, 2023, with 1,146 transferred to rescue facilities. The government has been obliged to shoulder nearly RM 1 billion in damages and losses[9].

Floods are bodies of water that overflow, drowning land, or cause a deluge in coastal, urban, and flood plain areas. Drainage basin characteristics, soil characteristics, land use and development, and climate change can all worsen them. Due to uneven growth and drainage water surplus, Malaysia, a South-East Asian country with an equatorial climate and 250 cm of annual rainfall, suffers considerable flooding challenges[11]. Improved stormwater management, upgraded infrastructure, floodplain restoration, and improved forecasting and early warning systems are all examples of climate change adaptation techniques. The four primary flood adaptation strategies are raising dykes, retention areas, flood proofing, and relocation[8].

Flood forecasting is an important technique in hydrology that predicts and warns of possible floods using scientific methods, data analysis, and predictive models[19]. It assists communities in planning and implementing preventative actions, hence lowering fatalities and financial losses. It also helps with resource distribution, emergency response, and flood education in the community.

The Hydrologic Modelling System (HEC-HMS) is a hydrologic modeling application created by the United States Army Corps of Engineers' Hydrologic Engineering Center. It uses nine loss approaches and seven transformation methods to model runoff and estimate streamflow. The model is used to simulate rainfall-runoff processes in a variety of locations[14]. The HEC-HMS model may be used to investigate flood frequency, urban flooding, reservoir spillway capacity, flood warning system development, stream restoration, and other issues[18]. It is important for calculating flood frequency, urban flooding, reservoir spillway capacity, flood warning system planning, and stream restoration. It has four primary discharges. The HEC-HMS model is used to simulate rainfall-runoff processes in both gauged and ungauged catchments, providing useful information and analytical capabilities for hydrology and water resource assessment[7].

GIS is a type of computer software that is used to manage geographical data, analyze connections, and simulate spatial processes[2]. It is critical for risk assessment and natural disaster management, since it aids in the identification of flood-prone areas[12]. Using open-source software, a web-based GIS/spatial visualization tool was developed, allowing users to see data in a web browser[20]. GIS technologies improve decision-making by supplying a plethora of data for resource allocation and improving decision-making in urban areas[10].

The paper discusses the creation of HMS-PrePro, a GIS pre-processing tool that automatically extracts authoritative datasets, generates a topologically consistent watershed network, estimates hydrological parameters, and converts the results into a format compatible with the USACE Hydrologic Engineering Center's Hydraulic Modelling System (HEC-HMS) software. It allows simple access to authoritative datasets by supporting parameterization for frequently used subbasin loss and transform methods, as well as popular reach routing algorithms[5].

## 1.1 Problem statement

The Panchor area in Muar, Johor, is under risk of flooding, endangering the local population, infrastructure, and ecology. The present flood warning system of the area is out of date and ineffective at predicting flood occurrences and magnitudes. It also fails to account for the geographical and temporal variability of the hydrological processes in the area, resulting in inaccurate flood projections. Furthermore, the system fails to manage flood forecast uncertainties, which are worsened by intrinsic uncertainties in hydrological modeling and input data, HEC-HMS software limits, and GIS integration. Furthermore, the system lacks adequate communication channels for communicating timely flood warnings to the general public, emergency responders, and policymakers. Using HEC-HMS software and GIS, the project seeks to improve local community flood forecast capacity and resilience, enabling improved preparedness, early warnings, and effective decision-making to mitigate flood consequences in the Panchor region.

## 1.2 Objective

The research focuses on flood warning prediction in Panchor, Johor, utilizing HEC-HMS sostware and GIS. The goals include testing and calibrating moel historical flood occurences, assuring the precision and dependability of the model, and properly capturing the hydrological dynamics of the area in order to accurately estimate flood discharge.

## 2. Methodology

The Disaster Risk Reduction (DRR) framework highlights the need of taking a comprehensive strategy to identifying and managing risks associated with natural disasters such as flooding. It contains flood warning prediction components such as Hazard Assessment, Vulnerability Analysis, and Capacity Building. Early Warning Systems rely on a variety of data sources to make accurate forecasts, whereas risk communication entails developing clear, understandable messages that take cultural and linguistic aspects into account. The DRR framework intends to help effective response actions and to reduce flood threats.

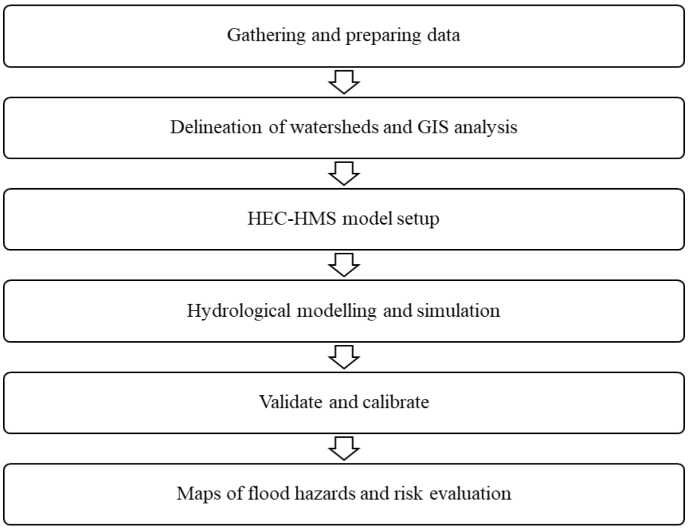


**Fig. 1** *Research framework for the study*

## 2.1 Research framework

For model calibration and understanding river dynamics during rainfall events, historical rainfall data from local weather stations and meteorological offices is critical. To describe topography and identify flood-prone areas, the Panchor River basin requires high-resolution Digital Elevation Model (DEM) data. In order to understand runoff and water flow, detailed maps of land cover and usage are required. Permeability, infiltration rates, and moisture retention are all factors to consider. Pre-processing, cleaning, spatial integration, and watershed identification are all part of the process. Pre-processing assures GIS and HEC-HMS format conformity, while cleaning checks for mistakes. For spatial integration, all geographical information must be aligned inside the same coordinate system. Delineating a watershed entails defining boundaries, pinpointing runoff regions, and ensuring all data is appropriately aligned within the same coordinate system using GIS tools.

## 2.2 Study area

Panchor, located in Johor, has a surface area of 23.8 km$^2$ and is prone to flooding due to heavy rainfall during the northeast monsoon. Valleys, coastal areas, and alluvial fans are all part of the research area. Kawasan Perindustrian Grisek is home to SMEs and industrial clusters, but Kampung Ayer Panchor, located on the Grisek River, is particularly vulnerable and regularly floods as a result of its closeness. Panchor, Johor is separated into two sections: the eastern Gerisek Range and the western Bukit Pengkalan and Bukit Gambir. The eastern section has rocky terrain, and the western section has undulating hills, little ponds, and vast vistas.

Population density, urbanized land area, and socioeconomic variables all have an impact on urbanization in Panchor, Johor. There are 2,376 hectares of land in the research region, with agricultural land having the highest LULC (75%), developed areas (16.5%), and water bodies (8.5%). Despite the fact that farmland has been converted to built-up areas since the 1950s, forest cover exists, although it is steadily decreasing owing to poor recording, mapping, and public awareness. Panchor's land uses include residential, commercial, and industrial zones.

Panchor, Johor, Malaysia has a tropical climate with an average temperature of 28°C. Showers and thunderstorms are common during the dry season, whereas heavy rains are common during the wet season. The humidity level is between 85% and 95%, making the weather hotter.


**Fig. 2** *Study area*

## 2.3 Data collection

This study analyzes flood risk using both geographical and non-spatial data, such as topography, soil, land use, hydrological characteristics, climatic and meteorological data, historical hydrological data, hydrological parameters, infrastructure, population data, and emergency response plans. Using historical data and other pertinent information, it assists in comprehending geography, forecasting flow patterns, projecting precipitation, and estimating flood risks.

The study will use spatial data combined with QGIS 3.32.2 to develop a database for Panchor, Johor, comparing land usage trends with a topographical map using a 2023 satellite picture from Google Earth.

. For rainfall and water discharge statistics, this study relies on non-spatial data from the Department of Drainage and Irrigation (DID). The average temperature is 26.6°C, and rainfall data is frequently used by the HEC-HMS. The analysis includes data from 2013 to 2023, with the Panchor area represented by the Ladang Tanjung Olak station. Long-term analysis requires precise rainfall data, and solutions such as statistical procedures or interpolation can be employed to deal with missing numbers.

## 2.4 Hydrologic modelling HEC-HMS model set up

The spatial database of QGIS enables for the efficient storing of numerous geographical datasets in the Panchor area, such as DEMs, land cover, hydrological parameters, and administrative borders. It makes sophisticated geographical modeling and investigations easier, increases processing performance for large datasets, and encourages collaborative effort. Data security, integrity, and scalability are also ensured by QGIS databases, enabling for future analysis and reusability. They also fulfill regulatory compliance standards and provide capabilities for traceability, auditing, and documentation. This methodical approach to geographic data management may improve productivity, security, collaboration, and scalability.

## 2.5 Set up for the Muar River Basin

The research focuses on using High-Resolution Digital Elevation Model (DEM) data to define watershed borders and anticipate runoff or streamflow in the Panchor basin. Using historical data and independent datasets, the model is developed, calibrated, and verified. The model outputs are examined using hydrographs, time series data, and statistical indicators, and the results are graphically presented using graphs, maps, and tables. Documentation and reporting are critical stages in the modeling process, and include a detailed report outlining the study, model setup, calibration and validation findings, and analysis-derived conclusions.

The rainfall station for this study is Station Ladang Ben Heng, and the streamflow data ranges from 2014 to 2023. The HEC-HMS program is used to simulate subbasin hydrology by parameterizing factors such as curve numbers, lag lengths, initial losses, and infiltration rates. The Loss Method is used to simulate baseflow and groundwater losses as a function of rainfall intensity. The SCS Unit Hydrograph is used in the study to examine hydrograph data and show the relationship between precipitation and runoff in distinct subbasins.

Baseflow is a Panchor basin model parameter that represents the proportion of total rainfall that goes into the model's baseflow. Understanding reaches is critical for modeling flow parameters, channel characteristics, and water movement throughout the river network. The Muskingum routing approach simplifies flow equations and allows reservoir operations to be solved analytically. The three main components of the model setup are the Basin, Reach, and Subbasins.

## 2.6 Data calibration, validation, and simulation

To reduce inaccuracies between simulated and observed data, model parameters are modified during data calibration. Data validation, which involves comparing model performance with a fresh dataset, ensures model reliability, allowing for more informed decision-making in environmental assessments and flood forecasts.

# 3. Result and discussion

## 3.1 Calibration and validation data

Results can be presented in the form of tables, figures, charts, diagrams or other suitable formats. If required, raw data that is too lengthy to be put in this section can be moved to the appendix. Calibration results show how accurate a hydrological model is in simulating watershed dynamics. A tight match between simulated and actual flows demonstrates a thorough grasp of the mechanism. The correctness of future outcomes cannot be guaranteed.

Performance statistics such as peak discharge, volume, and Nash-Sutcliffe goodness of fit are included in the calibration report. The model fits the data well, with the goodness of fit rating of 0.931, displaying very little bias and capturing substantial discharge peaks.

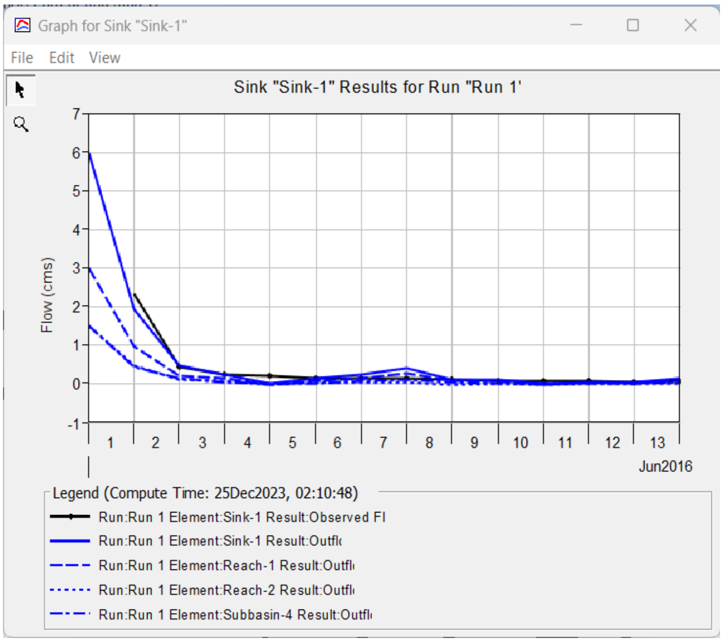


**Fig. 3** *Calibration data*

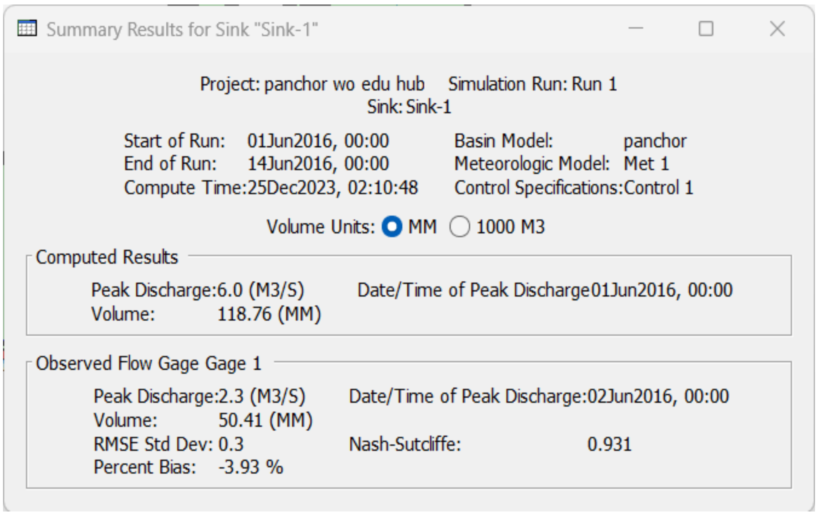


**Fig. 4** *Summary results for calibration*

The validation of the model for Sink "Sink-1" is satisfactory since the anticipated outflow values and actual flow values are almost identical. The model forecasts water routing within upstream reaches Reach-1 and Reach-2 with high accuracy, exhibiting successful water transfer.

The validation summary findings from Built Environment and Ecosystems Engineering (BEE) reveal improved model performance with a Nash-Sutcliffe efficiency of 0.755 and adequate accuracy in recreating basin flow, with modest variances shown by the RMSE Standard Deviation metric.

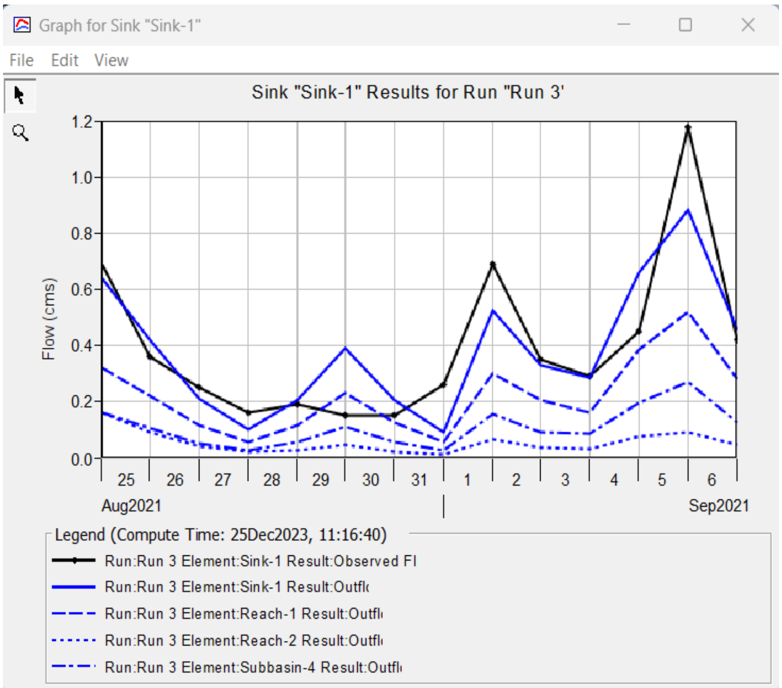


**Fig. 5** *Validation data*

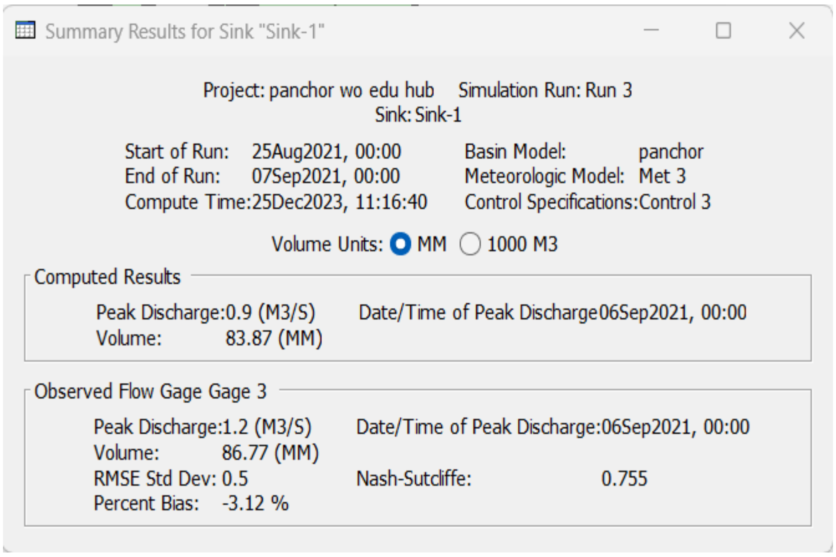


**Fig. 6** *Summary results for validation*

## 3.2 Coefficient of determination

The HEC-HMS evaluates the goodness-of-fit between simulated and observed hydrological data using the $R^2$ value, with a higher score indicating better model performance. It is advised to supplement $R^2$ results with additional measurements.

The model's $R^2$ value of 0.931 during calibration indicates that it is very accurate in reproducing hydrological processes in a watershed, demonstrating that calibration and fitting of observed data were effective. The $R^2$ score of 0.755 during validation, on the other hand, indicates possible uncertainty in unique circumstances. The decreased $R^2$ value during validation underscores the relevance of model correctness and dependability to continued improvement and validation.

Model complexity has a major influence on hydrological model performance, especially when it comes to interpreting $R^2$ values. Regularization and model selection processes ensure trustworthy $R^2$ interpretations by balancing complexity and generalizability. Input data quality is critical for accurately representing real-world occurrences, and erroneous data might degrade model performance. Model calibration guarantees that real-world circumstances are accurately represented by changing parameters to decrease discrepancies between observed and simulated data. Parameter selection, sensitivity assessments, and data-driven parameter estimation are all critical components for accurate parameterization and better $R^2$ estimates. The accuracy of assumptions and simplifications in hydrological models has a substantial impact on their capacity to reproduce actual data and effect metrics such as $R^2$. Using data quality evaluations and uncertainty quantification methodologies to address observed uncertainties enhances model dependability. Finally, the quality and representativeness of the validation dataset have a major impact on model performance evaluations and future $R^2$ evaluations.

## 4. Conclusion

In the Panchor region, the use of HEC-HMS software and GIS in flood prediction has considerably enhanced flood risk management and resilience-building strategies. The use of HEC-HMS allowed for a better understanding of rainfall-runoff relationships, land use effect, and flow routing dynamics within the watershed. The information was further supplemented by GIS-based spatial analysis, which included topographical data, land use classifications, and soil attributes. For continued development, the study focuses data quality assurance, model calibration and validation, and sensitivity analysis. It is a foundational study for flood prediction in Panchor, setting the platform for future research. The research acknowledges the complicated complexity of hydrological systems and employs cutting-edge approaches. Future researchers should continually record rainfall and runoff data, collect data at correlated time intervals, and have competent authorities create water quality stations at each rainfall station for reliable water quality model simulation.

## Acknowledgement

The authors warmly recognize the Ministry of Higher Education Malaysia and Universiti Tun Hussein Onn Malaysia (UTHM) for financial help with this experimental effort.

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