IECL 2025 Conference

The 2nd International Electronic Conference on Land

04–05 September 2025 | Online

MDPI

Rainfall-Runoff Simulation Using HEC-HMS and GIS for Climate-Resilient Watershed Management: A Case Study of the Mangla Watershed, Pakistan

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INTRODUCTION & AIM

Water scarcity challenges:

- Growing demand (agriculture, energy, households, industry) outpaces supply, threatening sustainability.
- Hydrological modeling is critical for predicting availability and managing resources.

Key tools:

- **HEC-HMS** (GIS-integrated, free, robust) simulates runoff using:
  - SCS Curve Number (runoff estimation)
  - SCS Unit Hydrograph (rainfall-to-runoff)
  - Muskingum (channel routing).

Study focus:

- Simulate Mangla Watershed runoff (1991–2000 for calibration, 2000-2010 for validation).
- Enhance hydrological assessments for sustainable water management.

METHOD

The methodology used in hydrological modelling can be divided into the following major tasks:

- DEM Data preprocessing in HEC-HMS, such as fill sink, flow direction, flow accumulation, identification of streams, and the delineation of the catchment.
- Model parameters calculation like (Initial Abstraction, Curve Number, Lag Time, Recession Constant, Muskingum Constant K and X)
- Input the Model parameters and Rainfall data to run the Model.
- Input the observed flow data to calibrate the model. (We used a manual calibration method)
- Run the model for different years to validate the model.

RESULTS & DISCUSSION

Model Calibration (1991–2000)

- Adjusted CN, lag time, Muskingum K/X to match observed vs. simulated hydrographs (Figure 4a).
- Calibrated CN reduced by ~35% (e.g., Subbasin-1: 84.2 → 53.9), improving runoff accuracy.

Statistical Performance:

- Nash-Sutcliffe Efficiency (NSE): 0.919 (Excellent: >0.75)
- PBIAS: -13.53% (Good: |±15%|)

Model Validation (2001–2010)

- Validated with independent data; hydrographs showed strong correlation (Figure 4b).
- Improved Metrics:
  - NSE: 0.945 (Near-perfect fit)
  - PBIAS: -2.91% (Minimal bias)

CONCLUSION

The results of the study suggested that the hydrological modeling using HEC-HMS for the Mangla Watershed is applicable for future work on rainfall-based runoff modeling, and to reduce the impact of floods, it is crucial to have strong flood protection measures and emergency response strategies.

FUTURE WORK / REFERENCES

- Multi-model CMIP6 analysis → Reduce climate uncertainty.
- ML-enhanced hydrology → Boost flood prediction.
- Land use + climate coupling → Realistic future scenarios.
- Policy tools → Interactive dashboards for stakeholders.

FIGURES AND TABLES

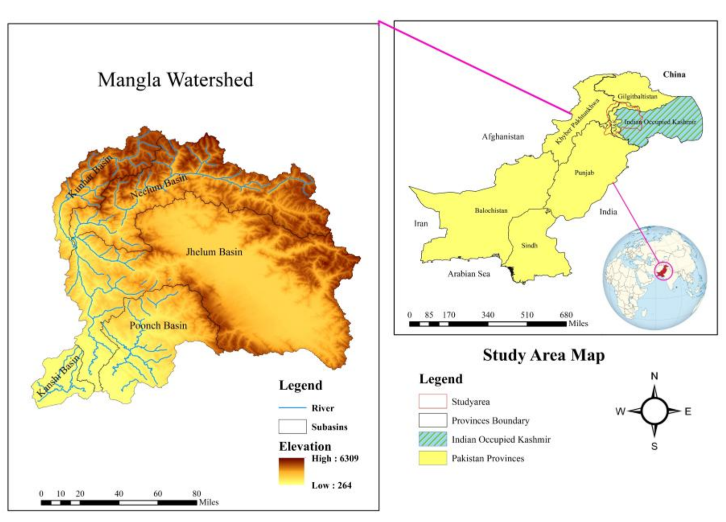

Figure 1: Study area map of Mangla Watershed

Data Type	Source	Spatial/Temporal Resolution
Digital Elevation Model	USGS Shuttle Radar Topography Mission	30 × 30 m
Land use data	European Space Agency (ESA) Global Land Cover map	300 × 300 m
Soil data	FAO World Soil Database V 1.2	1 km
Climate data	Pakistan Metrological Department (PMD) and Water and Power Development Authority (WAPDA)	Daily
Hydrological data	Water and Power Development Authority (WAPDA)	Daily

Table 1: Type of datasets used in this study, along with sources

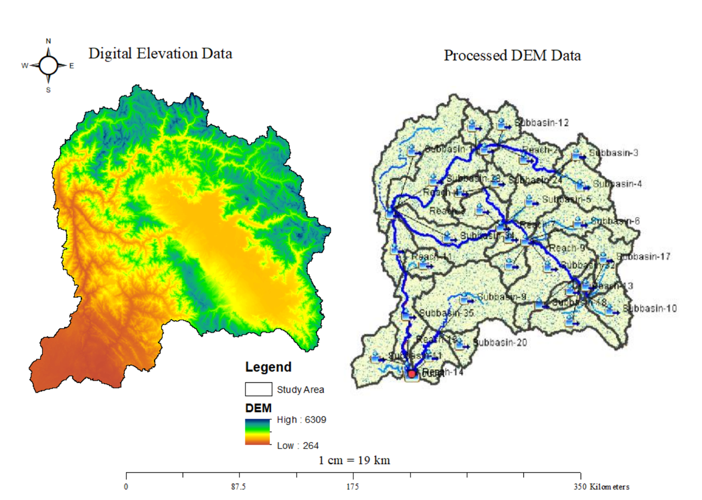

Figure 2: DEM Processing

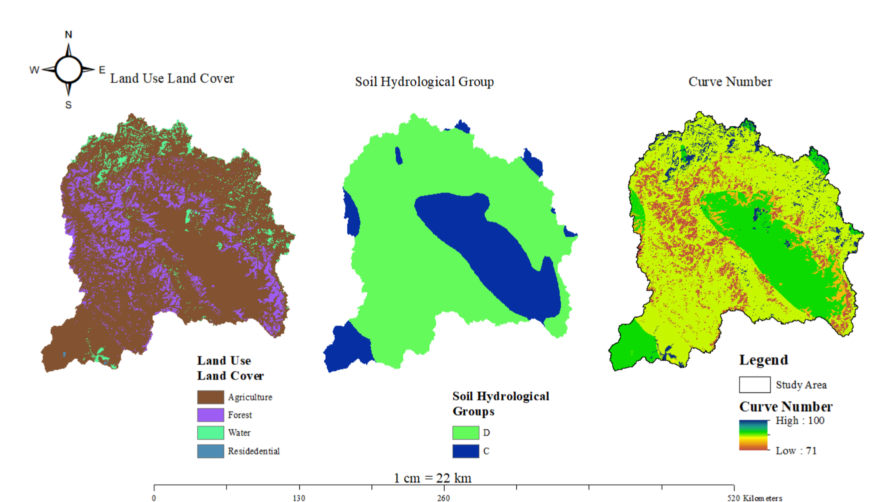

Figure 3: Curve Number Map with LULC and Soil Hydrological Group Map

Sr No.	Model	Method	Equation	Parameter Required (Unit)
1	Loss	SCS Curve Number Method	$CN = \frac{\sum A_i CN_i}{\sum A_i}$ (1)	Initial Abstraction, Curve Number, and Impervious Area (%)
2	Transform	SCS Unit Hydrograph	$Lag = \frac{(S+1)^{0.7} L^{0.8}}{1900 \times Y^{0.5}}$ (2)	Lag Time (min)
3	Reach Routing	Muskingum	-	Muskingum Constant K and X

(1) A_i is the area (Km^2) and CN_i is the curve number

(2) S is potential maximum retention = (25400/CN)-254 (mm), Lag = Basin Lag time (hr), L = longest flow path length (ft), and Y= Bassin Slop (%).

Table 2: Input Parameters of HEC-HMS Rainfall-based Runoff Model.

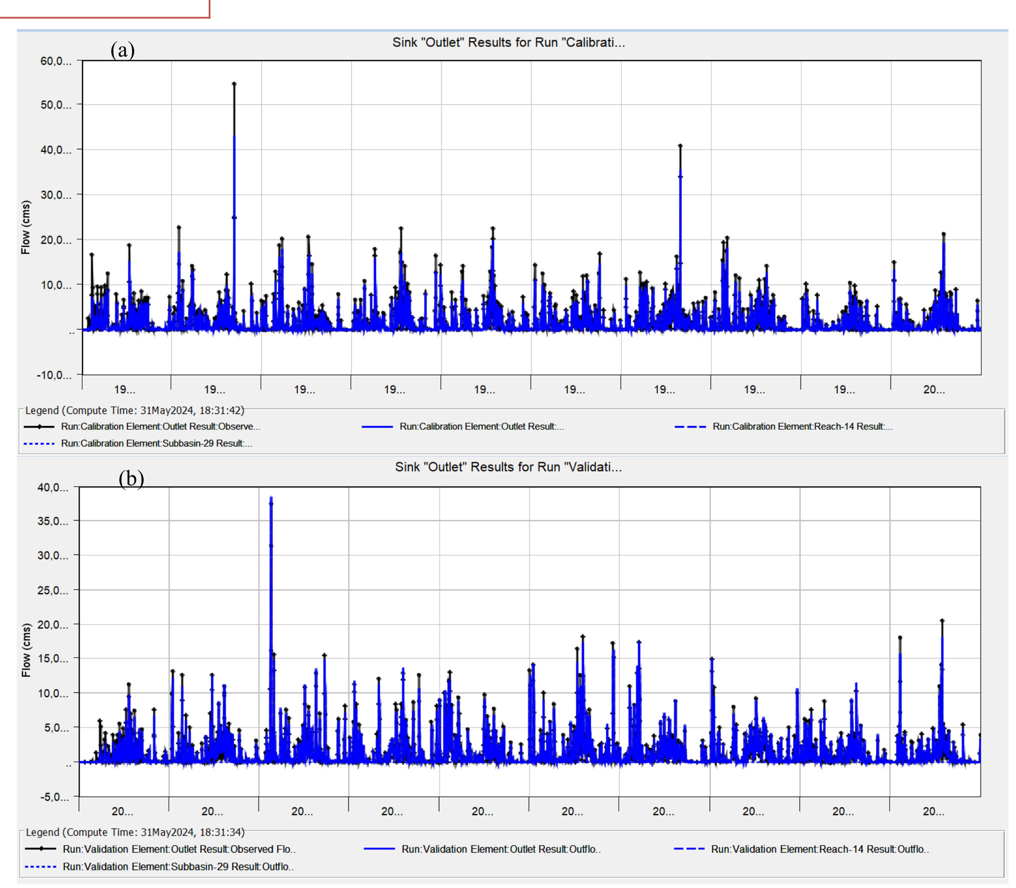

Figure 4: Hydrograph for (a) Calibration (1990-2000) and (b)Validation (2000-2010) Periods

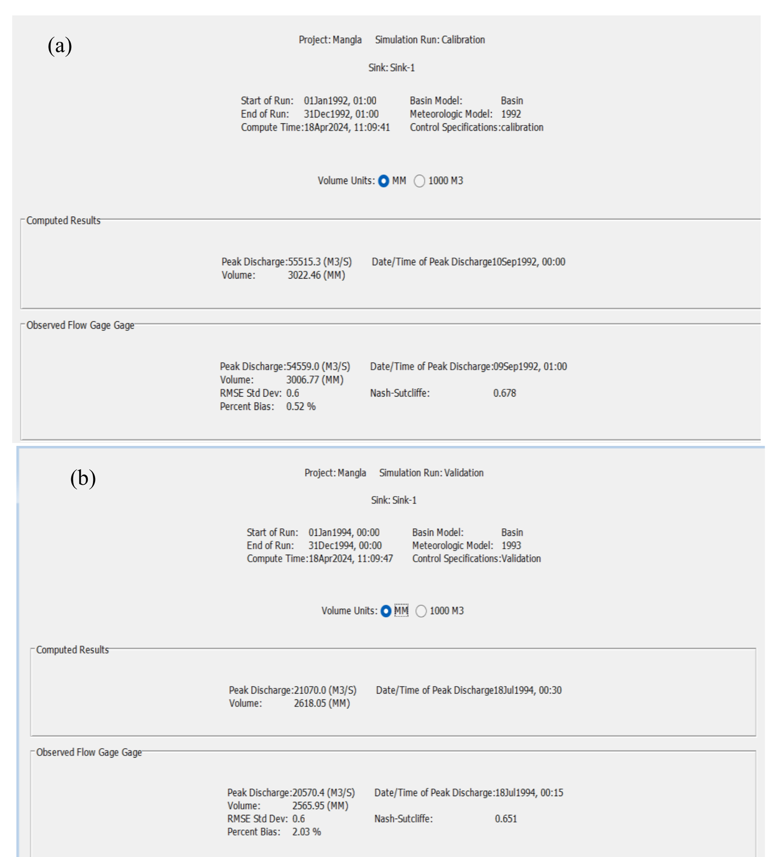

Figure 4: Statistical Parameters for (a) Calibration (1990-2000) and (b)Validation (2000-2010) Periods