NATIONAL HIGHWAY AUTHORITY
GOVERNMENT OF PAKISTAN

RECONSTRUCTION OF NATIONAL HIGHWAY N-5 UNDER PAKISTAN'S RESILIENT RECOVERY, REHABILITATION AND RECONSTRUCTION FRAMEWORK PROJECT – PHASE 1A

RAWALPINDI – HASSANABDAL ROAD SECTION

CLIMATE CHANGE ASSESSMENT, HYDROLOGICAL AND HYDRAULIC STUDIES FOR CROSS DRAINAGE STRUCTURES REPORT

JANUARY 2025

NATIONAL ENGINEERING SERVICES PAKISTAN (PVT.) LTD.
HEAD OFFICE: NESPAK HOUSE, 1-C, BLOCK-N, MODEL TOWN EXTENSION LAHORE, PAKISTAN

**CLIMATE CHANGE ASSESSMENT,
HYDROLOGICAL AND HYDRAULIC STUDIES
FOR CROSS DRAINAGE STRUCTURES REPORT
RAWALPINDI-HASSANABDAL SECTION**

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

Page No.

LIST OF TABLES

Page No.

RECONSTRUCTION OF NATIONAL HIGHWAY N-5 UNDER PAKISTAN'S RESILIENT RECOVERY, REHABILITATION AND RECONSTRUCTION FRAMEWORK PROJECT – PHASE 1A

RAWALPINDI – HASSANABDAL ROAD SECTION

1. CLIMATE CHANGE STUDIES

1.1 INTRODUCTION

The N5 road, a critical transportation artery, is undergoing an expansion from 4 lanes to 6 lanes to accommodate increasing traffic demand and promote regional economic growth. As part of this expansion, it is essential to assess the potential risks associated with climate change to ensure the long-term resilience and sustainability of the infrastructure.

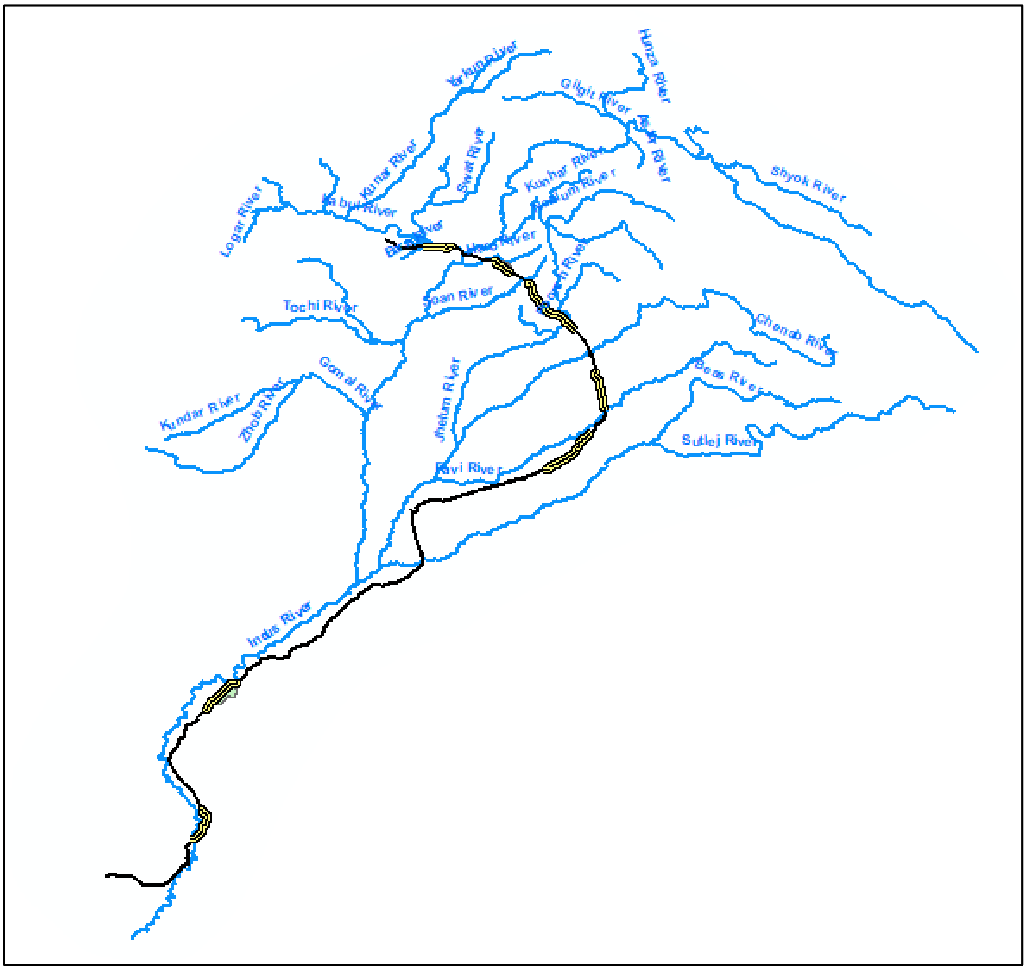

Figure 1.1: N5 Road Alignment with Dualization Sections (highlighted in Yellow color)

1.2 REVIEW OF CLIMATE CHANGE FOR PAKISTAN

Pakistan is influenced by different climate zones, particularly by Monsoon climate in the south and mountain climate in the north. The general climatic conditions are altered by Pakistan's diverse geography with the far north reaching into the Himalayas and the southern and western regions being lowland plains of the Indus River, contributing to the diversity in climatic conditions in different regions of the country. The climate is respectively characterized by diverse conditions. Average temperatures are strongly dependent on the topography, with coolest annual temperatures below zero in the far North (the Himalayan region), and higher average temperatures in the lower-lying south-east. Rainfall is low throughout the year in large parts of the country (20-30mm per month), but the northern regions, on the southern side of the Himalayan mountains, receive rainfall of up to 200mm per month as a result of the summer monsoon through July to September.

1.3 CURRENT CLIMATOLOGY

Pakistan's climate context for the current climatology, 1991-2020, derived from observed, historical data (see, **Figure 1.2**, **Figure 1.3** and **Figure 1.4**). Information should be used to build a strong understanding of current climate conditions in order to appreciate future climate scenarios and projected change. Observed, historical data is produced by the Climatic Research Unit (CRU) of University of East Anglia. Data is presented at a 0.5º x 0.5º (50km x 50km) resolution.

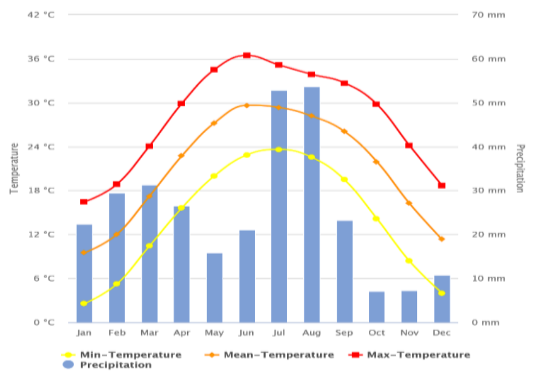

Figure 1.2: Monthly Climatology of Min, Max and Mean Temperature with Rainfall (1991-2020) (Source: World Bank)

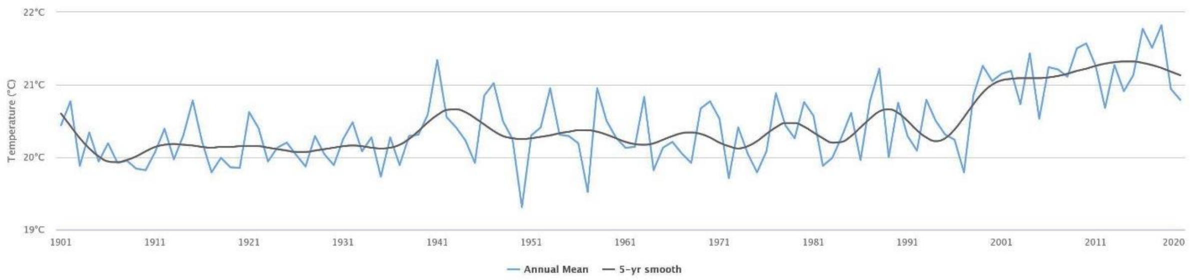

Figure 1.3: Observed Average Annual Mean- Temperature of Pakistan for 1901-2020

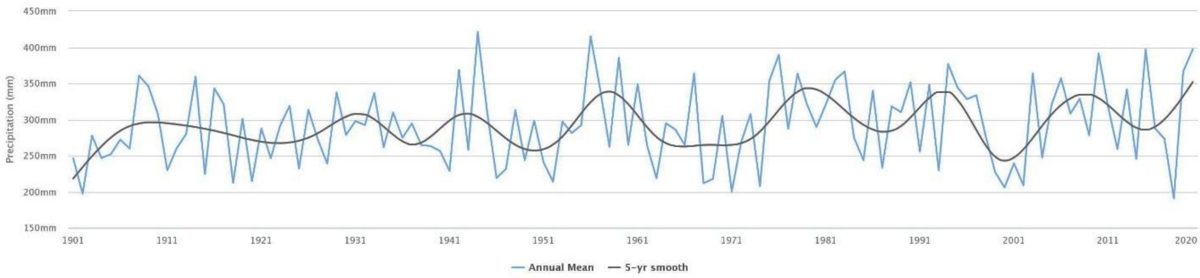

Figure 1.4: Observed Average Annual Rainfall of Pakistan for 1901-2020

<u>Temperature</u>

- Warming in Pakistan was estimated at 0.57°C over the 20th century, but has accelerated more recently, with 0.47°C of warming measured between 1961–2007.
- Increases in temperature is strongly biased towards the winter and post-monsoon months (November–February). On a sub-national level, warming is also strongly biased towards the more southerly regions, with Punjab, Sind, and Baluchistan all experiencing winter warming in the region of 0.91°C–1.12°C between 1961–2007, and Khyber Pakhtunkhwa in the north experiencing only 0.52°C.
- The rise in average daily maximum temperatures (0.87°C between 1961–2007) has been slightly stronger than the rise in average temperatures. A concurrent increase in the frequency of heat wave days has been documented, particularly in Sindh Province.

<u>Rainfall</u>

- Mean rainfall in the arid plains of Pakistan and the coastal belt has decreased by 10-15% since 1960. Most other regions have experienced a slight increase, seen both in the monsoon and dry seasons.
- The number of heavy rainfall events has increased since 1960, and the nine heaviest rains recorded in 24 hours were recorded in 2010.
- Recent evidence suggests that glaciers in the headwaters of the Indus Basin may be expanding due to increased winter rainfall over the Himalayan region in the last 40 years.

1.4 PROJECTED CLIMATOLOGY

Climate projection data is modeled data from the global climate model compilations of the Coupled Model Inter-comparison Projects (CMIPs), overseen by the World Climate Research Program. Data presented is CMIP6, derived from the Sixth phase of the CMIPs. The CMIPs form the data foundation of the IPCC Assessment Reports. CMIP6 supports the IPCC's Sixth Assessment Report. Data is presented at a 0.25º x 0.25º (25km x 25km) resolution. Projected multi model mean temperature and rainfall trend for Pakistan is shown in **Figure 1.5** and **Figure 1.6** respectively.

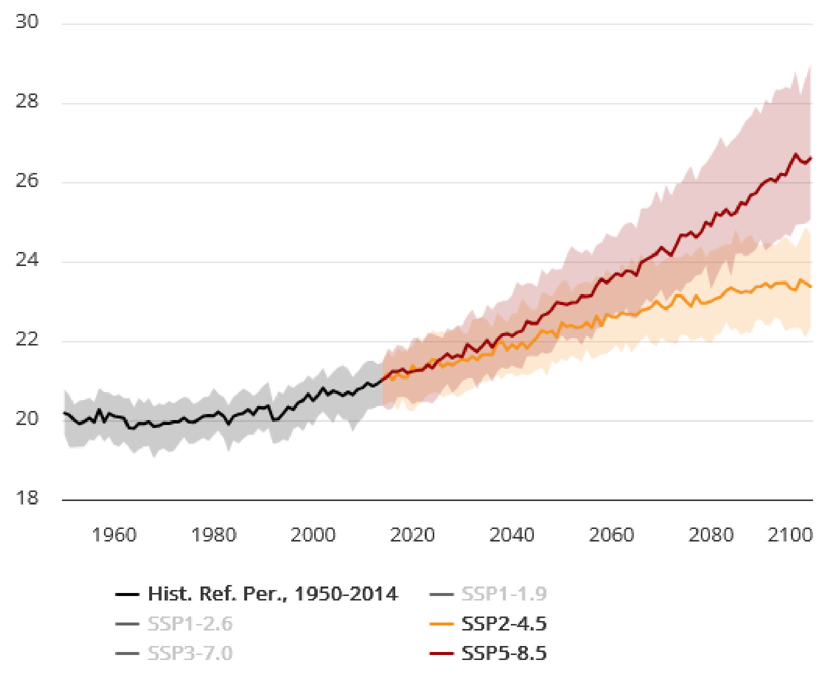

Figure 1.5: Projected Mean Temperature (Multi-Model Ensemble) Pakistan

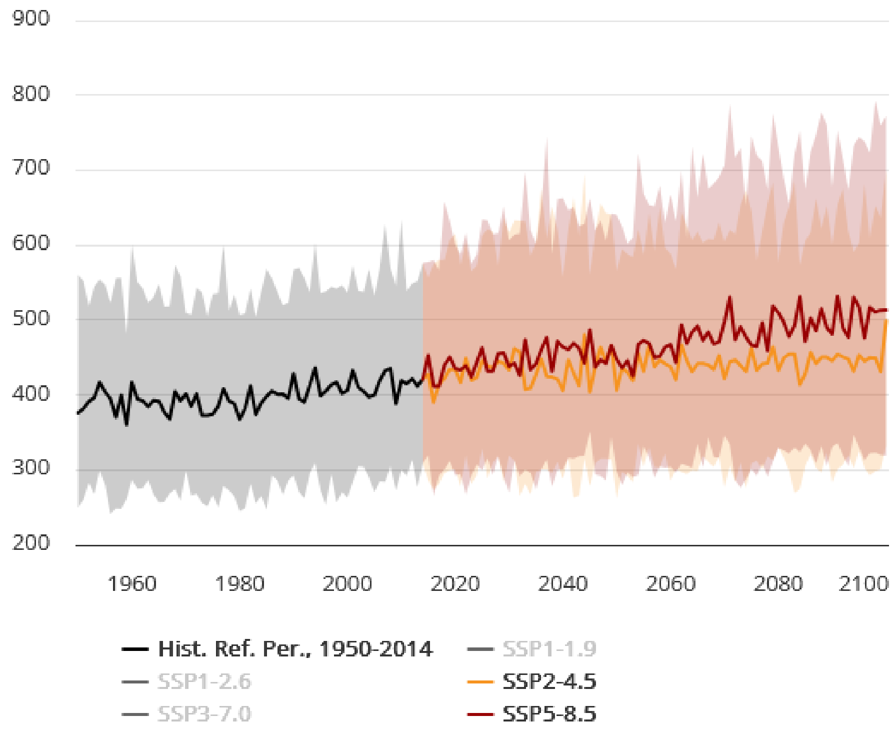

Figure 1.6: Projected Rainfall (Multi-Model Ensemble) Pakistan

1.5 CLIMATE DIAGONISTIC

Consultants performed climate risk assessment as per International standard practice for climate change projects following the guidelines of Intergovernmental Panel for Climate Change.

1.6 MODELLING FRAMEWORK

Climate change scenarios is retrieved and analyzed at different spatial and temporal resolutions. Daily climate data (rainfall, maximum and minimum temperature) is retrieved from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset (Sheffield et al. 2006; Thrasher et al. 2022), which are available at a spatial resolution of 25 km. Daily climate data (rainfall, maximum and minimum temperature) is retrieved from the ERA5 dataset which is available at a spatial resolution up to 11 km. For both datasets, current and future climate conditions are retrieved and analyzed (see **Table 1.1**).

Table 1.1: Available climate information for climate change assessment

Dataset	Conditions	Resolution		Period	Description
		Spatial	Temporal		
ERA5	Historic	11 km	Daily	1985-2014	Mean temperature (ºC) Rainfall (mm)
NEX-GDDP-CMIP6	Current	25 km	Daily	1985-2014	Mean temperature (ºC) Rainfall (mm)
	Future	25 km	Daily	Until 2099	Mean temperature (ºC) Rainfall (mm)

Future conditions included the Intergovernmental Panel on Climate Change Sixth Assessment (IPCC6) climate projections from global climate models (GCMs) for different shared socio-economic pathways (SSPs). Different climate scenarios (SSP 2-4.5 and SSP 5-8.5) are used according to data availability of IPCC6.

SSP 2-4.5 is a scenario that represents the medium range of future forcing pathways and serves as an update to the RCP4.5 pathway. It is utilized as a reference experiment by several CMIP6-Endorsed MIPs. SSP 2-4.5 was chosen because its land use and aerosol pathways are not extreme compared to other SSPs, making it central to the concerns of Detection and Attribution MIP (DAMIP)[1] and Decadal Climate Prediction Project (DCPP)[2]. Additionally, it is relevant to Integrated Assessment Modeling (IAM) and Impact, Adaptation, and Vulnerability (IAV) research as it represents a scenario that combines intermediate societal vulnerability with an intermediate forcing level.

SSP 5-8.5 represents the high end of future pathways in the IAM and serves as an update to the RCP8.5 pathway. This scenario is specifically chosen to address scientific questions across various CMIP6-Endorsed MIPs. SSP 5-8.5 is unique among the SSP scenarios

[1] Gillett, N. P., Shiogama, H., Funke, B., Hegerl, G., Knutti, R., Matthes, K., Santer, B. D., Stone, D., and Tebaldi, C.: The Detection and Attribution Model Intercomparison Project (DAMIP v1.0) contribution to CMIP6, Geosci. Model Dev., 9, 3685-3697, doi:10.5194/gmd-9-3685-2016, 2016

[2] Boer, G. J., Smith, D. M., Cassou, C., Doblas-Reyes, F., Danabasoglu, G., Kirtman, B., Kushnir, Y., Kimoto, M., Meehl, G. A., Msadek, R., Mueller, W. A., Taylor, K. E., Zwiers, F., Rixen, M., Ruprich-Robert, Y., and Eade, R.: The Decadal Climate Prediction Project (DCPP) contribution to CMIP6, Geosci. Model Dev., 9, 3751-3777, doi:10.5194/gmd-9-3751-2016, 2016

because it exhibits emissions high enough to generate a radiative forcing of 8.5 Wm^{-2} in 2100. The selection of SSP 5-8.5 as the forcing pathway is significant due to its ability to capture the upper bounds of potential future climate conditions. This scenario is essential for understanding the potential outcomes and developing appropriate strategies to mitigate and adapt to the impacts of climate change.

1.7 ERA5

ERA5 is the fifth-generation reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). It provides comprehensive and high-resolution data on various atmospheric, oceanic, and land-surface variables, including rainfall and temperature, from 1950 to the present. ERA5 provides consistent global data coverage, enabling analysis across different geographic scales, from local to global levels. ERA5 rainfall and temperature data are extensively used in climate research, weather forecasting, hydrology, and environmental impact assessments. They are valuable for understanding historical climate trends, evaluating extreme weather conditions, and supporting adaptation and mitigation planning. The Consultant uses ERA5 data to evaluate and correct climate change data, considering catchments and its spatial coverage in N5.

1.8 NEX-GDDP-CMIP6

Climate change forecasts are estimates of the climate system's response to potential greenhouse gas and aerosol emissions over the next century. These projections are often based on climate model simulations. Ongoing climate change may impact on the dynamics of extreme events as well as the availability of water supplies. We may prepare the community and manage infrastructure based on scientific understanding of projected changes and situations, allowing us to take actions to adapt to the new conditions. The complexity of climate models varies; some include more procedures than others. This means that each model will produce distinct results. The magnitude of these fluctuations can be big or small, depending on the model, area, season, variable, etc. A model may perform well in one area/season/ variable but poorly in another, whereas another model excels in yet another.

To estimate the probable future climatic change in this region, a complete analysis of thirty-five (35) global climate models (GCMs) (**Table 1.2**) from the current set of the Coupled Model Intercomparison Project Phase 6 (CMIP-6) by the NEX-GDDP-CMIP6[3] was performed. The collection contains scenarios for all four "Tier 1" greenhouse gas emissions scenarios, known as Shared Socioeconomic Pathways (SSPs). The CMIP6 GCM simulations were produced to help the Intergovernmental Panel on Climate Change (IPCC AR6) prepare its Sixth Assessment Report. This dataset provides downscale predictions based on Scenario MIP model runs. The predictions are daily scenarios developed and shared by the Earth System Grid Federation. The goal of this dataset is to provide a collection of reliable climate change projections on a worldwide scale, with high resolution and bias correction. These forecasts can be used to evaluate the impact of climate change on systems affected by more detailed climate variations, as well as the influence of local topography on climate conditions. For this investigation, 30-year baseline data (1985-2014) were employed. By adopting this dependable

[3]Thrasher, B., Wang, W., Michaelis, A. et al. NASA Global Daily Downscaled Projections, CMIP6. Sci Data 9, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4

and well accepted methodology, the Consultants establish a solid foundation for their study and estimates of climate change consequences in this region.

Table 1.2: List of Available GCMs used for Study Area

ACCESS-CM2	CanESM5	HadGEM3-GC31-MM	MPI-ESM1-2-HR
ACCESS-ESM1-5	EC-Earth3	IITM-ESM	MPI-ESM1-2-LR
BCC-CSM2-MR	EC-Earth3-Veg-LR	INM-CM4-8	MRI-ESM2-0
CESM2	FGOALS-g3	INM-CM5-0	NESM3
CESM2-WACCM	GFDL-CM4-1	IPSL-CM6A-LR	NorESM2-LM
CMCC-CM2-SR5	UKESM1-0-LL	KACE-1-0-G	NorESM2-MM
CMCC-ESM2	GFDL-ESM4	KIOST-ESM	TaiESM1
CNRM-CM6-1	GISS-E2-1-G	MIROC-ES2L	GFDL-CM4-2
CNRM-ESM2-1	HadGEM3-GC31-LL	MIROC6	

To address this, bias correction through ground station data or satellite estimates will be necessary to improve the accuracy of future climate projections.

Data was downloaded for the period 2035-2064 (hereafter referred to as projections to 2050) for climate change assessments. Since the project roads mainly involve upgradation, projections to 2050 are suitable for the road project design life. However, for locations involving bridge construction, data was also downloaded for the period 2070-2099 (projections to 2085) to account for a longer design life suitable for the bridges.

1.9 IMPACT OF CLIMATIC CHANGE

1.9.1 Climate Change Assessment Over Rawalpindi – Hassanabdal Section

Specifically, temperature and rainfall variation over different timeframes and climate scenarios are considered for Rawalpindi and Hassanabdal road section (see **Figure 1.7**). Key highlights are:

- **Temperature Projections:**
    - Under SSP 2-4.5: Temperatures are expected to increase by 1.8°C by 2050 and 2.5°C by 2085.
    - Under SSP 5-8.5: Temperatures could increase by 2.9°C by 2050 and 4.9°C by 2085.
- **Rainfall Projections (Annual):**
    - Under SSP 2-4.5: Total annual rainfall is projected to increase by 8.2% by 2050 and 7.5% by 2085.
    - Under SSP 5-8.5: Rainfall could increase by 11% by 2050 and 21% by 2085.

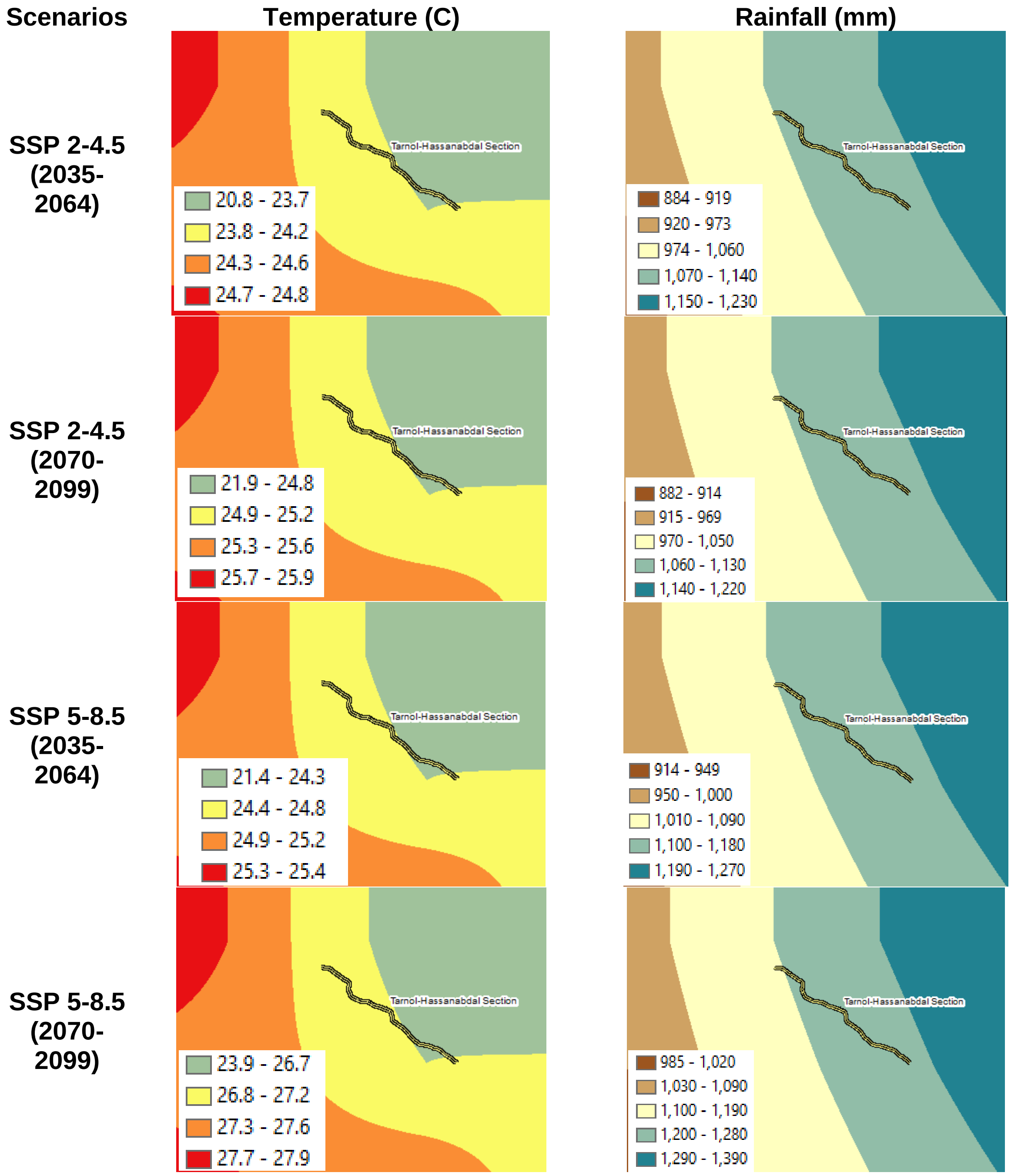

Figure 1.7: Temperature and Rainfalls under Different Timeframes and Climate scenarios over Rawalpindi – Hassanabdal Section

1.9.2 Flood assessment for Rawalpindi – Hassanabdal Section

The most important factors for climate-proofing the project infrastructure are the projected changes in the climatic extremes. The projections regarding changes in daily maximum rainfall (RX1DAY) climate extreme was done based on the ERA5 gridded data. Consultants have employed a baseline period spanning from 1985 to 2014, which encompasses 30 years of data, to analyze rainfall data. Rainfalls have been estimated for both historic and future data (area can be seen in **Figure 1.8**. The impact of climate change is assessed on floods and these results (Table 7) will be used in Hydrological Modeling and hydraulics study for climate resilient analysis.

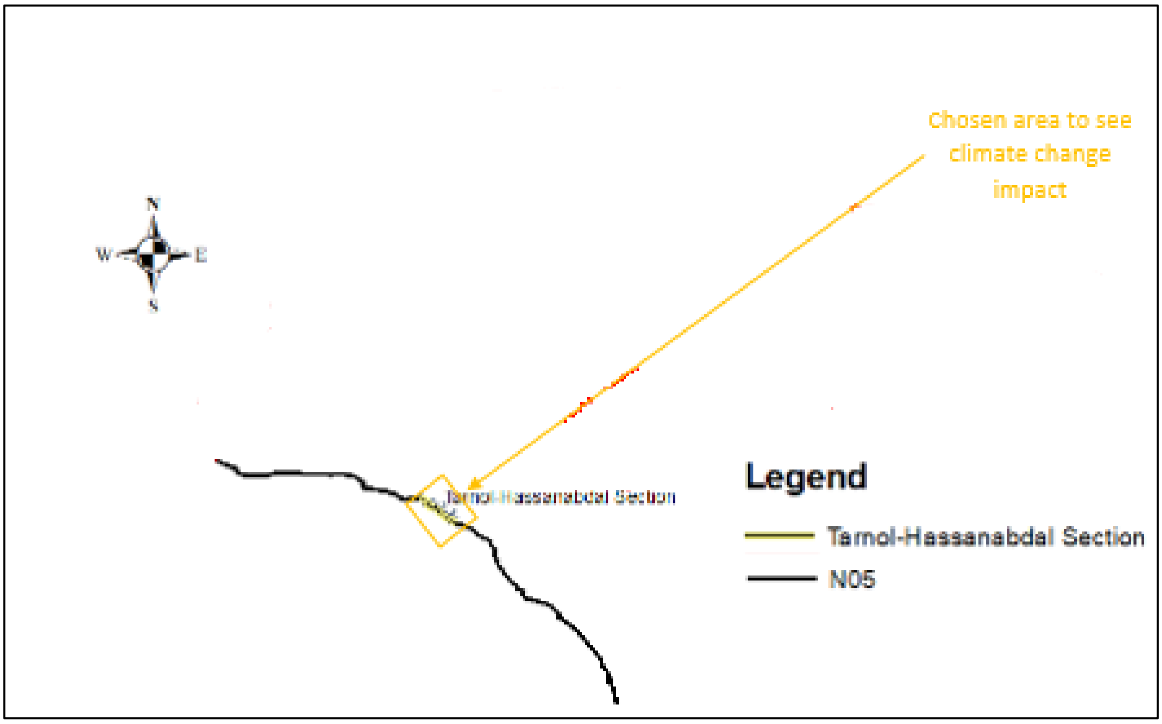

Figure 1.8: N5 road Sections for Climate Change Analysis on Flooding (chosen area is highlighted in orange color)

A. Selection of General Circulation Models (GCMs)

As outlined in the previous section, to estimate the probable future climatic change in this area, a complete analysis of thirty-five (35) GCMs (**Table 1.3**) from the current set of the Coupled Model Intercomparison Project Phase 6 (CMIP-6) by the NEX-GDDP-CMIP6 was performed. **Figure 1.9** illustrates the overall process used for this climate change study. By adopting this dependable and well accepted methodology, the Consultants establish a solid foundation for their study and estimates of climate change consequences in this region.

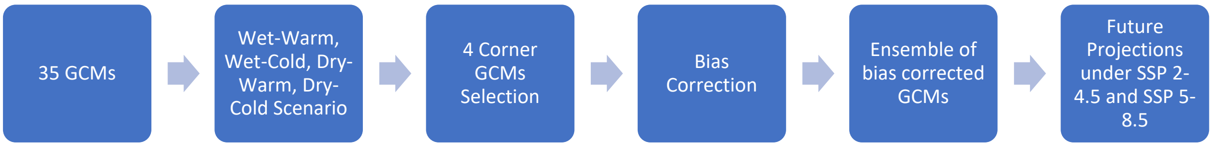

Figure 1.9: Overall Methodology Adopted for Climate Change Study

In the process of selecting GCMs for the study, a comparison is made between the maximum daily rainfall derived from the climate models and the data from historic ERA5 estimates (**Figure 1.10**). These findings indicate discrepancies in rainfall estimates among different models, with some underestimating and others overestimating maximum rainfall in the region. To address this, bias correction will be necessary to improve the accuracy of future climate projections.

Of the available scenarios SSP 2-4.5 (middle of the road) and SSP 5-8.5 (business as usual) (extreme) scenario are used for climate change inclusive hydrological impact assessment study.

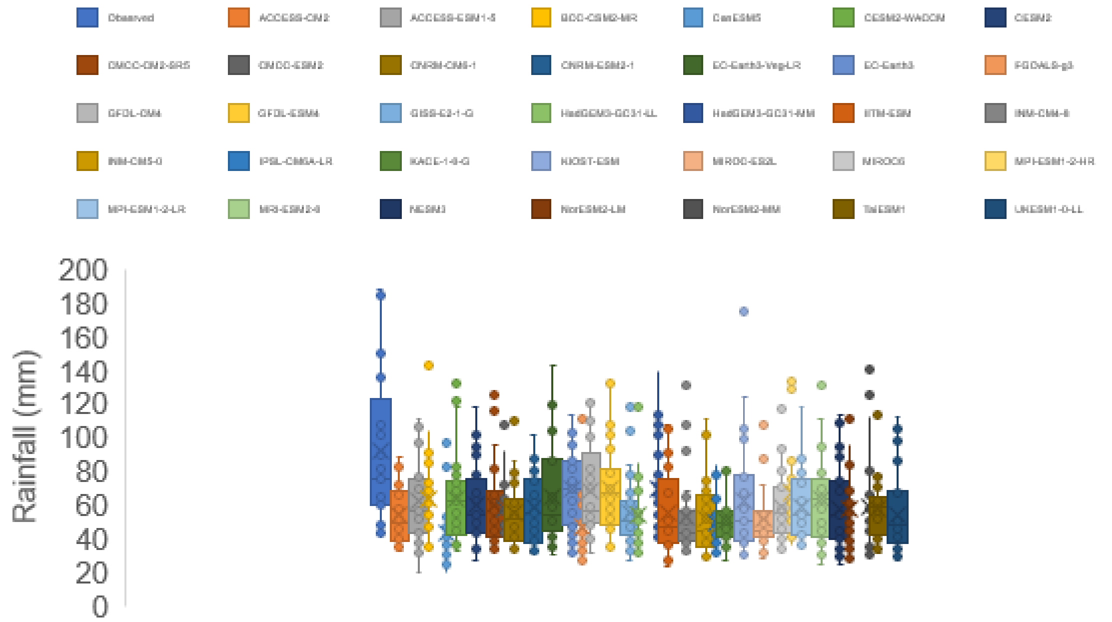

Figure 1.10: Raw GCMs Comparison with ERA5 Rainfall (Whisker Plot)

B. Shortlisting of GCMs

The selection of GCMs will be determined using the delta approach for rainfall and temperature. The base data utilized for this purpose will extend from 1985 to 2014, while the projected future data will encompass the time frame from 2015 to 2100 for the SSP 2-4.5 and SSP 5-8.5 scenarios. The median GCMs falling within the designated percentile range (10% and 90%) will be selected during the second stage. This strategy seeks to decrease the level of uncertainty surrounding anticipated future data. Consultant utilizes corner model approaches to check the possible rainfall variations in this region[4&5].

Details of the different parts of the full spectrum considered during this study are as follows:

- the Dry-Cold corner, represented by the 10th percentile ΔP as well as 10th percentile value of ΔT;
- the Dry-Warm corner, represented by the 10th percentile ΔP but the 90th percentile value of ΔT;
- the Wet-Cold corner, represented by the 90th percentile ΔP and the 10th percentile value of ΔT;
- the Wet-Warm corner, represented by the 90th percentile values for both ΔP as well as ΔT;

[4] NESPAK Project “Emergency flood assistance project, Khyber Pakhtunkhwa, Pakistan”, ADB, 2023
[5] NESPAK Project “Study and evaluation of the safety of existing dams in different regions of the Kingdom of Saudi Arabia” (2023-2026).

Four corner models under SSP 2-4.5 (HadGEM3-GC31-LL, MIROC-ES2L, CESM2 and CESM2-WACCM) and SSP 5-8.5 (EC-Earth3-Veg-LR, FGOALS-g3, GFDL-CM4-1, TaiESM1) have been selected for bias correction application in this area. Average results have been adopted for analysis with variation range.

C. Bias Correction

Climate models often include inherent biases when simulating variables. To guarantee accurate applications in contexts with nonlinear sensitivities to biases, these biases must be addressed and eliminated beforehand. Bias correction strategies are important in climate change impact studies because they have the potential to influence model-projected mean changes. Consultant chose statistical downscaling[6] because dynamic downscaling is too time-consuming and computationally intensive. To develop relationships using statistical methods, observational records are required; long-term records from 1985 to 2014 are available as baseline data. Consequently, a comprehensive review of the most employed and latest bias correction techniques has been conducted to identify the most suitable method. Considering the analysis, Consultants adopted Quantile Delta Mapping (QDM)[7,8] for bias correction of rainfall data.

The bias correction procedures mentioned above, while chosen as the best possible alternative given the availability of time, resources, and data, are not without limits. These bias correction approaches increase the agreement of climate model output with observations, reducing the uncertainty range of forecasts and simulations; but they do so without a solid physical basis. This bias corrected GCM will allow us to provide average forecasts for future forecasted data.

D. Frequency Analysis

To estimate the return period of maximum daily rainfall, generalized extreme value (GEV) distribution is used. The GEV distribution is widely used for estimating the magnitude and occurrence probability of hydrological extreme events. The results indicate that extremes of more intense rainfall are expected. The ensemble of bias corrected GCMs for this region showed that there will be average increase in rainfall of about 2.5%, 2.3% and 2.1% for return period of 25, 50 and 100 years, respectively under SSP 2-4.5 while there will be increase in rainfall of about 3.9%, 4.1% and 4.3% for return period of 25, 50 and 100 years respectively under SSP 5-8.5 (see **Table 1.3**) which are used in the project's engineering design. However, it is important to note that there will always be some residual risk associated with the performance of individual GCMs. There climatic change increase factors be used to increase the rainfall depths for inclusion in flood studies.

[6] Flaounas, E., P. Drobinski, M. Vrac, S. Bastin, C. Lebeaupin-Brossier, M. Stefanon, M. Borga, and J.-C. Calvet (2013), Precipitation and temperature space-time variability and extremes in the Mediterranean region: Evaluation of dynamical and statistical downscaling methods, *Clim. Dyn.*, 40(11-12), 2687–2705, doi:10.1007/s00382-012-1558-y.

[7] Xavier, A. C. F., Martins, L. L., Rudke, A. P., de Morais, M. V. B., Martins, J. A., & Blain, G. C. (2022). Evaluation of Quantile Delta Mapping as a bias-correction method in maximum rainfall dataset from downscaled models in São Paulo state (Brazil). International Journal of Climatology, 42(1), 175-190.

[8] Project "Emergency flood assistance project, Khyber Pakhtunkhwa, Pakistan", ADB, 2023

Table 1.3: Estimated increase in rainfall under SSP 2-4.5 and SSP 5-8.5

Return Periods	SSP 2-4.5	SSP 5-8.5
25	2.5%	3.9%
50	2.3%	4.1%
100	2.1%	4.3%

1.10 CONCLUSION

This report initiates a detailed **climate change assessment** for the **N5 road expansion**, specifically focusing on the Rawalpindi and Hassanabdal areas. By addressing climate-related risks upfront, it aims to ensure long-term sustainability and resilience of critical infrastructure in the face of future climate changes.

In the road project area, **average monthly temperatures** are projected to rise significantly by 2085, with increases as high as 4°C. Under the **SSP 2-4.5** scenario, temperatures are expected to increase by **1.8°C by 2050** and **2.5°C by 2085**, whereas under **SSP 5-8.5**, the rise could reach **2.9°C by 2050** and **4.9°C by 2085**. Additionally, **annual rainfall** is anticipated to rise by **8.2% by 2050** and **7.4% by 2085** under SSP 2-4.5, while under SSP 5-8.5, rainfall could increase by **11% by 2050** and **21% by 2085**.

Floods and **extreme temperatures** are identified as key climate-related hazards that the road projects will face in the future. The analysis shows that extreme rainfall is expected to intensify. An ensemble of bias-corrected GCMs predicts a rise in rainfall by **2.5% for a 25-year return period**, **2.3% for a 50-year return period**, and **2.1% for a 100-year return period** under SSP 2-4.5. Under SSP 5-8.5, the projected increases are **3.9%**, **4.1%**, and **4.3%**, respectively, all of which have been incorporated into the project's engineering design. It is recommended to adopt SSP 5-8.5 results in the design.

2. HYDROLOGICAL STUDIES

2.1 GENERAL

National Highway 5 (N-5), Pakistan's longest and most pivotal highway, spans over 1,800 kilometers, linking Karachi in the south and to Peshawar in the north. As an integral part of the historic Grand Trunk Road, N-5 serves as a critical conduit for trade, transportation, and communication, connecting major urban and industrial centers across the country.

The Rawalpindi-Hassanabdal section, approximately 35 kilometers long, is one of the key stretches of National Highway 5 (N-5). It connects Rawalpindi, a significant suburban area of Islamabad, with Hassanabdal, a historically and economically important town. This corridor plays a crucial role in supporting regional and national economic activity, handling significant freight traffic that moves raw materials and finished goods between major industrial and commercial centers. Additionally, it facilitates daily commuters and intercity travelers, enhancing connectivity across the region. The strategic importance of this section underscores its role as a vital link in Pakistan’s transportation network.

2.2 LOCATION of PROJECT AREA

Rawalpindi, a prominent suburban locality near Islamabad, Pakistan's capital, is strategically positioned along National Highway 5 (N-5). It acts as a key junction linking Islamabad with neighboring cities like Rawalpindi and northern regions of the country. Rawalpindi’s terrain, characterized by the flat to gently rolling features of the Potohar Plateau, includes scattered agricultural fields and small industrial zones. It is known for its vibrant markets, commercial activities, and efficient transport links. Rawalpindi is blend of residential and industrial developments. Due to its strategic location, it makes an essential hub for freight transport and logistical operations.

Hassanabdal, a town of historical importance in Punjab, is also located along National Highway 5 (N-5) at the foothills of the Margalla and Hazara ranges. The town’s diverse landscape of flat plains and rolling hills adds to its scenic appeal. It is renowned for its cultural heritage. Hassanabdal hosts significant landmarks, including the sacred Sikh pilgrimage site Gurdwara Panja Sahib and Mughal-era monuments. Serving as a critical junction between the Potohar Plateau and northern Pakistan, it facilitates trade, travel, and connectivity.

Considering the economic significance of Rawalpindi and Hassanabdal, the client, National Highway Authority (NHA), intends to widen and upgrade the existing metaled road connecting the two locations. This section of National Highway 5 (N-5) plays a crucial role in facilitating trade, transportation, and daily commuting, linking Islamabad and surrounding urban hubs to northern Pakistan. The proposed improvements aim to enhance road capacity, reduce congestion, and ensure a smoother flow of freight and passenger traffic. Upgrading this critical corridor will not only support the growing economic activities in Rawalpindi and Hassanabdal but also strengthen regional connectivity, boosting overall economic efficiency. The approximate length of the road under study is about 35 kilometers. The location map is shown in
Figure 2.1.

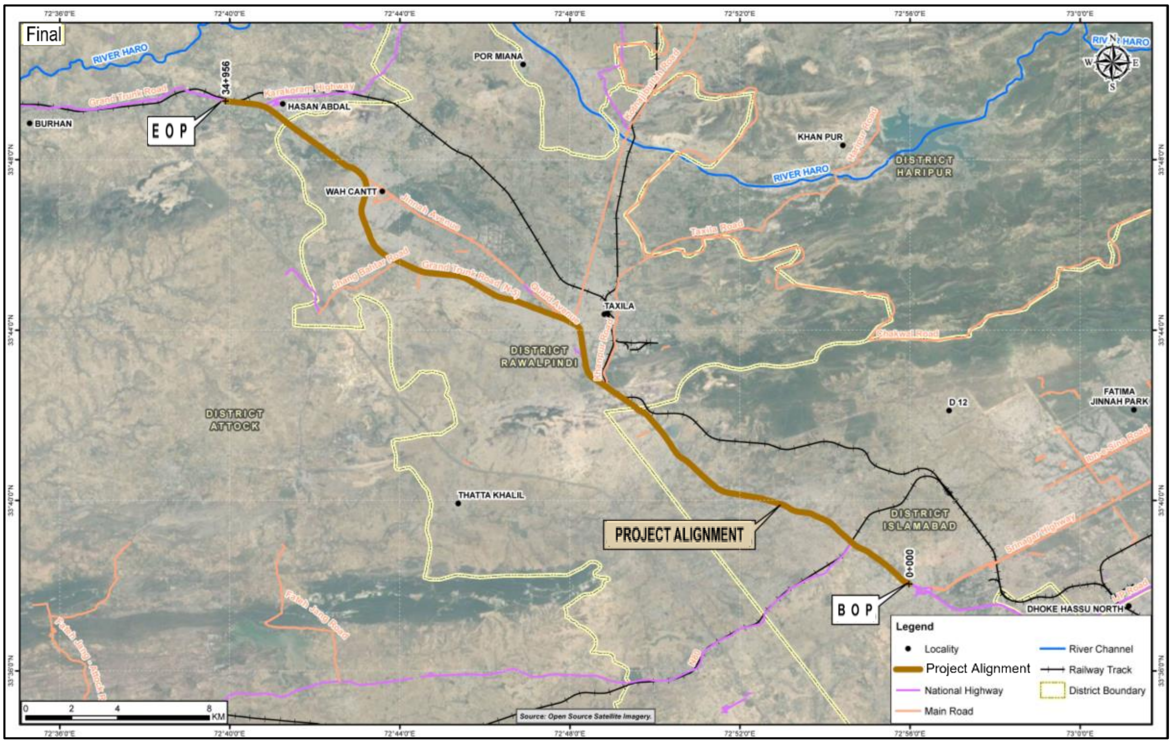

Figure 2.1: Location Map of Project Area

2.3 SCOPE OF HYDROLOGICAL STUDIES

Rawalpindi-Hassanabdal section of National Highway 5 (N-5) is characterized by a varied landscape, blending flat plains with gently rolling hills. The route traverses the Potohar Plateau, which is known for its undulating terrain. As the highway progresses towards Hassanabdal, the terrain begins to gently ascend towards the foothills of the Margalla and Hazara mountain ranges. The road passes through agricultural land, with patches of industrial development along the way.

As per the Term of Reference (ToR) of the project, the scope of hydrological studies includes locating the streams and nullahs etc., crossing the road and estimation of discharges of these streams and nullahs against various return periods.

2.4 CLIMATIC STATIONS IN VICINITY OF PROJECT AREA

There is no discharge gauging for any stream/nullah crossing the road. In the vicinity of the project area there exists one rain gauge station, which is being operated and maintained by Pakistan Meteorological Department (PMD). The location of this station is shown in **Figure 2.2**. Selection of suitable climatic station involves careful considerations to ensure accurate and reliable data available for analysis. Keeping into consideration the appropriate length of data available and its minimum distance from the project area, Islamabad (Zero Point) station has been selected. This station gives a fair representation of the climate of the project area.

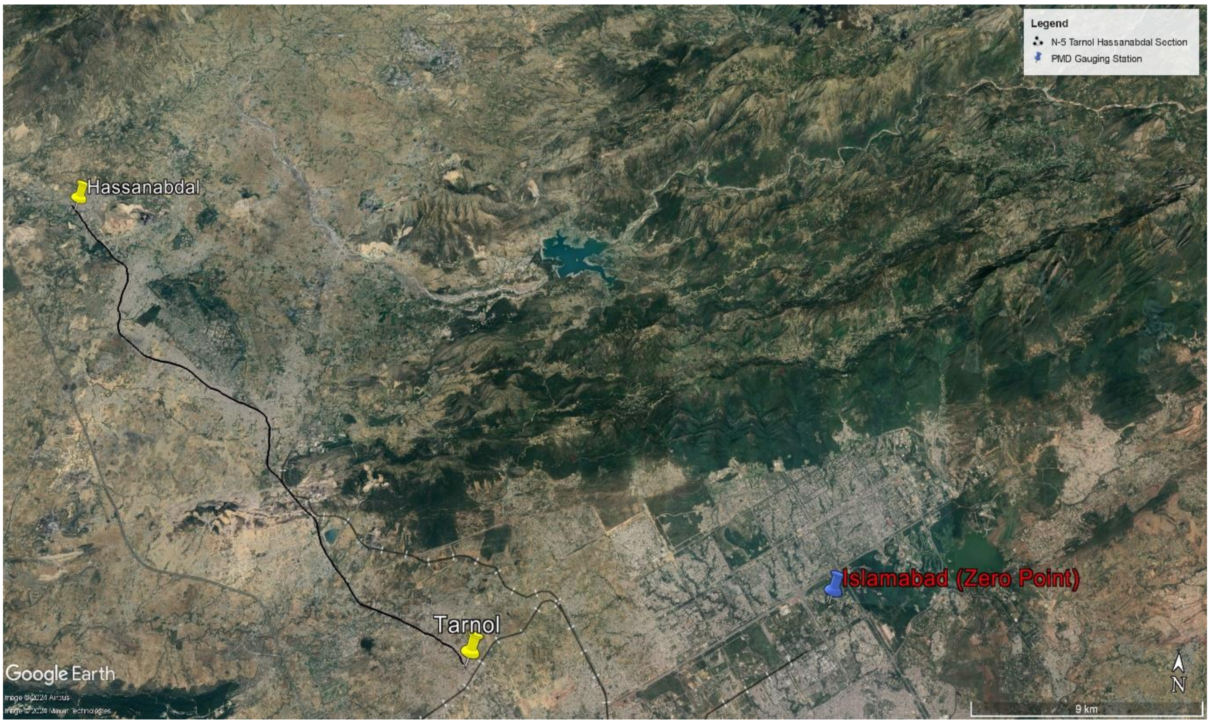

Figure 2.2: Rainfall Gauging Station in Vicinity of Road Section

2.5 CLIMATE OF ISLAMABAD

Islamabad, the capital of Pakistan, is known for its moderate climate, characterized by four distinct seasons: summer, monsoon, autumn, and winter. It is located at the foothills of the Margalla Hills and enjoys a humid subtropical climate with continental influences.

In summer from April to June, temperatures can rise to around 40°C but the evening cools off due to the city's elevation. The monsoon season from July to September brings relief with heavy rains and high humidity, reducing daytime heat, with temperatures ranging from 30°C to 35°C. Autumn from October to November is marked by pleasant, dry weather with clear skies and moderate temperatures between 20°C and 30°C. Winter are from December to February and ranges from cool to mild. The temperature ranges from 3°C to 20°C and nights are occasionally chilly. Snowfall is rare but can occur in the nearby hills.

2.5.1 Precipitation

Mean monthly rainfall data and the number of rainy days recorded at Islamabad Station are given in **Table 2.1.** The average annual rainfall of the area is about 1320.7 mm (Ref.1). While on average the maximum monthly rainfall is 332.0 mm during the month of August and a minimum of 16.4 mm in November. The maximum rainfall occurs during the months of July to September, which is about 61% of the annual rainfall. Winter rains generally occur during the months of January to March, whereas December is normally the month with the least precipitation. The distribution of average monthly rainfall and number of rainy days in Islamabad have been shown in **Figure 2.3** and **Figure 2.4** respectively**.**

Table 2.1: Mean Monthly Rainfall in Islamabad

Months	Precipitation (mm)	Rainy Days (No.)
January	62.2	5.5
February	96.0	7.5
March	95.7	9.0
April	63.7	9.0
May	40.0	7.7
June	78.4	7.9
July	329.6	15.4
August	332.0	14.9
September	144.4	8.6
October	33.4	3.8
November	16.4	2.7
December	28.7	3.3

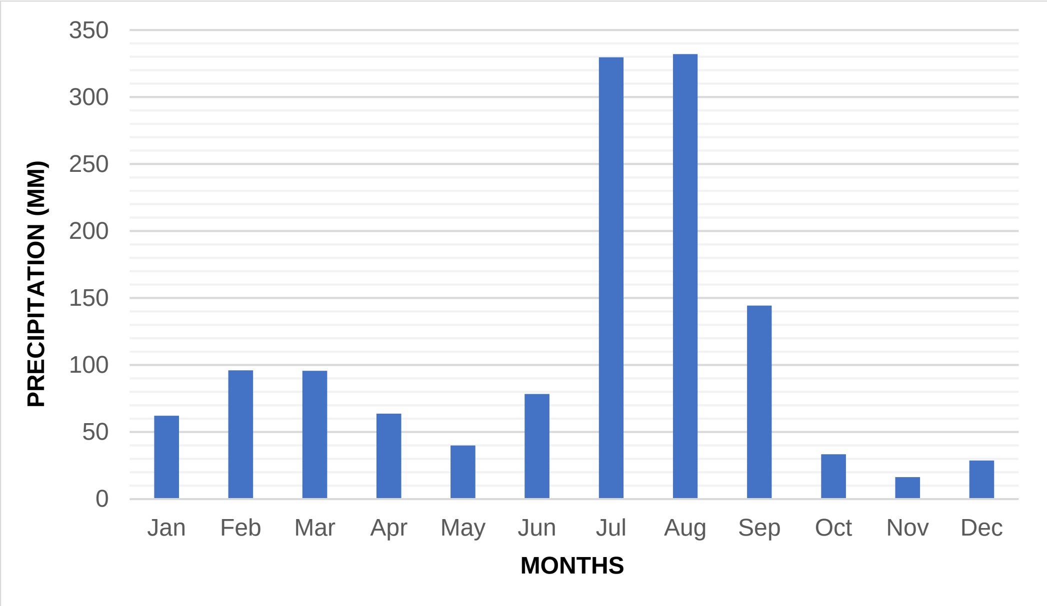

Figure 2.3: Mean Monthly Distribution of Rainfall in Islamabad

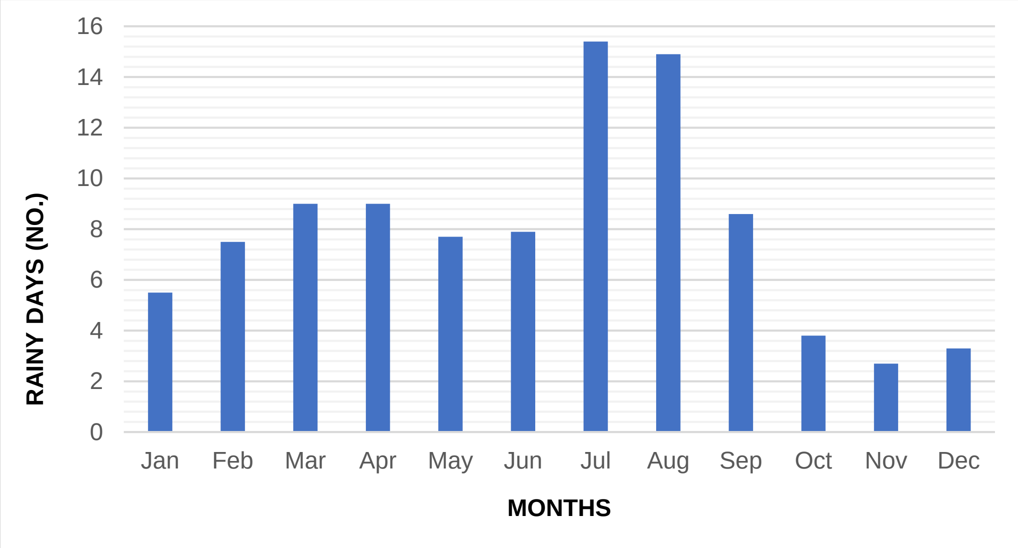

Figure 2.4: Number of Rainy Days in Islamabad

2.5.2 Temperature

The mean daily temperature ranges from (June and July being the hottest month) 26.8ºC to 30.3ºC in the summer season (May to September) and 10.2ºC to 13.3ºC in winter season (December to February). Mean monthly temperature in June and July rises to a highest value of 30.3ºC and falls to the lowest value of 10.2ºC in January. June, July and August are the hottest months in the summer season. December, January and February are the coldest months in the winter season. The monthly averages of minimum, maximum and mean daily temperatures are given in **Table 2.2** and shown graphically in **Figure 2.5**.

Table 2.2: Mean Monthly Temperatures in Islamabad

Month	Min Temp (°C)	Max Temp (°C)	Mean Temp (°C)
January	2.5	18.0	10.2
February	5.7	20.1	13.3
March	10.0	24.8	17.4
April	14.6	30.4	22.5
May	18.9	35.8	27.4
June	22.6	37.9	30.3
July	24.0	35.1	29.4
August	23.5	33.5	28.6
September	20.5	33.0	26.8
October	13.8	30.5	22.2
November	7.6	25.4	16.5
December	3.2	20.6	12.0

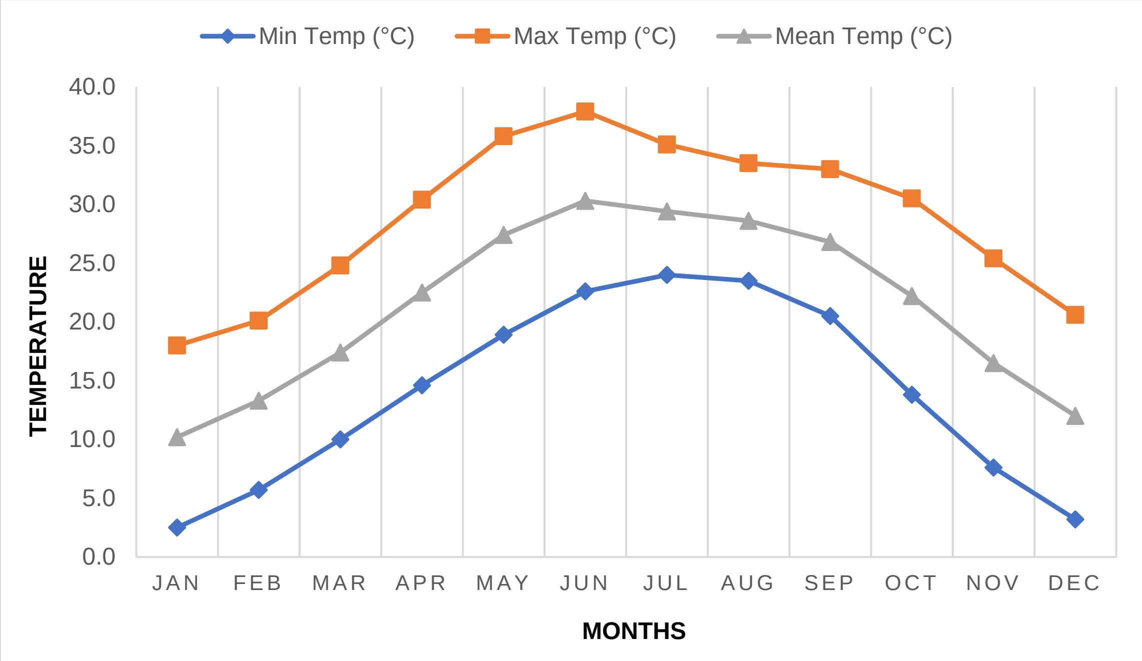

Figure 2.5: Mean Monthly Temperatures in Islamabad

2.5.3 Relative Humidity

The relative humidity data at 00:00, 03:00 and 12:00 hours has been collected from PMD. Mean monthly relative humidity is given in **Table 2.3** and shown graphically in **Figure 2.6**. At 00:00 hour the relative humidity varies from lowest value of 71.8% in May to highest value of 92.7% in November. At 12:00 hour the lowest value is 30.9% in May and highest value of 64.5% in August.

Table 2.3: Mean Monthly Relative Humidity in Islamabad

Month	Relative Humidity (%)		
	00 UTC	03 UTC	12 UTC
January	91.5	90.8	52.7
February	88.6	86.7	48.4
March	86.9	80.7	43.3
April	83.1	69	38.3
May	71.8	54.3	30.9
June	72.7	56.1	34.3
July	86.7	77.3	56.2
August	92.1	84.6	64.5
September	91.5	82.9	58.4
October	91.4	84.8	53.2
November	92.7	89.8	56.4
December	92.6	92.1	55.3

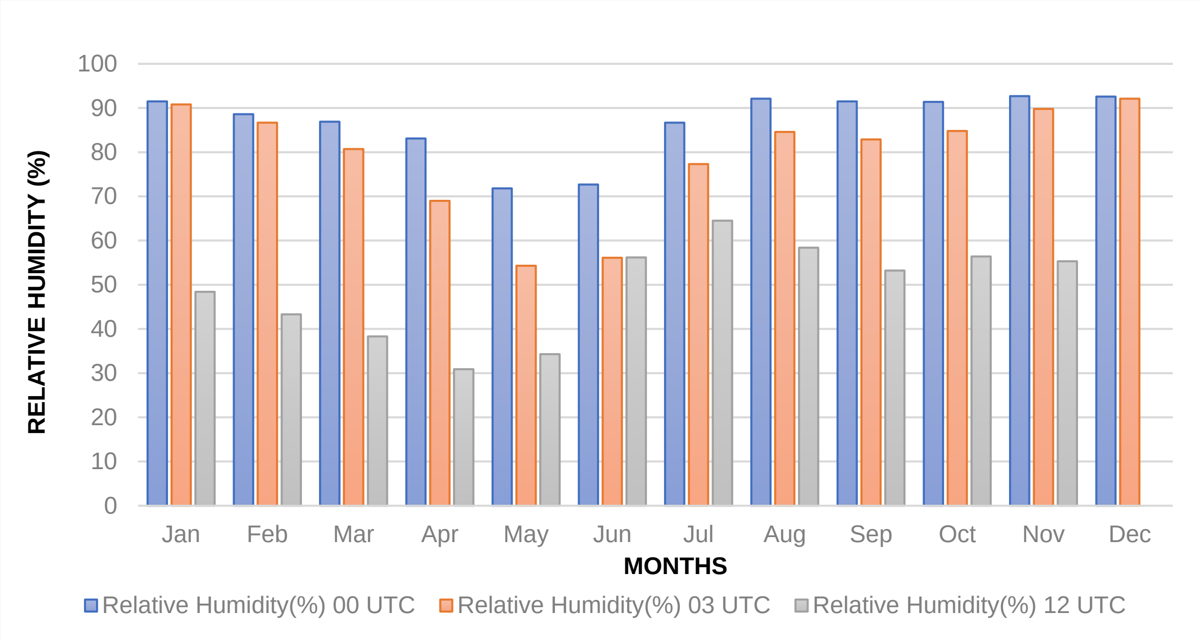

Figure 2.6: Monthly Relative Humidity in Islamabad

2.5.4 Wind Speed

The mean monthly wind speed in knots is given in **Table 2.4** and shown graphically in **Figure 2.7**. The data reveals that at 12:00 hours wind speed is higher. During summers, wind speeds are generally higher than wind speeds in winters.

Table 2.4: Mean Monthly Wind Speed in Islamabad

Month	Mean Wind at Synoptic Hours (Knots)		
	0:00	3:00	12:00
January	0.2	0.2	1.4
February	0.3	0.3	2.4
March	0.5	0.4	2.9
April	0.5	0.6	2.5
May	0.6	0.5	2.5
June	0.4	0.6	2.8
July	0.7	0.6	2.1
August	0.5	0.5	1.3
September	0.2	0.2	0.9
October	0.2	0.1	0.7
November	0.1	0.1	0.4
December	0.1	0.1	0.7

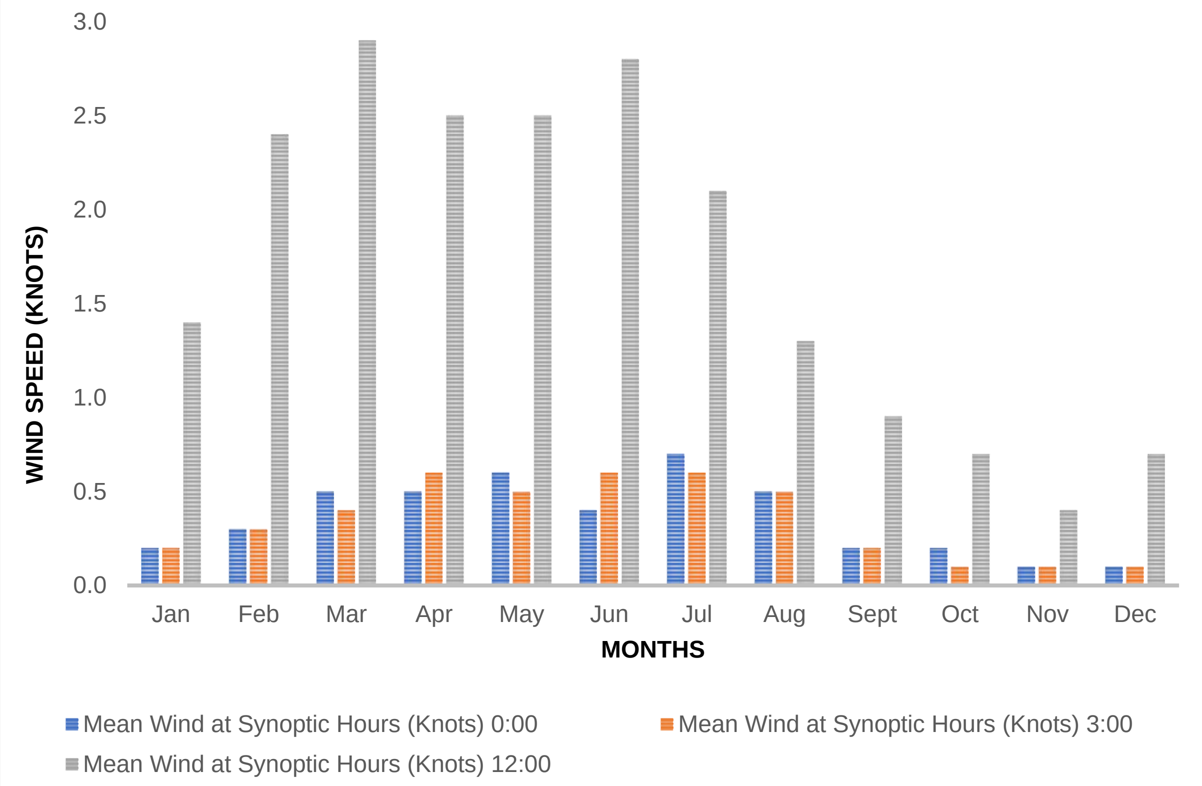

Figure 2.7: Mean Monthly Wind Speed in Islamabad

2.6 ISOHYETAL METHOD

The isohyetal method is a technique used to estimate precipitation over catchment based on observed rainfall data from multiple weather stations. The method involves drawing lines called isohyets which connect points of equal rainfall intensity similar to contour lines on a topographic map. Annual normal rainfall Isohyetal map (1981-2010) has been collected from Pakistan Metrological Department (PMD).

The road section has been overlayed on the isohyetal map. According to this, isohyet of 1000 to 1400 mm rainfall traverses through the project area as shown in **Figure 2.8**.

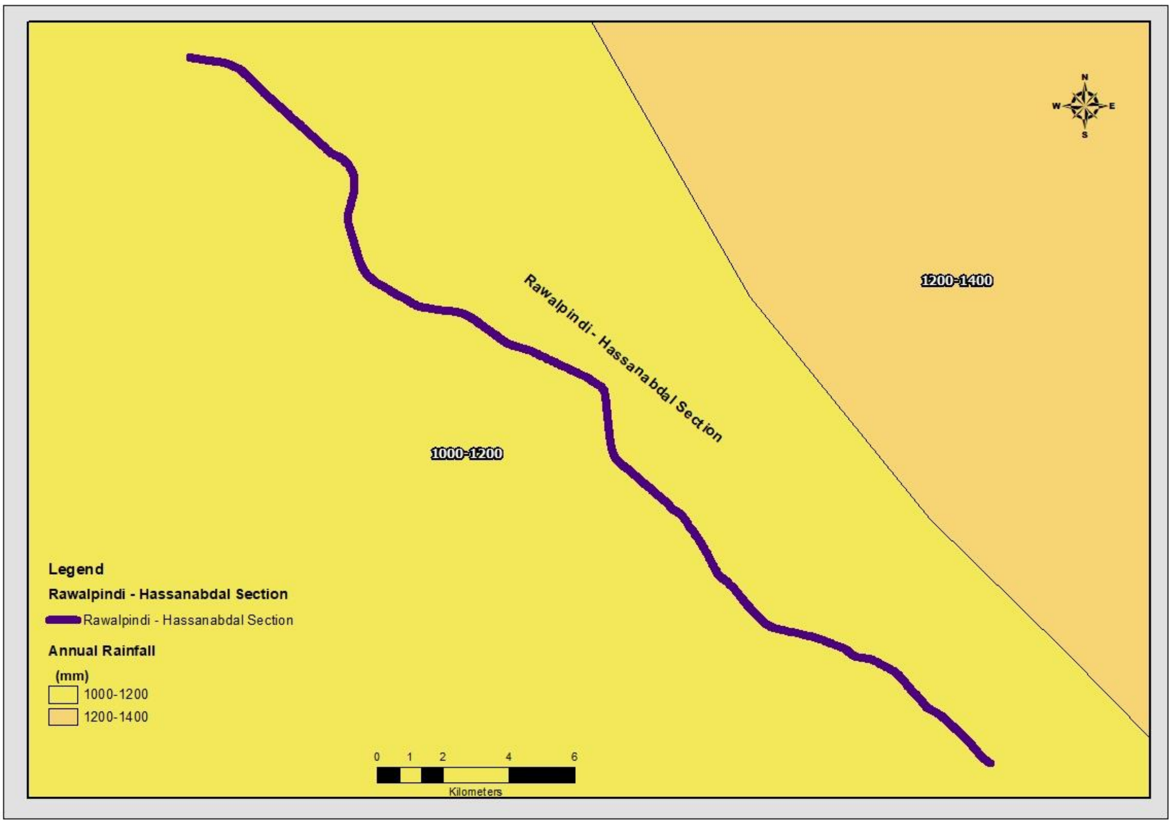

Figure 2.8: Road Section Overlayed on Annual Normal Isohyetal Map

2.7 SOIL PROPERTIES OF PROJECT AREA

Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration. The soil type and land cover play a crucial role in the rainfall-runoff model and require comprehensive evaluation. Surface runoff is influenced by factors such as rainfall intensity and duration, weather conditions (including temperature), soil properties, vegetation cover, land use patterns, initial soil moisture content, entrapped air, and the depth of the groundwater table.

Vegetation cover serves to mitigate the impact of rain drops and enhances infiltration rates, whereas built-up areas and rocky surfaces tend to increase runoff. To accurately assess these factors, various sources of information are utilized, including maps of soil surveys from Pakistan, global land use datasets, field investigations, and satellite imagery.

Natural Resources Conservation Services (NRCS) divides soils into four hydrologic soil groups based on infiltration rates (Groups A-D).

Group A: Group A soils have a low runoff potential due to high infiltration rates even when saturated (0.30 in/hr. to 0.45 in/hr. or 7.6 mm/hr. to 11.4 mm/hr.). These soils primarily consist of deep sands, deep loess, and aggregated silts.

Group B: Group B soils have a moderately low runoff potential due to moderate infiltration rates when saturated (0.15 in/hr. to 0.30 in/hr. or 3.8 mm/hr. to 7.6 mm/hr.). These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (shallow loess, sandy loam).

Group C: Group C soils have a moderately high runoff potential due to slow infiltration rates (0.05 in/hr. to 0.5 in/hr. or 1.3 mm/hr. to 3.8 mm/hr. if saturated). These soils primarily consist of soils in which a layer near the surface impedes the downward movement of water or soils with moderately fine to fine texture such as clay loams, shallow sandy loams, soils low in organic content, and soils usually high in clay.

Group D: Group D soils have a high runoff potential due to very slow infiltration rates (less than 0.05 in./hr. or 1.3 mm/hr. if saturated). These soils primarily consist of clays with high swelling potential, soils with permanently high-water tables, soils with a clay pan or clay layer at or near the surface, shallow soils over nearly impervious parent material such as soils that swell significantly when wet or heavy plastic clays or certain saline soils.

The soil properties of the project area are shown by **Figure 2.9**.

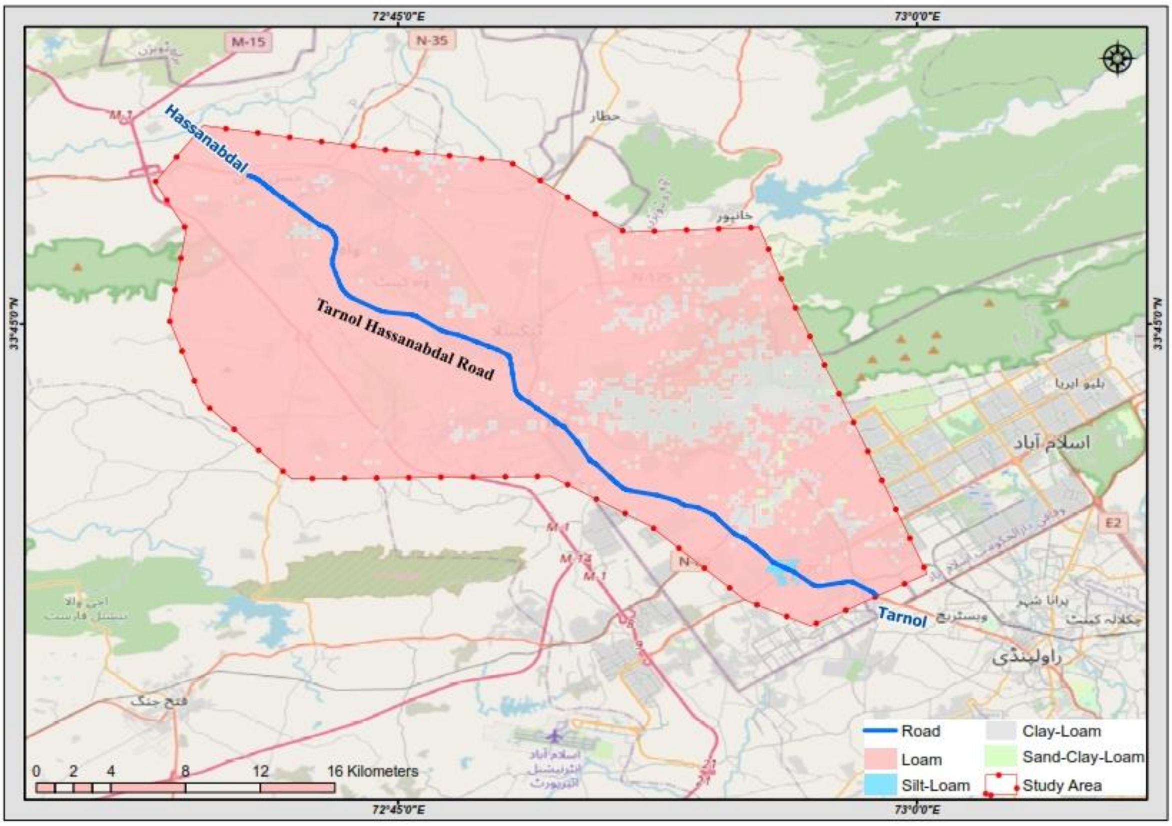

Figure 2.9: Soil Properties of Rawalpindi - Hassanabdal Road Section

2.8 LAND USE PROPERTIES OF PROJECT AREA

The land use is used for watershed delineation of project catchment. All the major categories are marked, and CN numbers are given accordingly. In addition to that, these maps illustrate the Hydraulic Soil Type within the project area, derived from remote sensing data, the Soil

Survey Map of Pakistan, and on-site verification. These maps are instrumental in characterizing the soil properties critical for hydraulic modeling and infrastructure planning.

Land use maps provide critical input for modelling runoff and designing effective water management strategies. The Anderson Land use classification is given below:

- Bare Areas
- Built up Areas
- Waterbodies
- Cropland
- Grassland
- Shrubland
- Tree covers

The land use properties of the project area are shown in **Figure 2.10**.

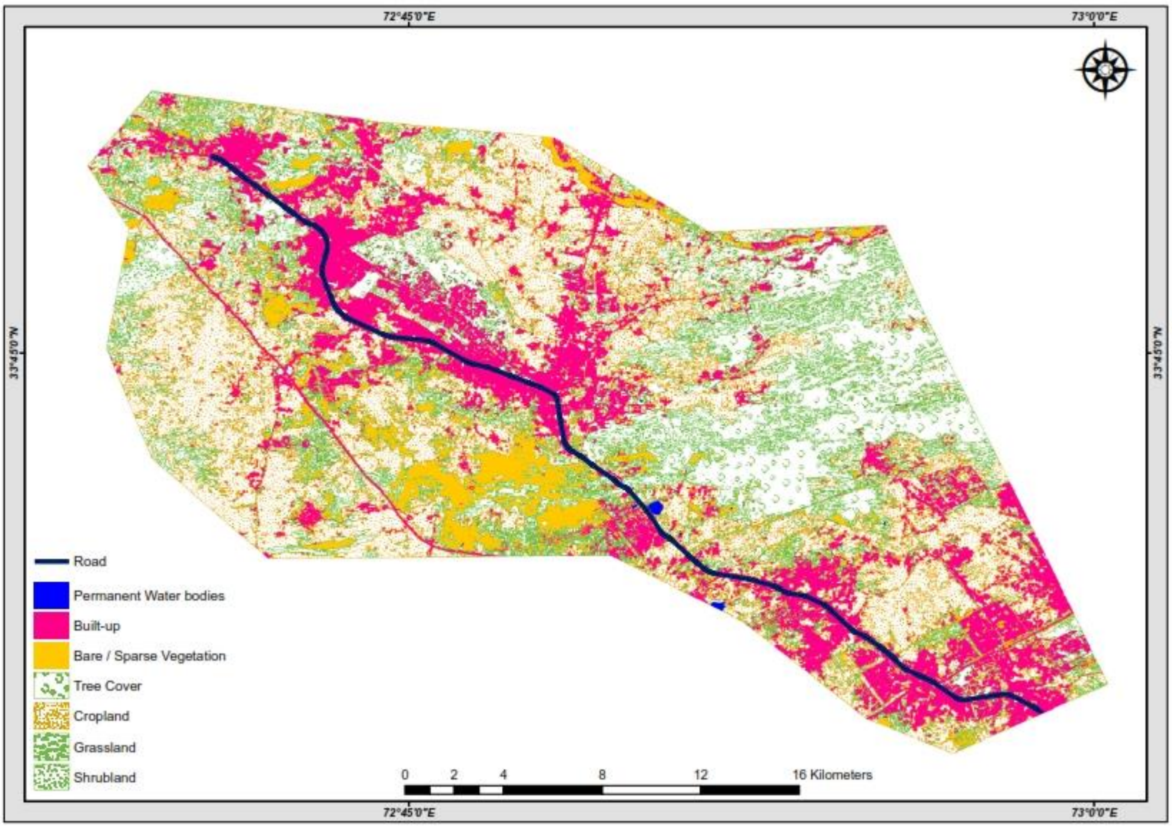

Figure 2.10: Land Use Properties of Rawalpindi - Hassanabdal Road Section

2.9 CATCHMENT AREA DELINEATION AND GENERATION OF STREAM NETWORK

Catchment characteristics can be sub-divided mainly into two categories i.e., physical characteristics and hydrological characteristics. Physical characteristics of the catchment include catchment area, length and weighted slope of the longest stream draining to the point of interest. These physical characteristics have been determined from the topographic maps of 1:50,000 scale and Digital Elevation Model (DEM) obtained from Shuttle Radar Topographic Mission (SRTM) and GLO-30. The catchment areas of all the desired points have been marked using DEM data and have been verified using topographic maps.

Stream network development using Digital Elevation Models (DEMs) is a foundational technique in hydrology for mapping and analyzing water flow paths across a landscape. DEMs provide a digital graphical representation of terrain, capture variations in land elevation, enabling detailed analysis of water movement and channel formation. Flow direction and flow accumulation has been identified by using this technique. For Rawalpindi Hassanabdal road section, Arc-Hydro and Topaz tools have been used for generating stream network by GLO-30 Dem.

Defining the catchment area of the generated stream network is known as watershed delineation. The longitudinal slopes and lengths of the natural streams/nullahs have been determined from the topographic maps, DEM data and by using tools i.e. WMS (Water Management System) and Arc-Hydro. The hydrologic characteristics of the catchments, i.e., conditions of the area; soil cover, land use, soil type and extent, and other flow controlling parameters have been investigated through soil maps and satellite imagery. **Figure 2.11**, **Figure 2.12** represent the stream network and catchment area delineation respectively by above mentioned techniques.

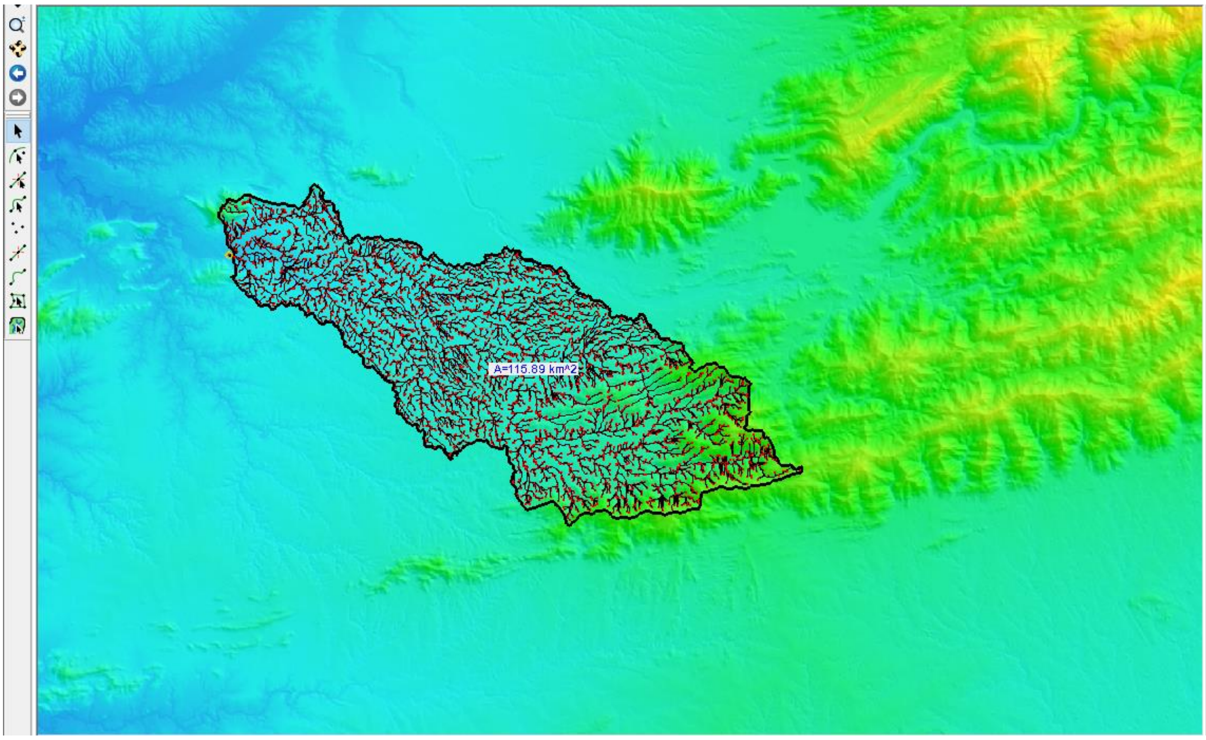

Figure 2.11:Stream Network Generation and Watershed Delineation using Topaz Tool

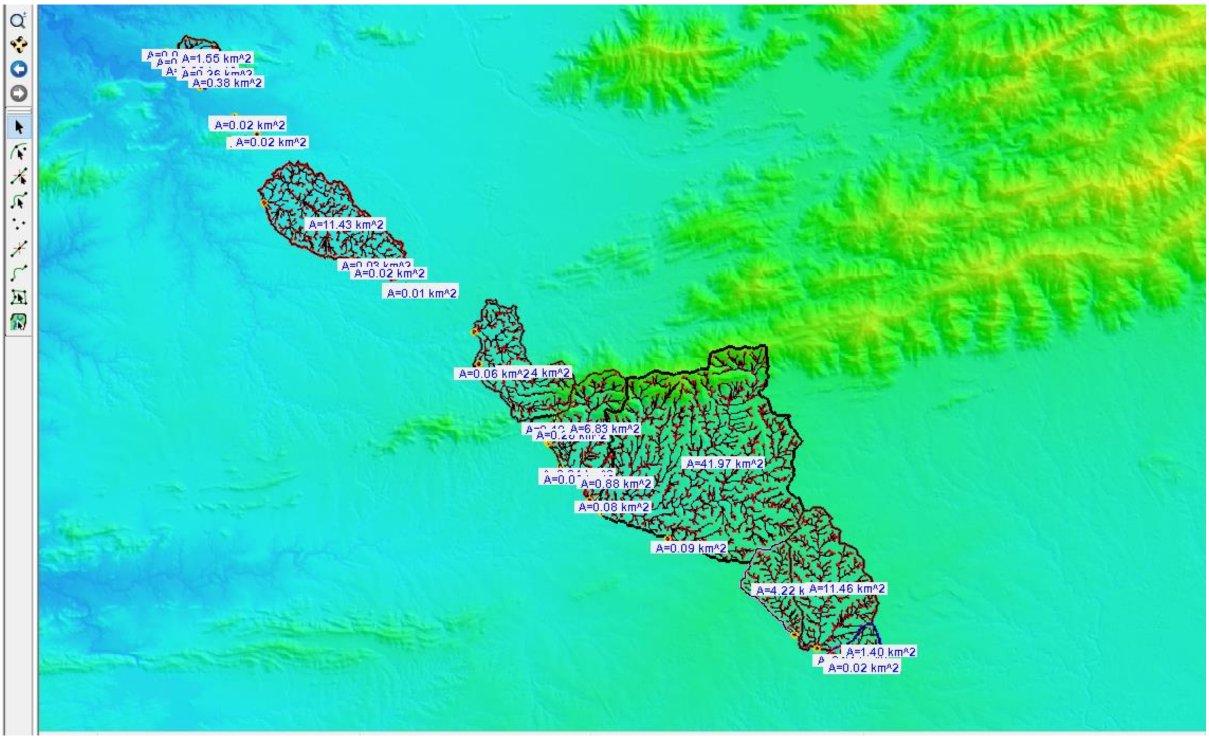

Figure 2.12: Stream Network Generation and Watershed Delineation using Topaz Tool

2.10 HYDRO-METROLOGICAL DATA USED

The flood study for a location depends upon the hydro-meteorological data of the location/area. For gauged locations, recorded data is used to estimate peak flood discharges, whereas, for ungauged locations synthetic storm is used which is estimated with recorded intense rainfall events in the area. In case of non-availability of rainfall data in the study area, the data of a station in the vicinity with similar climatic conditions is synthesized over study area.

The discharge data for the streams flowing in the proposed project area is not available. Thus, studies for the computation of the flood discharges have been carried out using rainfall data.

One-day annual maximum rainfall data of Islamabad stations has been collected from Pakistan Metrological Department and their inventory is given in **Table 2.5**.

Table 2.5: Inventory of Rainfall Gauging Stations

Sr. No.	Station	Data Type	Data Period (Years)	Agency
Rainfall Gauging Stations				
1	Islamabad Zero Point	One Day Annual Maximum Rainfall	1994-2023	PMD

2.11 ANALYSIS OF RAINFALL DATA

Islamabad (Zero Point)

One-day annual maximum rainfall data of Islamabad is available for 1994-2023 (30 years) as given in **Table 2.6**.

Table 2.6: 1-Day Annual Rainfall in Islamabad

Year	Rainfall (mm)	Year	Rainfall (mm)
1994	170.0	2009	82.0
1995	149.4	2010	120.0
1996	163.0	2011	126.0
1997	200.0	2012	127.0
1998	95.0	2013	124.0
1999	94.0	2014	298.0
2000	82.0	2015	132.0
2001	200.0	2016	69.0
2002	70.0	2017	72.0
2003	80.0	2018	163.4
2004	135.0	2019	83.1
2005	50.0	2020	97.1
2006	138.0	2021	169.0
2007	158.0	2022	85.0
2008	82.0	2023	110.0

Historic data since 1994 suggest an average value of 124.1 mm, the maximum magnitude of rainfall witnessed till date is 298.0 mm in year 2014. **Figure 2.13** shows the trends of annual maximum rainfalls observed at Islamabad Zero Point station.

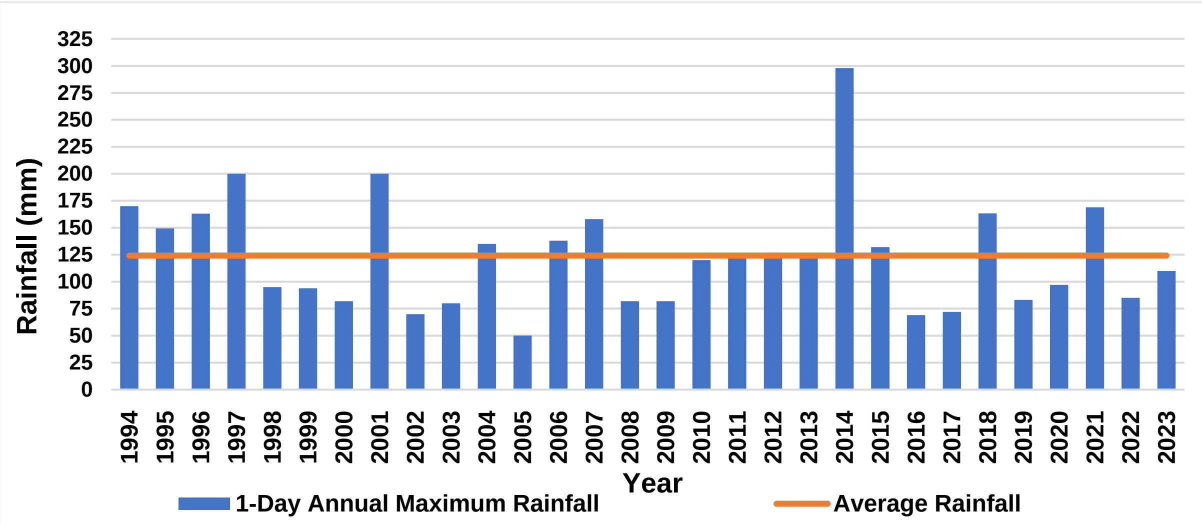

Figure 2.13: One-Day Annual Maximum Rainfall in Islamabad

2.12 FREQUENCY ANALYSIS OF RAINFALL DATA

Frequency analysis for the 1-day annual maximum rainfall data of Islamabad Zero Point station has been carried out using Log-Person-III distribution.

The Log-Pearson Type III (LP-III) distribution is a three-parameter probability model commonly used in hydrology for frequency analysis of extreme events such as floods and rainfall. It is particularly suitable for datasets with significant skewness, as it incorporates a logarithmic transformation that stabilizes variability and enhances the representation of positively skewed data. The three parameters of the LP-III distribution; location, scale, and shape, offer flexibility in modeling a wide range of hydrological scenarios, including rare and extreme events. This distribution is especially favored in applications where conservative estimates are required, as it provides robust predictions for average conditions while effectively capturing the influence of high values in the data. Widely adopted for designing water resource infrastructure, LP-III has been endorsed by the U.S. Water Resources Council as a standard for flood frequency analysis. Its ability to model both central tendencies and extremes makes it a cornerstone of hydrological statistical methods.

Result of frequency analysis for Islamabad is given in **Table 2.7** and shown graphically by **Figure 2.14**.

Table 2.7: Results of Rainfall Frequency Analysis at Islamabad

Return Period (years)	**Rainfall Depth** (mm)
2.33	113.9
5	159.3
10	191.2
25	224.0
50	271.9
100	313.7
500	441.0

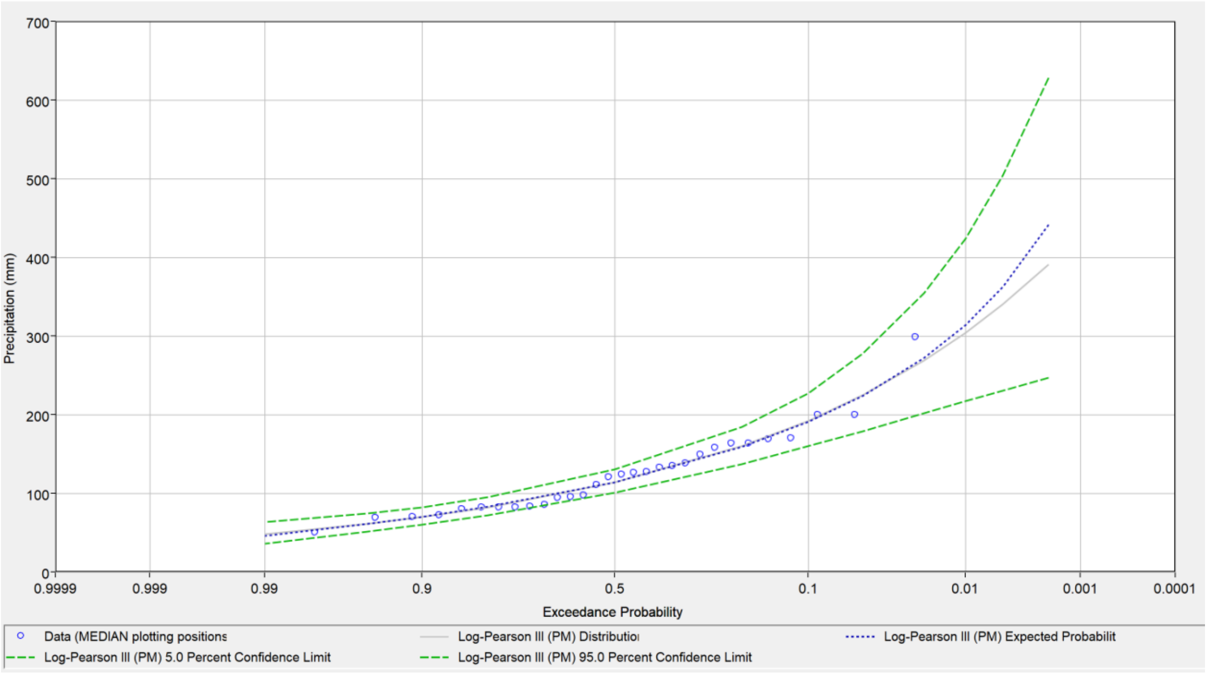

Figure 2.14: Frequency Fitting of 1-Day Annual Maximum Rainfall at Islamabad

2.13 DESIGN FLOOD ESTIMATION

Design flood for the streams crossing the road has been estimated by using three methods:

- Synthetic Hydrograph Method
- Rational Method

2.14 SYNTHETIC HYDROGRAPH METHOD

For catchments having area greater than 1km^2, US Soil Conservation Services Unit Hydrograph Method (SCS-UH) has been used to estimate peak discharges. This method requires the following information about the catchment.

- Maximum 24-hour rainfall for the design return period
- Length of stream measured along the longest path travelled by storm water from head to the site
- Slope of stream from head to site
- Catchment area
- Antecedent soil moisture condition
- Soil group

Maximum discharge is calculated from the following formulae:

$$S = \frac{1000}{CN - 10}$$

$$Q = \frac{(P-0.2S)^2}{P + 0.8S}$$

$$t_c = 0.00013 \times \frac{L^{0.77}}{m^{0.385}}$$

$$D = 0.133 \times t_c$$

$$t_p = \frac{D}{2} + (0.6 \times t_c)$$

$$Q_p = \frac{484 \times A \times Q}{t_p}$$

Where;

S	=	Potential maximum retention
CN	=	Curve number
Q	=	Volume of runoff in inches
P	=	Maximum 24 hours rainfall in inches of the required return period
L	=	Length of longest stream in feet
m	=	Slope of the stream
t_c	=	Time of concentration in hours
t_p	=	Time to peak in hours
D	=	Unit storm duration in hours
Q_p	=	Peak rate of flow in cusecs
A	=	Catchment area in sq. miles.

Time of Concentration

Time of concentration (Tc) is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. Kirpich formula has been used for computation of time of concentration which is given below:

$$Tc = \frac{(L)^{1.15}}{7700*(H)^{0.385}}$$

Where;

T_c	=	Time of Concentration (hours)
L	=	Length of the longest stream (feet)
H	=	Fall in length L (feet)

Selection of Curve Number

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for estimation of initial abstraction. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based on the area's hydrologic soil group, land-use, treatment and hydrologic condition. The USNRCS equation for conversion of rainfall into runoff is given hereunder:

$$\text{Runoff} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where;

P = Daily rainfall (inches)

S = Potential maximum retention after runoff begins $\left(\frac{1000}{CN-10}\right)$

Time Distribution of Rainfall Storm

Total storm rainfall determines the magnitude of flood, while its pattern gives the shape of hydrograph. The storm pattern of rainfall is used as a relationship between time and rainfall which is as stated below:

$$P_t = \left(\frac{t}{24}\right)^n$$

Where P_t is ratio of rainfall at time 't' with 24-hr rainfall, t is time in hours and n is an exponent depending on hourly rainfall pattern.

2.15 RATIONAL METHOD

For the catchments having area less than 1km^2 rational method has been used to compute the floods. Rational method technique is described as under:

$$Q = CIA$$

Where;

Q = Peak discharge (cusecs)
C= Coefficient of discharge
I = Intensity of rainfall (mm/hour)
A = Catchment area (acres)

Runoff Coefficient (C)

The catchment area of the crossings consists of settlements as well as agricultural land. Therefore, runoff coefficient for the catchments has been taken keeping in view its soil cover and future land use.

Rainfall Intensity

Rainfall intensity is defined as the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period. It is expressed in depth units per unit time, usually as mm/hour or inch/hour. The use of uniform rainfall intensity for duration equal to the time of concentration is a simplifying assumption since rainfall does not truly persist at a uniform intensity for even a short time like 5 min. Rainfall intensity has been calculated by the formula given below.

$$\text{Rainfall Intensity} = \frac{\text{Rainfall magnitude in a duration equal to time of concentration}}{T_c}$$

Intensity-Duration-Frequency curves have been developed for Islamabad rain gauging station and shown in **Figure 2.15**. The rainfall distribution with time is then re-oriented to have a centrally loaded rainfall pattern.

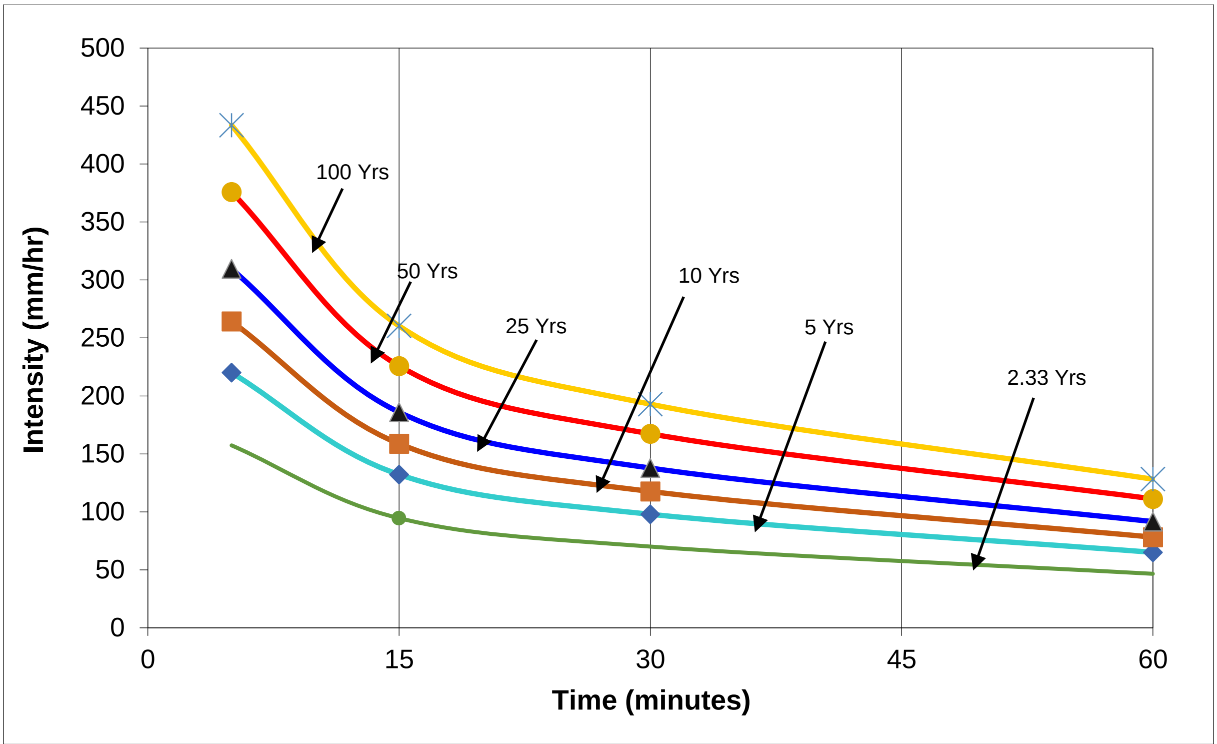

Figure 2.15: Intensity-Duration-Frequency Curve for Islamabad

2.16 FLOOD DISCHARGES

The floods estimated against various return periods for the streams crossing the Rawalpindi – Hassanabdal road section are given in **Table 2.8.**

Table 2.8: Discharges against Various Return Periods

Sr. No	Catchment RD's	Existing Structure	Catchment Area (km^2)	Peak Flood Discharges (cumecs)			Remarks
				25 yrs	50 yrs	100 yrs	
1		1545+780					Local Flow
2	1548+000 to 1549+600	1549+160	1.790	12	15	17	
3	1549+600 to 1550+500	1550+225	0.420	13	16	18	

Sr. No	Catchment RD's	Existing Structure	Catchment Area	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
			(km²)	cumecs			
4		1550+655					Local Flow
5	1550+655 to 1551+400	1550+735	10.80	110	145	177	
6	1551+400 to 1554+500	1551+715	4.230	52	69	85	
7		1551+977					Local Flow
8		1552+845					Local Flow
9		1555+520					Local Flow
10		1556+475					Local Flow
11		1556+575					Local Flow
12		1557+620					Local Flow
13		1558+435					Local Flow
14		1558+638					Local Flow
15	1554+500 to 1560+500	1560+300	42.300	394	523	637	
16	1560+400 to 1560+700		0.100	4	4	5	
17	1560+700 to 1560+800		0.004	0.14	0.17	0.20	
18	1560+800 to 1561+200	1560+970	0.910	13	15	18	
19	1561+200 to 1561+400		0.002	0.07	0.09	0.10	
20	1561+200 to 1561+300 (Left Side)		0.001	0.04	0.04	0.05	
21	1561+300 to 1561+400 (Left Side)		0.002	0.07	0.09	0.10	
22	1561+500 to 1563+400	1561+855	6.870	92	124	153	
23		1562+170					Local Flow
24	1563+400 to 1563+650	1563+520	0.250	8	10	12	
25	1563+650 to 1564+450	1563+690	0.470	17	20	23	
26		1564+050					Local Flow
27		1564+130					Local Flow

Sr. No	Catchment RD's	Existing Structure	Catchment Area (km^2)	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
				cumecs			
28	1564+450 to 1564+700		0.010	0.36	0.43	0.50	
29	1564+700 to 1564+800		0.010	0.36	0.43	0.50	
30	1564+600 to 1564+800 (Left Side)		0.010	0.36	0.43	0.50	
31	1564+800 to 1564+900 (Left Side)		0.022	0.8	0.9	1.1	
32	1564+900 to 1565+100 (Left Side)		0.110	4	5	5	
33	1564+800 to 1565+100		0.050	1.8	2.2	2.5	
34		1566+200					Local Flow
35		1566+965					Local Flow
36		1567+510					Local Flow
37	1565+200 to 1568+900	1568+690	8.100	104	136	164	
38	1567+200 to 1567+500 (Left Side)	1567+510	0.030	1.1	1.3	1.5	
39	1569+900		0.001	0.04	0.04	0.05	
40	1569+960		0.002	0.07	0.09	0.10	
41	1570+000		0.002	0.07	0.09	0.10	
42	1570+050		0.002	0.07	0.09	0.10	
43	1570+100		0.003	0.11	0.13	0.15	
44	1570+200		0.004	0.14	0.17	0.20	
45	1571+700 to 1571+820	1571+820	0.040	1.4	1.7	2.0	
46		1573+200					Local Flow
47	1572+300 to 1578+600	1578+120	11.400	116	150	180	
48		1580+755					Local Flow
49	1579+700 to 1581+800	1581+745	116.000	510	648	770	
50	1580+800 to 1580+900 (Left Side)		0.040	1.4	1.7	2.0	

Sr. No	Catchment RD's	Existing Structure	Catchment Area	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
			(km^2)	cumecs			
51	1581+000 to 1581+200 (Left Side)		0.040	1.4	1.7	2.0	
52	1581+200 to 1581+300 (Left Side)		0.050	1.8	2.2	2.5	
53	1581+350 to 1581+500 (Left Side)		0.150	5.3	6.5	7.5	
54	1581+500 to 1581+600 (Left Side)		0.100	3.6	4.3	5.0	
55	1581+600 to 1581+700 (Left Side)		0.040	1.4	1.7	2.0	
56	1583+300 to 1583+500	1583+460	0.380	14	16	19	
57	1583+600 to 1583+900	1583+960	0.350	12	15	17	
58	1583+900 TO 1584+300	1584+250	0.150	5	6	7	
59		1584+660					Local Flow
60		1584+685					Local Flow
61	1583+300 to 1584+730	1584+715	1.600	46	63	78	
62	1585+100 to 1585+300	1585+175	0.030	1.1	1.3	1.5	

2.17 FLOOD DISCHARGES WITH CLIMATE EFFECT

The floods estimated against various return periods with climate change effect under SSP 585 for the streams crossing the road are given in **Table 2.9.**

Table 2.9: Discharges with Climate Impact SSP 585 against Various Return Periods

Sr. No	Catchment RD's	Existing Structure	Catchment Area	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
			(km^2)	cumecs			
1		1545+780					Local Flow
2	1548+000 to 1549+600	1549+160	1.790	12	15	18	

Sr. No	Catchment RD's	Existing Structure	Catchment Area (km²)	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
				cumecs			
3	1549+600 to 1550+500	1550+225	0.420	13	16	19	
4		1550+655					Local Flow
5	1550+655 to 1551+400	1550+735	10.80	116	154	188	
6	1551+400 to 1554+500	1551+715	4.230	55	74	90	
7		1551+977					Local Flow
8		1552+845					Local Flow
9		1555+520					Local Flow
10		1556+475					Local Flow
11		1556+575					Local Flow
12		1557+620					Local Flow
13		1558+435					Local Flow
14		1558+638					Local Flow
15	1554+500 to 1560+500	1560+300	42.300	417	554	675	
16	1560+400 to 1560+700		0.100	4	4	5	
17	1560+700 to 1560+800		0.004	0.15	0.18	0.21	
18	1560+800 to 1561+200	1560+970	0.910	13	16	19	
19	1561+200 to 1561+400		0.002	0.07	0.09	0.10	
20	1561+200 to 1561+300 (Left Side)		0.001	0.04	0.04	0.05	

Sr. No	Catchment RD's	Existing Structure	Catchment Area	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
			(km^2)	cumecs			
21	1561+300 to 1561+400 (Left Side)		0.002	0.07	0.09	0.10	
22	1561+500 to 1563+400	1561+855	6.870	98	132	162	
23		1562+170					Local Flow
24	1563+400 to 1563+650	1563+520	0.250	9	11	12	
25	1563+650 to 1564+450	1563+690	0.470	17	21	24	
26		1564+050					Local Flow
27		1564+130					Local Flow
28	1564+450 to 1564+700		0.010	0.37	0.45	1	
29	1564+700 to 1564+800		0.010	0.37	0.45	1	
30	1564+600 to 1564+800 (Left Side)		0.010	0.37	0.45	1	
31	1564+800 to 1564+900 (Left Side)		0.022	0.8	1.0	1.1	
32	1564+900 to 1565+100 (Left Side)		0.110	4	5	6	
33	1564+800 to 1565+100		0.050	2	2	3	
34		1566+200					Local Flow
35		1566+965					Local Flow
36		1567+510					Local Flow

Sr. No	Catchment RD's	Existing Structure	Catchment Area (km^2)	Peak Flood Discharges cumecs			Remarks
				25 yrs	50 yrs	100 yrs	
37	1565+200 to 1568+900	1568+690	8.100	110	143	173	
38	1567+200 to 1567+500 (Left Side)	1567+510	0.030	1.1	1.3	1.6	
39	1569+900		0.001	0.04	0.04	0.05	
40	1569+960		0.002	0.07	0.09	0.10	
41	1570+000		0.002	0.07	0.09	0.10	
42	1570+050		0.002	0.07	0.09	0.10	
43	1570+100		0.003	0.11	0.13	0.16	
44	1570+200		0.004	0.15	0.18	0.21	
45	1571+700 to 1571+820	1571+820	0.040	1.5	1.8	2.1	
46		1573+200					Local Flow
47	1572+300 to 1578+600	1578+120	11.400	122	158	189	
48		1580+755					Local Flow
49	1579+700 to 1581+800	1581+745	116.000	535	681	809	
50	1580+800 to 1580+900 (Left Side)		0.040	1.5	1.8	2.1	
51	1581+000 to 1581+200 (Left Side)		0.040	1.5	1.8	2.1	
52	1581+200 to 1581+300 (Left Side)		0.050	1.8	2.2	2.6	
53	1581+350 to 1581+500 (Left Side)		0.150	5.5	6.7	7.8	
54	1581+500 to 1581+600 (Left Side)		0.100	3.7	4.5	5.2	

Sr. No	Catchment RD's	Existing Structure	Catchment Area	Peak Flood Discharges			Remarks
				25 yrs	50 yrs	100 yrs	
			(km^2)	cumecs			
55	1581+600 to 1581+700 (Left Side)		0.040	1.5	1.8	2.1	
56	1583+300 to 1583+500	1583+460	0.380	14	17	20	
57	1583+600 to 1583+900	1583+960	0.350	13	16	18	
58	1583+900 TO 1584+300	1584+250	0.150	6	7	8	
59		1584+660					Local Flow
60		1584+685					Local Flow
61	1583+300 to 1584+730	1584+715	1.600	48	66	82	
62	1585+100 to 1585+300	1585+175	0.030	1.1	1.3	1.6	

3. HYDRAULIC DESIGN OF CROSS DRAINAGE STRUCTURES

3.1 SCOPE OF HYDRAULIC STUDIES

Culverts and bridges are normally provided as cross drainage structures where natural drain i.e. river, stream or nullah crosses the roadway. Here in the reach of this project road total 36 structures are provided comprising box culverts and bridges in order to pass natural streams and storm water nullahs.

Considering the estimated discharges concluded by hydrologic studies, hydraulic analyses for storm-water drainage through the existing seventeen (17) box culverts, twelve (12) pipe culverts and eight (8) bridges have been carried out by adopting comprehensive methodology for each structure which described in the subsequent sections.

3.2 DESIGN APPROACH FOR THE CULVERTS AND BRIDGES

Keeping in view the site requirements and the compatibility of the terrains of the project area, hydraulic design review of the storm-water drainage structures comprising existing box culverts, pipe culverts and bridges have been carried out using manning's approach by extracting required input parameters from available road layout plans, natural topographic, google earth maps and previous design report[1] provided by the Client. All the existing culverts along the road have been analyzed considering the provided condition survey of the structures, wherein, fair conditioned box culverts with required flow capacity have been retained while with insufficient capacity box culverts have been proposed to add specified barrel with the culverts. The eight bridges are also analyzed based on manning's approach due to non-availability of nullahs cross sectional survey.

Summary of cross drainage structures including retained and proposed culverts and bridges along with suggested remarks to be adopted for each structure for the project, based on of hydraulic analyses are given in the **Table 3.1** as follows:

Table 3.1: Summary of Existing Cross Drainage Structures

Sr. No.	Structure I.D	Road Chainage	Estimated SSP 5-8.5 Discharge (m^3/sec)	Existing Structure				Estimated Capacity (m^3/sec)		Capacity Check	Remarks
				Roadside	No. of Cell / Span	Span / width (m)	Height (m)	Individual	Combined		
1	PC-1	1545+780	-	-	1	0.8	-	1.33	1.33	-	Local Flow
2	BC-1	1549+160	12	-	1	3.35	2.3	16.49	16.49	Capacity OK	Cleaning and Maintenance Required
3	BC-1	1550+225	13	-	1	2	1.5	14.54	14.54	Capacity OK	-
4	PC-2	1550+655	-	-	1	0.3	-	0.14	0.14	-	Local Flow
3	BR-01	1550+735	188	-	3	6+10.35+6	3.35	271	271	Capacity OK	Cleaning and Maintenance Required
4	BR-02	1551+715	90	-	1	10	9	156.32	156.32	Capacity OK	Cleaning and Maintenance Required
5	BC-2	1551+977	-	-	1	1.5	1	4.16	4.16	-	Local Flow
6	BC-3	1552+845	-	-	1	1	1	2.22	2.22	-	Local Flow
7	BC-4	1555+520	-	-	1	1.5	1	3.93	3.93	-	Local Flow
8	PC-3	1556+475	-	-	1	0.61	-	0.45	0.45	-	Local Flow
9	PC-4	1556+575	-	-	1	0.61	-	0.46	0.46	-	Local Flow
10	PC-5	1557+620	-	-	1	0.61	-	0.51	0.51	-	Local Flow
11	PC-6	1558+435	-	-	1	0.85	-	1.19	1.19	-	Local Flow
12	BC-5	1558+638	-	-	1	2.5	2.5	22.17	22.17	-	Local Flow
13	BR-03	1560+300	675	-	3	13	7	736.32	736.32	Capacity OK	Cleaning and Maintenance Required
14	BC-6	1560+970	13	-	1	5	1.9	31.36	31.36	Capacity OK	-

Sr. No.	Structure I.D	Road Chainage	Estimated SSP 5-8.5 Discharge (m^3/sec)	Existing Structure				Estimated Capacity (m^3/sec)		Capacity Check	Remarks
				Roadside	No. of Cell / Span	Span / width (m)	Height (m)	Individual	Combined		
15	BR-04	1561+855	162	-	1	9.1	8.2	216.64	216.64	Capacity OK	Some Maintenance Required
16	BC-7	1562+170	-	-	1	1	5	15.26	15.26	-	Local Flow
17	PC-7	1563+520	9	-	1	0.91	-	1.49	1.49	*Less Capacity*	Increase 1 barrel of 1.5x1.5 to catter the Climate Resilience flood
18	PC-8	1563+690	17	-	2	0.91	-	2.94	2.94	*Less Capacity*	Increase 1 barrel of 2.0x2.0 to catter the Climate Resilience flood
19	PC-9	1564+050	-	-	1	0.91	-	1.51	1.51	-	Local Flow
20	PC-10	1564+130	-	-	2	0.91	-	2.86	2.86	-	Local Flow
21	BC-8	1566+200	-	-	1	2	1.5	10.46	10.46	-	Local Flow
22	BC-9	1566+965	-	-	1	1.5	1.5	7.00	7	-	Local Flow
23	BC-10	1567+510	1	-	1	1.5	1.5	7.26	7.26	Capacity OK	Desilting/Cleaning and Maintenance Required
24	BR-05	1568+690	173	-	3	23.4	13	717	716.88	Capacity OK	-
25	BC-11	1571+820	1	-	1	1.5	1	4.34	4.34	Capacity OK	Cleaning Required
26	BC-12	1573+200	-	-	1	1.2	0.65	1.67	1.67	-	Local Flow
27	BR-06	1578+120	189	P-H	1	23.8	10	883.68	883.68	Capacity OK	Cleaning and Maintenance Required
				H-P	1	13.5	10				

Sr. No.	Structure I.D	Road Chainage	Estimated SSP 5-8.5 Discharge (m^3/sec)	Existing Structure				Estimated Capacity (m^3/sec)		Capacity Check	Remarks
				Roadside	No. of Cell / Span	Span / width (m)	Height (m)	Individual	Combined		
28	BC-13	1580+755	-	-	1	3	2.4	15.28	15.28	-	Local Flow
29	BR-07	1581+745	809	P-H	6	20.5	4	847.48	847.48	Capacity OK	-
				H-P	12	10.3	3				
30	BC-14	1583+460	14	-	1	1.7	1.6	10.52	10.52	*Less Capacity*	Increase 1 barrel of 1.5x1.5 to catter the Climate Resilience flood
31	BC-15	1583+960	13	-	1	2	2.4	15.55	15.55	Capacity OK	-
32	BC-16	1584+250	6	-	1	2.5	1	9.19	9.19	Capacity OK	Full of Mud, Cleaning Required.
33	PC-11	1584+660	-	-	1	0.65	-	0.62	0.62	-	Local Flow
34	BC-17	1584+685	-	-	1	1.7	2	10.77	10.77	-	Local Flow
35	BR-08	1584+715	82	P-H	3	6+12+6	3	123.88	123.88	Capcity OK	Cleaning and Maintenance Required
				H-P	1	12	3				
36	PC-12	1585+175	1	-	1	0.91	-	1.95	1.95	Capacity OK	Cleaning Required

Note- PC = Pipe Culvert

BC = BOX Culvert

P-H = Pindi to Hassanabdal Side

H-P = Hassanabdal to Pindi Side

Capacity of structure, in case of difference on P-H & H-P, is estimated of smaller one

3.3 CONCLUSIONS OF HYDRAULIC ANALYSES

Hydraulic design review of the existing culverts and bridges, being used for storm-water drainage, have been carried to check the adequacy to safely pass the design floods with climate change effect under SSP 5-8.5. It is observed that existing box culverts, pipe culverts are present on small drain/ nullahs and bridges exist on some bigger nullahs at Rawalpindi – Hassanabdal section.

Considering the slopes, topography of the project area and development on the sides of the road at some locations the hydraulic analyses for the cross drainage structures have been taken up. As per hydraulic design guidelines the hydraulic design and review have been carried for the culverts against 25 year return period flood and checked to pass 50 year return period flood, while, 100 year return period flood is used for the bridges

. Here, in this reach the structures with individual estimated discharge have been reviewed for capacity check and proposed additional barrel where required as shown in Table-1.

Some structures are moderately choked and filled with mud. At some locations as mentioned in the summary at remarks, the existing cross drainage structures with mud blockage and minor damages are required cleaning, repair and periodic maintenance for the proper drainage of the design floods. Culvert at three (03) locations are required an additional barrel for each of the size mentioned above for safely pass the flood discharge with climate change effect.

4. REFERENCES

- NEX-GDDP-CMIP6 Climate Model Data (1985-2099).
- Earth Resources Observation and Science (EROS) Center. 2017. Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global.
- Flaounas, E., P. Drobinski, M. Vrac, S. Bastin, C. Lebeaupin-Brossier, M. Stefanon, M. Borga, and J.-C. Calvet (2013), Precipitation and temperature space-time variability and extremes in the Mediterranean region: Evaluation of dynamical and statistical downscaling methods, Clim. Dyn., 40(11-12), 2687–2705, doi:10.1007/s00382-012-1558-y.
- NESPAK Project "Emergency flood assistance project, Khyber Pakhtunkhwa, Pakistan", ADB, 2023.
- NESPAK Project "Study and evaluation of the safety of existing dams in different regions of the Kingdom of Saudi Arabia" (2023-2026).
- R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/.
- Sheffield, J., Goteti, G., & Wood, E.F. 2006. Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling. Journal of Climate 19: 3088–3111.
- Thrasher, B., Wang, W., Michaelis, A. et al. NASA Global Daily Downscaled Projections, CMIP6. Sci Data 9, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4
- World Bank Group & Asian Development Bank. 2021. Climate Risk Country Profile: Pakistan. World Bank.
- Xavier, A. C. F., Martins, L. L., Rudke, A. P., de Morais, M. V. B., Martins, J. A., & Blain, G. C. (2022). Evaluation of Quantile Delta Mapping as a bias-correction method in maximum rainfall dataset from downscaled models in São Paulo state (Brazil). International Journal of Climatology, 42(1), 175-190.
- Climatic Normals of Pakistan (1991-2020)
- Chow V. T., "Handbook of Applied Hydrology".
- Kirpich Z. P., "Time of Concentration of Agricultural Watersheds", Civil Engineering Volume 10, No. 6 Pages 362, June 1940.
- Open Channel Hydraulics by VEN T CHOW
- Irrigation and Hydraulic Structures by SK Garg Irrigation
- Feasibility study and detailed engineering design of Rawalpindi - Hassanabdal Road (N- 5)- 38 km (condition survey report – Dec-2021) by Associated Consultancy Centre (Pvt.) Ltd. Islamabad in association with Associated Consulting Engineer - TES Ltd (ACE)-Lahore.