Watershed Delineation and HRU Analysis of Haro River Basin Using ArcSWAT

Advanced Environmental System Analysis

Submitted by:

Yawar Abbas & Huzaifa Farooq

Registration No:

251011012 & 251011006

Submitted to: ***Dr. Muhammad Shaid Iqbal***

Batch: MS-RS & GIS-15

Institute of Space Technology, Islamabad

Contents

Abstract

The Haro River Basin, a critical hydrological unit of the Potwar Plateau in Northern Pakistan, faces significant challenges related to water scarcity, sediment yield, and seasonal flooding. This study utilizes the Soil and Water Assessment Tool (SWAT) within a Geographic Information System (GIS) environment to perform a comprehensive watershed delineation and Hydrologic Response Unit (HRU) analysis. The study area, covering approximately 3,100 km², is delineated using Digital Elevation Models (DEM) to define drainage patterns and sub-basin boundaries. By integrating spatial data on land use, soil properties, and slope, the basin is divided into distinct HRUs to simulate hydrological processes such as surface runoff and sediment transport. Understanding the morphometric and hydrological characteristics of the Haro River is essential for sustainable water resource management, particularly for the downstream Khanpur Dam and local agricultural needs. This report details the methodology and initial findings of the watershed delineation process, providing a baseline for future hydrological assessments in the region.

1. Introduction

Water resource management in Pakistan is becoming increasingly critical due to population growth and shifting climate patterns, which threaten the sustainability of river basins like the Indus and its tributaries. The Haro River, a major tributary in the Upper Indus Basin, serves as a vital source of water for the Potwar Plateau and the Khanpur Dam reservoir. However, the basin is subject to environmental pressures, including high sediment yields, erratic runoff caused by seasonal precipitation, and water scarcity during dry periods.

Hydrological modeling has emerged as a primary tool for agriculture and sustainable watershed planning. Specifically, the Soil and Water Assessment Tool (SWAT) is widely used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use and management practices. SWAT operates by dividing a river basin into smaller, manageable sub-basins and further into Hydrologic Response Units (HRUs), unique combinations of land use, soil type, and slope.

This project focuses on the foundational steps of hydrological modeling: watershed delineation and HRU analysis. By employing ArcMap and the ArcSWAT interface, this study aims to accurate delineate the Haro River catchment from Digital Elevation Model (DEM) data and characterize its physical properties. This analysis is a prerequisite for accurate prediction of flood peaks, sediment transportation, and water availability in the region.

2. Study Area: Haro River Basin

2.1 Geographic Location and Extent

The Haro River Basin is located in Northern Pakistan, situated between latitudes 33.77° N to 34.06° N and longitudes 72.20° E to 73.43° E. It is a distinct hydrological unit of the Potwar Plateau, bounded by the Himalayan foothills. The basin covers a catchment area of approximately 3,100 km² and extends across parts of the Punjab and Khyber Pakhtunkhwa provinces, including the districts of Abbottabad, Haripur, and Rawalpindi.

2.2 Topography and Relief

The basin exhibits a diverse topography, ranging from high-altitude mountains to lower-lying valleys. The Haro River originates near Moshpuri village at an elevation of approximately 9,217 feet (2,809 meters) above mean sea level. The surrounding mountains in the upper basin reach heights of up to 9,000 feet and remain snow-covered for significant portions of the year. The basin relief is calculated to be approximately 2,521 meters, indicating a moderate-to-high gradient that influences flow velocity and sediment transport. The river flows through deep "V"-shaped gorges in its upper reaches before entering the broader Khanpur area.

2.3 Drainage Network and Hydrology

The drainage pattern of the Haro River is primarily dendritic to semi-dendritic, suggesting a strong structural control by the underlying geology. The overall flow direction is from Northeast to Southwest. The river is fed by four major tributaries:

- **Stora Haro:** Rising in the Galiat/Malach hills.
- **Lora Haro:** Rising in the Murree Hills.
- **Neelan Kas:** Rising in the Nara Hills.
- **Kunhad:** Flowing through the Dubran and Siribang areas.

The Stora Haro and Lora Haro merge near Jabri to form the main stem of the Haro River. The river eventually drains into the Indus River near Ghazi/Attock.

2.4 Climate and Geology

The climate of the region is strongly influenced by seasonal precipitation and temperature variations. The area experiences significant rainfall, which serves as the primary input for the river's flow, alongside snowmelt from the upper elevations. Geologically, the basin is part of the Nimandric Basin and includes formations from the Triassic to Eocene periods, characterized by tightly folded anticlines and synclines. The Kala Chitta Range defines the lower boundary of the basin. The overburden on the hills consists mostly of clay mixed with boulders and stones, which impacts soil permeability and runoff generation.

3. Methodology

3.1 Data Acquisition and Preparation

The accuracy of the hydrological simulation depends heavily on the quality of the spatial and temporal data used. For this study, the following datasets were acquired to characterize the Haro River Basin:

- **Digital Elevation Model (DEM):** To analyze the basin's topography and drainage patterns, Shuttle Radar Topography Mission (SRTM) data was utilized. The DEM was processed to remove sinks and peaks to ensure a continuous hydrological surface for flow direction calculations.

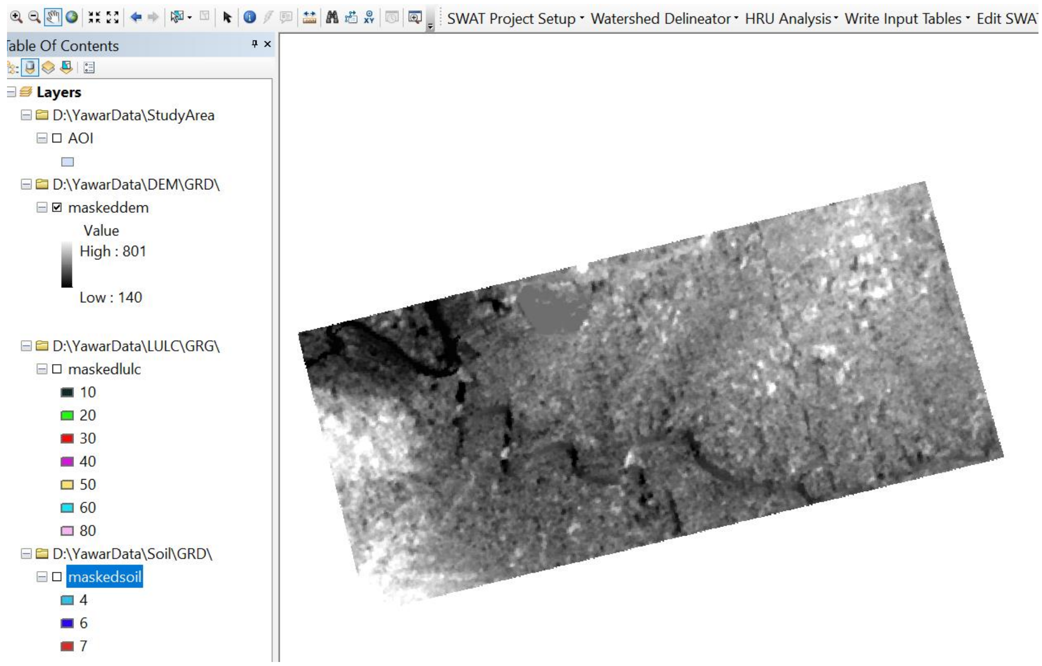

Figure 1: Raw Digital Elevation Model (DEM) of the Haro River study area

- **Land Use/Land Cover (LULC):** Land use data, which influences evapotranspiration and surface runoff, was derived from the USGS Global Land Cover Characterization (GLCC) database. This dataset categorizes the basin into various classes such as agriculture, forest, and barren land.
- **Soil Data:** Soil properties, including texture and organic carbon content, were obtained from the FAO/UNESCO Digital Soil Map of the World. These properties are essential for determining the infiltration capacity and water holding capacity of the watershed.

3.2 Hydrological Model Description (SWAT)

This study employs the Soil and Water Assessment Tool (SWAT), a physically-based, semi-distributed hydrological model designed to simulate the impact of land management practices on water, sediment, and agricultural chemical yields.

The model operates on a daily time step and uses the water balance equation as its fundamental driver. SWAT is particularly effective for ungauged or data-scarce catchments like the Haro River because it quantifies the spatial heterogeneity of the basin by dividing it into Hydrologic Response Units (HRUs).

3.3 Watershed Delineation

The watershed delineation was executed using the ArcSWAT interface. The DEM was first processed to fill sinks and calculate flow direction and accumulation. A stream definition threshold was applied to generate the drainage network. The main outlet was manually defined at the confluence point downstream. Consequently, the model successfully discretized the Haro River Basin into **63 distinct sub-basins** (Figure 2). The parameter calculation step quantified the geometric properties of each sub-basin, including slope, channel length, and width.

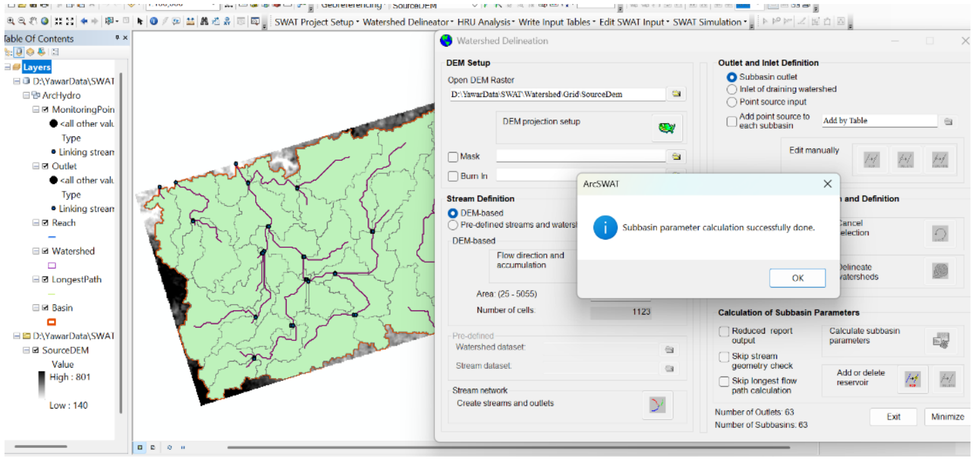

Figure 2: Watershed delineation results showing the calculation of sub-basin parameters

3.4 Hydrologic Response Unit (HRU) Analysis

Following delineation, the basin was subdivided into Hydrologic Response Units (HRUs) based on unique combinations of land use, soil, and slope.

- **Land Use Reclassification:** The raw LULC raster values were mapped to SWAT-specific codes (e.g., Value 40 to 'CROP').
- **Soil Definition:** Soil raster values were linked to the UserSoil database to define physical properties.
- **Slope Discretization:** To capture the topographic variation of the terrain, the slope was classified into five specific bands: **0-1%, 1-2%, 2-3%, 3-4%, and >4%** (Figure 7).
- **Overlay:** The three spatial layers were overlaid to generate the final HRU report

3.5 Surface Runoff Estimation

The surface runoff for each HRU was estimated using the Soil Conservation Service Curve Number (SCS-CN) method. This empirical method predicts runoff based on the curve number, which is a function of the soil's permeability, land use, and antecedent soil moisture conditions.

4. Results and Discussion

4.1 Morphometric Characteristics

The watershed delineation process identified a complex drainage network comprising **63 sub-basins** and an equal number of outlets. The stream network exhibits a dendritic pattern, typical of the region's topography, feeding into the main stem of the Haro River. Figure 3 illustrates the spatial arrangement of these sub-basins, highlighting the extensive catchment area required to support the river's flow.

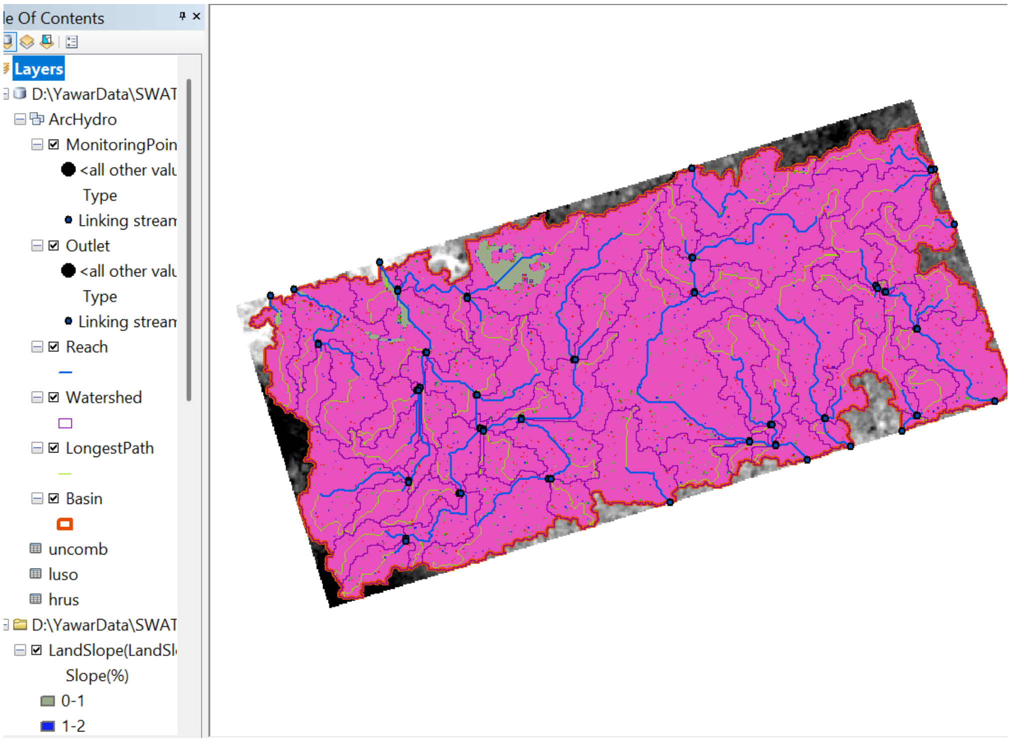

Figure 3: The delineated Haro River watershed divided into 63 sub-basins with the generated stream network

4.2 Hydrologic Response Unit (HRU) Distribution

The HRU analysis provided a detailed breakdown of the basin's physical characteristics, which are critical for hydrological simulation.

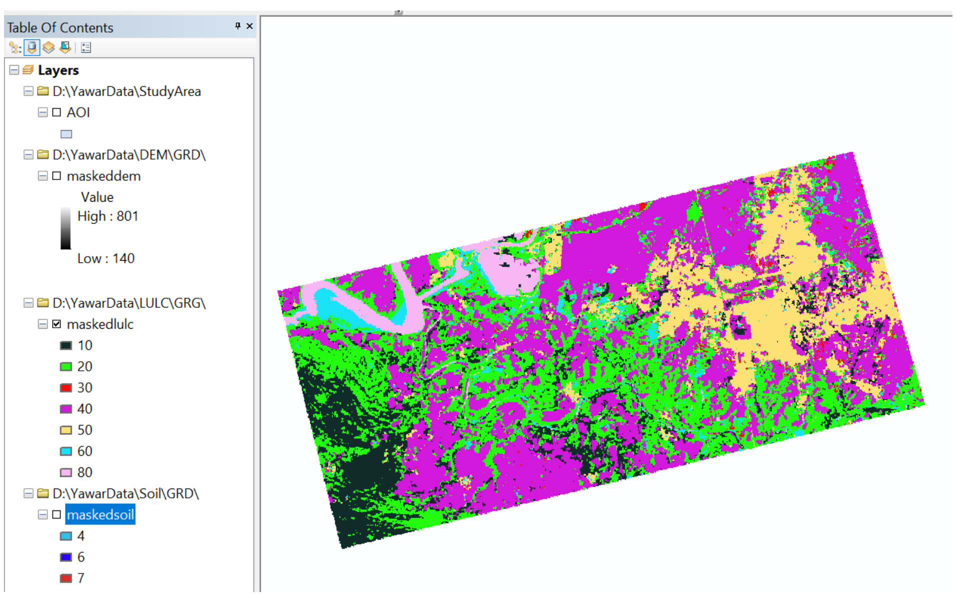

Figure 4: Spatial distribution of Land Use/Land Cover (LULC) classes across the basin

Land Use Distribution: The reclassification of land use data (Figure 5) revealed that the Haro River Basin is predominantly agricultural. The analysis identified seven primary land use classes:

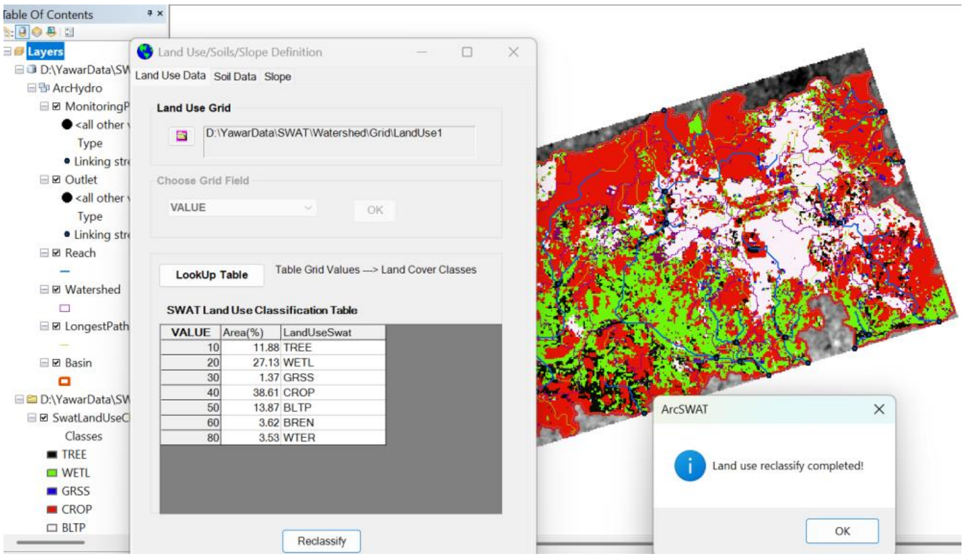

Figure 5: Reclassification of Land Use classes showing the dominance of Agricultural Land (CROP) and Wetlands (WETL)

- **Agricultural Land-Generic (CROP):** Covers the largest portion of the basin at **38.61%**, indicating intense cultivation activity.
- **Wetlands (WETL):** Constitutes a significant **27.13%** of the area, playing a vital role in water retention and biodiversity.
- **Built Up/Urban (BLTP):** Accounts for **13.87%**, reflecting human settlement patterns within the catchment.
- **Forest (TREE):** Covers **11.88%** of the basin, primarily in the upland areas.
- **Range-Brush (BREN) & Water (WTER):** Comprise smaller fractions of 3.62% and 3.53%, respectively.

Soil and Slope Characteristics: The soil analysis (Figure 6) indicates a relatively homogeneous soil composition across the basin, with the dominant soil type (Value 7) covering **75.47%** of the watershed area. A secondary soil type (Value 4) covers **24.48%**.

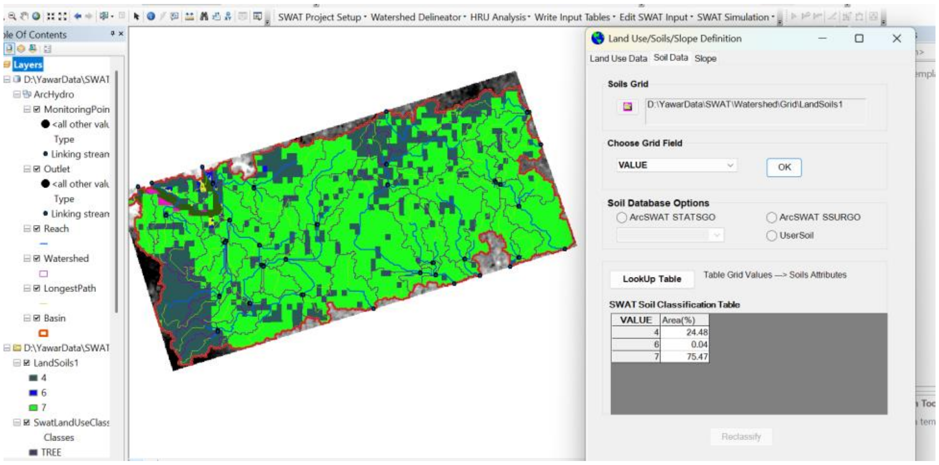

Figure 6: Soil classification and areal extent of soil types within the watershed

Topographically, the basin was analyzed using a multiple slope discretization method (Figure 7). The defining of slope classes (0-1%, 1-2%, 2-3%, 3-4%, and >4%) allows the model to differentiate between flat areas, where infiltration is higher, and steeper slopes, which are more prone to rapid surface runoff and soil erosion. The successful overlay of these datasets (Figure 8) establishes the framework for the subsequent simulation of streamflow and sediment yield.

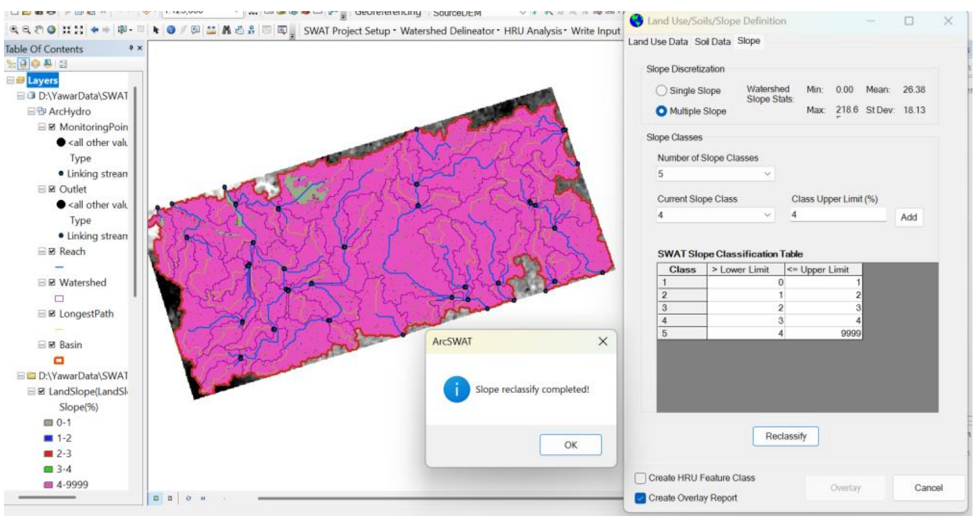

Figure 7: Slope discretization into five distinct classes for HRU definition

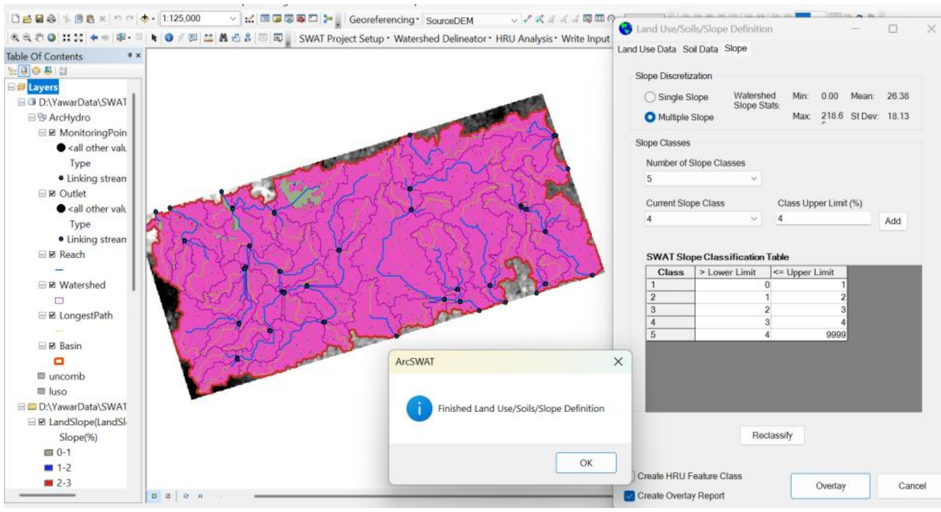

Figure 8: Completion of the Full HRU overlay process combining Land Use, Soil, and Slope layers

5. Recommendations

Based on the model setup and the morphometric characteristics identified in this study, the following recommendations are proposed to improve the accuracy of the hydrological simulation and support sustainable watershed management in the Haro River Basin:

5.1 Integration of High-Resolution Local Data

While this study successfully established a baseline model using global datasets (FAO Soil and USGS GLCC), the accuracy of future simulations can be significantly enhanced by incorporating local data. Specifically, more precise data regarding local cropping structures, irrigation practices, and water transfer schemes should be collected. The current model relies on generalized global land use classes; however, a refined input database reflecting the specific agricultural management practices of the Potwar region would reduce uncertainty in water yield and deep aquifer recharge estimations.

5.2 Calibration and Validation at Sub-basin Level

To ensure the model's reliability for policy-making, it is essential to calibrate the simulated results against observed streamflow data. The Gariala telemetric station, located on the Haro River, provides a critical control point for this purpose. Future studies should focus on calibrating the model parameters (such as curve numbers and groundwater delay) using historical discharge records to minimize the uncertainty band between simulated and observed flows.

5.3 Sediment and Erosion Management

The morphometric analysis revealed a basin relief of approximately 2,521 meters, indicating a moderate-to-high gradient. Combined with the finding that 38.61% of the basin is agricultural land, there is a potential risk of soil erosion and sediment transport into the Khanpur Dam reservoir. It is recommended to use the model to identify "Critical Source Areas" (CSAs) within the 63 sub-basins that contribute disproportionately to sediment yield. Targeted soil conservation measures should be prioritized in these high-risk sub-basins.

5.4 Climate Change Scenario Analysis

Given the region's reliance on seasonal precipitation and the variability of flows in the Upper Indus Basin, future research should utilize this calibrated SWAT model to simulate climate change scenarios. By inputting projected temperature and precipitation data, the model can quantify the potential impacts of changing climate patterns on water resources availability, helping to develop adaptive strategies for water scarcity in the region.

Executive Summary

The Haro River Basin, a vital tributary of the Indus River system in Northern Pakistan, plays a crucial role in the region's hydrology, feeding the Khanpur Dam and supporting local agriculture. This study employed the Soil and Water Assessment Tool (SWAT) within a GIS environment to delineate the watershed and characterize its Hydrologic Response Units (HRUs). The primary objective was to establish a foundational hydrological model to address challenges related to water scarcity, seasonal flooding, and sediment transport in the Potwar Plateau.

Using 30-meter resolution SRTM Digital Elevation Models (DEM), the study successfully delineated a catchment area of approximately 3,100 km². The automated watershed delineation process discretized the basin into **63 distinct sub-basins**, revealing a dendritic drainage pattern strongly influenced by the underlying geological structures of the Kala Chitta and Margalla ranges.

Detailed HRU analysis was conducted by integrating spatial datasets for topography, soil, and land use. The results indicate that the basin is predominantly agricultural, with **Agricultural Land (CROP)** constituting **38.61%** of the total area, followed by **Wetlands (27.13%)** and **Built-up areas (13.87%)**. Soil analysis revealed a relatively homogeneous profile, with **75.47%** of the watershed covered by a single dominant soil type, suggesting uniform infiltration characteristics across large portions of the basin. The integration of these parameters into the ArcSWAT interface provides a robust framework for future simulation of runoff, sediment yield, and water quality, offering valuable insights for sustainable water resource management in the region.

Maps

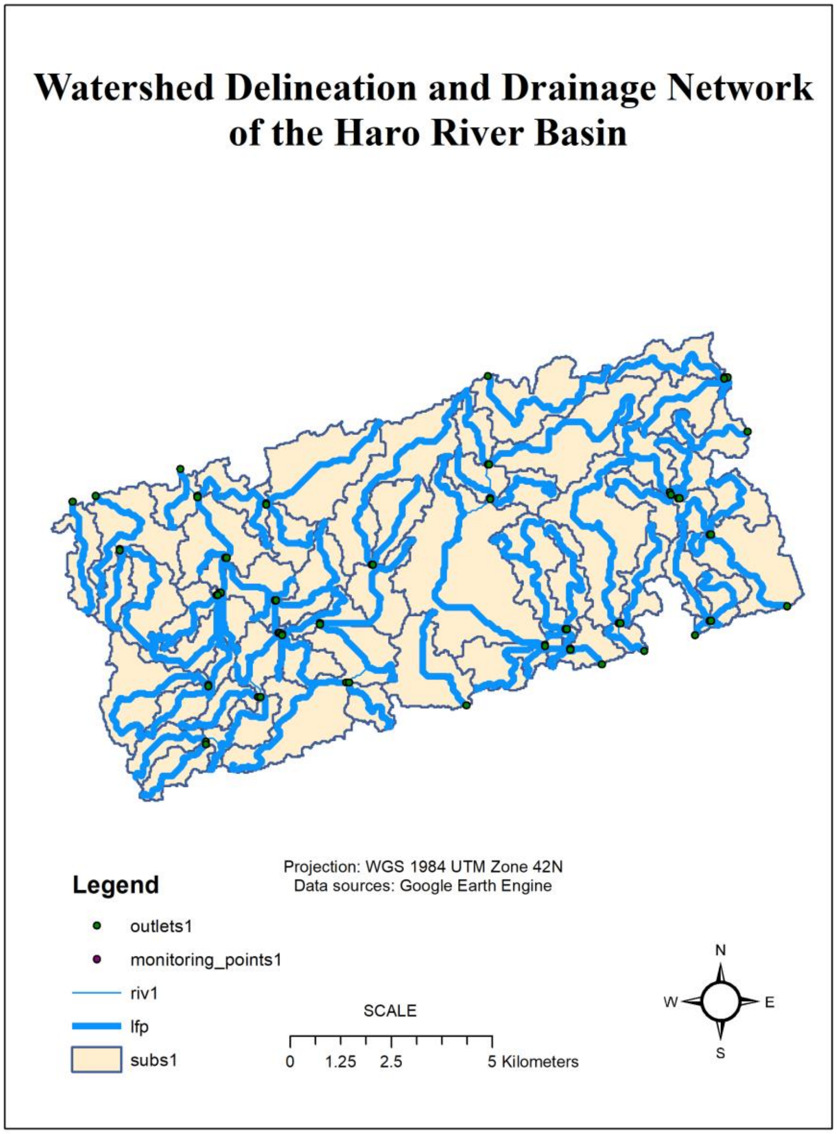

Figure 9:Watershed Delineation and Drainage Network of the Haro River Basin

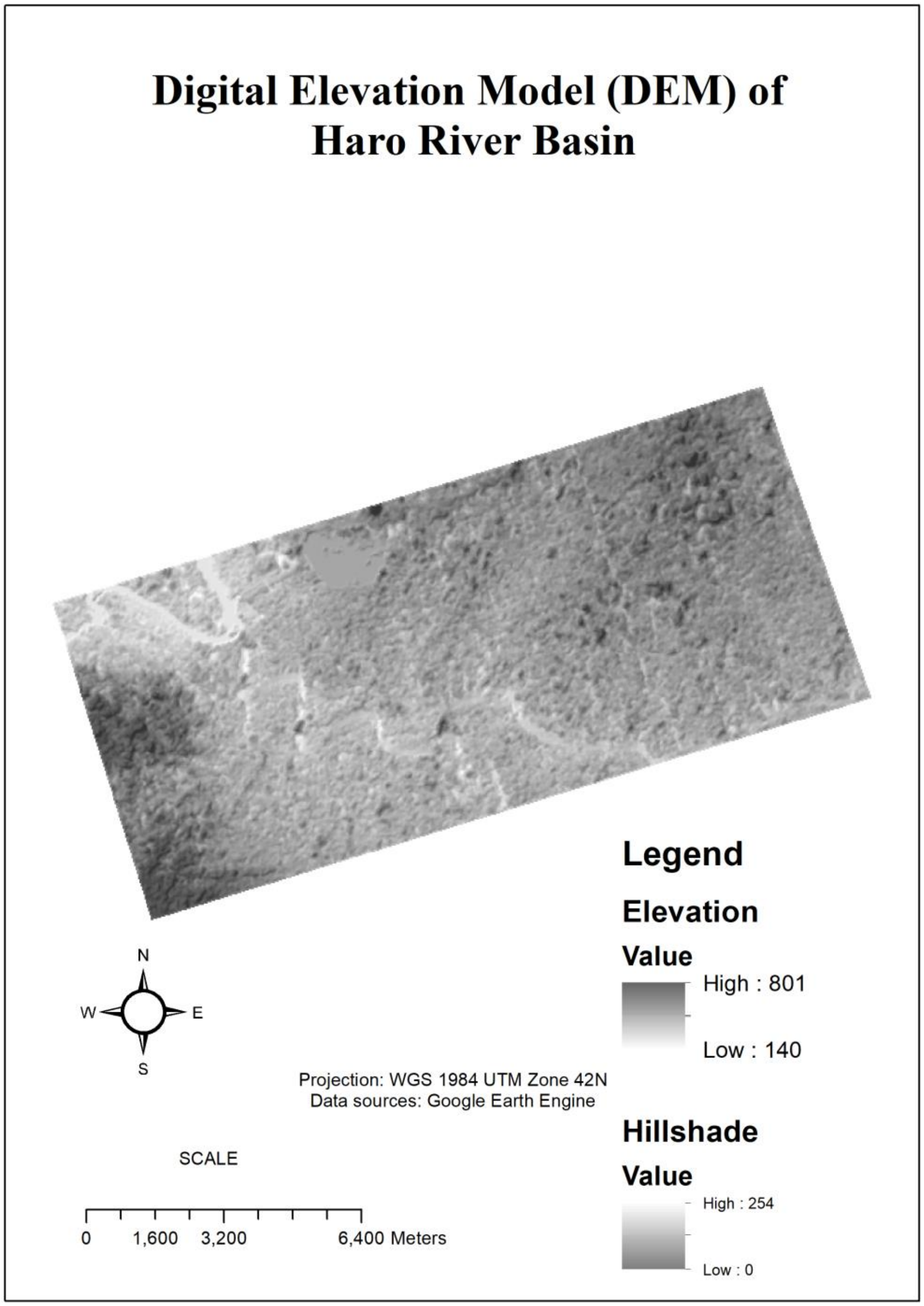

Figure 10: Digital Elevation Model (DEM) of Haro River Basin

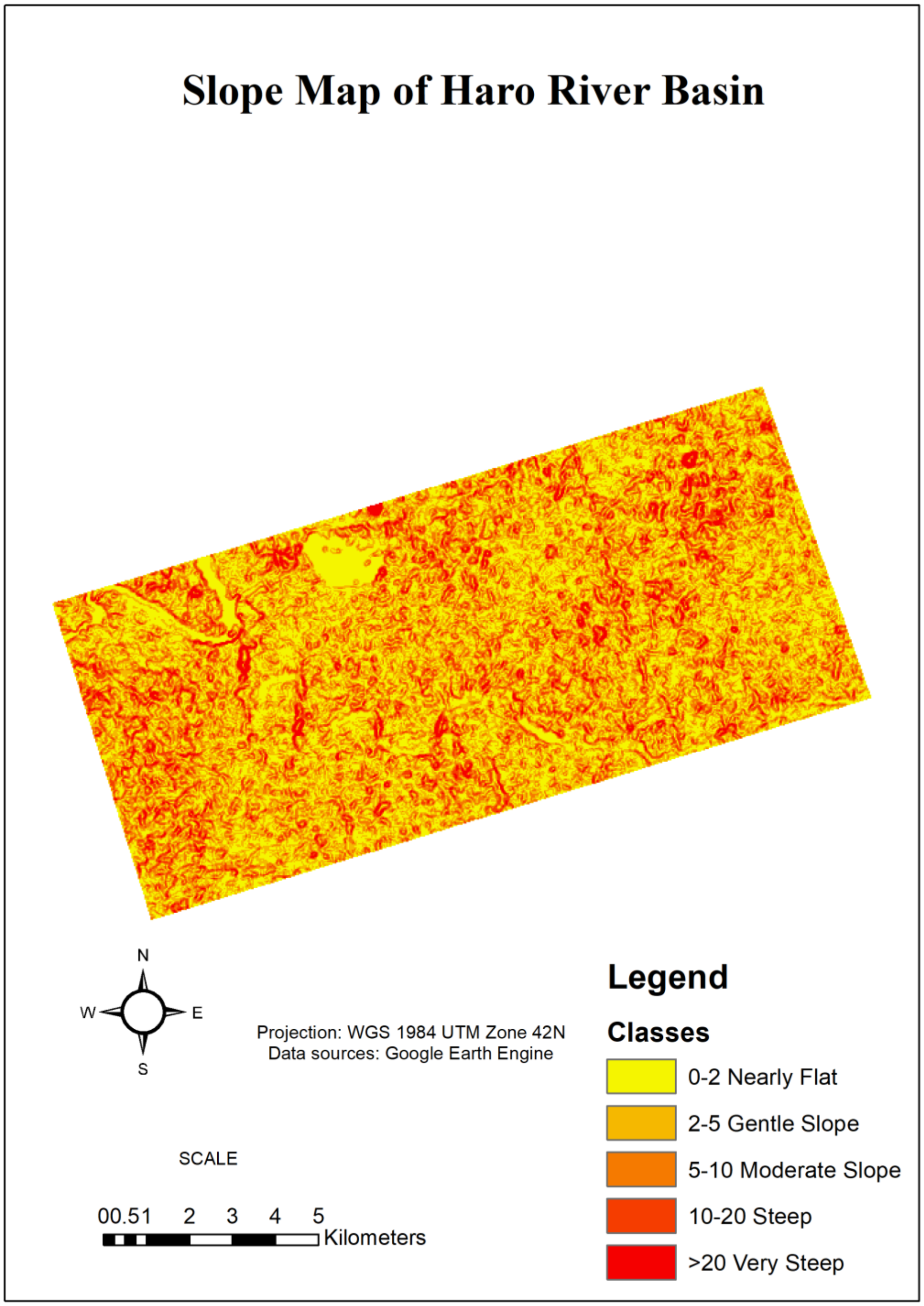

Figure 11:Slope Map of Haro River Basin

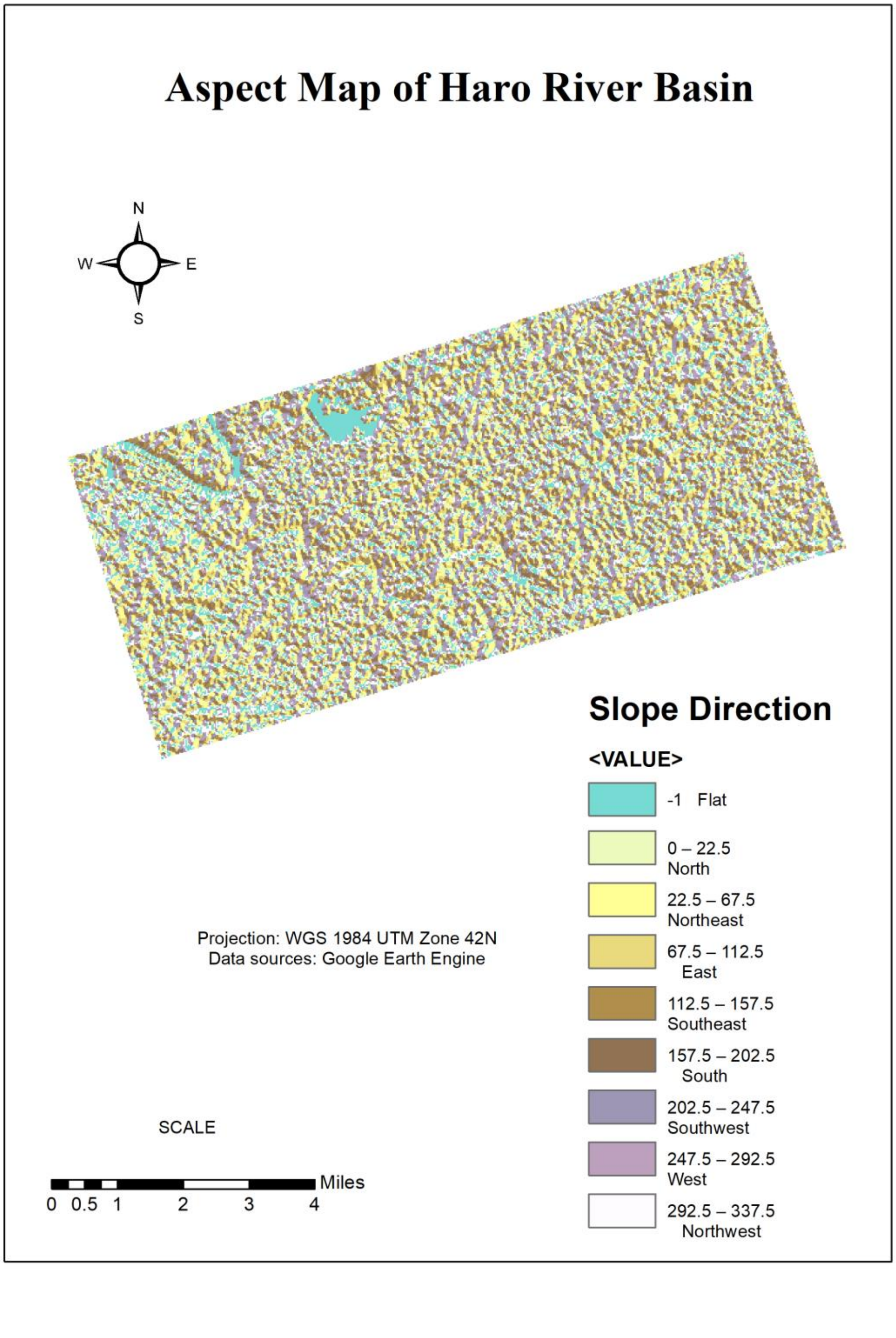

Figure 12: Aspect Map of Haro River Basin

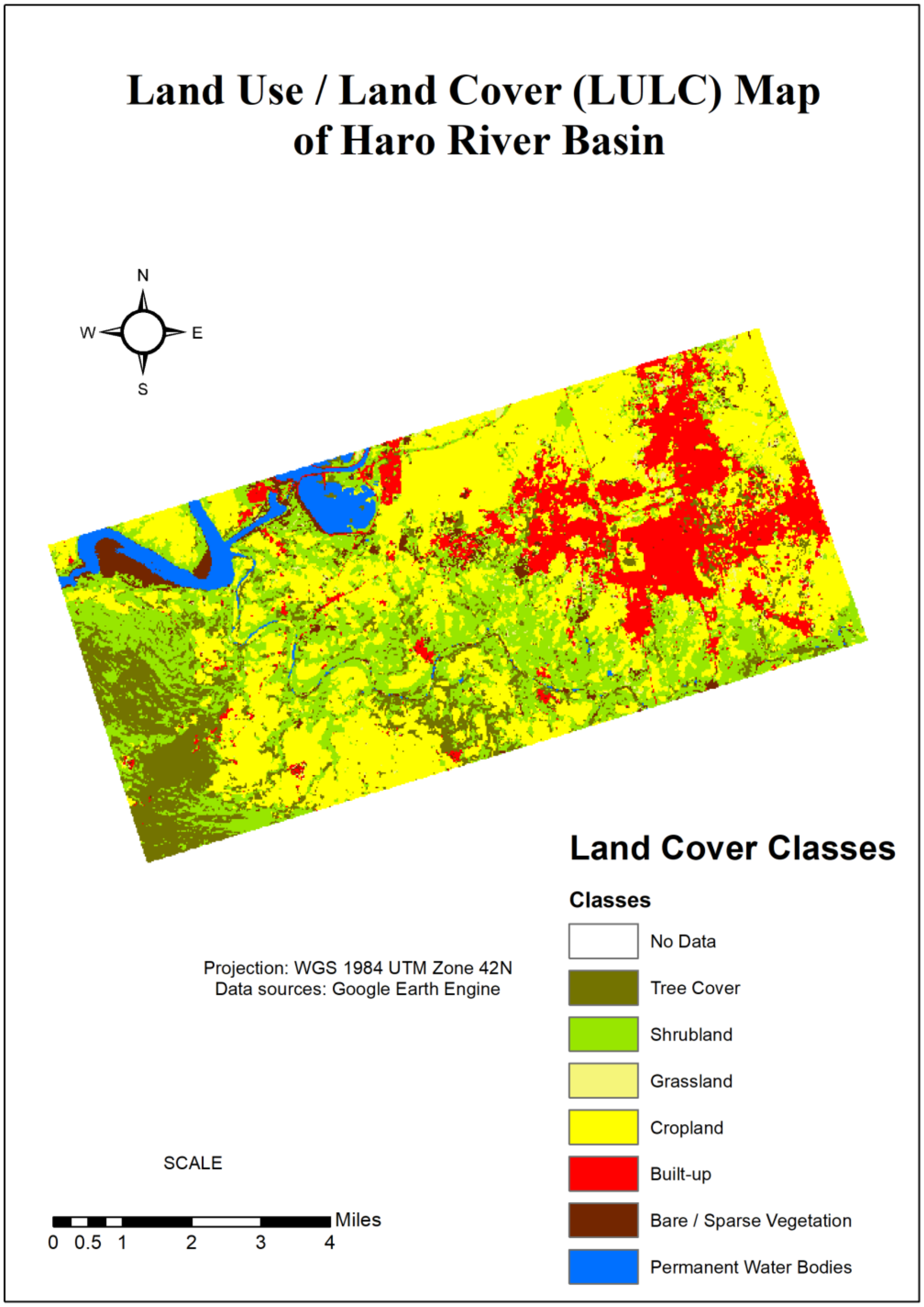

Figure 13: Land Use / Land Cover (LULC) Map of Haro River Basin

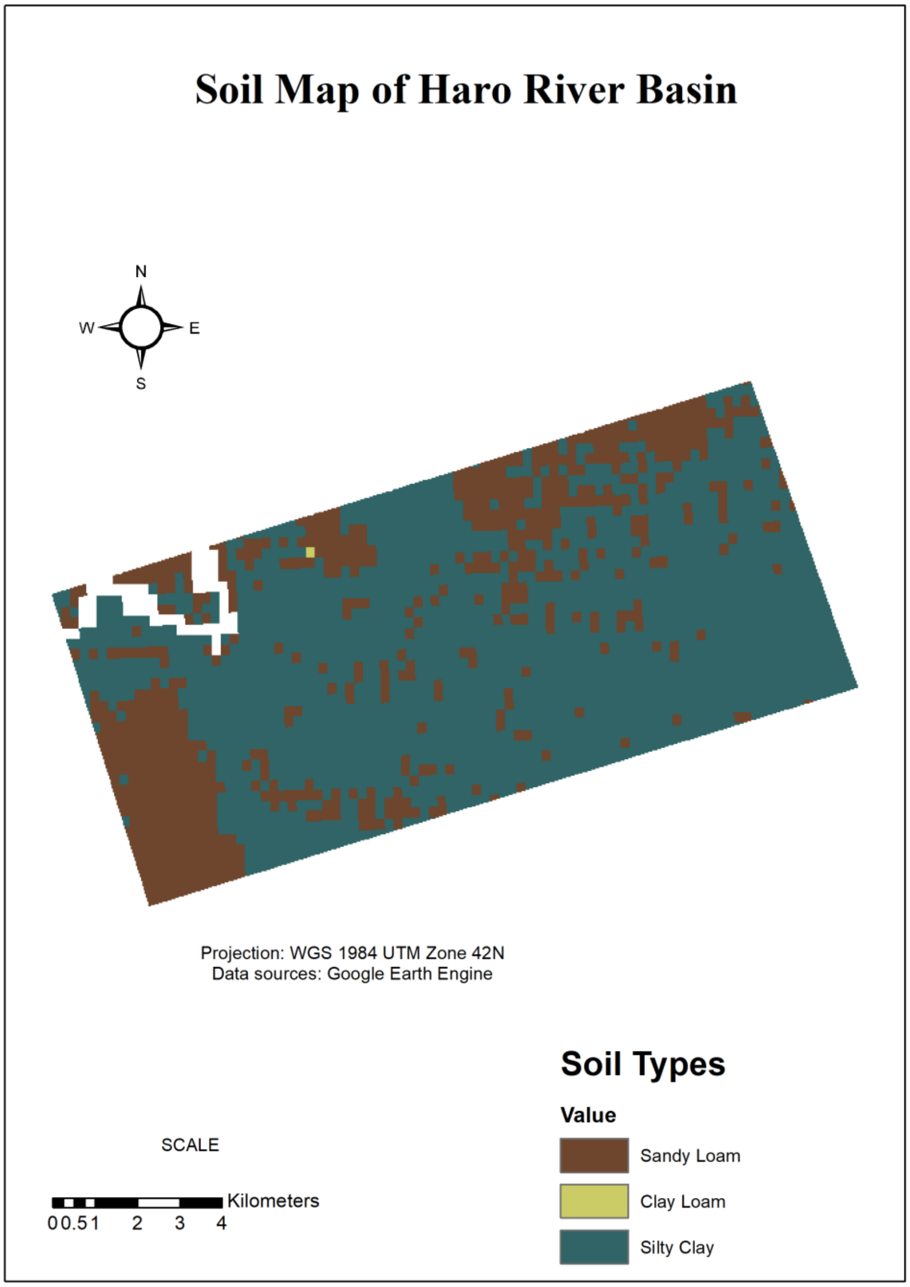

Figure 14:Soil Map of Haro River Basin

Graphs

Land Use / Land Cover Distribution of the Haro River Basin

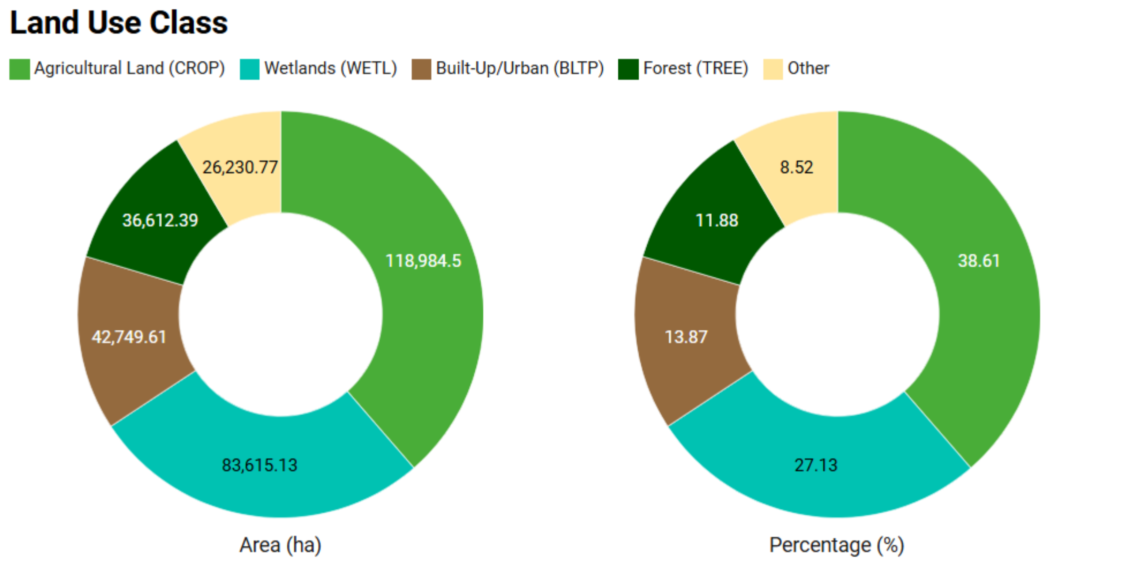

Figure 15:Area and percentage distribution of land use and land cover classes in the Haro River Basin

Percentage Distribution of Dominant Soil Types in Selected Sub-basins of the Haro River Basin

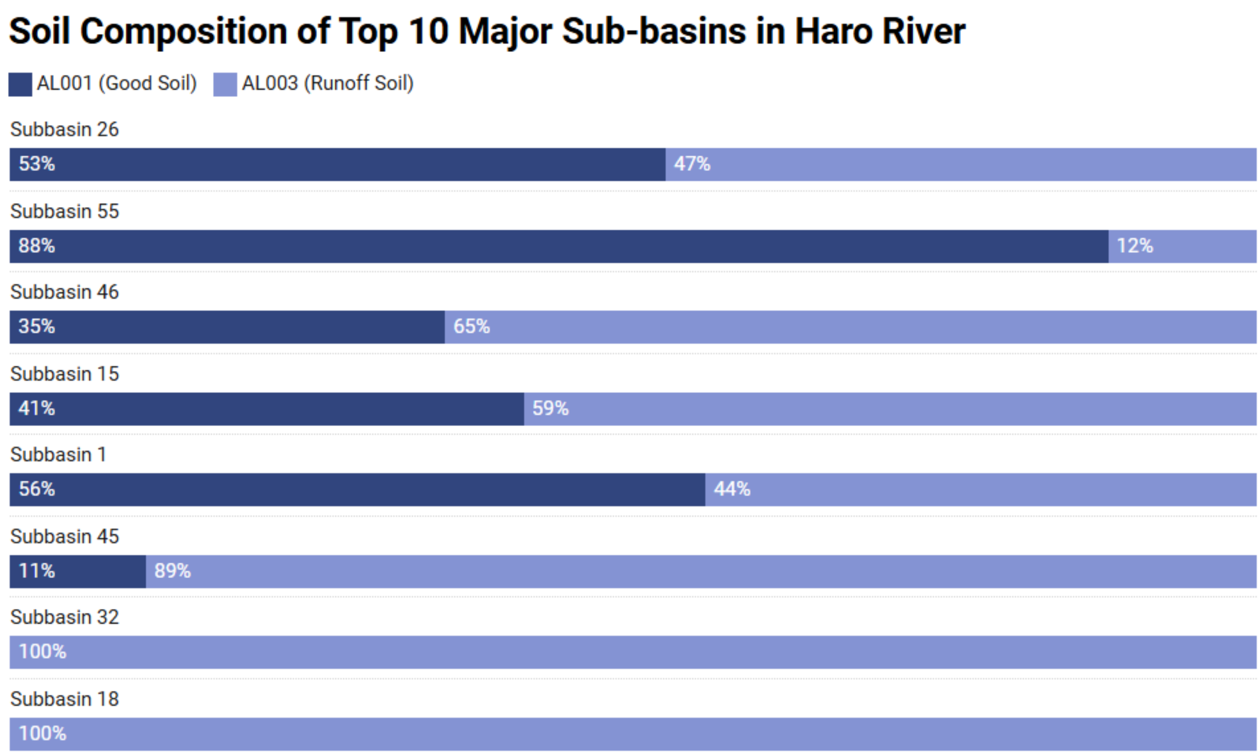

Figure 16: Percentage composition of dominant soil types (AL001 and AL003) across selected sub-basins of the Haro River Basin

Areal Contribution of the Largest Sub-basins in the Haro River Basin

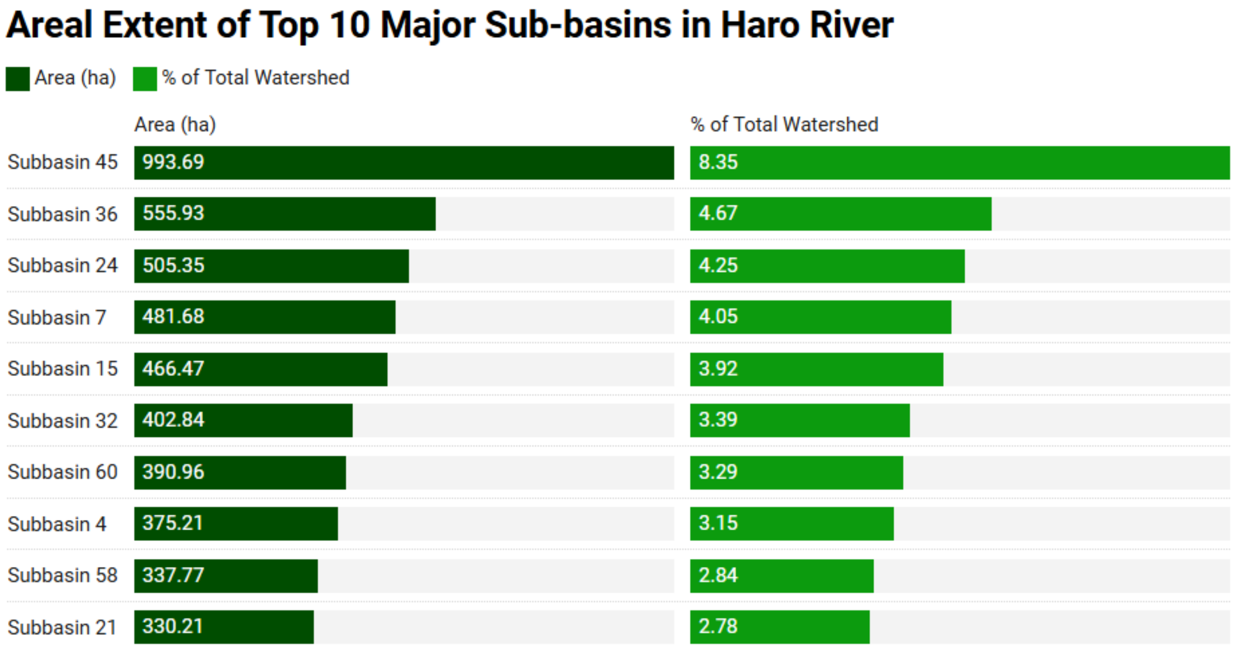

Figure 17: Areal contribution of the ten largest sub-basins within the Haro River Basin expressed in hectares and percentage of total watershed area.

References

1. **Sanaullah, M., Ahmad, I., Arslan, M., Ahmad, S. R., & Zeeshan, M. (2018).** Evaluating Morphometric Parameters of Haro River Drainage Basin in Northern Pakistan. *Polish Journal of Environmental Studies*, 27(1), 459-465. DOI: 10.15244/pjoes/68425.

2. **Ali, W. R. M., Chen, N. S., Umar, W. R. M., Sundas, A., & Mahfuzur, R. (2020).** Assessment of Runoff, Sediment Yields and Nutrient Loss Using the SWAT Model in Upper Indus Basin of Pakistan. *Journal of Geoscience and Environment Protection*, 8, 62-81. DOI: 10.4236/gep.2020.89004.

3. **FAO/UNESCO.** (2003). *Digital Soil Map of the World and Derived Soil Properties*. Food and Agriculture Organization of the United Nations, Rome.

4. **USGS.** (2004). *Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global*. United States Geological Survey. Available at: earthexplorer.usgs.gov

5. **USGS.** (2008). *Global Land Cover Characterization (GLCC) Database*. United States Geological Survey.