Assessing GSMaP Satellite-Based Precipitation for Runoff Modeling in a Data-Scarce Mountainous Basin: A Case Study of the Abra River Basin, Philippines

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Abstract *Accurate runoff estimation is vital for flood risk modeling and disaster preparedness, particularly in river basins with limited ground-based hydrometeorological observations. This study evaluates the applicability of GSMaP (Global Satellite Mapping of Precipitation) satellite-based rainfall data for hydrologic simulation in the Abra River Basin, a mountainous and data-scarce watershed in Northern Luzon, Philippines. A hydrologic model was developed using the HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System) software, incorporating topographic inputs from a 5-meter IFSAR Digital Elevation Model (DEM). Land cover and soil data were processed in a GIS environment to generate a spatially distributed Curve Number (CN) map for estimating runoff potential. The model was calibrated using observed discharge and GSMaP rainfall data from Typhoon Ompong (Mangkhut, 2018), achieving a Nash-Sutcliffe Efficiency (NSE) of 0.763 and a percent bias of only 0.06%. Model validation using Typhoon Marce (Sinlaku, 2008) resulted in an NSE of 0.614, indicating reasonable model performance. These results demonstrate that GSMaP data can be effectively used to support hydrologic modeling and runoff estimation in ungauged or poorly instrumented basins. This study highlights the practical use of satellite-derived precipitation in flood modeling and early warning applications, contributing to disaster risk reduction and climate resilience. The integration of remote sensing and GIS in hydrologic modeling offers valuable insights for water resource planning and supports the broader application of remote sensing technologies in disaster-prone regions.*

Keywords: Satellite-based precipitation, Remote sensing for flood modeling, GIS-integrated hydrologic modeling, Disaster risk reduction, Abra River Basin

Introduction

Climate change makes the Philippines an extremely vulnerable country, with approximately twenty typhoons entering the Philippine Area of Responsibility every year. As a result, communities located near rivers encounter severe risks from flooding. Flooding poses a threat to the safety of residents, as well as their properties and livelihoods. It cannot be overstated that the presence of flood data and forecasts enables residents in flood-prone areas to prepare effectively for potential disasters. By implication, the lack of reliable and accessible information regarding the severity of flooding could be a matter of life and death for the most affected individuals. In generating flood data, relevant datasets are required.

Discharge data represents one of these fundamental datasets; it is useful for defining the upstream boundary conditions in flood simulation. Furthermore, it is also essential to consider the water flow throughout the entire subbasin, since the river flow moves downstream toward the coastal area.

The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) software derives its significance from its capability to utilize satellite precipitation or rainfall data, whereby the resultant model could be calibrated and validated using only the available discharge data captured by streamflow gauges within the basin to generate runoff or discharge data for flood map simulation. Its successful application alongside other technologies, in data-scarce watersheds as the Abra River Basin watershed, for example, where most of the streamflow gauges operated by concerned government agencies are non-operational, particularly during significant typhoon occurrences, would be significant.

Following the calibration, validation, and achievement of the desired goodness of fit for the HEC-HMS model, recent typhoon event rainfall data from Global Satellite Mapping of Precipitation (GSMaP) can be obtained and utilized for flood map simulation purposes. The GSMaP dataset was used, as it is the primary system employed by the Department of Science and Technology (DOST) for meteorological forecasting. Although the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) operated a station in Ilocos Sur, it is located considerably far from the watershed area, particularly from the mountainous regions. For context, GSMaP was a project developed by the Japan Aerospace Exploration Agency (JAXA) under the Global Precipitation Mission (GPM) to provide high-resolution global precipitation maps. The dataset served various scientific and operational purposes. This included flood forecasting and monitoring, weather prediction and climate assessment, crop yield estimation and drought monitoring, as well as research on climate change and atmospheric processes.

This research study aimed to develop a reliable methodology for generating upstream discharge data or hydrographs to support the flood simulation in the Abra River Basin, where observed streamflow data from ground gauges had been limited and only available intermittently in selected years, such as 2005-2008, 2014, 2018, 2019, and 2020. The existence of data gaps made precise flood prediction and modeling very challenging. The research focused on assessing how efficiently satellite precipitation data from GSMaP performs as a replacement for hydrological inputs to estimate runoff in the basin. Throughout the assessment of GSMaP rainfall data accuracy in river discharge simulation, the study aimed to enhance flood forecasting and risk management for enhanced protection of vulnerable communities along the Abra River Basin.

Objectives of the Study

This study aimed to evaluate the suitability of GSMaP satellite-based precipitation data for accurate runoff estimation in the Abra River Basin, with the aim of enhancing hydrologic modeling and supporting effective water resource management.

Specific Objectives:

1. To develop a Curve Number (CN) Grid using QGIS for the Abra River Basin
2. To develop a HEC-HMS hydrological model for the Abra River Basin utilizing GSMaP satellite-based precipitation data
3. To calibrate and validate the HEC-HMS model using observed discharge data from DPWH monitoring stations.

Literature Review

Importance of Precipitation Data in Hydrologic Modeling

The accuracy of hydrological models heavily relies on the quality of precipitation data, which is challenging due to its variability across space and time. Numerous studies have demonstrated that the performance of these models is greatly affected by how densely and evenly rain gauges are distributed (Song & Kim, 2025; Zeng et al., 2018). Additionally, it has been found that the use of different types of precipitation data, such as observations from ground stations, satellite measurements, and reanalysis products, can yield varying results in modeling (Al Khoury et al., 2024; Sciuto et al., 2025).

To address these issues, recent research has focused on data fusion techniques that combine multiple precipitation data sources to create more accurate and comprehensive datasets (Reis et al., 2022). Furthermore, employing modeling approaches that explicitly account for rainfall variability, like area-weighted averaging methods applied to gridded precipitation data, has substantially improved simulation accuracy (Jiang et al., 2024). Overall, these developments underscore the continuing need to enhance precipitation data collection and integration methods to improve the reliability and predictive performance of hydrological models.

Global Satellite Mapping of Precipitation (GSMaP)

The GSMaP, derived from the Global Precipitation Measurement (GPM) mission—a collaboration between NASA and JAXA—provides high-resolution precipitation data with a spatial resolution of 0.1° × 0.1° and updates on an hourly basis. Its latest version, V08, exhibits notable improvements over its predecessor, the TRMM Multi-Satellite Precipitation Analysis (TMPA), particularly for near-real-time applications and in dry, mid-to-high-latitude regions (Huang et al., 2025).

Various studies assessing GSMaP's performance in different geographic and hydrological settings confirm its effectiveness. For example, research on the eastern edge of the Qinghai-Tibet Plateau demonstrated GSMaP's strong ability to detect rainfall events during the wet season (Zhou et al., 2024). This study also highlighted that the Gauge product consistently maintained high hit rates and fewer false alarms as elevation increased (Zhou et al., 2024). Furthermore, comparisons of GPM hourly precipitation products showed that GSMaP excels at accurately capturing the duration of precipitation events better than other available products (Cao et al., 2025). In the Philippines, GSMaP successfully represented the daily changes in both rainfall amount and frequency, making it especially useful for studying frequent, light rainfall events that occur on an hourly scale (Taña et al., 2025).

Hydrologic Modeling Using HEC-HMS

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), a software developed by the United States Army Corps of Engineers, is widely recognized as a top tool for simulating flood hydrology. It is capable of handling both short-term and long-term hydrological events (Guduru et al., 2023). Extensive research has consistently demonstrated the effectiveness of this approach across diverse geographic and hydrological contexts, consistently delivering accurate simulations that highlight the model's strength at the watershed scale. For instance, in the Meki River watershed in Ethiopia, HEC-HMS was successfully used to simulate streamflow and predict floods, achieving strong statistical performance during its calibration and validation stages (Guduru et al., 2023). Similarly, in Ethiopia's Tikur Wuha River Basin, high values of Nash-Sutcliffe Efficiency (NSE) and coefficient of determination (R^2) were reported. This confirmed the model's reliability in replicating watershed hydrological processes (Guduru & Mohammed, 2024).

Besides natural watershed applications, HEC-HMS has also been effectively adapted for modeling urban floods. In the Wakad Watershed in India, the integration of HEC-HMS with GIS-based rainfall-runoff modeling led to a substantial increase in accuracy, including a 44.23% improvement in the NSE after calibration (Jawale & Thube, 2025).

A recurring insight in the literature is that the combination of HEC-HMS with other technologies enhances modeling efficiency and helps address data limitations. For example, the GIS-based preprocessing tool HMS-PrePro automates labor-intensive tasks such as watershed delineation and parameter estimation, making model setup easier and faster (Castro & Maidment, 2020). Additionally, in areas with limited data, such as Italy's Dittaino River Basin, incorporating remote sensing and reanalysis data, like ERA5-Land precipitation and satellite-derived land cover, has significantly improved runoff simulation accuracy (Sciuto et al., 2025). Overall, while HEC-HMS is a powerful modeling system in its own right, its best results come about by combining it with diverse data sources and advanced technological tools.

Curve Number Method and GIS Integration

The Soil Conservation Service Curve Number (SCS-CN) method is a widely used, relatively simple technique for estimating direct surface runoff from rainfall (Verma et al., 2020; Yu et al., 2025). Developed by the U.S. Department of Agriculture (USDA), it forms a key part of many hydrological models, such as the Soil and Water Assessment Tool (SWAT) and the Storm Water Management Model (SWMM) (Yu et al., 2025; Wang et al., 2025). The method's central parameter, the Curve Number (CN), depends on factors like the hydrologic soil group, land use and land cover, and prior moisture levels in the soil (Verma et al., 2020; Moon et al., 2016). Although widely used, the use of the original SCS-CN approach has been challenged for relying on fixed categories for soil and hydrologic conditions, which can lead to sudden changes in CN values and inconsistent runoff estimates (Verma et al., 2020). To address these issues, researchers have developed improved versions that take into account additional factors such as vegetation cover, soil saturated hydraulic conductivity, and slope-adjusted CN values, improving runoff prediction accuracy (Yu et al., 2025; Wang et al., 2025; Moon et al., 2016).

The combination of Geographic Information Systems (GIS) and remote sensing has significantly enhanced the use of the SCS-CN method, especially for modeling rainfall-runoff with spatial detail (Kumari et al., 2024). GIS tools help create thematic maps—such as land use, land cover, and hydrologic soil group layers—that are crucial for assigning accurate CN values over varied watershed areas (Kumari et al., 2024). This integrated approach allows for more accurate runoff and discharge estimates and supports detailed analyses of how changes in land use and rainfall patterns affect hydrological responses. For example, a study in the Umiam Catchment in India used GIS to show that increases in agricultural and urban areas led to higher runoff, demonstrating the effectiveness of this combined method for watershed management and planning (Kumari et al., 2024).

Methodology

Study Area

The Abra River Basin is the sixth largest river in the Philippines with an approximate 5,125 km^2 drainage area and an annual runoff of 12,551 million m^3, which covers the three provinces within the Cordillera Administrative Region, the provinces of Abra, Benguet, and Mountain Province, as well as the province of Ilocos Sur in Luzon, Philippines. The river basin is characterized by a distinct dry season, extending from November to April, followed by a wet season from May to September. The amount of rainfall during these seasons fluctuates year by year, and extreme weather events occur occasionally. Rainfall and weather patterns are often linked to El Niño and La Niña phenomena. Most of the river basins and watersheds are classified under Type 1 climate classification according to the DOST-PAGASA's Coronas Climate Classification System. A smaller area in the eastern part of the basin is categorized as Type 2. The average rainfall in the region ranges between 2500 mm and 3000 mm. Rainfall varies depending on elevation, and the average monthly air temperature typically falls between 23°C and 33°C (Paringit & Pascua, 2017).

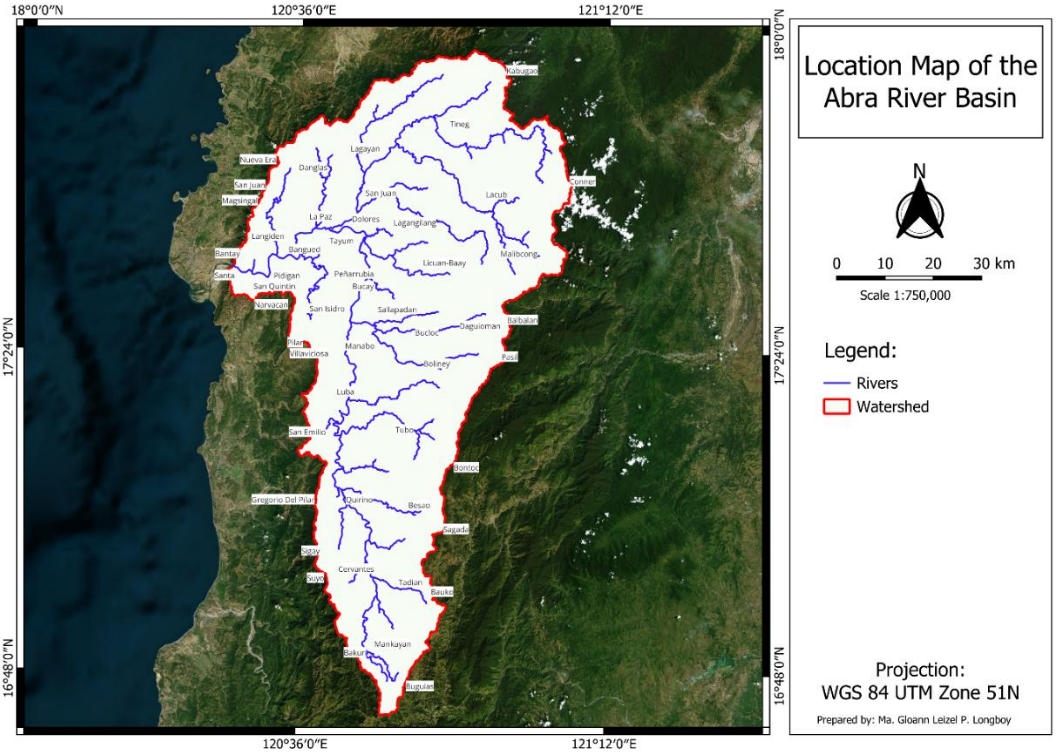

Figure 1. Location of the Study Area

Procedural Framework

This procedural framework presented a comprehensive hydrological modeling approach that integrated multiple data sources and analytical tools to generate accurate discharge predictions. The methodology began with data acquisition from three primary sources: soil data from DA-BSWM, landcover, and the IfSAR Digital Elevation Model (DEM) from NAMRIA. These datasets were processed through QGIS for curve number generation and HEC-HMS for watershed delineation, which subsequently informed the basin parameterization phase. The framework incorporated essential hydrological parameters, including loss methods using SCS Curve Numbers, transform methods through Snyder Unit Hydrographs, constant monthly baseflow, and lag routing techniques. The core HEC-HMS model was then calibrated and validated using GSMaP rainfall data from JAXA and discharge data from DPWH, ultimately producing reliable hydrograph outputs for water resource management and flood forecasting applications.

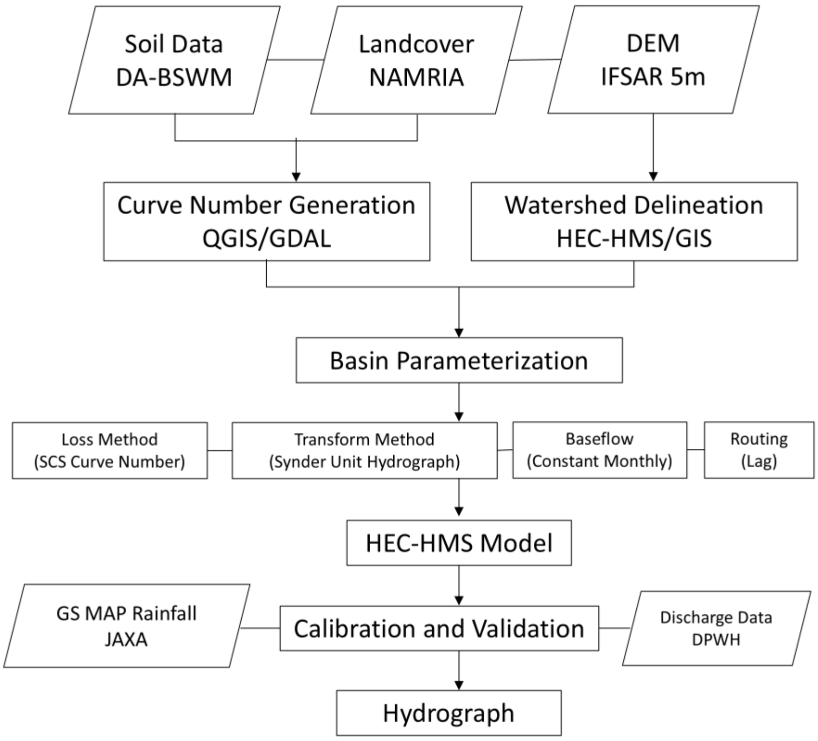

Figure 2. Procedural Framework of the Study

Data Collection

Digital Elevation Model. To delineate the Abra River Basin watershed, IFSAR North Luzon DEM was acquired from NAMRIA. The Digital Elevation Model (DEM) was then processed using ArcMap 10.4. This process involved clipping the DEM with a watershed boundary that had been downloaded from Global Watersheds (https://mghydro.com/watersheds/). The resulting terrain file, which was projected in WGS UTM Zone 51N, was subsequently used in HEC-HMS software to delineate the elements of the watershed basin. The clipped DEM is shown in Figure 1.

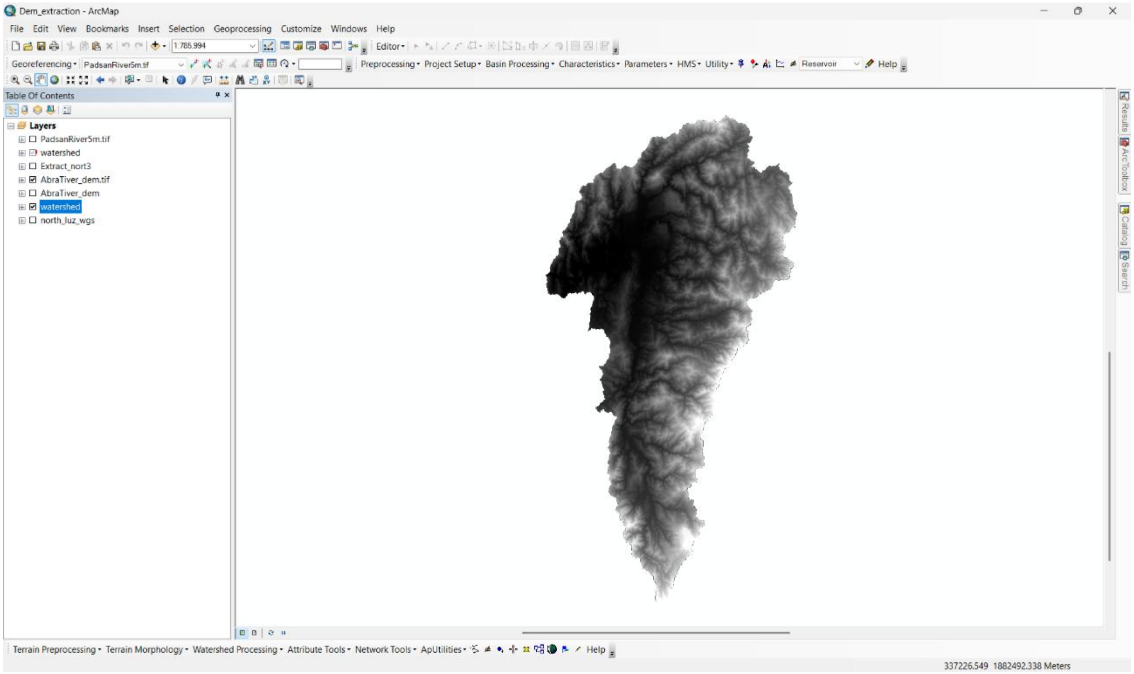

Figure 3. DEM extraction of the Abra River Basin Watershed

GSMap Jaxa Rainfall. The JAXA Global Satellite Mapping of Precipitation (GSMaP) Rainfall Watch provides near-real-time global precipitation data with a spatial resolution of 0.1° latitude/longitude (about 10 km) and an hourly temporal resolution. This satellite-based rainfall product combines microwave and infrared data from multiple satellites to deliver accurate and timely precipitation information. It is widely used for weather monitoring, disaster management, and climate studies worldwide. GSMaP is part of the Global Precipitation Measurement (GPM) mission, operated by JAXA and its partners, which produces hourly global rainfall maps that are typically available within a few hours after observation.

Discharge. The discharge data for the Abra River Basin were obtained from the Department of Public Works and Highways (DPWH) streamflow monitoring system, which was accessible via their official website (https://apps.dpwh.gov.ph/streams_public/station_public.aspx). The DPWH maintains operational gauging stations within the basin, including stations along the Abra River, which provide continuous measurements of river water levels and discharge. These data sets, which included daily streamflow records, served as the primary basis for model calibration and validation, ensuring the accurate simulation of river discharge.

Land Cover Data and Soil Data. The landcover data were downloaded from the 2020 National Mapping and Resource Information Authority (NAMRIA) in shapefile format from the Philippine Geoportal database (https://www.geoportal.gov.ph/). The soil data was also acquired from the same database. The general soil type data were taken from the Bureau of Soils and Water Management under the Department of Agriculture (DA-BSWM). This data was used for generating a curve number for the required parameters in hydrologic modeling.

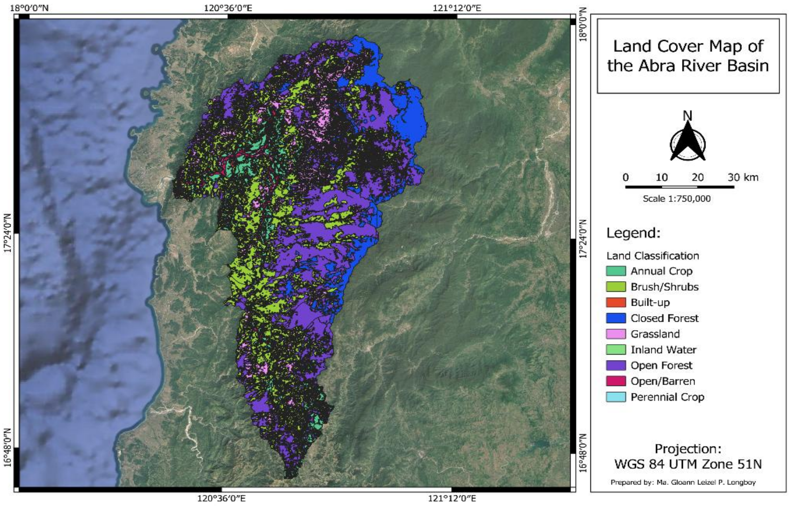

Figure 4. Landcover Map of the Abra River Basin

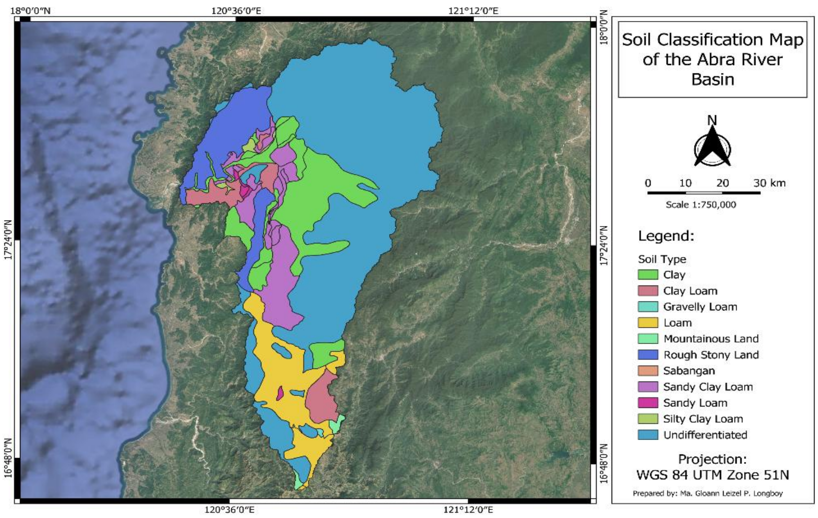

Figure 5. Soil Classification Map of the Abra River Basin

Utilizing GSMaP Rainfall Data for Hydrological and Climatic Applications

Utilizing GSMaP rainfall data for hydrological and climatic applications involved a comprehensive workflow that began with user registration on the JAXA Global Rainfall Watch platform, which provided access to the data. Users specified geographic coordinates and temporal ranges to retrieve satellite-derived precipitation data, which were available in hourly measurements expressed in millimeters and provided in CSV format. This data can be aggregated spatially or temporally to match catchment areas or modeling requirements.

Generating Curve-Number Grid (CN)

Land Cover Preparation. The land cover map was prepared using data from the 2020 National Mapping and Resource Information Authority (NAMRIA) polygon shapefiles and benchmarked against the National Land Cover Data (NLCD) dataset to ensure compliance with NRCS standards. This resulted in a standard and efficient model for the Local Land Cover Classification (LULC) scheme, reducing the number of LULC layers to be processed.

Table 1. Benchmarked NAMRIA-based LULC classes and codes

NLCD Land Classes	LUC Code	NAMRIA Land Classes	LULC Gridcode
Description	**Gridcode**	**Description**	**Gridcode**
Barren Land	31	Open/Barren	1
Planted/Cultivated	81, 82	Annual Crop	2
Grassland/Herbaceous	71	Grassland	3
Planted/Cultivated	81, 82	Perennial Crop	4
Developed	21, 24	Built-up	5
Open Water	11	Fishpond	6
Wetlands	96-99	Mangrove Forest	7
Shrubland	51, 52	Brush/Shrubs	8
Open Water	11	Inland Water	9
Forest	41, 42	Closed Forest	10
	43	Open Forest	11
Wetlands	90-99	Marshland/Swamp	12

Source: MRLC, 2001; Dag-uman, 2022

Hydrologic Soil Group Preparation. General soil type data were obtained from the Bureau of Soils and Water Management (DA-BSWM) via Geoportal Philippines. The hydrologic soil group (HSG) classification followed the USDA system, which categorized soils into four groups based on their infiltration capacities, reflecting key physical soil properties. Alternatively, soil types were classified into HSGs based on soil texture according to USDA nomenclature, which includes coarse, moderately coarse, moderately fine, and fine textures. The USDA guidelines for estimating HSG classifications also considered the effects of increasing impervious surfaces due to urbanization and development. Table 2 presents the HSG reclassification matrix applied in this study based on soil texture (Alcober et al., 2024).

Table 2. Hydrologic Soil Group Reclassification Matrix by Soil Texture

DA-BSWM Classification	**Revised Classification**	
Description	**HSG**	**Value**
Sand	A	1
Loamy sand	B	2
Sandy loam	B	2
Loam	C	3
Silty loam	C	3
Silt	C	3
Clay loam	C	3
Sandy clay loam	C	3
Sandy clay loam	D	4
Silty clay	D	4
Clay loam	D	4

Source: USDA, 2009

Some soils, referred to as special soils, require further study to determine their hydrologic soil group (HSG) due to their unique textures, drainage, or hydrologic conditions. These soils were assigned HSG classifications based on inferred infiltration potentials. Soils with dual HSG classifications were conservatively assigned to group D, representing the slowest infiltration rates and highest runoff potential (Alcober et al., 2024).

Table 3. Hydrologic soil group reclassification matrix for special soils

DA-BSWM Classification	**Revised Classification**	
Description	HSG	Value
Rock/rough stony/rough broken/rubble land	A	1
Complex	C	3
Filled up soil	C	3
Mountainous land	C	3
Undifferentiated soil	D	4
Tarlac soil	D	4
Beach sand	A/D	4
Peat	A/D	4
River sand	A/D	4
Lava	B/D	4
Sabangan soil	B/D	4
Clay loam adobe	C/D	4
Hydrosol	D/D	4

Generating CN Grid. The preprocessed land cover (LULC) and hydrologic soil group (HSG) datasets were integrated with the curve number (CN) lookup table using the Geospatial Data Abstraction Library (GDAL) raster calculator within QGIS. This spatial overlay produced a distributed CN map that represented average antecedent runoff conditions (ARC) across the study area. Implementation utilized a GDAL raster calculator expression that systematically matched every unique combination of LULC and HSG to its designated curve number, as defined in the CN lookup table. In this process, the LULC raster grid codes and HSG group values were used as inputs, and logical operations assigned the appropriate CN value to each pixel. The resulting high-resolution CN grid provided spatially explicit characterization of runoff potential, enabling robust surface runoff modeling and supporting reliable flood risk and hydrologic assessments in Philippine watersheds (Alcober et al., 2024).

Table 4. Curve number lookup table for LULC-HSG pairs

Land Cover Description	**Curve Number for Various HSGs**			
	A	**B**	**C**	**D**
Open/Barren	63	77	85	88
Annual Crop	67	78	85	89
Gassland	30	58	71	78
Perennial Crop	45	66	77	83
Built-up	89	92	94	95
Fishpond	99	99	99	99
Mangrove Forest	98	98	98	98
Brush/Shrubs	30	48	65	73
Inland Water	99	99	99	99
Closed Forest	30	55	70	77
Open Forest	36	60	79	79
Marshall/Swamp	72	81	88	91

Source: Quijano et al., 2015

Conversion of Curve Number (CN) values from average antecedent runoff conditions (CN II) to dry (CN I) and wet (CN III) conditions was conducted using empirical equations prescribed by the Natural Resources Conservation Service (NRCS). The dry condition CN (CN I) was calculated using the following equation:

$$CN\ I = \frac{4.2\ x\ CN\ (II)}{10 - 0.058\ x\ CN\ (II)}$$

where CN(I) represented the curve number for dry antecedent runoff conditions, and CN(II) corresponded to the curve number for average antecedent runoff conditions. This conversion was implemented in a spatial environment using the GDAL raster calculator with the expression:

$$CN\ (I) = \frac{4.2\ x\ A}{10 - 0.058\ x\ A}$$

where A denotes the CN II value of an individual grid cell.

Similarly, conversion to wet antecedent runoff conditions (CN III) employed the equation:

$$CN\ (III) = \frac{23\ X\ CN\ (II)}{10 + 0.13\ x\ CN\ (II)}$$

and was applied using the GDAL expression:

$$CN\ (III) = \frac{23\ x\ A}{10 + 013\ x\ A}$$

These conversions enabled the generation of spatially explicit CN maps that reflected varying soil moisture antecedent conditions, which were critical inputs for hydrologic modeling and runoff estimation under different climatological scenarios.

HEC-HMS Modelling Framework

The HEC-HMS model consisted of several essential components that needed to be defined before running a hydrologic simulation. These included the basin model, which represented the physical watershed elements such as subbasins, reaches, junctions, reservoirs, and other hydrologic features; the meteorological model, which provided the precipitation inputs, often specified as hyetographs or other precipitation datasets; and the control specifications, which defined the simulation's start and end times, as well as the computation time steps. Additionally, a terrain data manager was used to incorporate GIS-based watershed delineation and elevation data, while a time series data manager handled precipitation, discharge, and other time-dependent input data required for model runs. These components interacted within the HEC-HMS interface, allowing users to build, organize, and run simulations that calculated the precipitation-runoff response of the basin given meteorological inputs under specified conditions.

Subbasin Loss Estimation. The SCS Curve Number method was applied to estimate direct runoff from rainfall within the subbasins. Curve number values were derived using QGIS and the associated topographic data analysis. The initial abstraction (Ia), which represents the fraction of rainfall lost before runoff begins, was estimated based on the potential maximum soil retention (S) related to the curve number (CN) and the antecedent moisture condition. The relationship between these parameters is defined as follows:

$$S = \frac{(25400 - 254\ CN)}{CN}$$

$$Ia = 0.2\ x\ S$$

Imperviousness for each subbasin was calculated by extracting built-up areas from the land use map. The percent impervious was computed as:

$$Percent\ impervious = \frac{Built - up\ Area}{Total\ Area} x100$$

Subbasin Transform. The Snyder Unit Hydrograph method estimated watershed runoff hydrographs based on basin characteristics. The basin lag time (tptp) was calculated by:

$$tp = Ct\ x\ (L\ x\ Lc)^{0.3}$$

where Ct is a regional timing coefficient, L was the length of the main stream channel, and Lc was the distance to the watershed centroid, all of which were typically measured in kilometers.

Subbasin Baseflow. The Constant Monthly Baseflow method assigned fixed baseflow values for each month to simulate groundwater contribution in hydrologic models. It was simple and suited for basins with stable baseflow, but did not adjust dynamically to rainfall events or conserve flow mass during simulations.

Reach Routing. The Lag routing method was the simplest hydrologic channel routing technique, representing only the translation of the inflow hydrograph without any attenuation or change in shape. The outflow hydrograph was the inflow hydrograph shifted forward in time by a constant lag time.

Calibration of the HEC-HMS Model. The calibration of the model utilized rainfall and discharge data from Typhoon Sinlaku (Marce) in 2008. The simulated hydrograph was calibrated to match the observed discharge recorded by the Department of Public Works and Highways (DPWH) at the Bangued, Abra, gauge station. Typhoon Marce was a powerful typhoon that brought intense rainfall to the Philippines in August 2008, producing significant hydrologic impacts. Sinlaku brought torrential and almost endless rain over most of Luzon, causing floods throughout the region. Using this event for calibration ensured the model accurately represented watershed response under extreme rainfall conditions observed during the typhoon, relying on one of the available datasets for the area during this significant flooding event.

Table 5. Final performance evaluation criteria for recommended statistical performance measures for watershed Models.

Measured Watershed Scale	Performance Evaluation Criteria			
	Very Good	Good	Satisfactory	Not Satisfactory
R^2	$R^2 > 0.85$	$0.75 < R^2 \leq 0.85$	$0.60 < R^2 \leq 0.75$	$R^2 \leq 0.60$
NSE	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.65	NSE ≤ 0.50
PBIAS (%)	PBIAS < ± 5	± 5 ≤ PBIAS < ± 10	± 10 ≤ PBIAS < ± 15	PBIAS > ± 15

Validation of the HEC-HMS Model. For model validation, the same calibrated parameters were applied without modification. The validation used rainfall and discharge data from the 2018 Typhoon Ompong event, which represented the only available and reliable dataset in the DPWH database for typhoon conditions. This approach ensured that the model's predictive performance was evaluated independently using observed data distinct from the calibration period.

Results and Discussion

Curve Number Grid

The Abra watershed's twelve subbasins vary widely in area (1.84–1,668.84 km²) and runoff potential, as indicated by CN II values. The highest CNs are found in the small S10 (91.99) and S11 (89.00), indicating high runoff, while S12, the second-largest subbasin, has the lowest CN (56.35), suggesting high infiltration. Most subbasins have moderate to high CNs, reflecting a generally strong runoff response expected across much of the watershed.

Table 6. Curve-Number Values for the Abra River Basin.

Subbasin	Area (km2)	Latitude	Longitude	Curve Number
S1	562.8051	17.81139693	120.9606883	78.27
S2	284.1327	17.64811383	120.8629608	76.94
S3	425.2932	17.65372131	120.9820455	77.48
S4	261.8325	17.57276414	120.8306699	78.63
S5	433.7451	17.42047273	120.8784069	76.25
S6	1668.8421	17.12133981	120.7602559	75.12
S7	280.6227	17.83232391	120.7697113	75.80
S8	9.1692	17.65311081	120.6909803	82.57
S9	171.7839	17.50882054	120.7383998	74.00
S10	1.8387	17.62433211	120.7273333	91.99
S11	43.8732	17.62696109	120.7072913	89.00
S12	720.4554	17.62235591	120.5987773	56.35

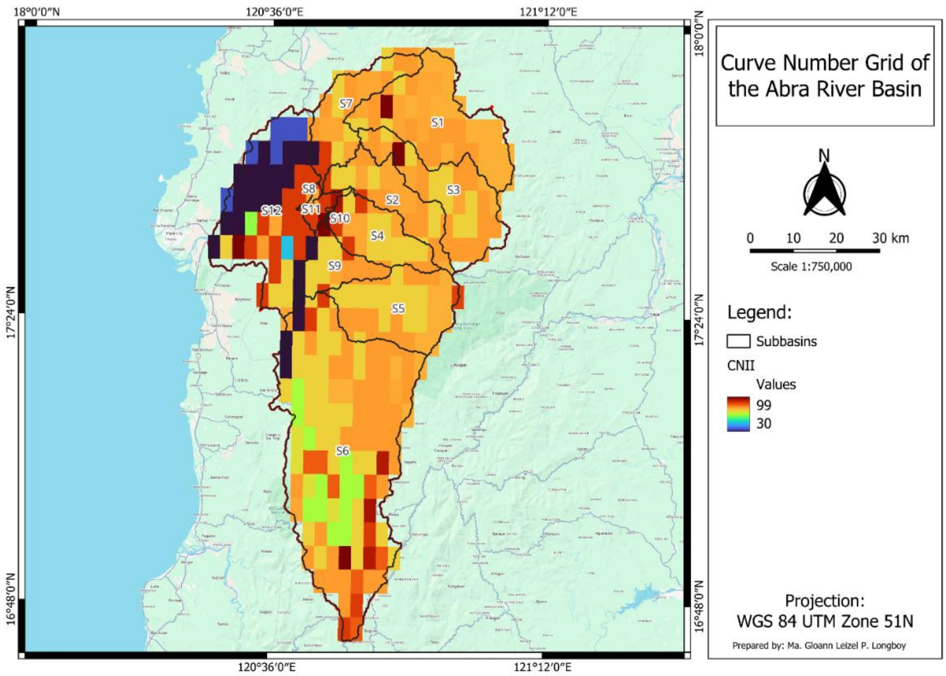

Figure 6. CN Grid Map of the Abra River Basin

HEC-HMS Model

The HEC-HMS model was applied to simulate the hydrologic response of the Abra watershed, which was delineated into 12 subbasins with areas ranging from 1.84 km² (S10) to 1,668.8 km² (S6). Using rainfall inputs and hydrologic parameters calibrated against observed discharge at the Bangued, Abra, gauge station, the model effectively generated runoff hydrographs for each subbasin. The spatial variability in subbasin areas allowed for detailed capture of watershed runoff processes, reflecting the diverse hydrologic characteristics across the basin. The results demonstrated the model's capability to simulate surface runoff and flow routing accurately within this large dendritic watershed system.

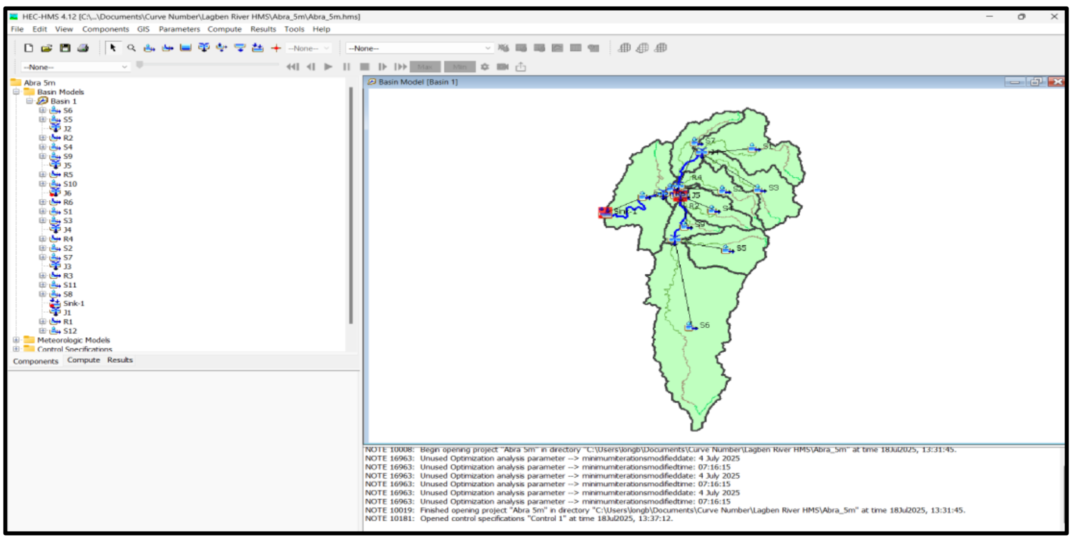

Figure 7. HEC-HMS Model of the Abra River Basin

Table 7. Subbasins Area of the Abra Watershed

Subbasin	Area (km^2)
S6	1668.8
S5	433.75
S4	261.83
S9	171.78
S10	1.8387
S1	562.81
S3	425.29
S2	284.13
S7	280.62
S11	43.873
S8	9.1692
S12	720.46

Calibration of the Model

The HEC-HMS model was calibrated using data from the Typhoon Ompong 2018 event at the Abra River junction J6. The computed peak discharge was 4,553.5 m³/s, occurring at 10 pm on September 15, 2018, which slightly overestimated the observed peak discharge of 4,410.6 m³/s recorded at midnight on September 16, 2018. The simulated runoff volume of 592.48 mm was nearly identical to the observed volume of 592 mm. Model evaluation resulted in a Nash-Sutcliffe Efficiency (NSE) of 0.763, an RMSE standard deviation of 0.5, and a percent bias of 0.06%. These results showed that the calibrated model captured some aspects of the flood hydrograph magnitude and timing but also revealed discrepancies, suggesting further refinement was needed for accurate hydrologic analysis and flood forecasting in the Abra watershed.

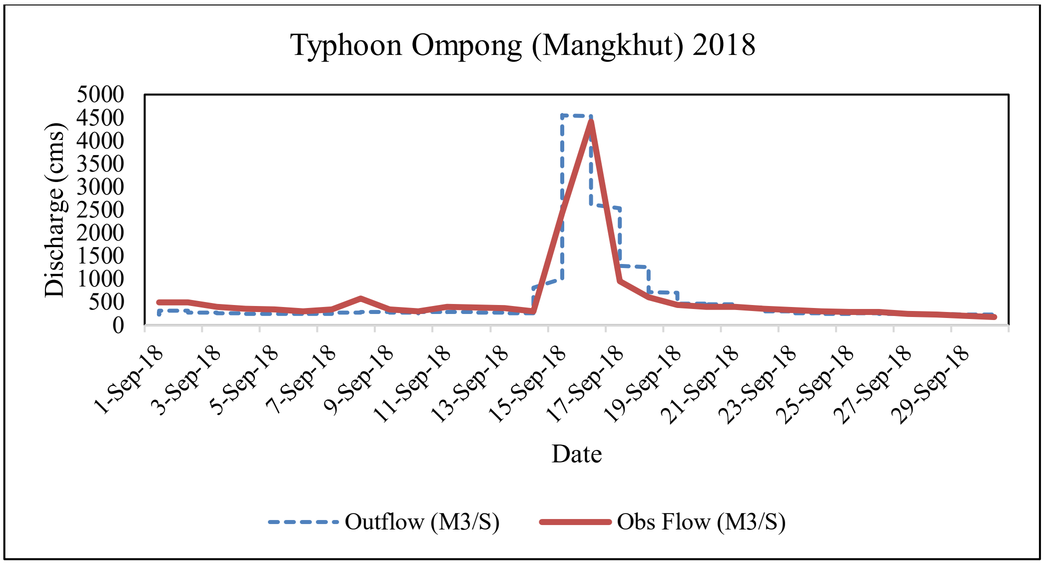

Figure 8. Calibration of the Hec-HMS Model

Table 8. Summary of the Abra River Basin HEC-HMS Model Validation Results (Typhoon Marce 2008)

Typhoon Marce 2008	Peak Discharge (m3/s)	Date of Peak Discharge	Time of Peak Discharge	Volume (mm)	NSE	PBIAS (%)	RMSE
Observed	18632.1	Aug. 21, 2008	0:00:00	2000.38	0.61	-26.38	0.60
Simulated	24629.2	Aug. 20, 2008	0:00:00	2716.19			

Validation of the Model

The validation of the HEC-HMS model for the Abra watershed, using data from Typhoon Sinlaku (Marce), showed strong agreement between simulated and observed streamflow at the Abra River junction J6. The model predicted a peak discharge of 18,632.1 m³/s at midnight on August 21, 2008, which significantly overestimated the observed peak discharge of 24,629.2 m³/s recorded at midnight on August 20, 2008. The simulated runoff volume of 2,000.38 mm was lower than the observed volume of 2,716.19 mm. Performance metrics indicated moderate model reliability, with a Nash-Sutcliffe Efficiency (NSE) of 0.614, an RMSE standard deviation of 0.6, and a percent bias of -26.38%. These results showed that the calibrated model captured some aspects of the flood hydrograph magnitude and timing but also revealed discrepancies, suggesting further refinement was needed for accurate hydrologic analysis and flood forecasting in the Abra watershed. These results indicate that the model accurately captures both the timing and magnitude of peak flow, demonstrating reliable predictive performance. Although minor discrepancies were noted, the model proved to be a valuable tool for hydrologic analysis and flood forecasting in the Abra watershed.

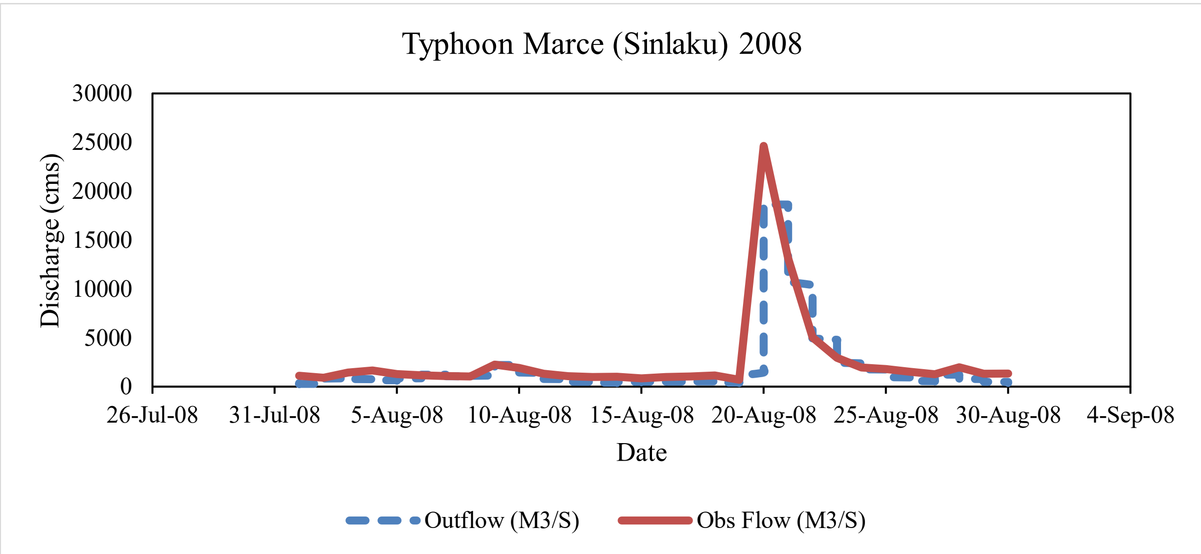

Figure 9. Validation of the HEC-HMS Model

Table 9. Summary of the Abra River Basin HEC-HMS Model Validation Results (Typhoon Ompong 2018)

Typhoon Ompong 2018	Peak Discharge (m3/s)	Date of Peak Discharge	Time of Peak Discharge	Volume (mm)	NSE	PBIAS	RMSE
Simulated	4553.5	September 15, 2018	22:00:00	592.48	0.763	0.06%	0.5
Observed	4410.6	September 16, 2018	0:00:00	592.00			

Conclusion

This study evaluated the suitability of GSMaP (Global Satellite Mapping of Precipitation) satellite-based rainfall data for runoff estimation in the Abra River Basin, Philippines, through developing a comprehensive hydrological modeling framework using HEC-HMS. The approach integrated multiple datasets, including high-resolution IfSAR digital elevation, GSMaP precipitation, DPWH discharge records, and detailed land use and soil classifications, to delineate the watershed into 12 subbasins and generate spatially distributed curve number grids for runoff estimation. Hydrologic methods such as the SCS Curve Number for loss estimation, the Snyder Unit Hydrograph for transformation, and lag routing for flow routing were applied effectively.

Model calibration using Typhoon Ompong 2018 data demonstrated moderate performance, achieving an NSE of 0.763. The model simulated a peak discharge of 4553.5 m^3/s compared to an observed peak of 4410.6 m^3/s and a runoff volume of 592.48 mm with a percent bias of 0.06%. Validation with the 2008 Typhoon Marce event showed improved performance, with an NSE of 0.614, accurately capturing peak discharge and runoff volumes. Spatial analysis revealed significant variability in runoff potential across the basin, with curve numbers ranging from 56.35 to 91.99 and subbasin areas varying from 1.84 to 1,668.8 km^2, demonstrating the model's capability to represent diverse hydrologic performances.

This research demonstrates that GSMaP satellite precipitation data is an effective tool for runoff estimation and hydrologic modeling in data-scarce tropical watersheds such as the Abra River Basin. The study addressed the lack of sufficient discharge data during typhoon events by using the calibrated and validated HEC-HMS model to generate upstream discharge estimates. These estimated discharges were then used in the analysis of river system to simulate flood extents and model river hydraulics, which provided important floodplain delineation and water surface profile information. While the model revealed some limitations in reliably simulating extreme rainfall events, indicating a need for further refinement under extreme typhoon conditions, this study advances satellite-based hydrologic modeling in the Philippines.

It offers a practical tool for flood forecasting, water resource planning, and climate impact assessments in regions with limited ground-based monitoring.

Recommendations

Based on the study findings, the following recommendations are proposed for future research and operational applications:

Bias Correction Implementation. Despite its wide coverage and resolution, GSMaP tends to underestimate rainfall in certain regions, making bias correction techniques such as blending satellite data with ground rain gauge observations essential for improving accuracy.

Enhanced Parameter Calibration. Further refinement of model parameters is recommended to improve accuracy during extreme rainfall events through region-specific calibration procedures.

Climate Change Applications. Extend the framework to assess climate change impacts on watershed hydrology using projected precipitation scenarios from global climate models.

Uncertainty Analysis. Conduct a comprehensive uncertainty analysis to quantify the confidence intervals of model predictions and guide decision-making processes.

The successful application of GSMaP data in this study opens new possibilities for hydrological modeling in ungauged basins across the Philippines and similar tropical regions.

References

Alcober, C. A., & Macuha, R. (2024). Development and analysis of a GIS-based curve number map of the Philippines. *ASEAN Engineering Journal, 14*(2), 173–181. https://doi.org/10.11113/aej.v14.21013

Al Khoury, I., Boithias, L., Sivelle, V., Bailey, R. T., Abbas, S. A., Filippucci, P., Massari, C., Labat, D. (2024). Evaluation of precipitation products for small karst catchment hydrological modeling in data-scarce mountainous regions. *Journal of Hydrology*, 645, 132131.

Balahadia, F. F., Mamuad, A. L., Tongson, E. E., & Clemente, M. A. (2018). Hydrological modeling and flood mapping at Quinali A Watershed, Albay, Philippines using HEC-HMS and HEC-RAS. International Journal of Engineering and Technology, 7(3), 251-257.

Cao, M., Chen, M., & Walker, J. (2025). Intercomparison of GPM hourly precipitation products: Assessing the strengths in capturing precipitation events and their properties. *Atmospheric Research*, 325, 108231.

Castro, C. V., & Maidment, D. R. (2020). GIS preprocessing for rapid initialization of HEC-HMS hydrological basin models using web-based data services. *Environmental Modelling and Software*, 130, 104732.

E.C. Paringit and C. Pascua. (Eds.). (2017), LiDAR Surveys and Flood Mapping of Abra River, in Enrico C. Paringit, (Ed.), Flood Hazard Mapping of the Philippines using LIDAR, Quezon City: University of the Philippines Training Center for Applied Geodesy and Photogrammetry.

Guduru, J. U., Jilo, N. B., Rabba, Z. A., & Namara, W. G. (2023). Rainfall-runoff modeling using HEC-HMS model for Meki River watershed, rift valley basin, Ethiopia. *Journal of African Earth Sciences*, 197, 104743.

Guduru, J. U., & Mohammed, A. S. (2024). Hydrological modeling using HEC-HMS model, case of Tikur Wuha River Basin, Rift Valley River Basin, Ethiopia. *Environmental Challenges*, 17, 101017.

Huang, Z., Wu, H., Gu, G., Yilmaz, K. K., Nanding, N., & Li, C. (2025). How GPM IMERG and GSMaP advance hydrological applications: A global perspective. *Journal of Hydrology*, 661, 133514.

Jiang, A., Zhang, W., Liu, X., Zhou, F., Li, A., Peng, H., Wang, H. (2024). Improving hydrological process simulation in mountain watersheds: Integrating WRF model gridded precipitation data into the SWAT model. *Journal of Hydrology*, 639, 131687.

Jawale, P. S., & Thube, A. D. (2025). Rainfall-runoff modeling of urban floods using GIS and HEC-HMS. *MethodsX*, 15, 103437.

Kumari, M., Diksha, Kalita, P., Mishra, V. N., Choudhary, A., & Abdo, H. G. (2024). Rainfall-runoff modelling using GIS based SCS-CN method in umiam catchment region, Meghalaya, India. *Physics and Chemistry of the Earth*, 135, 103634.

Moon, G. W., Ajmal, M., Ahn, J. H., & Kim, T. W. (2016). Investigating practical alternatives to the NRCS-CN method for direct runoff estimation using slope-adjusted curve numbers. *KSCE Journal of Civil Engineering*, 20(7), 3022–3030.

Moriasi, D. N., Gitau, M. W., Pai, N., & Daggupati, P. (2015). Hydrologic and water quality models: Performance measures and evaluation criteria. *Transactions of the ASABE*, *58*(6), 1763-1785.

Reis, A. A., Weerts, A., Ramos, M.-H., Wetterhall, F., Fernandes, W. d. S. (2022). Hydrological data and modeling to combine and validate precipitation datasets relevant to hydrological applications. *Journal of Hydrology: Regional Studies*, 44, 101200.

Sciuto, L., Vanella, D., Cirelli, G. L., Consoli, S., Licciardello, F., & Longo-Minnolo, G. (2025). Improving runoff estimation in hydrological models using remote sensing and climate data reanalysis in the Dittaino River Basin (Eastern Sicily, Italy). *Journal of Hydrology: Regional Studies*, 60, 102569.

Song, J.-H., & Kim, H. (2025). Impact of precipitation station density and homogeneous regions on hydrological modeling performance. *Journal of Hydrology*, 661, 133618.

Taña, E. A. S., Olaguera, L. M. P., Visaga, S. M. A., Magnaye, A. M. T., Llorin, A. G. A., Cruz, F. A. T., Villarin, J. R. T., & Matsumoto, J. (2025). Assessing the performance of GSMaP and IMERG in representing the diurnal cycle of precipitation in the Philippines during the southwest monsoon season. *Atmospheric Research*, 317, 107983.

U.S. Army Corps of Engineers. (2000). Hydrologic Modeling System HEC-HMS User's Manual. Hydrologic Engineering Center.

U.S. Army Corps of Engineers (USACE). (2000). *Hydrologic Modeling System HEC-HMS User's Manual*. Hydrologic Engineering Center. Retrieved from https://www.hec.usace.army.mil/software/hec-hms/documentation.aspx

U.S. Army Corps of Engineers (USACE). (2002). *HEC-HMS Applications Guide*. Hydrologic Engineering Center. Retrieved from https://www.hec.usace.army.mil/software/hec-hms/documentation.aspx

Verma, S., Singh, P. K., Mishra, S. K., Singh, V. P., Singh, V., & Singh, A. (2020). Activation soil moisture accounting (ASMA) for runoff estimation using soil conservation service curve number (SCS-CN) method. *Journal of Hydrology*, 589, 125114.

Wang, M., Zhao, Y., Shi, W., Yu, J., Chen, T., Bao, J., Song, W., & Chen, H. (2025). A modified curve number method for runoff prediction of different soil types in China. *Catena*, 254, 108957.

Yu, J., Chen, H., Wang, M., Bao, J., Song, W., He, X., & Shi, W. (2025). A modified curve number method for runoff prediction of different vegetation types at the slope scale in China. *Soil & Tillage Research*, 254, 106737.

Zeng, Q., Chen, H., Xu, C.-Y., Jie, M.-X., Chen, J., Guo, S.-L., & Liu, J. (2018). The effect of rain gauge density and distribution on runoff simulation using a lumped hydrological modelling approach. *Journal of Hydrology*, 563, 106–122.

Zhou, C., Zhou, L., Du, J., Yue, J., & Ao, T. (2024). Accuracy evaluation and comparison of GSMaP series for retrieving precipitation on the eastern edge of the Qinghai-Tibet Plateau. *Journal of Hydrology: Regional Studies*, 56, 102017.