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IMPACT OF LULC CHANGE ON FLOOD EVENTS AND HEC-RAS TWO-DIMENSIONAL HYDRODYNAMIC MODELLING IN THE HIMALAYAN BEAS RIVER BASIN

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Abstract— Floods are the most significant and recurrent natural hazards. The Himalayan river basin has been facing increasing flood risk due to the combined effects of land use and land cover (LULC) changes, rapid urbanization, and climate change. The Beas basin in Himachal Pradesh is one of the most dynamic and hazard-prone river basins. In recent years, the region has experienced repeated flood events resulting in extensive property damage and loss of life. This necessitates an integrated approach for flood risk management. The present research uses HEC-RAS two-dimensional hydrodynamic modelling to assess the flood dynamics in response to LULC changes in the Beas River Basin. LULC changes have been analysed in GIS. A 2-D hydrodynamic model for the Beas River basin was developed using spatially extracted cross sections and recorded stream flow data to analyse extreme flood events. Analysis of water levels, stream discharges, and river cross sections was carried out. The model calibration and validation predict a good output agreement with a coefficient of determination (R2) value of 0.87. The flood simulation results were integrated into GIS to develop the flood inundation maps. The results of this study show considerable LULC changes in the region, with a significant increase in the built-up areas and a decrease in the green cover. The study also provides a scientific basis for flood hazard mapping, land use regulations, and integrated flood risk management in the Himalayan River basins.

Keywords*— *Beas river basin, Floods, Food inundation mapping, HEC-RAS 2D modelling, Himalayan rivers, LULC change

I. INTRODUCTION

The Himalayan river basin is one of the most dynamic and vulnerable hydrological systems around the world. These regions are vulnerable to natural disasters because of their steep topographical features, precipitation patterns, glacier-fed river flows, and rapidly changing land use patterns (Yalcin et al., 2020). These river basins act as the supporting systems for over 1.3 billion people across South Asia and provide critical ecosystem services, including water supply, hydropower generation, and agricultural productivity. However, in recent years, the region has experienced escalating flood risks driven by various factors. These factors include various topographical, anthropogenic, hydrological, and climatic factors. Floods become more common and destructive natural hazards in the Himalayan region due to steep slopes, fragile ecosystems, and intense hydro-meteorological conditions that lead to rapid runoff (Vashist et al., 2023; Rafiq et al., 2016). The frequency and magnitude of flood events in the Himalayan region have increased over the last two decades, primarily due to climate-driven extreme precipitation events, rising temperatures, and widespread human alterations to river corridors and land use changes (Afzal et al., 2022). In the Himalayan region, rapid urbanization, climate change, deforestation, agricultural expansion, and inadequate flood management infrastructure are the major contributors to the increased frequency and magnitude of floods during recent years (Feng et al., 2021).

Changes in land-use patterns alter basin characteristics such as infiltration capacity, channel geometry, surface roughness, impervious surfaces, peak-flow discharge, and flood frequency (Liu et al., 2024). The Himalayan region is extremely vulnerable to LULC changes and the subsequent flood events that have occurred in the basin. Hydrodynamic modelling helps in understanding the complex relationship between LULC change and flood dynamics in ecologically fragile Himalayan landscapes through leveraging tools that simulate flow behavior under a diverse set of conditions (Belay et al., 2025). Hydrodynamic models that incorporate flood inundation mapping provide important information for flood risk assessment and floodplain management. The Hydrologic Engineering Centre River Analysis System (HEC-RAS) model, developed by the U.S. Army Corps of Engineers, is one of the commonly used hydrodynamic modelling platforms that are used around the world for flood analysis (Abedin, 2024).

Its one-dimensional (1D) configuration, which simulates flow along the main channel axis, offers computational efficiency and data parsimony particularly valuable in data-scarce mountain environments (Zope et al., 2017). These models can integrate with a geographic information system (GIS) to perform geospatial analysis of flood events and to simulate flood extents under varied land use scenarios by calibrating Manning's roughness coefficients to observed LULC changes (Desalegn et al., 2021). For integrated flood risk management, flood modelling is a key component that offers data on flood level forecasting, evaluation of floodplain zones through flood inundation mapping, and evaluation of the advantages of natural flood management methods (Kumar et al., 2023). HEC-RAS has been applied in various river systems to predict flood levels and help in flood mitigation strategies (Namara et al. 2022). HEC-RAS can be a useful tool for the data-scarce Himalayan region as it can measure the sensitivity of the flood patterns to human alterations in LULC patterns and also maintain the computational efficiency (Bhattarai et al. 2022; Elkhrachy et al., 2021). Integrating future LULC change scenarios with hydrodynamic models is critical for a comprehensive flood risk assessment (Sun et al. 2025; Hayat et al., 2021). This will help to predict the geographical distribution of flood-prone areas and also help in urban planning and development decisions.

Despite the growing application of HEC-RAS in flood studies globally, significant knowledge gaps persist regarding its effectiveness for assessing LULC change impacts, specifically in Himalayan river basins. The unique characteristics of these systems, including snow and glacier melt contributions to river flows, extreme topographic gradients, monsoon-dominated hydrological behavior, and rapid anthropogenic transformations, present distinct modelling challenges for an effective and accurate simulation of the combined effects of LULC change and hydrological processes, especially in the data-scarce regions. And these challenges require a systematic investigation (Babaremu et al., 2024). The present study highlights the application of HEC-RAS 2D hydrodynamic modelling for flood assessment, particularly in the Himalayan river basin, with emphasis on LULC change impacts. The study includes modelling methodology, findings on the complex relationship of LULC change and flood risk, and model performance characteristics. The findings of the study contribute to a more reliable understanding of flood dynamics in mountainous river basins and help in the creation of flood risk maps for the formulation of appropriate flood risk management and mitigation strategies.

II. Literature Review

A. *Himalayan River Basin Characteristics*

Himalayan river basins differ from lowland systems in terms of their hydrological characteristics that influence flood generation mechanisms. The Himalayan river basin area is characterized by extreme elevation gradients ranging from over 8000 meters at mountain peaks to 500 meters in low-lying foothill regions, creating diverse climatic zones and runoff generation processes within single watersheds (Briandy et al., 2024). The monsoon precipitation in these river basins varies spatially and temporally, while the glacial melting and mixed rainfall-snowfall melt contribute to the hydrological behavior of the region (Molden et al., 2021). The Beas River Basin, originating from the Northern Himalayas illustrate this complex hydrological behavior. Studies pertaining to the Indus River Basin in the Western Himalayas underscore how flood events are a result of a combination of intense rainfall, snowmelt, and glacial lake outburst floods (GLOFs) (Tariq et al., 2021; Butt et al., 2019). Similarly, the Eastern Teesta River Basin in the Eastern Himalayas illustrates flash flood susceptibility of the region due to steep terrain, high-intensity rainfall, and limited valley storage capacity (Mandal et al., 2016). Geomorphologic features such as narrow valley configurations, high sediment loads, and active channel migration create dynamic flood hazard patterns that evolve over relatively short timescales and further influence flood behavior in the Himalayan landscapes (Kaushik et al., 2024). Additionally, the 2023 and 2025 Beas River floods illustrate how inundation extent and damage patterns caused by flood events are affected by channel morphology and floodplain characteristics.

B. *LULC Change Drivers and Patterns*

In Himalayan landscapes, land use transformation is mainly caused by a set of socio-economic and environmental factors operating at different scales. Exponential increase in population, rapid and haphazard urbanization, and economic development have resulted in the foothills and valley areas converting into agricultural land while patches of natural vegetation are replaced by built areas with an increase in impervious surfaces (Kuntiyawichai et al., 2020; Zope et al., 2017; Yousuf et al., 2022). Expansion of agricultural land that involves deforestation and terracing alters the infiltration capacity of the region while amplifying surface runoff and increasing the risks of soil erosion.

The magnitude of these LULC changes varies across the Himalayan ranges. In the Kashmir region, studies underscore substantial agricultural expansion and an increase in built-up area that have modified peak flood discharge and sediment yield patterns (Yousuf et al., 2022). Similarly, in Nepal, urbanization along the river corridors has altered flood regimes in the region (Briandy et al., 2024).

These changes in LULC affect flood generation in multiple ways as urbanization increases impervious surfaces, thereby reducing infiltration and accelerating surface runoff and peak discharge rates (Zope et al., 2017). Deforestation and agricultural conversion reduce evapotranspiration and soil water storage capacity, exacerbating the risks of landslides (Kuntiyawichai et al., 2020).

C. *Hydrodynamic Modelling Principles*

Hydrodynamic modelling acts as an important tools that help to simulate water flow through river channels and floodplains by solving fundamental equations of fluid mechanics. One-dimensional models, including HEC-RAS 1D, solve the Saint-Venant equations (also known as shallow water equations) along the primary flow direction, assuming that flow characteristics vary primarily in the longitudinal direction while remaining relatively uniform across channel cross-sections (Edamo et al., 2022).

The continuity equation (conservation of mass) and the momentum equation (conservation of momentum) serve as the governing equations, which together describe how water depth and velocity change through space and time in response to channel geometry, roughness, and boundary conditions. HEC-RAS 2D can perform both steady-state flow analysis, where flow conditions do not change with time, and unsteady flow analysis, which simulates time-varying flood waves (Gupta et al., 2026).

A critical component of HEC-RAS modelling is the representation of channel and floodplain roughness through Manning's n coefficient, which quantifies flow resistance due to bed material, vegetation, and channel irregularities. Land use types directly influence Manning's n values, with forested areas exhibiting higher roughness (n = 0.08-0.15) compared to agricultural land (n = 0.03-0.05) or urban channels (n = 0.02-0.04) (HEC-RAS, 2016). This linkage provides a primary mechanism through which land use change impacts are incorporated into hydrodynamic simulations.

III. Research Methodology

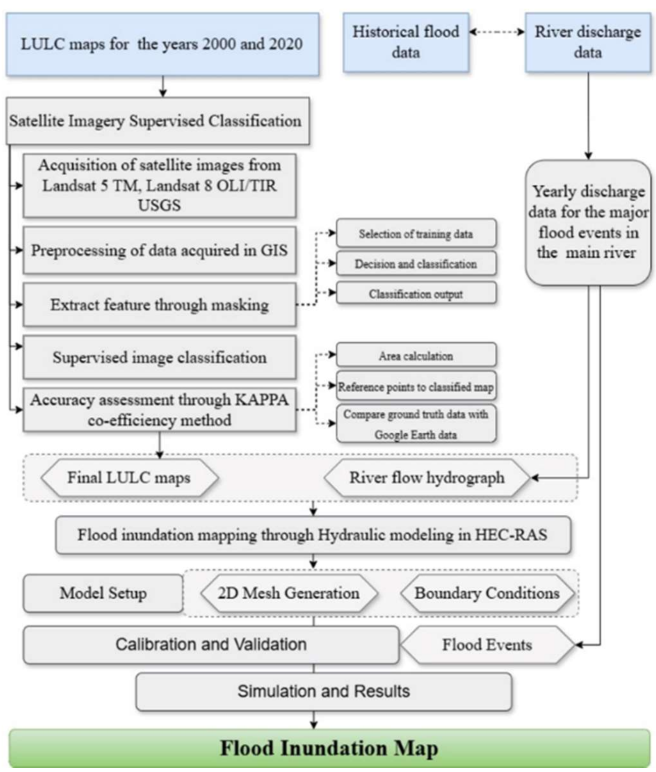

Fig. 1. Research methodology

The research methodology for the present study is shown in Fig. 1. The four stages of the study are as follows:

Stage 1 - Data collection and pre-processing: In this stage, data required for study area extraction, LULC change analysis, and hydrodynamic modelling were collected from various sources and pre-processed. The ALOS PALSAR DEM at 12.5m resolution has been used to extract the study area, stream networks, terrain models, geometric data, and river cross sections for model setup in HEC-RAS. The historical Landsat satellite imagery was acquired for LULC change analysis. The hydrological input data for model calibration and validation were collected from the Government department, including river discharge at the gauging stations. All the collected data were preprocessed for integrated data analysis.

Stage 2- LULC Change Analysis: The LULC maps for different time periods were prepared through supervised image classification on the acquired satellite imagery. Six main LULC classes were identified for image classification based on regional land cover features. These classes include water bodies covering rivers, streams, lakes, and reservoirs, built-up, forest cover, green areas, snow cover, and barren land. The change detection has been carried out to analyze the temporal change for each LULC class.

Stage 3- Hydrodynamic modelling in HEC-RAS: In this stage, the first part is model setup. A high-resolution DEM was used to extract the river geometry, including centerline, cross sections, and flow paths. Manning's 'n' value was assigned for different LULC types. And upstream and downstream boundary conditions were defined by the flow hydrograph and normal depth or water surface elevation, respectively. In the second part, the HEC_RAS model was calibrated using the historical flow data by comparing the simulated data with the observed data. To minimize the differences between observed and simulated data, various parameters, including Manning's 'n', were changed to a specific range. After the calibration and validation, the model was run for different LULC scenarios to get the results as water surface elevation, flow velocity, flood depth, and inundation extents.

Stage 4- Flood Impact Assessment: After the model simulation, the flood inundation maps were overlaid with different LULC maps to analyze the flood-prone areas due to LULC alterations and the various LULC classes, such as human settlements, various infrastructure, and agricultural lands that are at risk of floods.

IV. CASE STUDY

A. *The Beas River Basin*

The Beas River basin in the Himalayan region of Himachal Pradesh, India, has been the focus of significant HEC-RAS modelling research, particularly following the catastrophic 2023 and 2025 flood events. The Beas River basin in Himachal Pradesh is used as a study region for the present study, as shown in Fig. 2. The river originates from the Beas Kund near Rohtang Pass in the Northern Himalayas and covers a total length of 220 kilometers up to the Pong dam in the Kangra district. The river is the second largest river catchment for the state and covers a geographical area of approximately 12600 square kilometers. The river passes through major towns like Manali, Kullu, Bhuntar, Mandi, Sujanpur, and Nadaun. Based on the elevation profile, the basin is divided into two parts: the Upper basin with high mountains and steep slopes on the North East side, and the Lower part with comparatively flatter land on the South Western side of the basin. The region is susceptible to flood events and has experienced significant LULC changes in recent decades due to infrastructure development and deforestation activities.

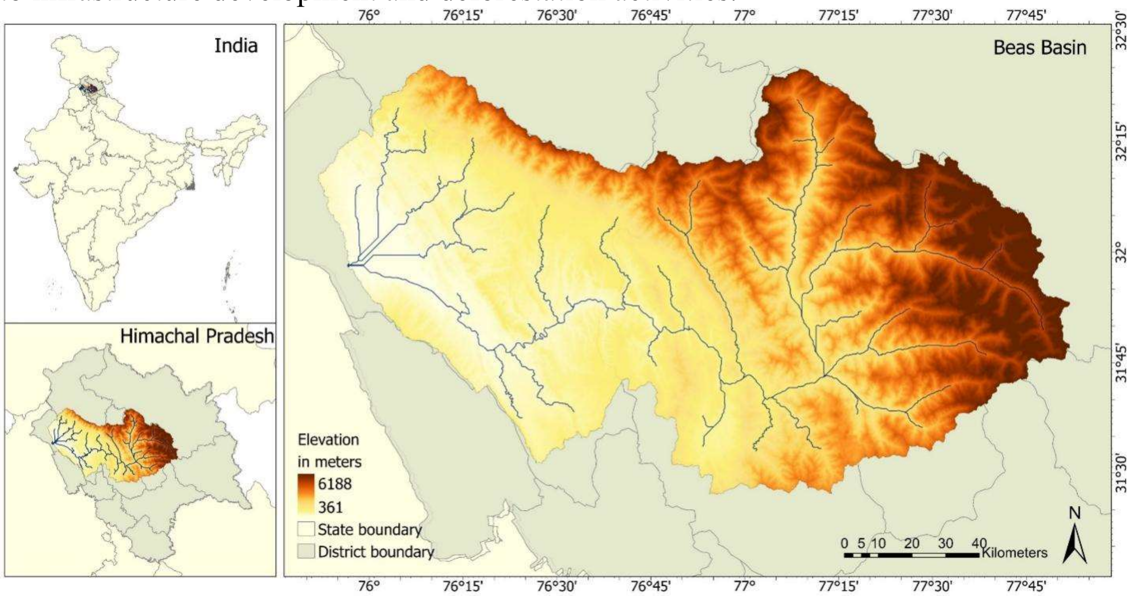

Fig. 2 Location map of study area: Beas basin upto Pong dam

Over the past few years, the region has experienced significant flood events that claimed people's lives and severely damaged the public infrastructure and the state's economy. The flood events that occurred during the 2025 and 2023 monsoon seasons were particularly severe, bringing extremely heavy rainfall and cloudburst-induced flash floods. The upper regions of the basin were majorly affected by these floods, with Manali, Kullu, Bhuntar, Mandi, Janjehli, and many more villages in the lower parts suffering significant property damage. The flood inundation spreading towards the historically unaffected areas has supported the hypothesis that LULC alterations have exacerbated the flood dynamics in the region. A small length of the Beas River from Bhuntar to Bajaura in Kullu District of Himachal Pradesh is considered for the hydrodynamic modelling in HEC-RAS.

B. *Data Collection and Preprocessing*

Table 1 shows the datasets used in this study, along with their purposes and sources. HEC-RAS Hydraulic modelling involves geometric data inputs to incorporate the physical characteristics of the floodplain into the model. For this purpose, there is a requirement for a good-quality DEM of the study area and a river discharge file for the boundary condition information. A 12.5 m resolution DEM consisting of a Synthetic Aperture Radar (SAR) data set from the ALOS PALSAR satellite was acquired from the Alaska Satellite Facility (ASF) website. The LULC data were acquired from USGS imagery, and the maps were prepared using supervised image classification in ArcGIS. The river discharge data for the gauging stations were acquired from the State Data Centre (CDC), Mandi, Himachal Pradesh, and were used as an input parameter for the inflow boundary condition. After collecting all the required datasets, the data were incorporated into HEC-RAS for model setup. The results from HEC-RAS 2D simulations are validated with data available in various literature studies and reports on the flood events.

TABLE I

Various Datasets and their Sources Used in the Study

Data	**Source**	**Description**	**Purpose**
DEM	Alaska Satellite Facility (ASF)	ALOS PALSAR-12.5m resolution	To generate the Terrain file and River Geometry.
LULC	USGS: Landsat Imagery	30m resolution	To prepare LULC maps and Change Analysis.
River Flow data (Hydrograph)	State Data Centre, Himachal Pradesh	Daily Discharge	2D Simulation and Validation.

C. LULC Classification and Change Analysis

The regional-scale LULC analysis in mountainous terrain was made feasible using satellite data with a 30m spatial resolution. The satellite data were preprocessed through geometric and atmospheric corrections, then mosaicked in ArcGIS. The DEM was used to derive the study area boundary, and the data were extracted for the study area. The succeeding stage involved image classification and change detection. Six main LULC classes were identified for image classification based on regional land cover features. These classes include water bodies such as rivers, streams, lakes, and reservoirs, built-up areas, forest cover, snow cover, and barren land. Followed by the identification of LULC classes, training samples were collected for each class. Additionally, Google Earth was used to generate detailed on-ground data, and it was verified with high-resolution imagery. After this step, the maximum likelihood classification (MLC) method in GIS was used to perform supervised image classification.

The Kappa coefficient rating for the classified LULC maps was processed with reference to the acquired dataset to check the accuracy of the classified LULC maps. After the accuracy assessment, the prepared LULC maps for the years 2000 and 2020 are shown in Fig. 3. After the supervised classification and accuracy assessment of the prepared LULC maps, change detection was performed for each LULC class.

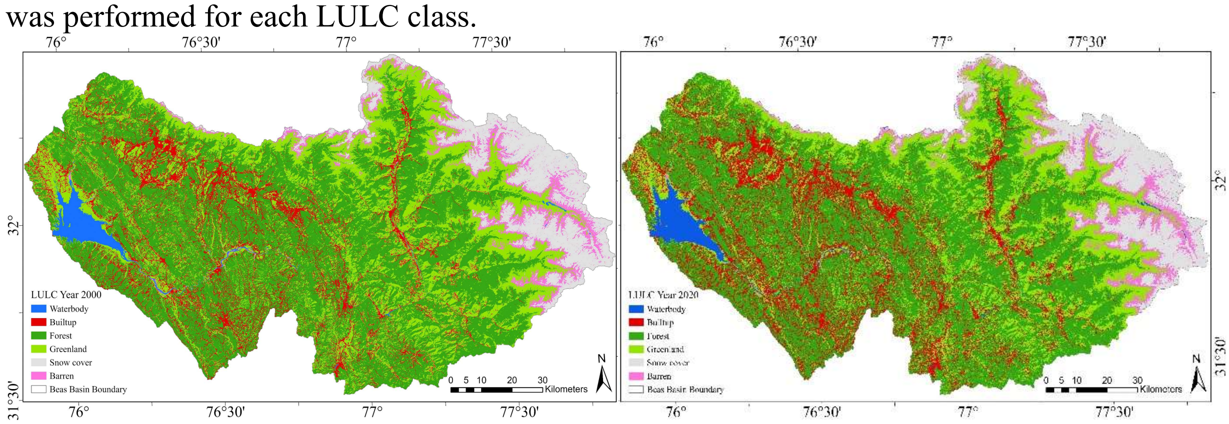

Fig. 3 LULC maps of the study area for the years 2000 and 2020

D. *HEC-RAS 2D Hydrodynamic Modelling*

The main focus of the present study was to simulate river flow dynamics and evaluate the effects of changing LULC on flood characteristics. The hydrodynamic models simulate the water flow through river channels and floodplains. The unsteady flow along the river network was analyzed by using a 2-D hydrodynamic modelling approach in HEC-RAS. For the present study, a 5km stretch of the main river channel was considered for 2D flood modelling. The stretch represents the zone of primary flood impacts, and the changes in LULC that affect flood inundation are most pronounced.

Model Setup and Mesh Generation: RAS Mapper, a spatial data integration and mapping tool in HEC-RAS. Hydraulic modelling and inundation mapping are performed using RAS Mapper. The development of RAS terrain, the layout of the geometric data, the extraction of terrain data, and the visualization of results as maps and tables can be initiated in RAS Mapper. The DEM is the primary source for extracting the geometric parameters, and accurate DEM data ensures reliable flood inundation mapping (Kechida et al., 2024). For the present study, DEM of 12.5 m resolution was used to develop a new terrain model. The DEM was used to extract the geometric features like river centerline, bank lines, and cross-sections. A river network was created from several cross sections, linked from upstream to downstream, as shown in Fig. 4. Cross sections were extracted and used as the major geometric data to execute the model. Using the RAS Mapper interface, a 2D computational mesh was generated. Bank lines were inserted along the river channel and main river banks.

Flow Hydrograph and Boundary Conditions: After generating the 2D computational mesh, the next part is to develop the flow hydrograph and to assign the boundary conditions. The boundary conditions were established for the 2D flow area to perform an unsteady flow analysis. The flow hydrograph was derived from the observed discharge data. The recorded streamflow data for one year (April 1, 2023, to March 31, 2024), which depict the volume of water entering the system, were used to define the upstream boundary conditions as flow hydrographs. The normal depth (slope = 0.003 m/m) was used to define the downstream boundary condition for the present study.

Assigning Manning's Roughness Coefficient: Manning's 'n' value is a critical component of HEC-RAS modelling, and its value was assigned to the river profile to simulate the resistance to flow within the river channels and over the floodplains. As the water flows from different terrains and LULC types, the 'n' value represents the hydraulic friction and energy loss during the stream flows. The 'n' values were assigned based on the LULC characteristics, which provide a primary mechanism to incorporate land use change impacts into hydrodynamic simulations. Different land use types influence the Manning's n value, with forest areas having higher roughness compared to the built-up area and agricultural land. The LULC layers were developed in ArcGIS and imported to HEC-RAS. The Manning's n value was assigned for each LULC class according to HEC-RAS Hydraulic Reference Manual and other literature studies (Toledo et al.,2025; HEC-RAS, 2016). After assigning all the required values, the next part is the model calibration and validation.

Model Calibration and Validation: The model was calibrated for the 2023 flood events in the study region. Calibration was performed by adjusting the Manning's n value within the physically feasible range until simulated values matched the observed water surface elevation and flood inundation extent. To evaluate the model performance, the Nash-Sutcliffe Efficiency (NSE) and Root Mean Square Error (RMSE) were used. The validation was conducted by comparing the simulated data with the observed data without further adjusting any parameters. The model performance is found to be satisfactory with NSE values of 0.84 and 0.82 during calibration and validation, respectively, as per the performance rating suggested by Lin et al. (2017).

V. RESULTS

A. *LULC Change Analysis*

The LULC maps prepared for the years 2000 and 2020 were analyzed, and the classification results reveal substantial LULC transformations across the study area over the 20-year analysis period. The LULC change is shown in Table 2. The expansion of Built-up area, which increased from 8.72% in 2000 to 15.11% in 2020, is the most significant trend in LULC change.

It was observed that the built-up area has almost doubled over the past 20 years, replacing forest patches and agricultural land. This led to a decline in forest cover, resulting in loss of biodiversity, disruption of wildlife corridors, and degraded ecosystem services. The LULC change analysis also highlights that land in the Beas River basin has been significantly degraded as the extent of barren land has increased in recent years. Water bodies and snow cover show minor fluctuations and remain relatively stable due to reservoir constructions and seasonal variations.

TABLE II

Table Showing the Percentage Change of Each LULC Class in the Study Area

LULC Category	**Area (%)**		**Change (%)**
	2000	**2020**	**(2000-2020)**
Water Bodies	4.13	3.8	-7.99%
Built-up	8.72	15.11	+73.28%
Forest	48	45.24	-5.75%
Green land	27.12	22.46	-17.18%
Snow Cover	8.4	8.03	-4.40%
Barren Land	3.63	5.36	+47.66%

The LULC change analysis reveals accelerating transformation rates, particularly for developed areas and forest losses. The change detection analysis shows the dominant transitions were from greenland to built-up, forest to built-up, greenland to barren land, and forest to greenland. These transitions in LULC have shown a rapid increase in built-up area, particularly in the major urban expansion corridors and floodplains near the river reaches.

B. *HEC-RAS 2D Flood Modelling Results*

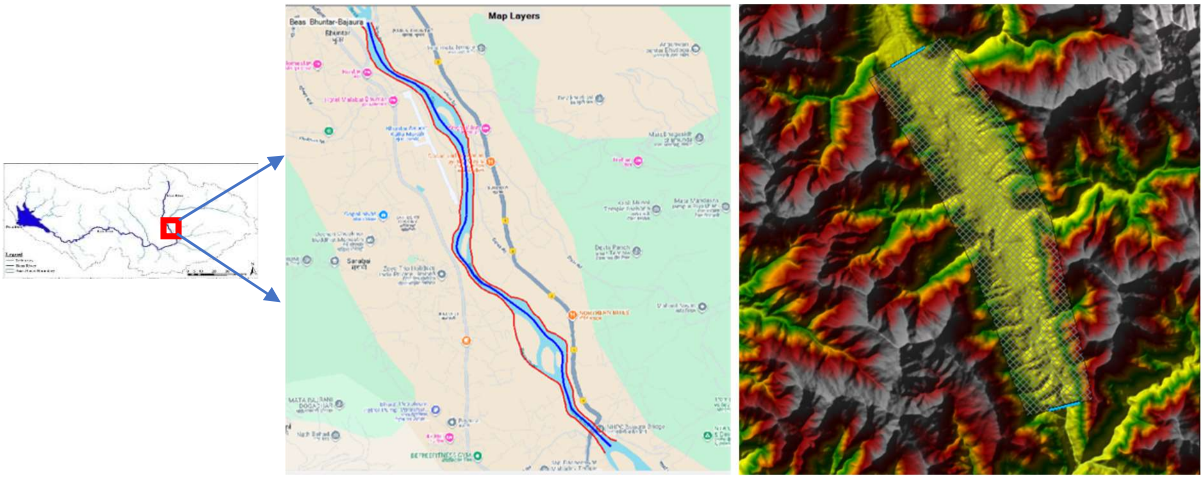

Fig. 4 River network and 2D mesh generation for HEC-RAS modelling

The model calibration with NSE value 0.84 meets the threshold for satisfactory to good performance as defined by Lin et al. (2017). The coefficient of determination R2 with value 0.87 was derived through model calibration and validation. A 2D model was developed, and the simulation results were used to compute floodwater inundation depth, velocity, and water surface elevation (WSE) over the terrain. Calibrations from a previous event, validated for flash floods of 2023 were used to optimize the simulation parameters for the model. The model illustrated significant predication abilities as represented by the standard deviation of simulated discharge values. The model was run for a simulation period corresponding to the 2023 flood event and Fig. 5 shows the graph comparing the observed and simulated discharge values. As shown in the inundation map highlighting water elevation, it is evident that water flows gently along natural stream channels through the flood plains and low-lying areas. The simulation results underscore the areas characterized by peak floods. The simulated flood inundation area map in Fig. 6 highlights areas severely impacted by floods, which complies with the data used for validation.

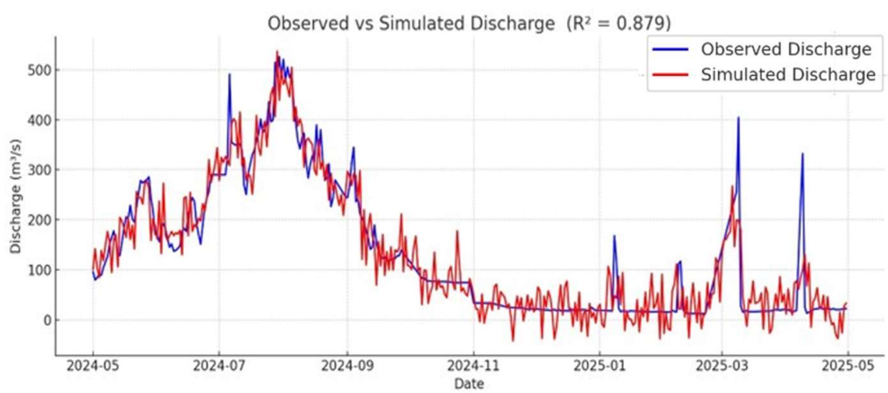

Fig. 5 Graph showing the observed vs simulated discharge for the simulated period

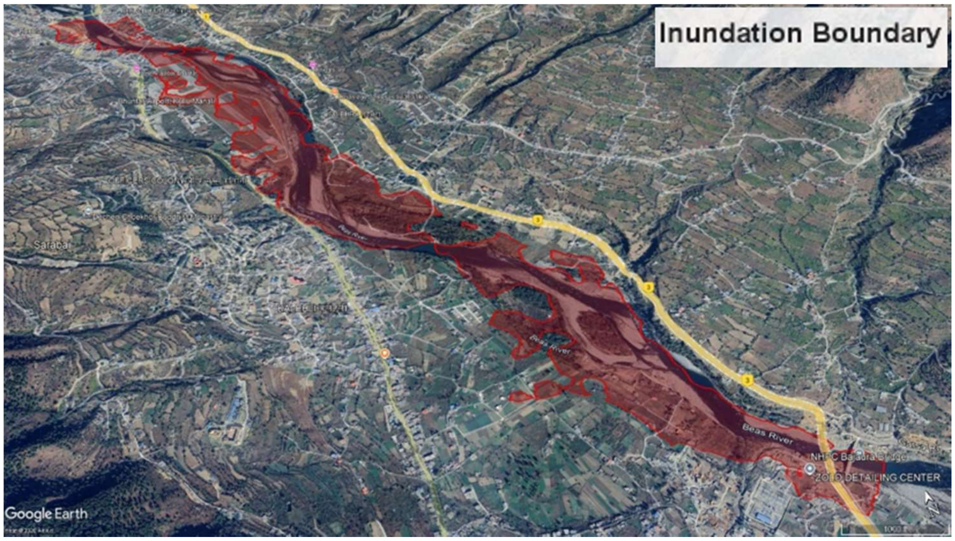

Fig. 6 Flood inundation map

Additionally, during the simulations, it was noted that floods occurred in close vicinity to the vulnerable areas. Results show the depth and average velocity in the large meander near the confluence. The maximum velocity of 1.65 m/s was observed in the downstream area. Subsequently, ArcGIS was used to create flood depth maps and HEC-RAS 2D was used to generate depth maps of the study area. The locations with low, medium and high flooding depths were identified by exporting the inundation depths (m) to ArcGIS. These locations represent low, moderate and high flood risk, respectively.

VI. Conclusion

The comprehensive review of the application of HEC-RAS two-dimensional hydrodynamic modelling in assessing the impacts of land use changes on flood events in the Himalayan River Basins shows that there have been remarkable achievements, as well as challenges. According to various literature studies, it is evident that the application of HEC-RAS 2D modelling, when appropriately used, is a powerful tool for mapping the flood-inundated area, flood damage assessment, and flood risk management in the Himalayan River Basins. HEC-RAS modelling has been successfully used in the Indus River Basin and the Himalayan River Tributaries to effectively identify major flood events, vulnerability of different land use types, and flood risk management (Tariq et al., 2021; Briandy et al., 2024; Mandal et al., 2016).

Studies conducted in the Himalayan and other similar mountainous regions have revealed significant effects of land use changes on floods. Urbanization increases peak discharge and flood extent through increased surface runoff from impervious surfaces (Zope et al., 2017). Deforestation and agricultural practices reduce infiltration and increase surface runoff response, which in turn increases flood generation during heavy precipitation events (Yousuf et al., 2022). Quantitative analyses have revealed that land use changes can increase flood extent by several square kilometers and peak discharge by 20-50% or more, depending on the magnitude and type of land use changes (Kuntiyawichai et al., 2020; Zope et al., 2017).

However, the existence of considerable research gaps creates limitations for the comprehensive understanding of the relationships between land use and floods. The lack of considerable studies evaluating the impacts of land use changes using the HEC-RAS 2D model in the Himalayan River basins is a major gap. Inadequate data availability, such as topography, hydrological data, and historical flood data, creates limitations for the development of the model. Moreover, quantification of uncertainty is also low, and the integration of climate change projections with land use changes should be emphasized (Sun et al. 2025; Mandal et al., 2016).

The future research needs include the extension of HEC-RAS modelling application with a focus on the impacts of land use changes in the varied environments of the Himalayas, improvement of data acquisition and sharing, methodological development in simulating the complexities of the hydrological regime of the mountainous regions, quantification of uncertainties, and evaluation of the impacts of climate as well as land use changes. Improvement of the interface between science and policy for the application of modelling outcomes in the development of flood risk management strategies is a vital need for the improvement of the resilience of the vulnerable communities of the Himalayas (Briandy et al., 2024).

In the face of continued high rates of land use changes in the Himalayan regions, which are also becoming highly prone to floods due to the effects of climate change, the necessity to develop highly effective hydrodynamic modelling tools becomes all the more imperative. HEC-RAS 2D models, along with the use of other tools and sources of data, can be highly beneficial tools to understand the complexities of floods and make informed decisions to tackle the issue effectively. However, to achieve this goal, continued investment is necessary to develop the data infrastructure and innovation to link science with application to tackle the issue of floods effectively in the Himalayan regions.

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