CLIMATE RESPONSIVE FLOOD MODELLING

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DEDICATED

TO

OUR PARENTS, TEACHERS AND COLLEAGUES

Acknowledgment

We are thankful to All Mighty Allah who gave us the strength and courage to accomplish this project. We would like to express our foremost gratitude and sincere appreciation to our advisor Dr. Ammara Mubeen for providing invaluable support and dedicated encouragement to us in our project. Her helpful suggestions, comments and advice are the impetus behind the successful completion of this work. We are profoundly grateful to Dr. Hamza Farooq for giving us access to data which proved to be of immense importance for the completion of our project. In the end, we pay our earnest gratitude with a sincere sense of respect to our parents for their unending support, encouragement, prayers and patience.

Abstract

Jhelum and Chenab rivers are one of the largest rivers of Pakistan. The Jhelum River originates in Kashmir, India, flowing through Srinagar and Wular Lake before entering Pakistan. It picks up tributaries like the Neelam and Kunhar rivers, then winds through the mountains and plains of Pakistani Punjab. The Chenab River is Formed by the Chandra and Bhaga rivers in the Himalayas (India), it flows through Jammu and Kashmir before entering Pakistan. The Chenab then collects the Jhelum River at Trimmu and continues southward until it merges with the Sutlej River to form the Panjnad River, which eventually joins the Indus River.

The flow projections in these rivers were made by hydrological modeling in Arc Swat. Mangla and Maralla were taken as gauging stations for Jhelum and Chenab rivers respectively.

The model was calibrated by comparing the projected values with the observed values. The comparison was satisfied with the help of different statistical parameters.

The model provides us with the flow projections for the coming years which provide us an insight into the future flow behavior which is helpful for flood forecasting and water resource managment.

Contents

Chapter 1

Introduction

1.1 Introduction

Flooding is a recurrent natural hazard in Pakistan, causing significant economic and social disruption. The rivers Jhelum and Chenab are major tributaries of the Indus River system.

The Jhelum River is a tributary of the Chenab River in the northern Indian subcontinent. It originates at Verinag Spring in Kashmir, India, and flows through the scenic Kashmir Valley before entering Pakistan. Major cities along the Jhelum include Srinagar, Muzaffarabad, and Jhelum. The Jhelum River is vital for irrigation and hydropower generation in the Kashmir region and the Pakistani Punjab province. The Mangla Dam on the Jhelum River is one of the largest dams in Pakistan. The total length of the Jhelum River is about 725 kilometers (450 mi).

The Chenab River is one of the major rivers of the Indus River System in Pakistan. It is formed by the confluence of the Chandra and Bhaga rivers in the Himalayas, India. The Chenab River flows through Jammu and Kashmir (India) before entering Pakistan. In Pakistan, it traverses the plains of Punjab province. The Chenab River is a crucial source of irrigation for agriculture in the Punjab region. The total length of the Chenab River is about 1,974 kilometers (1,227 mi), making it the longest tributary of the Indus River. After its confluence with the Jhelum River at Trimmu, the Chenab River merges with the Sutlej River to form the Panjnad River, which ultimately joins the Indus River.

These rivers and their watersheds are particularly susceptible to flooding due to factors such as:

- Intense monsoon precipitation
- Snowmelt from the Himalayas
- Land use changes that increase runoff

Climate change is expected to exacerbate these problems, with projections indicating more frequent and intense extreme weather events. Therefore, developing accurate flood models for the Jhelum and Chenab rivers is crucial for disaster preparedness and mitigation strategies.

This project investigates the application of Arc SWAT, a hydrologic and water quality modeling software, for simulating flood events in the Jhelum and Chenab River basins. The project incorporates the Mangla and Marala reservoirs, which play a vital role in flood control by regulating river flows.

1.2 Objectives of Study

The objectives of this project are as follows:

- To pre-process the data (DEM, Soil, Land Use and Climate) for hydrological modelling.
- To calibrate hydrological model for the study area.
- To project the surface flows using Realistic Model's climate data (RCP 8.5).
- To identify high flows in the future.

1.3 Scope of the Project

This thesis investigates the application of Arc SWAT, a hydrologic modeling software, to develop and evaluate hydrological models for the Jhelum and Chenab rivers in Pakistan. The primary objective is to utilize Arc SWAT's capabilities to simulate streamflow and potentially other hydrological processes within these critical river systems.

Some limitations associated with data availability, computational resources, and inherent uncertainties in hydrological modeling are there. However, strategies like spatial interpolation and sensitivity analysis can be adopted to mitigate these limitations.

1.4 Study Area

This project focuses on applying Arc SWAT for hydrological modeling of the Jhelum and Chenab rivers in Pakistan, encompassing a vast area of around 400,000 square kilometers. The map of the study area is provided in **Figure 1.1**. The watersheds originate in the Himalayas, with the Jhelum flowing through Kashmir and Punjab before meeting the Chenab formed by the Chandra and Bhaga rivers. The region experiences variations in precipitation and terrain, with snowmelt, glacial meltwater, and rainfall feeding the rivers. Land cover is diverse, ranging from forests in the Himalayas to agricultural plains and urban areas.

Several urban areas dot the landscapes around the Jhelum and Chenab rivers in Pakistan. Following the Jhelum's path, we find Muzaffarabad, the capital of Azad Kashmir, nestled along the upper reaches. Further downstream lies Jhelum City, situated directly on the river's banks in Punjab province. Mirpur, another major city in Azad Kashmir, is close to where the Jhelum meets the Poonch River, one of its tributaries. As the Jhelum flows through the plains, it sustains the growth of Gujrat, a populous city in Punjab. While slightly further away, Sialkot, a prominent industrial center in Punjab, relies heavily on the Jhelum's water resources for irrigation and its industries.

Bakhtiarabad, a town in Punjab, sits near the Chenab river's headwaters. Fort Munro, a scenic hill station, is also found close to the Chenab. Following the river downstream, we encounter Shorkot, a city directly on the Chenab's banks. Faisalabad, a significant industrial and agricultural hub, thrives due in large part to Chenab’s waters that irrigate its fertile lands. Further south lies Jhang, another city in Punjab, that utilizes the Chenab's canal network for irrigation, even though it has some distance from the main river itself. This list represents just a selection of the many urban centers that have flourished near these life-giving rivers.

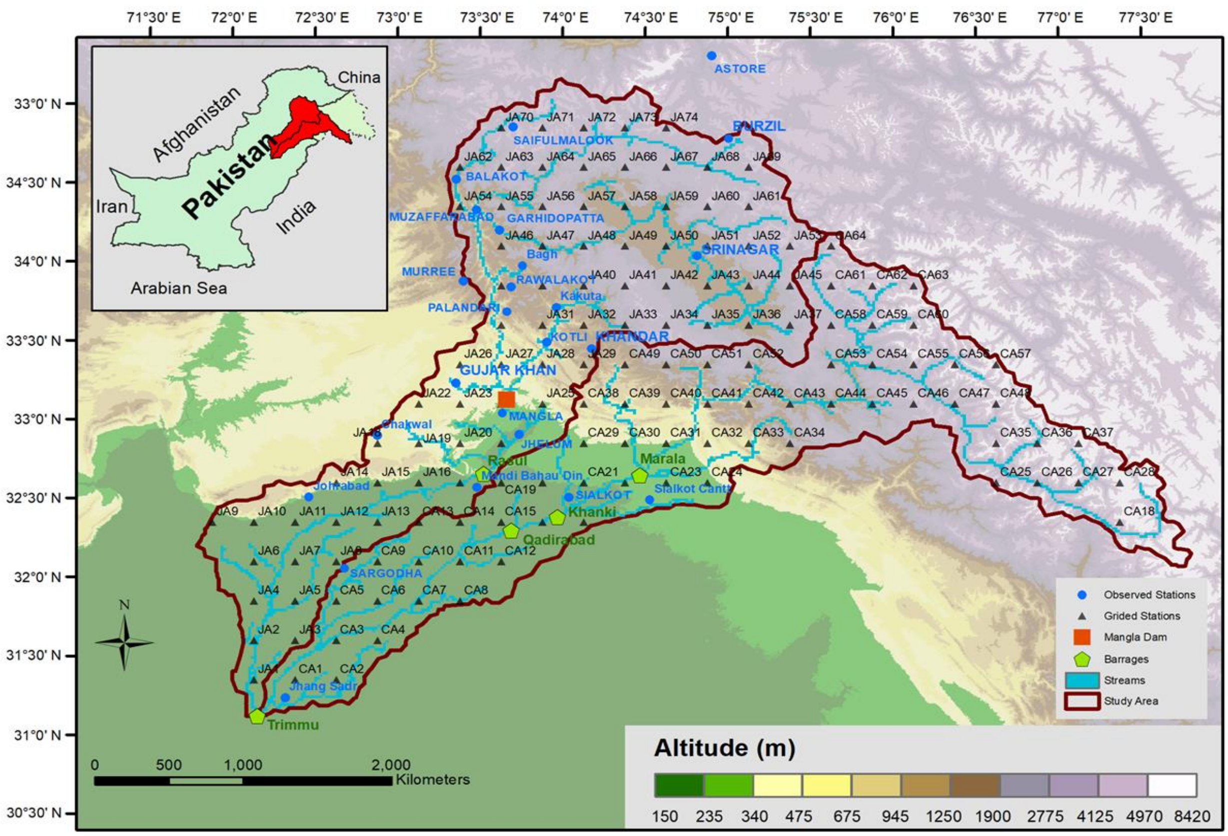

Figure 1.1-Study Area

Chapter 2

Literature Review

2.1 Introduction

This collection of research underscores the critical issues surrounding the UIB's hydrology and the increasing threats posed by climate change. Understanding rainfall-runoff processes, the impact of climate patterns on floods, and the potential effects of climate change on streamflow are all crucial for effective water resource management and flood risk mitigation strategies in the UIB. The studies also emphasize the importance of utilizing accurate modeling techniques and incorporating social factors when planning for climate change adaptation. The review examines recent research on the hydrology and climate change impacts in the Upper Indus Basin (UIB), focusing on the articles provided.

2.2 Rainfall-Runoff and Flow Dynamics

Rainfall and runoff in Pakistan exhibit a complex interaction. The country's mountainous north receives heavy summer monsoons, causing rivers to surge. Meanwhile, the Himalayas act as a giant water tower, storing winter snow that melts and sustains flows throughout spring and summer. However, this isn't uniform across Pakistan. Arid southern plains receive far less rain, leading to regional variations in runoff. Vegetation also plays a part. Forests in the mountains act like sponges, slowing down runoff and allowing water to seep into the ground. Deforestation disrupts this process, leading to faster runoff and increased risk of flash floods. Glacier melt in the high mountains further contributes to river flow, particularly for the Indus River system. The challenge lies in the erratic nature of rainfall. Intense downpours can trigger devastating flash floods, while uneven water distribution and growing demand create water scarcity in some areas. Understanding these dynamics is vital for Pakistan's water future.

(Ismail et al. 2018) investigated the effectiveness of rainfall-runoff models in simulating streamflow and its impact on the flow duration curve (FDC). This highlighted the importance of accurate flow simulations for water resource management.

(Booker et al., 2005) highlighted the significant spatial and temporal variability of rainfall in Pakistan. The mountainous north receives the bulk of summer monsoon precipitation, while the south experiences arid conditions. This uneven distribution significantly impacts runoff generation across the country.

(Xu et al., 2008) investigated the seasonality of river flows in Pakistan. They found that most rivers exhibit high flows during the monsoon season (July-September) due to concentrated rainfall, followed by a significant decrease throughout the remaining year.

(Nizam et al., 2013**)**This study explored the influence of topography on rainfall-runoff dynamics. The Hindu Kush, Karakoram, and Himalayan mountain ranges act as natural barriers, influencing precipitation patterns and contributing to snowmelt that sustains river flows.

(Ali et al., 2017) This research investigates the impact of land cover change on runoff patterns. They found that deforestation in mountainous areas can lead to increased surface runoff and flash floods due to reduced water infiltration.

(Singh et al., 2007) emphasized the significance of glacial meltwater to river flows, particularly in the Indus River system fed by the Himalayas. The melting rate of glaciers is influenced by factors like rising temperatures, impacting long-term water availability.

(Kaser et al., 2010) investigated the future projections for glacial melt in Pakistan. They warn of potential decreases in meltwater contribution to river flows in the coming decades, posing a significant challenge for water resources.

(Rasul et al., 2012) highlighted the growing challenges of erratic rainfall patterns and extreme weather events in Pakistan. Intense downpours can trigger devastating flash floods, while droughts pose threats to agricultural productivity.

(Ahmad et al., 2014) explored potential water management strategies. They emphasize the importance of sustainable land use practices like reforestation to regulate runoff and improve water infiltration. Additionally, employing hydrological modeling tools can aid in planning and adapting to changing water availability.

2.3 Flood Assessment and Climate Change

Floods pose a constant threat to Pakistan, a vulnerability compounded by the ever-present specter of climate change. The Indus River system, a vital artery traversing the nation, makes it inherently susceptible to flooding. Spring and summer witness rapid snowmelt from the northern mountains, further swelling the rivers. Climate change throws fuel on this fire, accelerating glacial melt and causing erratic, intense rainfall events. These downpours overwhelm rivers and drainage systems, triggering devastating flash floods. The consequences are dire - loss of life, damaged infrastructure, displaced communities, and ravaged agricultural lands leading to food insecurity. The most vulnerable populations are those residing near rivers and floodplains, often lacking proper protection. To build resilience, Pakistan needs to invest in early warning systems, strengthen flood defenses, and promote sustainable land management practices. Climate-smart agriculture is another crucial step towards adapting to a changing climate. While Pakistan itself contributes minimally to global emissions, it bears the brunt of climate change's effects. International cooperation is essential to address this challenge, both in mitigating climate change and supporting Pakistan's adaptation efforts. The path forward necessitates a multi-faceted approach to secure a safer, more water-secure future for Pakistan in the face of this growing threat.

(Nizam et al., 2018) employed Geographic Information Systems (GIS) and remote sensing techniques to assess flood vulnerability in the Swat River basin. Their work highlights the importance of spatial data analysis for identifying flood-prone areas and informing disaster preparedness strategies.

(Khan et al., 2020) focused on developing flood inundation maps using hydrological modeling tools like HEC-RAS for the Chenab River basin. Such maps are vital for evacuation planning and risk mitigation in flood-prone areas.

(Salman et al., 2012) investigated the link between climate change and extreme precipitation events in Pakistan. They found a trend towards increased frequency and intensity of rainfall, contributing to flash floods and riverine floods.

(Ahmad et al., 2016) explored the potential impacts of climate change on snowmelt and river flows in the Hindu Kush region using hydrological modeling. Their findings suggest an increased risk of floods due to earlier snowmelt and changes in precipitation patterns.

(Shenoy et al., 2010) demonstrated the application of satellite imagery for flood inundation mapping in Pakistan. Real-time monitoring using remote sensing provides valuable data for emergency response efforts during floods.

(Maqsood et al., 2015) explored the use of Synthetic Aperture Radar (SAR) data for flood monitoring, particularly in areas with cloud cover that might hinder optical satellite imagery.

(Ahmad et al., 2014) analyzed the socioeconomic impacts of the devastating 2010 floods in Pakistan. They found widespread damage to infrastructure, agricultural losses, and displacement of millions of people.

(Bhatti et al., 2017) investigated the long-term consequences of floods on mental health and social well-being in affected communities.

(Khan et al., 2019) explored the potential of community-based flood adaptation strategies in Pakistan. Empowering local communities to prepare for and respond to floods is crucial for building resilience.

(Ali et al., 2020) emphasized the importance of integrating climate change considerations into national water resource management plans. This includes investing in flood protection infrastructure and promoting water conservation practices.

Riverine flood assessment in Jhang district in connection with ENSO and summer monsoon rainfall over Upper Indus Basin for 2010 (2018) by an unspecified group explores the link between El Niño Southern Oscillation (ENSO) and summer monsoon rainfall with flood events in the Jhang district. This emphasizes the role of large-scale climate patterns in flood occurrences.

Streamflow response to projected climate changes in the Northwestern Upper Indus Basin (2019) investigates how future climate projections might affect streamflow in the northwestern UIB. Understanding these changes is crucial for water resource planning.

(Qazlbash et al. 2020) examined the impact of climate change on snow and glacier melt in the UIB's high-altitude sub-catchments, which are crucial contributors to river flows.

2.4 Climate Change Modeling and Adaptation

Pakistan is locked in a race against time, grappling with how to adapt to the intensifying threats of climate change. Climate change modeling, a crucial tool in this fight, utilizes advanced computer models to predict future scenarios. These models consider factors like greenhouse gas emissions, atmospheric patterns, and ocean temperatures, painting a picture of a future with rising temperatures, altered precipitation patterns (including intense downpours alongside droughts), and concerning glacial melt impacting river flows. Adaptation strategies are being formulated, particularly in the vulnerable mountainous north. Flood protection measures and improved early warning systems are being developed to manage the risks of floods from glacial melt and extreme rainfall events. Sustainable land management practices like reforestation are also being promoted to combat droughts by reducing soil erosion and improving water infiltration. Developing climate-smart agriculture is another crucial step, as it allows for the creation of crop varieties more resistant to changing weather patterns and water scarcity. However, challenges remain. Accurate climate modeling relies on robust data collection networks, which can be difficult to maintain in resource-limited settings. Implementing effective adaptation strategies also requires significant investment in infrastructure, technology, and training programs. Finally, raising public awareness about climate change and fostering community-based adaptation efforts are essential for long-term success. By prioritizing adaptation strategies informed by climate change modeling, Pakistan can work towards building a more resilient future, safeguarding its water resources, agricultural productivity, and the overall well-being of its citizens.

(Krishnan et al., 2013) employed regional climate models (RCMs) to assess future climate projections for Pakistan. They project an increase in average temperatures and changes in precipitation patterns, with more intense rainfall events and increased variability.

(Xu et al., 2019) investigated the impacts of climate change on the Indus River basin using a coupled atmosphere-ocean model. Their findings highlight potential changes in river discharge patterns, with implications for water resource management.

(Ahmad et al., 2020) focused on the Hindu Kush region, employing a weather research and forecasting (WRF) model to assess the impacts of climate change on extreme weather events. Their work emphasizes the need for high-resolution modeling for localized climate predictions.

(Hassan et al., 2019) explored various adaptation strategies for Pakistan, including investments in water infrastructure, developing drought-resistant crop varieties, and promoting climate-resilient agricultural practices.

(Khan et al., 2020) investigated the role of ecosystem-based adaptation (EBA) strategies in Pakistan. EBA approaches, such as restoring natural habitats and promoting sustainable land management, can provide cost-effective solutions for mitigating climate change impacts.

(Baloch et al., 2021) explored the importance of integrating climate change considerations into national development plans. They emphasize the need for a multi-sectoral approach that addresses both mitigation and adaptation strategies.

(Ahsan et al., 2014) highlighted the limitations of climate modeling in data-scarce regions like Pakistan. Improving data collection networks and collaboration with international research institutions is crucial for more accurate modeling.

(Bhatti et al., 2017) explored the socio-economic challenges of implementing adaptation strategies in Pakistan. Factors like poverty, limited access to resources, and institutional weaknesses can hinder progress.

(Safdar et al., 2020) emphasized the importance of community-based adaptation strategies. Empowering local communities to participate in decision-making and implementing adaptation measures is crucial for long-term sustainability.

A comparison of two model calibration approaches and their influence on future projections under climate change in the Upper Indus Basin (2020) analyzed the influence of different calibration methods on climate change projections in the UIB. Selecting appropriate calibration techniques is essential for reliable future projections.

(Ali et al. 2021) utilized high-resolution models to assess changes in precipitation patterns and monsoon behavior over Pakistan and the UIB in the 21st century. Understanding these changes is vital for flood risk management and water resource planning.

(Reboita et al. 2021) explored the social and economic factors influencing how flood-prone communities in the Indus Basin adapt to climate change. This highlights the need for social science considerations alongside hydrological studies.

Chapter 3

Hydrological Modeling Using Arc SWAT

3.1 Methodology

Our purpose is to create a hydrological model that will serve as a powerful tool for water resource managers, disaster preparedness agencies, and policymakers. By providing insights into the complex interactions between precipitation, runoff, and river flow, the model can support informed decision-making for sustainable water management, flood risk mitigation, and adaptation to climate change in these crucial basins. The methodology will be divided into the following steps:

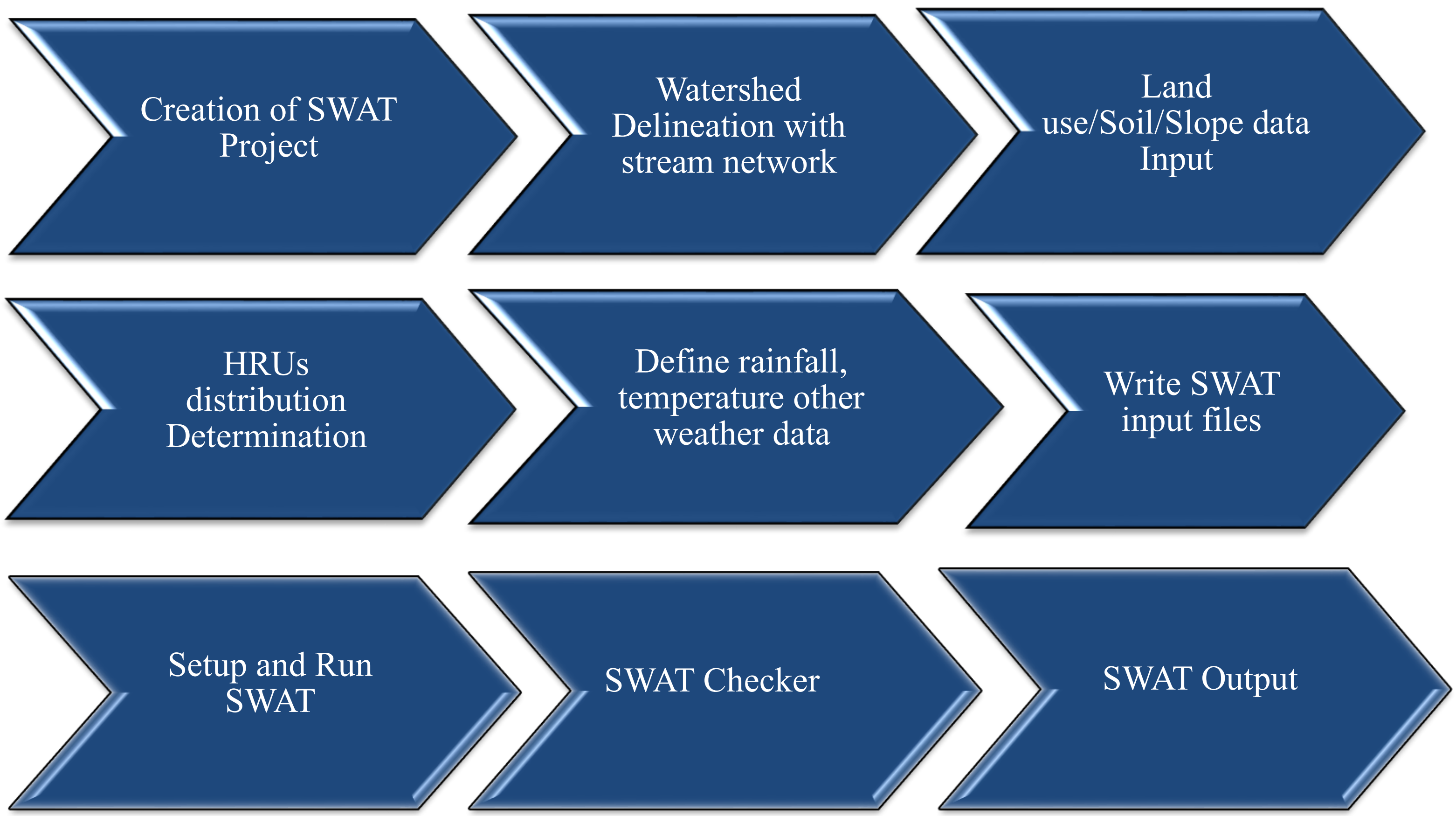

Figure 3.1-Methodology Flow Chart

3.1.1 Data Acquisition

3.1.1.1 Spatial Data

3.1.1.1.1 DEM

A Digital Elevation Model (DEM) is crucial for representing the topography of the basins. This data was obtained from USGS in the form of tiles, and they were merged and clipped in ArcGIS to obtain the DEM of our study area shown in **Figure 3.2**. This data was used to delineate watersheds, streams, and flow paths.

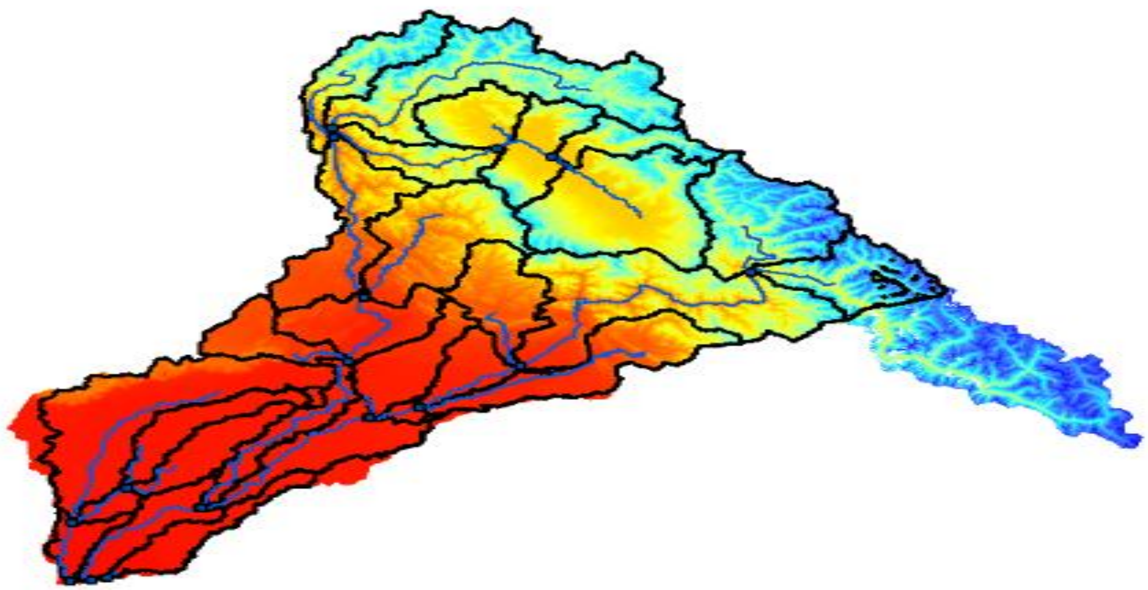

Figure 3.2-DEM

LEGEND	
Red	0 - 200 meters (Low elevation)
Orange	200 - 400 meters (Moderate-low elevation)
Yellow	400 - 600 meters (Moderate elevation)
Light Green	600 - 800 meters (Moderate-high elevation)
Green	800 - 1000 meters (High elevation)
Light Blue	1000 - 1500 meters (Very high elevation)
Blue	1500 - 2000 meters and above (Extremely high elevation)
Black Lines	Administrative or regional boundaries
Blue Lines	Major rivers and water bodies

3.1.1.1.2 Land Use

Information on land cover types (forests, agriculture, urban areas) is essential as these factors significantly influence water infiltration, runoff, and evapotranspiration. The land cover data was obtained from NASA Earth Data. A similar process as that of DEM was used to get the land use map (**Figure 3.3**) of our study area.

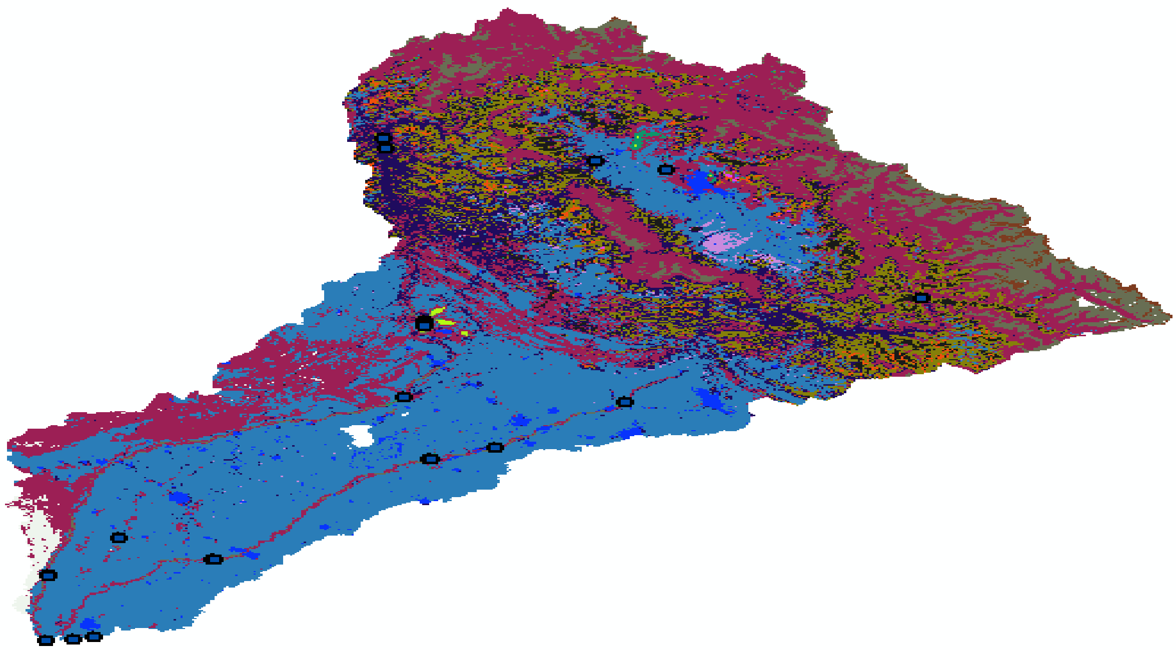

Figure 3.3-Land Use Map

LEGEND	
Red	Industrial areas
Dark Blue	Water bodies (lakes, rivers, reservoirs)
Yellow	Agricultural land
Pink	Residential areas
Green	Forests
Light Blue	Urban areas
Brown	Barren or sparsely vegetated land

3.1.1.1.3 Soil Data

Data on soil properties like texture and soil depth was obtained from FAO. Soil map (**Figure 3.4**) was obtained by following a similar process as that of DEM and land use.

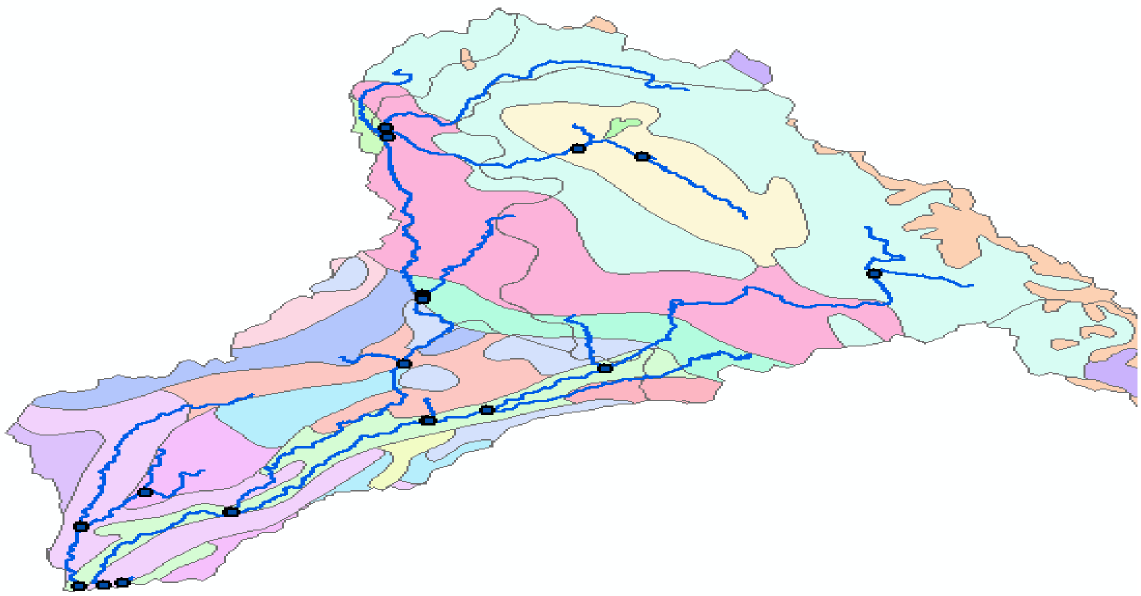

Figure 3.4-Soil Map

LEGEND	
Light Green	Alluvial soils
Dark Blue	Silt loam soils
Yellow	Sandy soils
Pink	Loamy soils
Orange	Clay loam soils
Light Blue	Clay soils
Brown	Sandy loam soils
Purple	Saline-alkaline soils

3.1.1.2 Time Series Data

3.1.1.2.1 Weather Data

Historical weather data, including precipitation and temperature (RCP 8.5), was obtained to drive the model simulations.

3.1.1.2.2 Streamflow Data

Observed streamflow data from gauging stations within the basins was used for model calibration and validation.

3.1.2 Model Setup and Processing

3.1.2.1 Watershed Delineation

Using the DEM, the Jhelum and Chenab River basins were delineated into sub-basins and further divided into Hydrologic Response Units (HRUs) shown in the **Figure 3.5**. HRUs are essentially unique land areas within a sub-basin that share similar characteristics like land use, soil type, and slope. HRUs subdivide a watershed into smaller, more manageable units with relatively homogeneous characteristics.

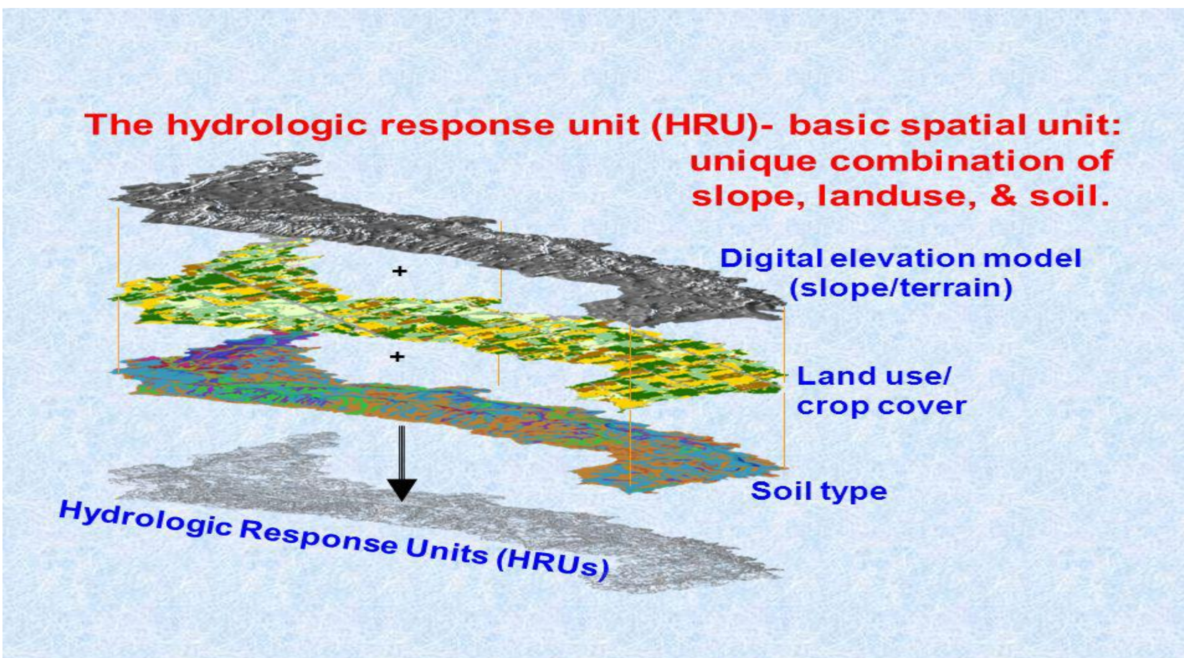

Figure 3.5-HRUs

3.1.2.2 Model Parameterization

Arc SWAT uses various parameters like Curve Number (CN) Manning's n, Soil Erodibility Factor (KFAC), etc. to simulate hydrological processes. These parameters were defined based on existing research, data availability, and potentially adjusted during calibration.

3.1.3 Model Evaluation

3.1.3.1 Sensitivity Analysis

Sensitivity analysis (SA) is a crucial step in developing a reliable Arc SWAT model. It helps you understand how sensitive the model's outputs (streamflow, sediment yield, etc.) are to changes in its various input parameters. By performing SA, you can identify the parameters that have the most significant impact on the model's behavior, allowing you to focus your calibration efforts on those that truly matter. The One-at-a-time (OAT) method was used for the sensitivity analysis of our hydrological model. This basic method involves individually adjusting each parameter and observing the resulting changes in the model outputs.

3.1.3.2 Model Calibration and Validation

The model parameters were adjusted iteratively to achieve a good match between the simulated streamflow and the observed streamflow data from gauging stations (Mangla and Marala). This ensured the model accurately reflects the real-world hydrology of the basins. After calibration, the model's performance was tested using an independent set of observed data. This step confirmed the model's ability to predict streamflow under various conditions beyond the calibration period. Different statistical measures like NSE and RMSE were calculated for calibration and validation of our hydrological model.

$$NSE = 1 - \left[\frac{\Sigma(Qobs - Qi)^2}{\Sigma\,(Qobs - Qmean\,)^2} \right]$$ **................ Equation No. 1**

Where Q_{obs} and Q_i represent the observed and simulated streamflow respectively; Q_{mean} is the average of observed streamflow during that period.

$$RMSE = \sqrt{\frac{\Sigma(Qobs - Qi)^2}{N}}$$ **................ Equation No. 2**

Where N represents the number of days.

$$R^2 = \left[\frac{\Sigma(Qobs - Qmean)(Qi - Qimean)}{\sqrt{\Sigma\,(Qobs - Qmean\,)^2 \Sigma\,(Qi - Qimean\,)^2}} \right]^2$$ **.......... Equation No. 3**

Where Q_{imean} represents the means of projected flows.

Calibration and Validation of the Jhelum River Discharge Model

The discharge model for the Jhelum River was calibrated using 1992 data, achieving a Nash-Sutcliffe Efficiency (NSE) of 0.86, a Coefficient of Determination (R^2) of 0.87, and a Root Mean Square Error (RMSE) of 470.3 cumecs, indicating high accuracy and strong predictive capability. Validation with 2014 data yielded an NSE of 0.81, R^2 of 0.829, and RMSE of 220 cumecs, maintaining high predictive accuracy and slightly improved performance. These results demonstrate the model's robustness and reliability in simulating river discharge, validating its suitability for forecasting and water resource management in the Jhelum catchment area.

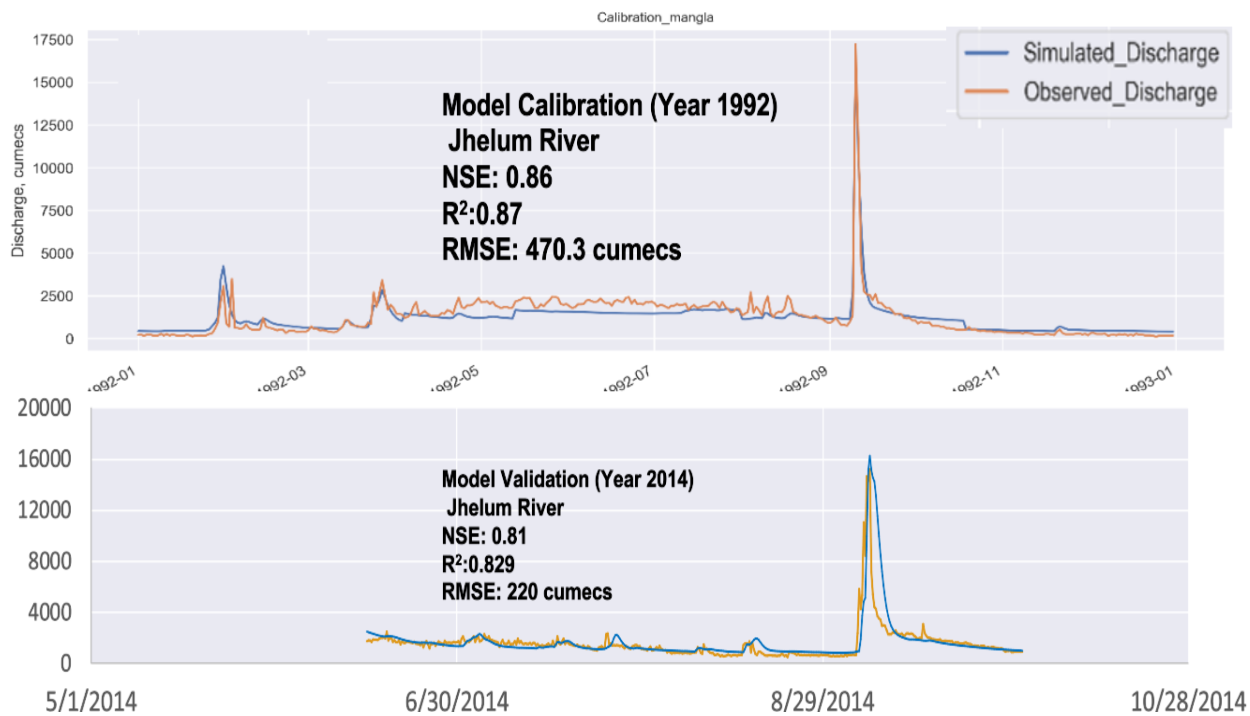

Figure 3.6-Jhelum River at Mangla

Calibration and Validation of the Chenab River Discharge Model

The discharge model for the Chenab River was calibrated using data from the year 1992 and validated with data from 2014. During calibration, the simulated discharge closely followed the observed discharge, achieving a Nash-Sutcliffe Efficiency (NSE) of 0.908, a Coefficient of Determination (R^2) of 0.93, and a Root Mean Square Error (RMSE) of 385.3 cumecs. These high values indicate the model's strong predictive accuracy and reliability in replicating historical discharge patterns. For validation, the model maintained good performance with an NSE of 0.79, R^2 of 0.81, and RMSE of 320 cumecs, demonstrating its robustness and generalization capability on new data. The validation phase showed a slight decrease in predictive accuracy compared to calibration, but the results still confirm the model's effectiveness in simulating river discharge, making it suitable for hydrological forecasting and water resource management in the Chenab catchment area.

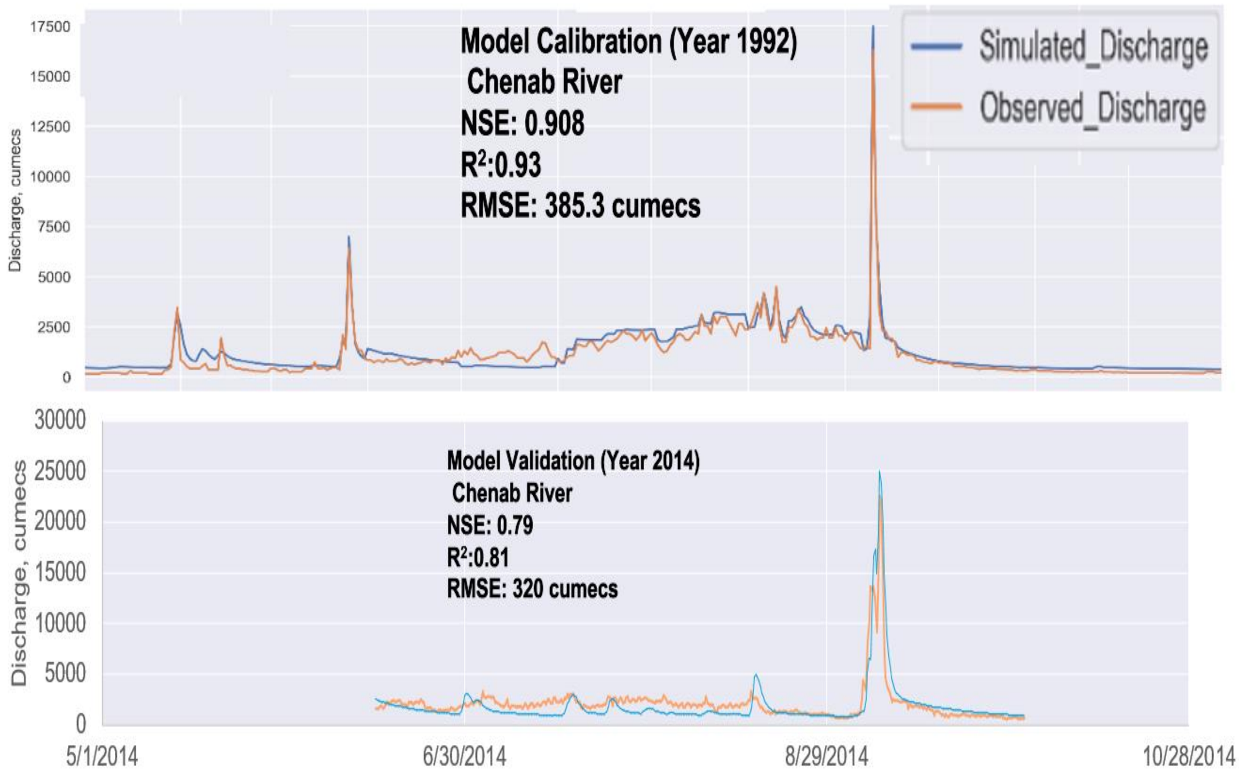

Figure 3.7-Chenab River at Marala

3.2 Results

Figure 3.8 presents the hydrograph on the Jhelum River at Mangla station. At Mangla station, a substantial increase in projected flow was observed in February, July and December and a substantial decrease in April and September. The projected flow was maximum in March with a maximum value of 11,000 cumecs and it was minimum in November with a value of 2000 cumecs. There was no substantial change in projected flow during September, October and November and the projected flow values ranged between 3000-2000 cumecs.

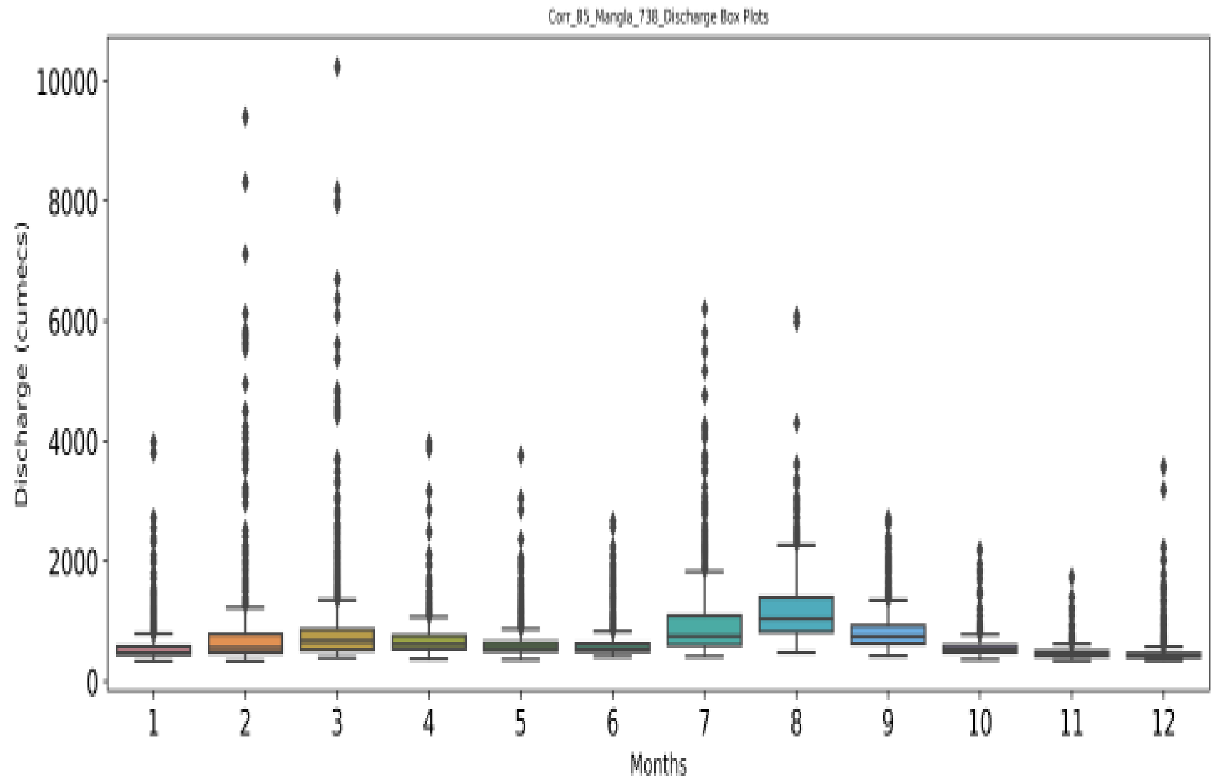

Figure 3.8-Hydrograph at Mangla Station on Jhelum River (2024-2050 , RCP 8.5)

Figure 3.9 presents the hydrograph on the Chenab River at Maralla station. At Marala station, a substantial increase in projected flows was observed in June and December and a substantial decrease in July and October. A similar trend of maximum and minimum projected flows was observed as that of Mangla station. The projected flow was maximum in March with a value of 12,000 cumecs and it was minimum in November with a value of around 2000 cumecs. There was no substantial change in projected flow during September, October and November and the projected flow values ranged between 3000-2000 cumecs.

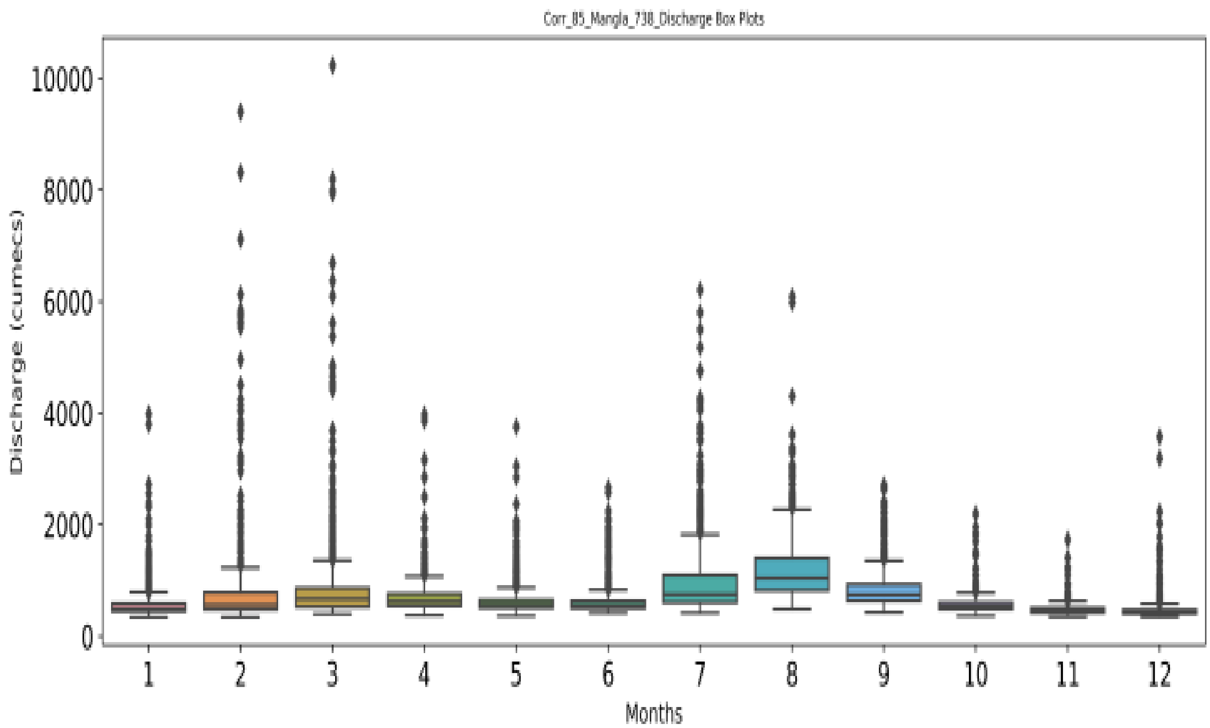

Figure 3.9-Hydrograph at Marala Station on Chenab River (2024-2050 , RCP 8.5)

3.3 Conclusion

This project successfully achieved its key objectives in developing a hydrological model for the study area and assessing future high-flow risks under climate change scenarios. Here's a detailed breakdown of the outcomes:

3.3.1 Data Pre-Processing

To ensure the chosen hydrological model could function correctly, essential spatial data like elevation (Digital Elevation Model or DEM), soil properties, and land use patterns were gathered. This data wasn't ready-made for the model, so it underwent pre-processing to make it compatible. This pre-processing likely involved cleaning up any missing information in the data, fixing any errors or inconsistencies in how locations were mapped, and reformatting everything into a structure that the model could understand and use for its calculations.

3.3.2 Hydrological Model Calibration

A crucial step in the process involved calibrating a hydrological model for the specific study area. This wasn't a simple plug-and-play exercise. Calibration entails fine-tuning the model's internal parameters by iteratively adjusting them. The goal is to achieve a close correspondence between the streamflow the model simulates and the actual streamflow data collected from gauging stations in the region. This meticulous calibration process ensures that the model accurately represents the real-world hydrological behavior of the area being studied.

3.3.3 Future Flow Projection

Having meticulously calibrated the hydrological model to reflect the study area's real-world conditions, researchers leveraged it to simulate future streamflow patterns. To achieve this, we incorporated data specific to a high-emission climate scenario, RCP 8.5. By factoring in these climate projections, the model can simulate how future climate changes might impact streamflow patterns in the region. This allows for a proactive assessment of potential risks and informed decision-making for water resource management.

3.3.4 Identification of High Flows

The power of the calibrated hydrological model lies in its ability to analyze the projected surface flows. By crunching these numbers, the model can pinpoint future periods with high flow events, essentially acting as a crystal ball for flood prediction. The model has predicted the high flows during February and March with values between 9000-12000 cumecs. Moreover, high flows are also projected in the monsoon season. During July and August, the projected flow is around 6000 cumecs. This information is critical for flood risk assessment. With a clearer picture of potential future floods, authorities can proactively develop mitigation strategies, such as improving flood defenses or implementing early warning systems. This proactive approach can significantly reduce the devastating impacts of floods on communities and infrastructure.

3.4 Recommendations

Further validation of the model with additional observed data might enhance confidence in the results. Exploring various climate scenarios (RCP 4.5, etc.) can provide a more comprehensive picture of potential future changes. Integrating the findings with social and economic vulnerability assessments can support the development of more holistic climate change adaptation plans.

This project provides valuable insights into the potential impacts of climate change on water resources in the study area. The identification of high flow events allows for:

3.4.1 Improved Flood Risk Management

Developing flood warning systems, evacuation plans, and designing flood control infrastructure based on projected high-flow scenarios.

3.4.2 Water Resource Planning

Ensuring adequate water availability for future needs by considering potential changes in streamflow patterns.

3.4.3 Adaptation Strategies

Formulating strategies for adapting to the potential water challenges posed by climate change.

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