NATIONAL HIGHWAY AUTHORITY
GOVERNMENT OF PAKISTAN

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

RANIPUR - SUKKUR ROAD SECTION

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

JANUARY 2025

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

RANIPUR – SUKKUR ROAD SECTION

CLIMATE CHANGE STUDIES

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.

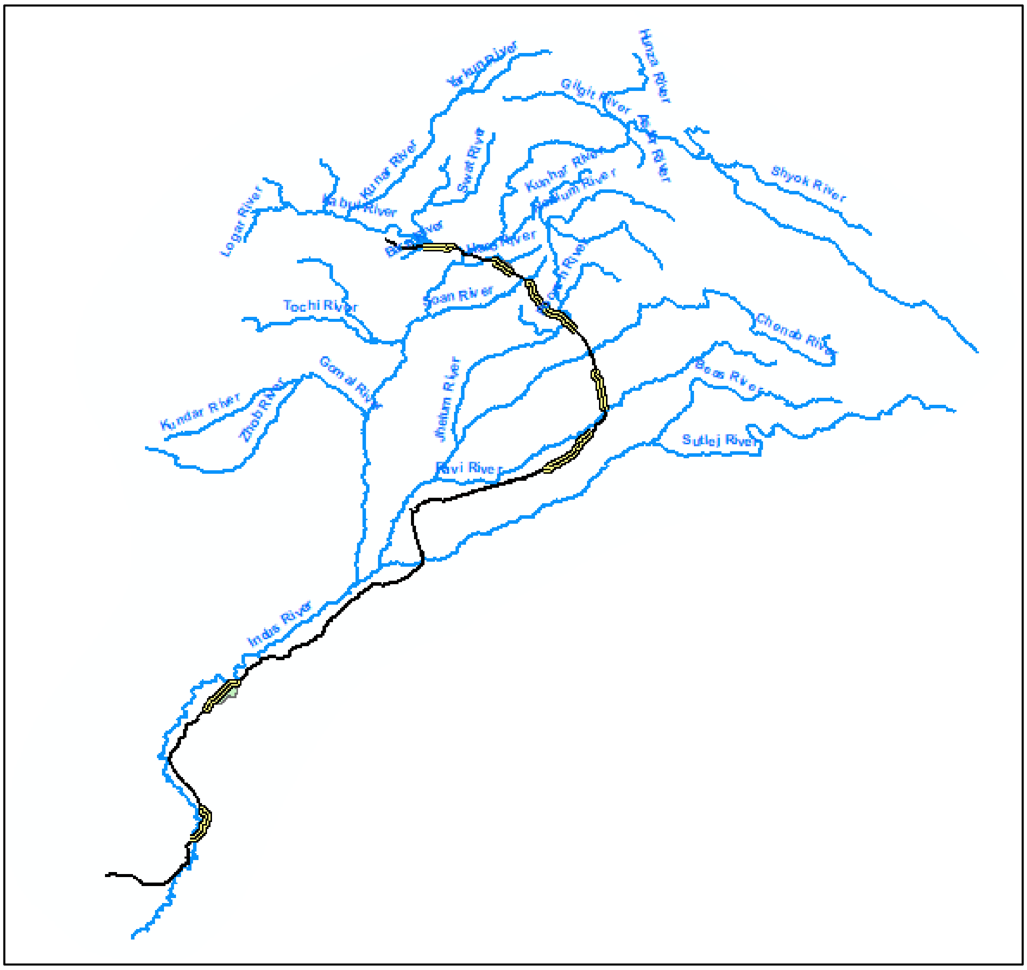


Figure 1.1: N5 Road Alignment with Dualization Sections
(Highlighted in Yellow Colour)

1.1 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.

1.1.1 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.

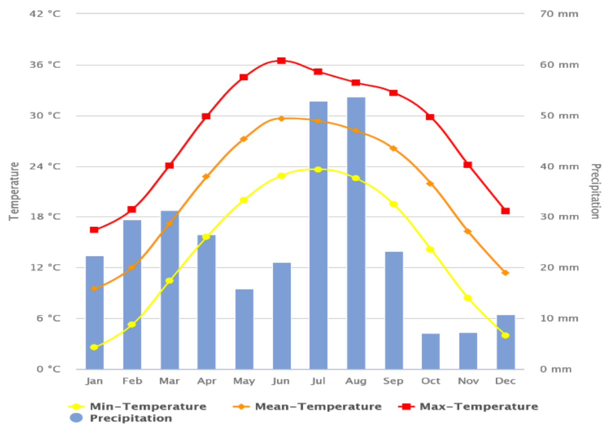


Figure 1.2: Monthly Climatology of Min, Max And Mean Temperature With Rainfall (1991-2020) (Source: World Bank)

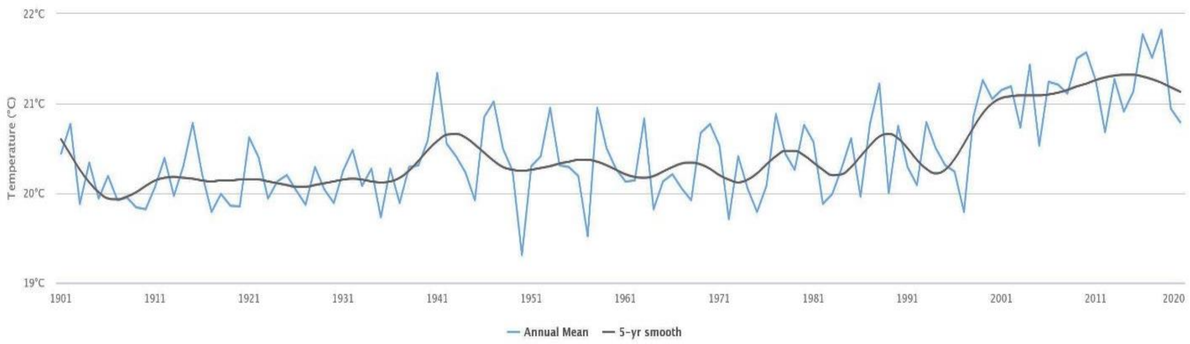


Figure 1.3: Observed Average Annual Mean- Temperature Of Pakistan For 1901-2020

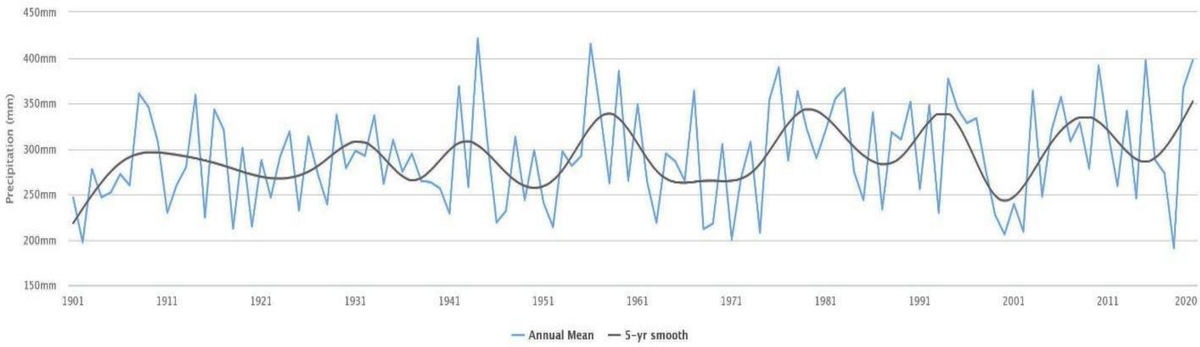


Figure 1.4: Observed Average Annual Rainfall of Pakistan for 1901-2020

Temperature

- 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.

Rainfall

- 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.

1.1.2 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.

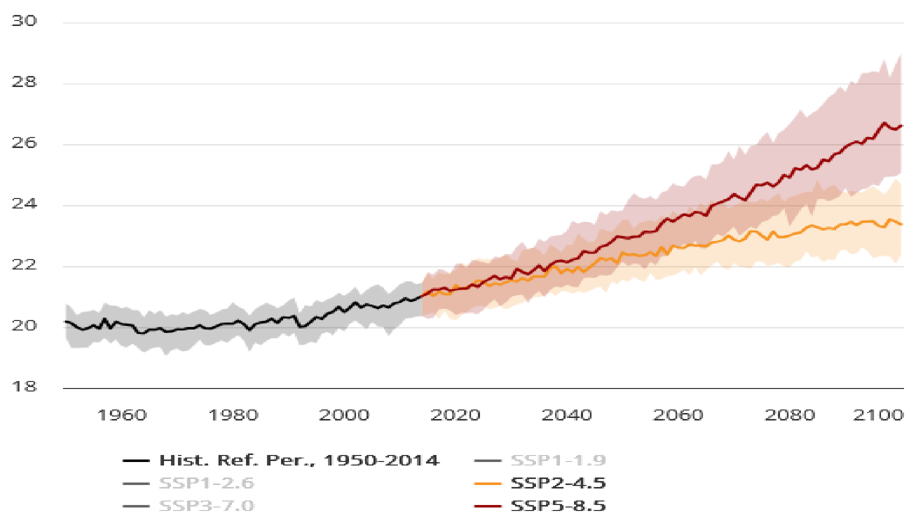


Figure 1.5: Projected Mean Temperature (Multi-Model Ensemble) Pakistan

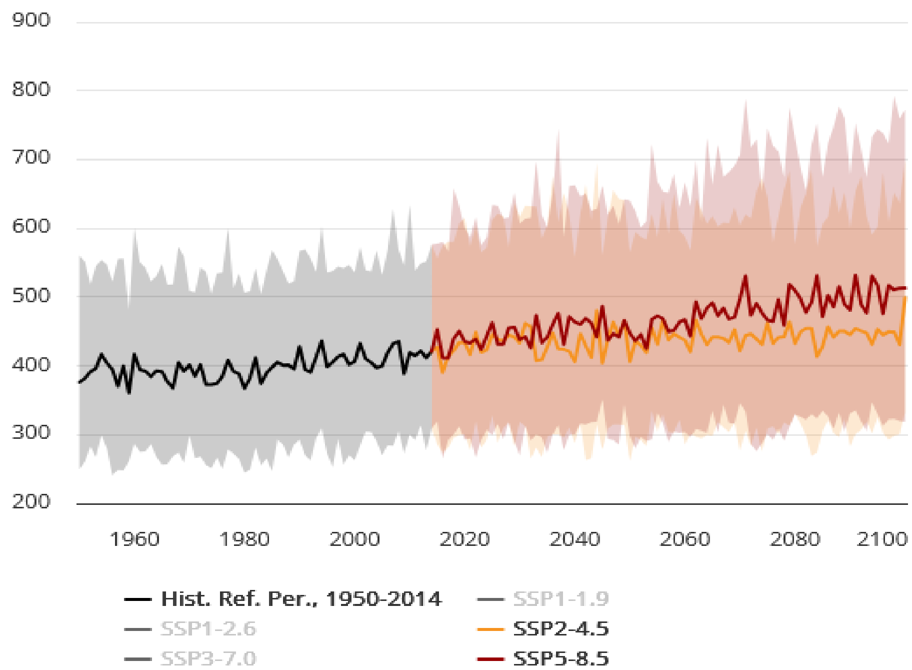


Figure 1.6: Projected Rainfall (Multi-Model Ensemble) Pakistan

1.2 CLIMATE DIAGNOSTIC

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

1.2.1 Modelling framework

Climate change scenarios is retrieved and analysed 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 analysed (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 Modelling (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 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.

1.2.2 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

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

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.

1.2.3 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 ScenarioMIP 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 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	

3Thrasher, 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

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

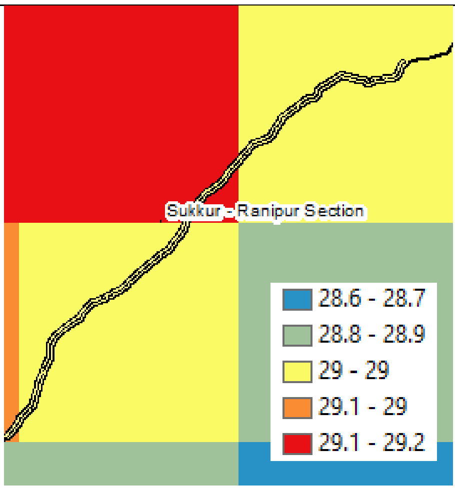
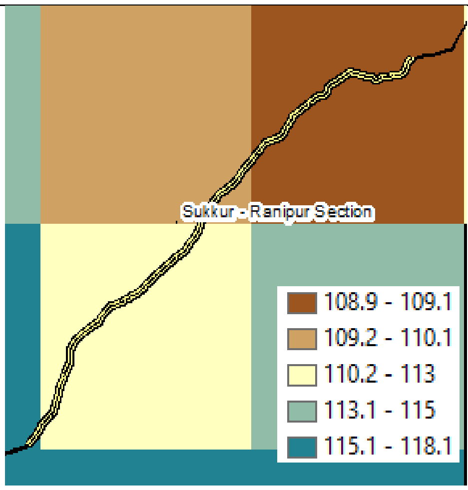
Data was downloaded for the period 2035-2064 (hereafter referred to as projections to 2050) for climate change assessments. Since the project roads mainly involve upgradation, projections to 2050 are suitable for the road project design life. However, for locations involving bridge construction, data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

1.3 IMPACT OF CLIMATIC CHANGE

1.3.1 Climate change assessment over Sukkur – Ranipur Section

Specifically, temperature and rainfall variation over different timeframes and climate scenarios are considered for Sukkur and Ranipur 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 2.8°C by 2085.
    - Under SSP 5-8.5: Temperatures could increase by 2.4°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 28.8% by 2050 and 43.5% by 2085.
    - Under SSP 5-8.5: Rainfall could increase by 43% by 2050 and 76% by 2085.

<table>
<tr><th>Scenarios</th><th>Temperature (C)</th><th>Rainfall (mm)</th></tr>
<tr><td>SSP 2-4.5
(2035-
2064)</td><td>
</td><td>
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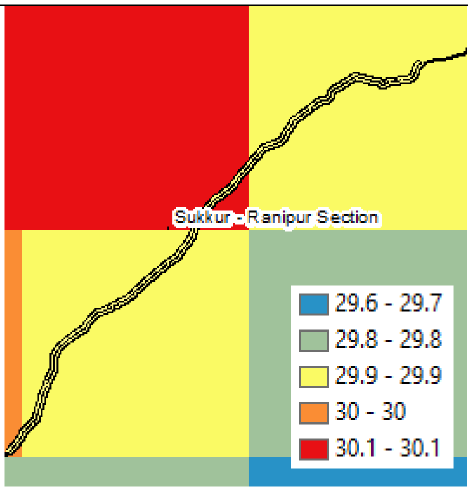
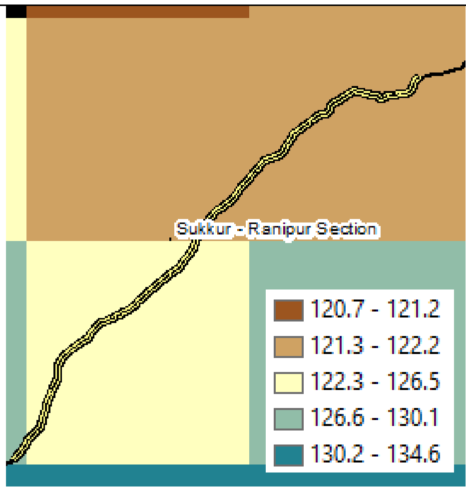
(2070-209 9)</td><td>
</td><td>
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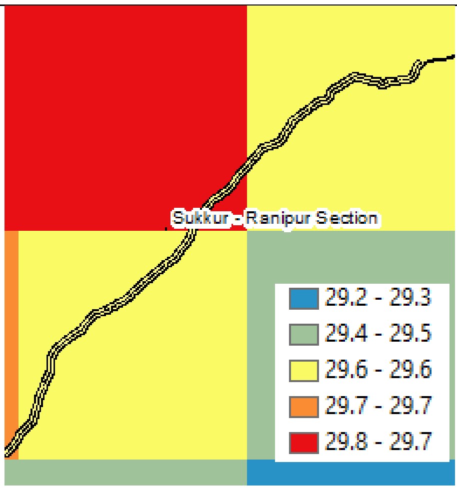
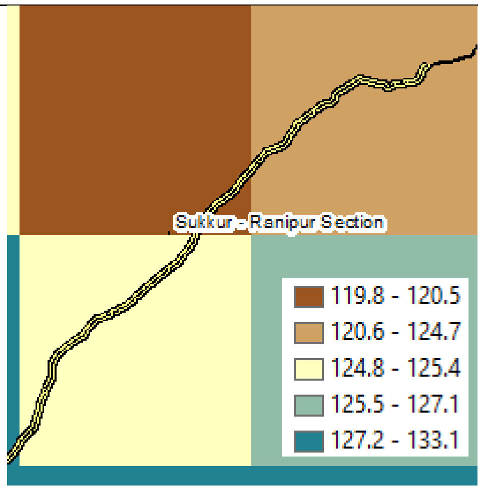
<tr><td>SSP 5-8.5
(2035-2064)</td><td>
</td><td>
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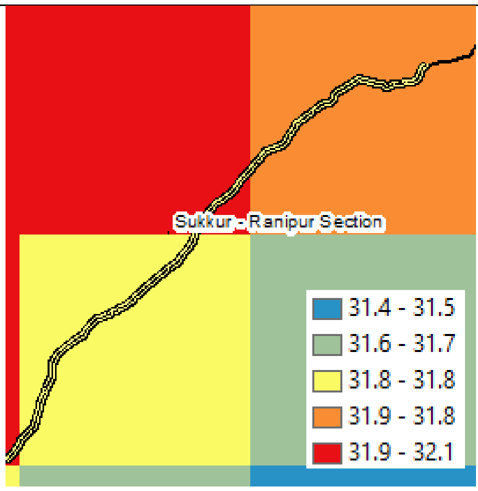
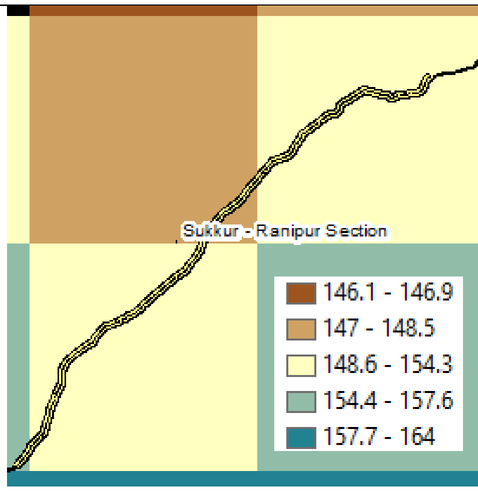
<tr><td>SSP 5-8.5
(2070-209 9)</td><td>
</td><td>
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Figure 1.7: Temperature and Rainfalls Under Different Timeframes And Climate Scenarios Over Sukkur – Ranipur Section

1.3.2 Flood Assessment for Sukkur – Ranipur 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 1.3**) will be used in Hydrological Modelling and Hydraulics study for climate resilient analysis.

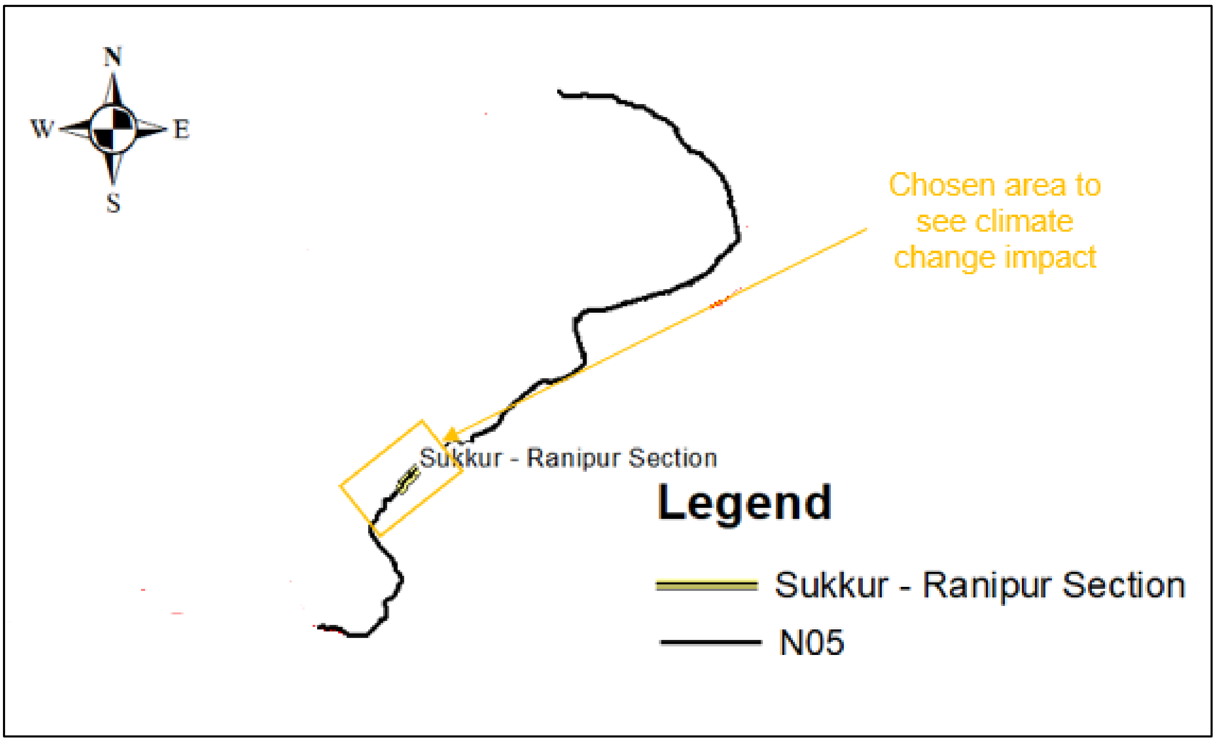

Figure 1.8: N5 Road Sections for Climate Change Analysis on Flooding (chosen area is highlighted in orange color)

1.3.2.1 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 1.2**) 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.

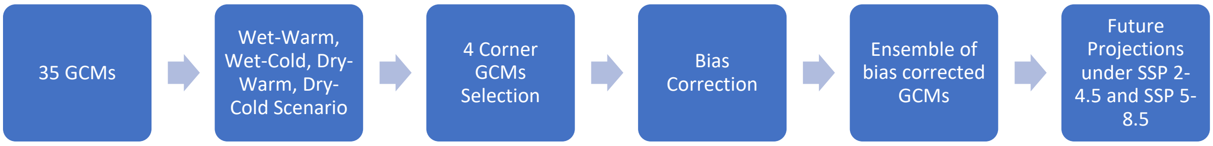

Figure 1.9: Overall Methodology Adopted for Climate Change Study

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.

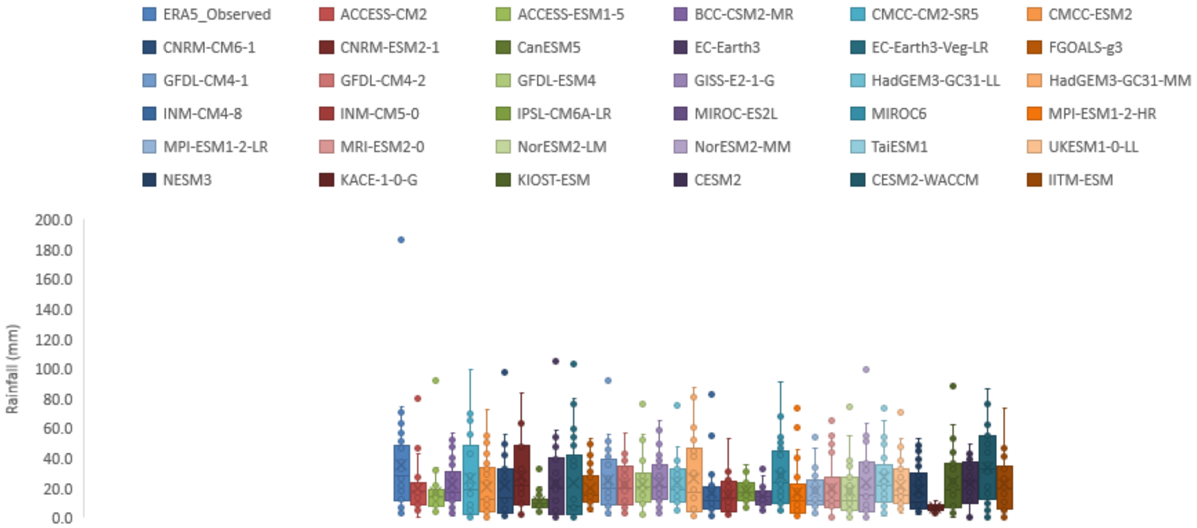

Figure 1.10: Raw GCMs Comparison with ERA5 Rainfall (Whisker Plot)

1.3.2.2 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

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).

- 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

Four corner models under SSP 2-4.5 (CMCC-ESM2, GFDL-CM4-1, MIROC6 and NESM3) and SSP 5-8.5 (GFDL-CM4-2, MIROC-ES2L, NorESM2-MM and NESM3) have been selected for bias correction application in this area. Average results have been adopted for analysis with variation range.

1.3.2.3 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.

1.3.2.4 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 no increase in rainfall under SSP 2-4.5 (low confidence of increase) while there will be increase in rainfall of about 6.8%, 4.3% and 2.2% for return period of 25, 50 and 100 years respectively under SSP 5-8.5 with medium confidence (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

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

climatic change increase factors be used to increase the rainfall depths for inclusion in flood studies.

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	Nil	6.8%
50	Nil	4.3%
100	Nil	2.2%

1.4 CONCLUSION

This report initiates a detailed **climate change assessment** for the **N5 road expansion**, specifically focusing on the Sukkur and Ranipur 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 **2.8°C by 2085**, whereas under **SSP 5-8.5**, the rise could reach **2.4°C by 2050** and **4.9°C by 2085**. Additionally, **annual rainfall** is anticipated to rise by **28.8% by 2050** and **43.5% by 2085** under SSP 2-4.5, while under SSP 5-8.5, rainfall could increase by **43% by 2050** and **76% 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 no rise in rainfall under SSP 2-4.5 (low confidence of increase). Under SSP 5-8.5, the projected increases are **6.8%**, **4.3%**, and **2.2%**, respectively with medium confidence, 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), spanning over 1,800 kilometers, is Pakistan's longest and most critical transportation corridor. It connects Karachi, the nation's economic hub in the south, to Peshawar, a historic and administrative center in the north, forming an indispensable part of the country's infrastructure. Serving as a modern adaptation of the legendary Grand Trunk Road, N-5 is a cornerstone of Pakistan's trade and logistics network. It ensures seamless connectivity across key metropolitan areas, industrial hubs, and agricultural regions, facilitating the efficient movement of goods, services, and people. This strategic artery underpins national development, fostering economic growth and enhancing regional integration.

The Ranipur-Sukkur section is an essential segment of National Highway 5 (N-5) which extends approximately 70 kilometers, linking Sukkur, a major commercial and logistical hub, with Ranipur, a town of significant agricultural importance in Sindh. This critical stretch plays a fundamental role in facilitating both regional and national economic activities. It efficiently manages substantial freight traffic, including agricultural produce, industrial goods, and raw materials destined for key markets and industrial centers.

Beyond freight transport, this segment is instrumental in facilitating the mobility of daily commuters and intercity travelers, bolstering connectivity between rural and urban areas. The Ranipur-Sukkur section enhances regional integration and sustains critical transportation flows. Its significance extends beyond local connectivity, serving as an essential link in Pakistan's broader economic framework.

2.2 LOCATION of PROJECT AREA

Sukkur, situated on the banks of the Indus River in Sindh province, is a dynamic city renowned for its strategic importance in Pakistan's trade and transportation networks. As a key commercial hub, Sukkur plays a pivotal role in connecting northern and southern regions of the country. Its well-established logistical infrastructure, including its proximity to National Highway 5 (N-5) and the Sukkur Barrage, supports the efficient movement of goods, particularly agricultural produce and industrial materials. The city is also known for its historical landmarks, such as the Lansdowne Bridge and Sadh Belo Temple, which reflect its cultural and historical significance.

Ranipur, a town located in the heart of Sindh, is renowned for its agricultural productivity and cultural heritage. It is positioned along National Highway 5 (N-5) and serves as a vital link in the region's transportation network, facilitating the movement of goods and people. The town is known for its lush fields, producing a variety of crops that contribute significantly to the local and national economy. Ranipur is also home to cultural landmarks such as the shrine of Sachal Sarmast, a symbol of the town's rich spiritual and literary legacy.

Considering the economic significance of Sukkur and Ranipur, the client, National Highway Authority (NHA), plans to widen and upgrade the existing metaled road connecting these two key locations. This section of National Highway 5 (N-5) plays a pivotal role in facilitating trade, transportation, and daily commuting, linking Sukkur's commercial and logistical hubs with

Ranipur's agricultural and cultural centers. The proposed enhancements aim to expand road capacity, alleviate traffic congestion, and ensure the efficient movement of freight and passenger vehicles. Upgrading this essential corridor will not only support the growing economic activities in Sukkur and Ranipur but also improve regional connectivity, fostering greater economic productivity. The length of the road under consideration is approximately 70 kilometers. The location map is given in **Figure 2.1**.

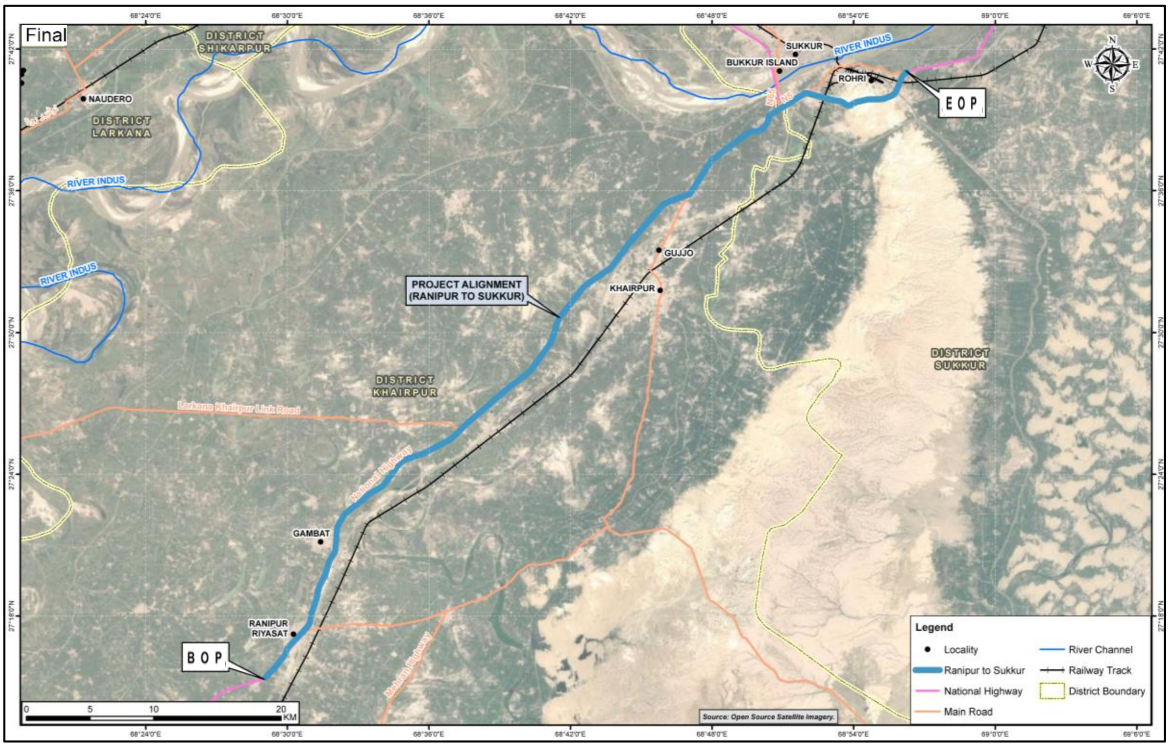

Figure 2.1: Location Map of Project Area

2.3 SCOPE OF HYDROLOGICAL STUDIES

The Ranipur-Sukkur section of National Highway 5 (N-5) traverses through a region characterized by its predominantly flat terrain, interspersed with agricultural fields and date farms that are a hallmark of the area. Despite its dry climate, the region thrives agriculturally due to the presence of the Indus River and the Rohri Canal, which run parallel to this segment of the highway. These critical water resources provide essential irrigation, transforming the arid landscape into a fertile zone capable of producing staple crops like wheat, rice, sugarcane, and high-quality dates.

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 considering the effect of climate change.

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 t 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 a 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, Sukkur gauging station has been selected. This station gives a fair representation of the climate of the project area.

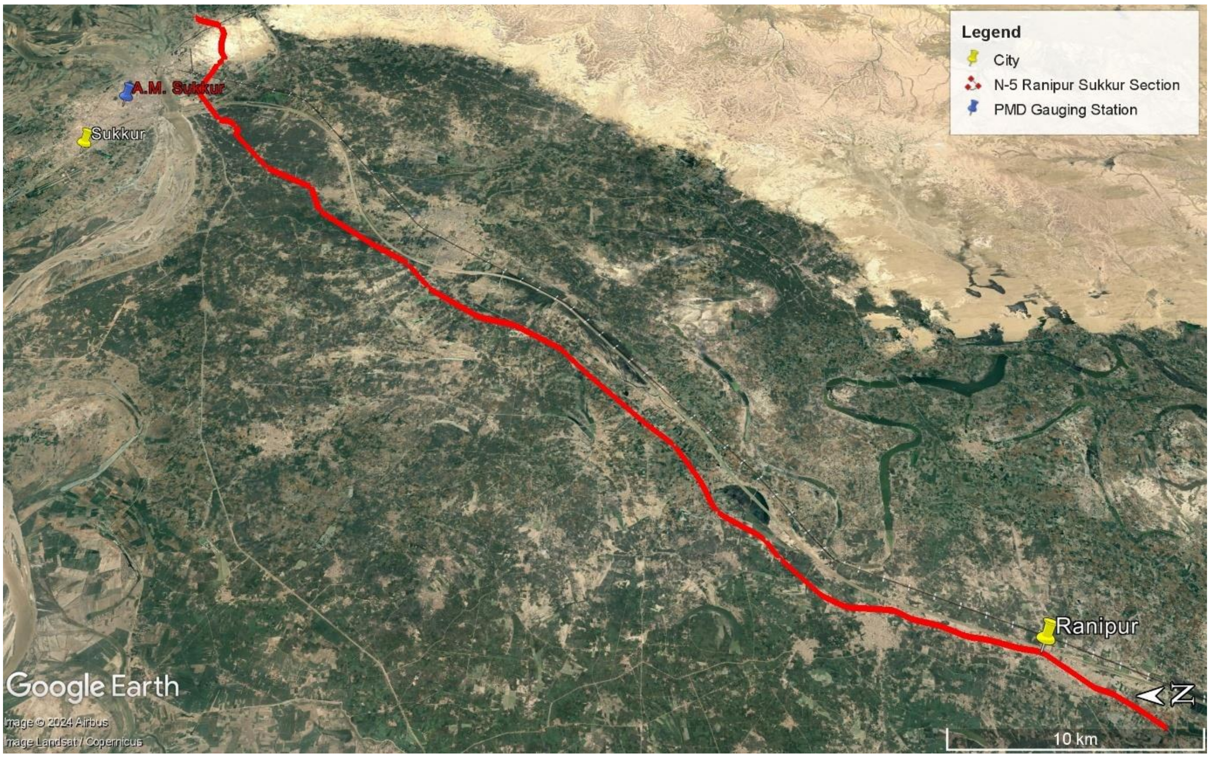

Figure 2.2: Rainfall Gauging Station in Vicinity of Road Section

2.4.1 Climate of Sukkur

Sukkur, located in the Sindh province of Pakistan, has an arid to semi-arid climate, marked by hot summers and mild winters. The region experiences extreme temperature fluctuations, with summer temperatures often exceeding 40°C, particularly from May to September. During this time, heatwaves are common, making the climate harsh and dry. Winters, on the other hand, are relatively mild, with temperatures ranging between 8°C to 25°C from December to February.

Precipitation in Sukkur is limited, with annual rainfall averaging between 150 mm and 200 mm, mostly occurring during the monsoon season from June to September. However, rainfall is often unpredictable and sparse, contributing to periods of drought and water scarcity. The Indus River, flowing near Sukkur, plays a significant role in moderating temperatures and supporting irrigation.

2.4.1.1 Precipitation

Mean monthly rainfall data and the number of rainy days recorded at Sukkur Station are given in **Table *2.1*.** The annual rainfall of the area is about 103 mm (Ref.1). While on average the maximum monthly rainfall is 23.5 mm during the month of August and a minimum of 3.6 mm in October. The maximum rainfall occurs during the months of July to September, which is about 52% of the annual rainfall. Winter rains generally occur during the month of February and March, whereas October is normally the month with the least precipitation. The distribution of average monthly rainfall and number of rainy days in Sukkur have been shown in **Figure 2.3** and **Figure 2.4** respectively**.**

Table 2.1: Mean Monthly Rainfall in Sukkur

Months	Precipitation (mm)	Rainy Days (No.)
January	3.7	0.4
February	8.1	0.8
March	7.7	1.1
April	6.1	0.5
May	4.5	0.5
June	5.0	0.6
July	17.7	1.1
August	23.5	1.0
September	13.3	0.3
October	3.6	0.1
November	4.2	0.3
December	5.8	0.3

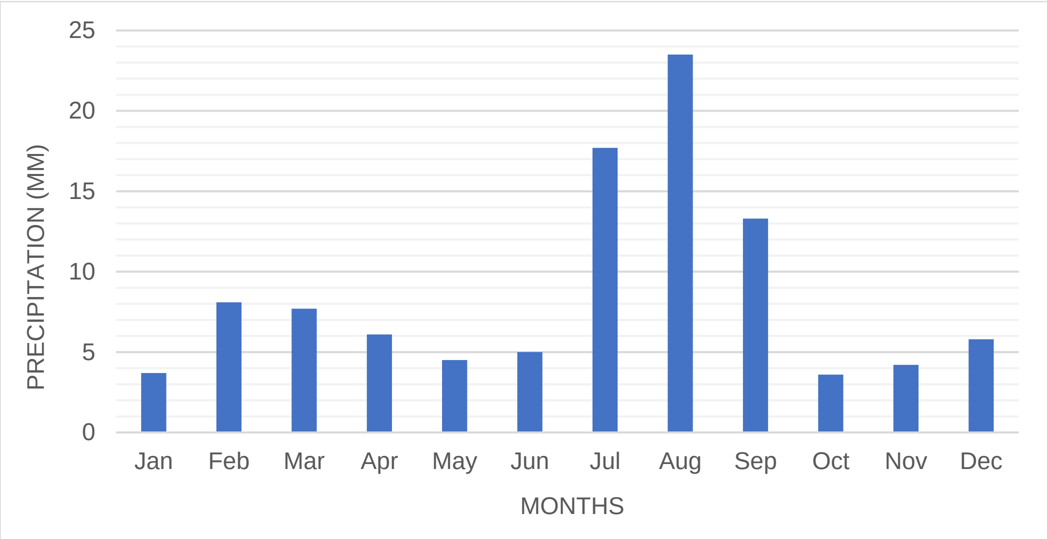

Figure 2.3: Mean Monthly Distribution of Rainfall in Sukkur

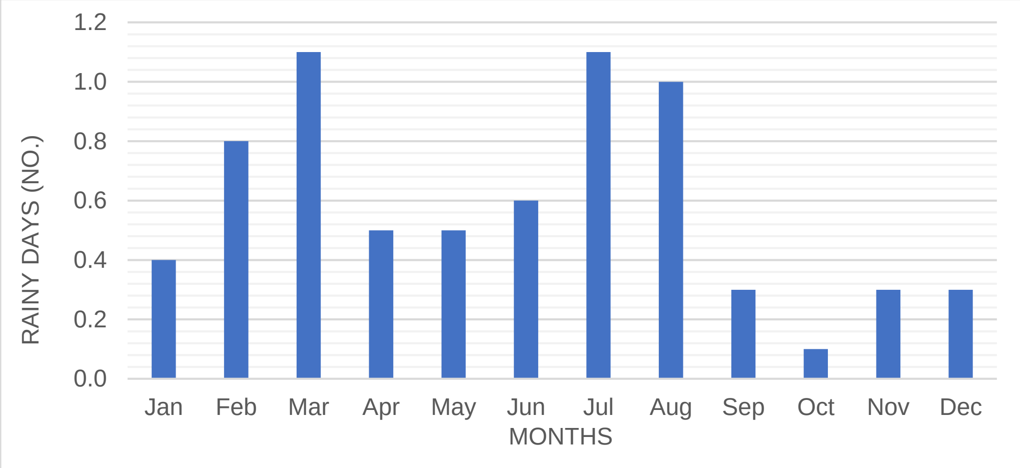

Figure 2.4: Number of Rainy Days in Sukkur

2.4.1.2 Temperature

The average daily temperature in Sukkur exhibits significant variation between the seasons. During the hot summer months from April to September, the mean daily temperature ranges from 30.4°C to 36°C, with May, June, and July being the hottest months. In contrast, the winter season, spanning from December to February, experiences relatively cooler temperatures, with the mean daily temperature ranging from 14.5°C to 18.2°C. December and January are typically the coldest months. The peak monthly temperature reaches 36°C in June, while the lowest temperature is recorded at 14.5°C in January. These seasonal temperature shifts underscore the stark difference between Sukkur's intense summers and its comparatively cooler winters. The monthly averages for minimum, maximum, and mean daily temperatures are detailed in **Table 2.2** and illustrated graphically in **Figure 2.5**.

Table 2.2: Mean Monthly Temperatures in Sukkur

Month	Min Temp (°C)	Max Temp (°C)	Mean Temp (°C)
January	7.1	22.6	14.5
February	10.3	26.1	18.2
March	15.5	32.1	23.8
April	21.5	39.1	30.4
May	26.2	43.4	34.8
June	28.7	43.5	36.0
July	28.8	41.3	35
August	27.6	39.4	33.1
September	25.4	38.2	31.9
October	20.3	35.9	28.1
November	13.8	30.3	22.1
December	8.4	24.7	16.5

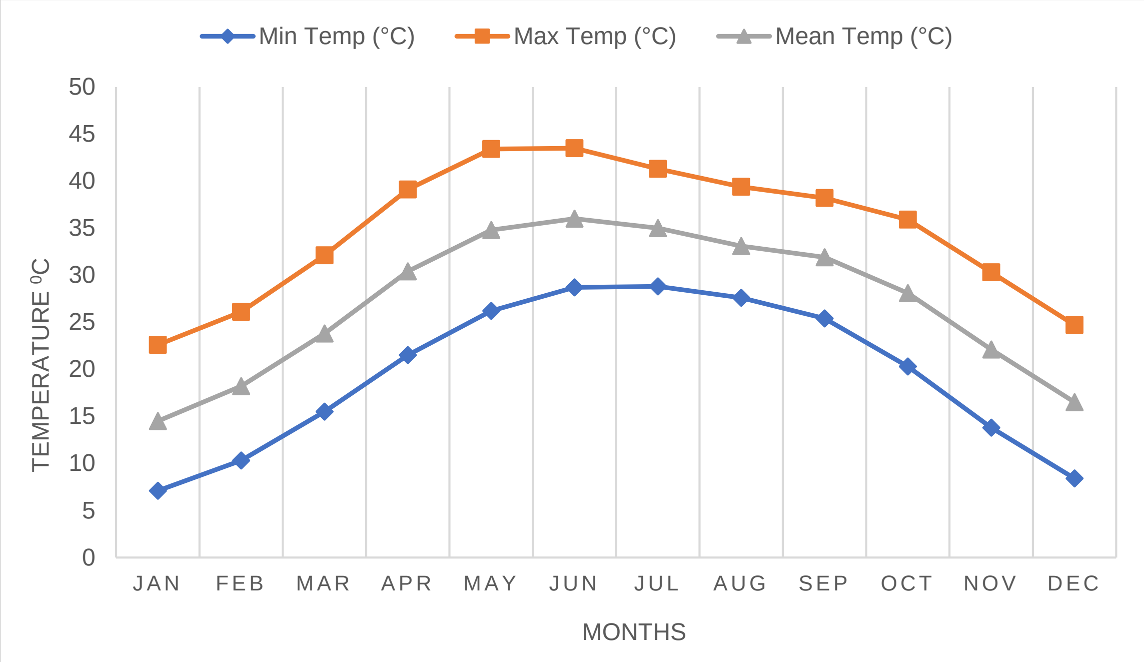

Figure 2.5: Mean Monthly Temperatures in Sukkur

2.4.1.3 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 59% in May to highest value of 83.6% in December. At 12:00 hour the lowest value is 25% in April and highest value of 48.9% in July.

Table 2.3: Mean Monthly Relative Humidity in Sukkur

Month	Relative Humidity (%)		
	00 UTC	03 UTC	12 UTC
January	82.7	85.5	39.7
February	78.3	79.5	34.4
March	74.0	71.9	25.2
April	61.2	56.1	25.0
May	59	54.3	32.7
June	66.3	63.4	44.1
July	73.1	71.6	48.9
August	77.2	75.1	46.5
September	80.4	77.9	46.5
October	81.1	78.8	42.9
November	81.2	81.5	44.5
December	83.6	86.0	48.3

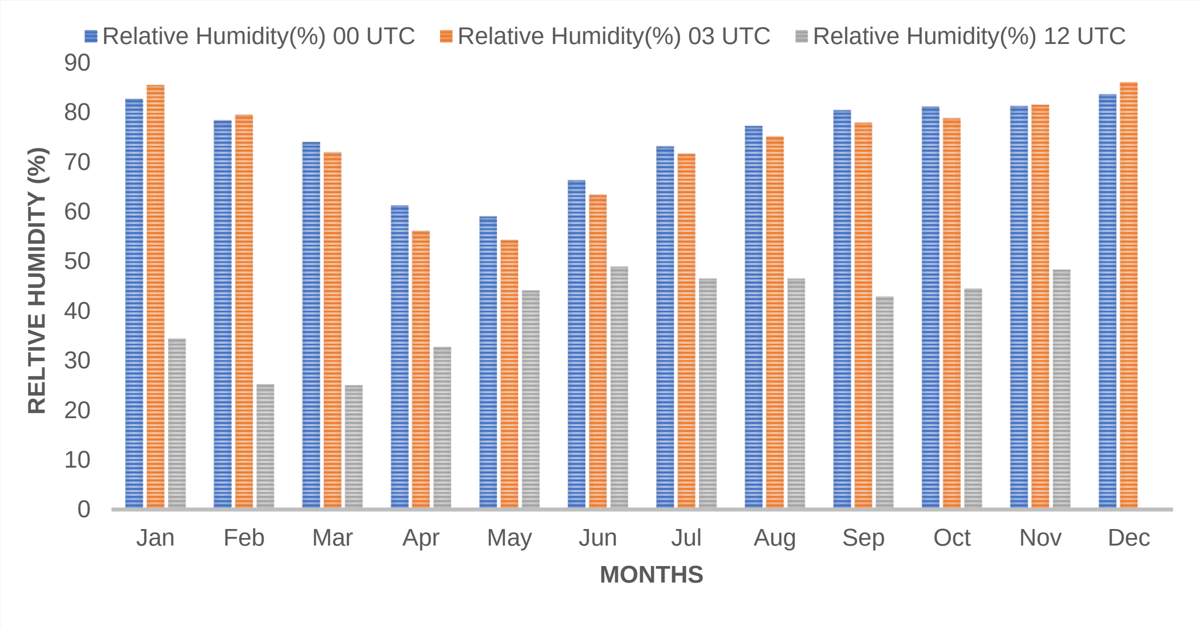

Figure 2.6: Mean Monthly Relative Humidity in Sukkur

2.4.1.4 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 Sukkur

Month	Mean Wind at Synoptic Hours (Knots)		
	0:00	3:00	12:00
January	1.2	1.9	2.6
February	1.7	2.7	3.5
March	2.4	3.3	3.9
April	2.9	4.0	4.8
May	3.9	5.3	5.7
June	5.3	6.8	7.0
July	4.8	5.6	6.1
August	3.8	4.9	4.7
September	2.9	3.8	3.9
October	1.2	1.9	2.1
November	1.1	1.8	1.2
December	0.6	1.3	1.4

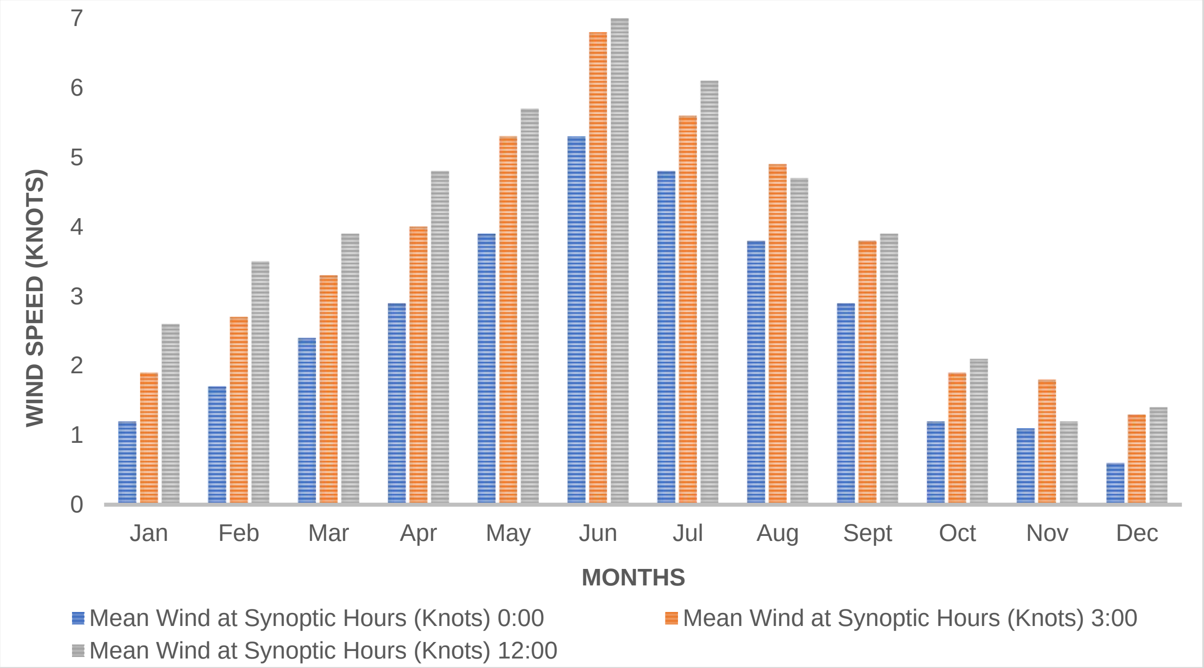

Figure 2.7: Mean Monthly Wind Speed in Sukkur

2.5 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 relative 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 100 to 150 mm rainfall traverses through the project area as shown in **Figure 2.8**.

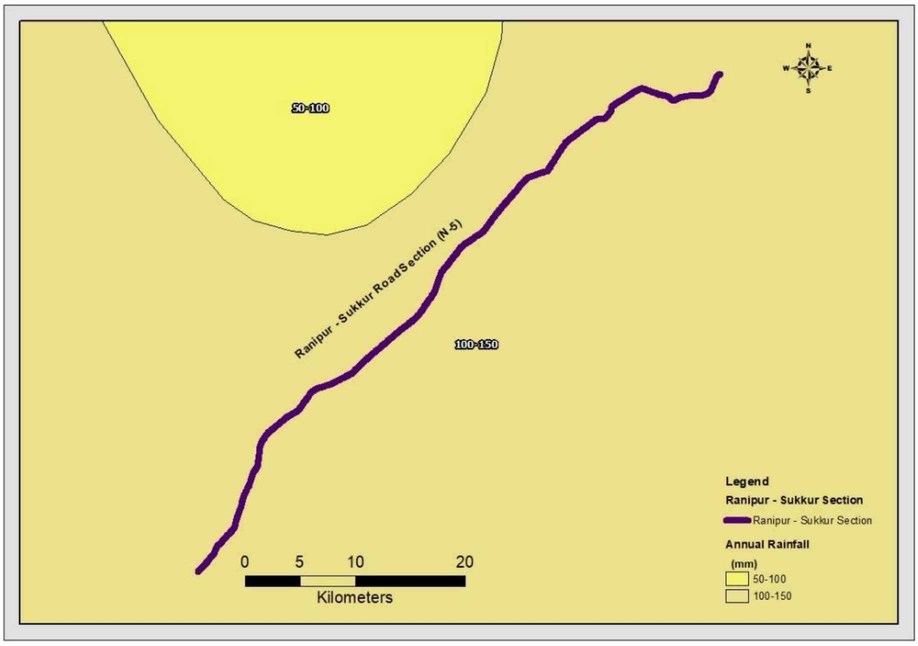

Figure 2.8: Road Section Overlayed on Annual Normal Isohyetal Map

2.6 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**.

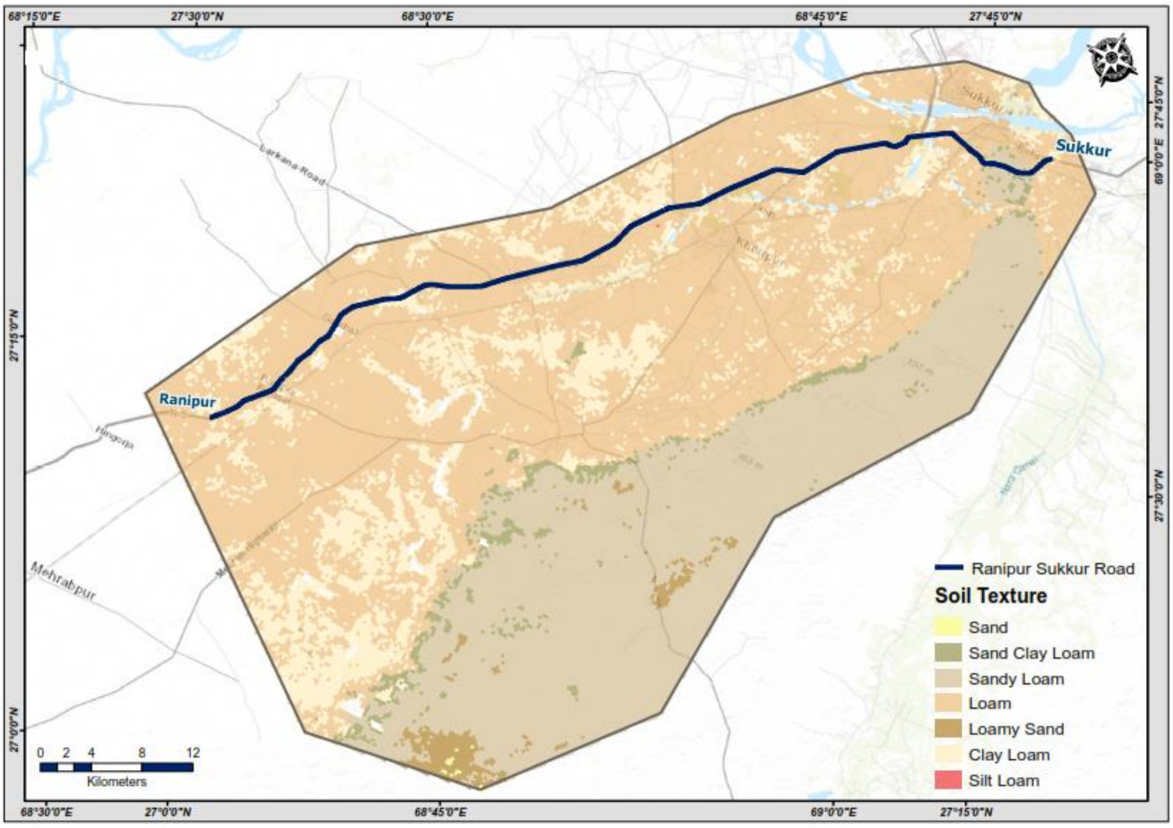

Figure 2.9: Soil Properties of Ranipur - Sukkur Road Section

2.7 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**.

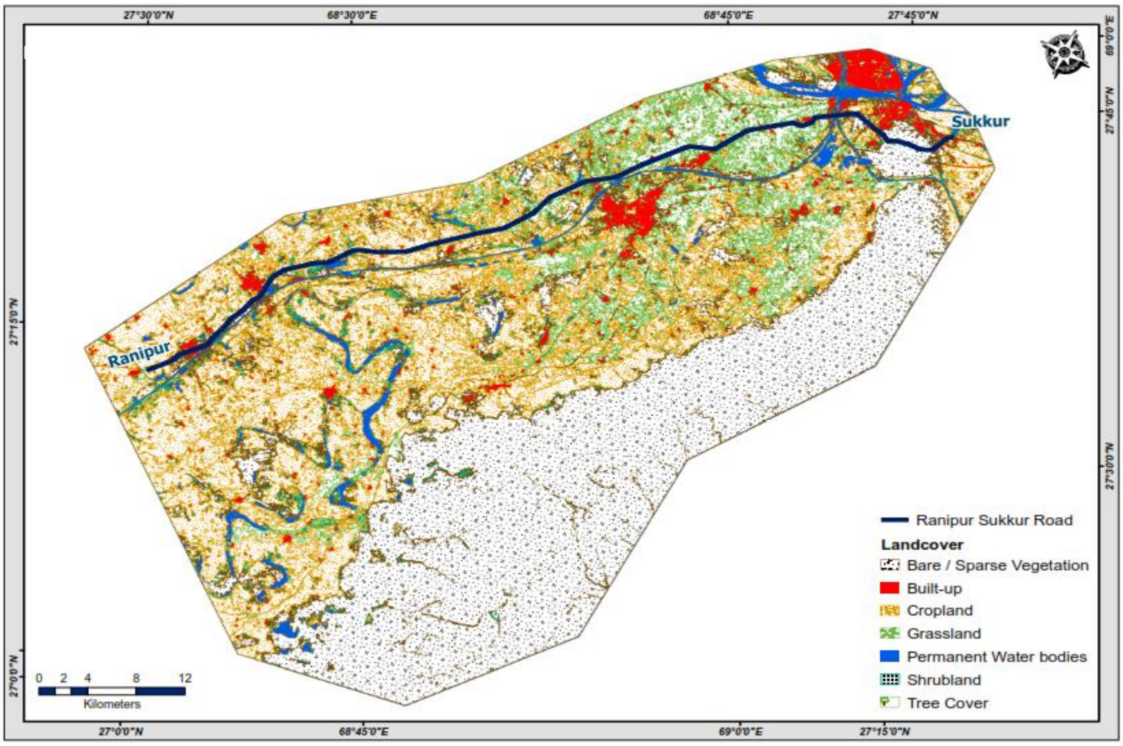

Figure 2.10: Land Use Properties of Ranipur - Sukkur Road Section

2.8 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 Ranipur-Sukkur Road section, Topaz and Arc-Hydro 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** and **Figure 2.12** represent the stream network by above mentioned techniques.

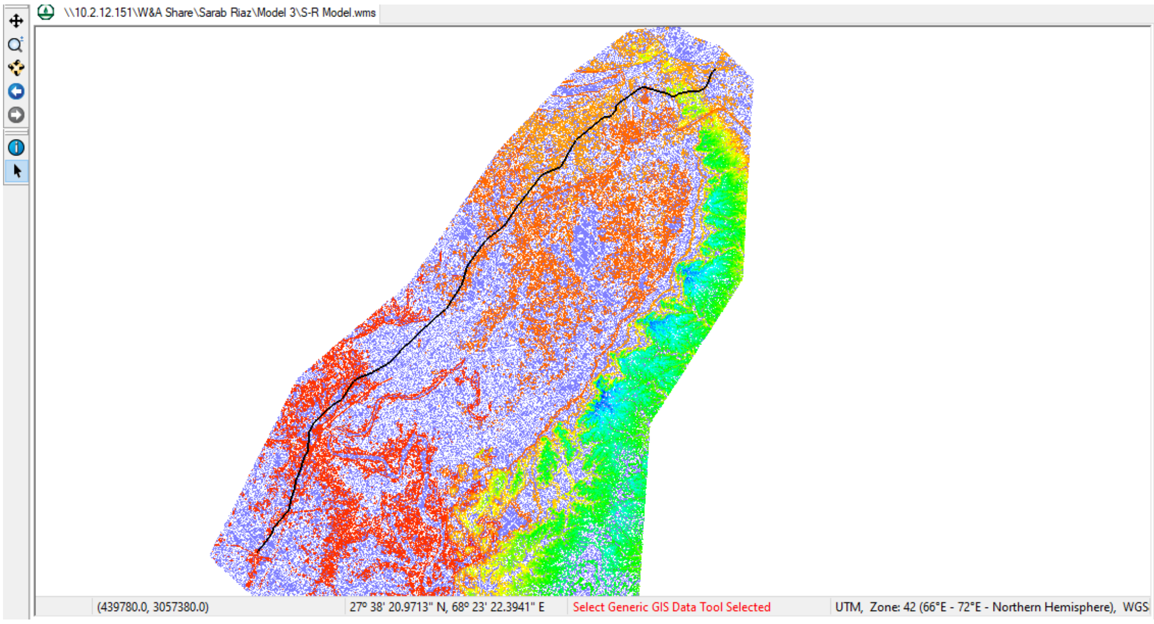

Figure 2.11:Stream Network Generation Using Topaz Tool

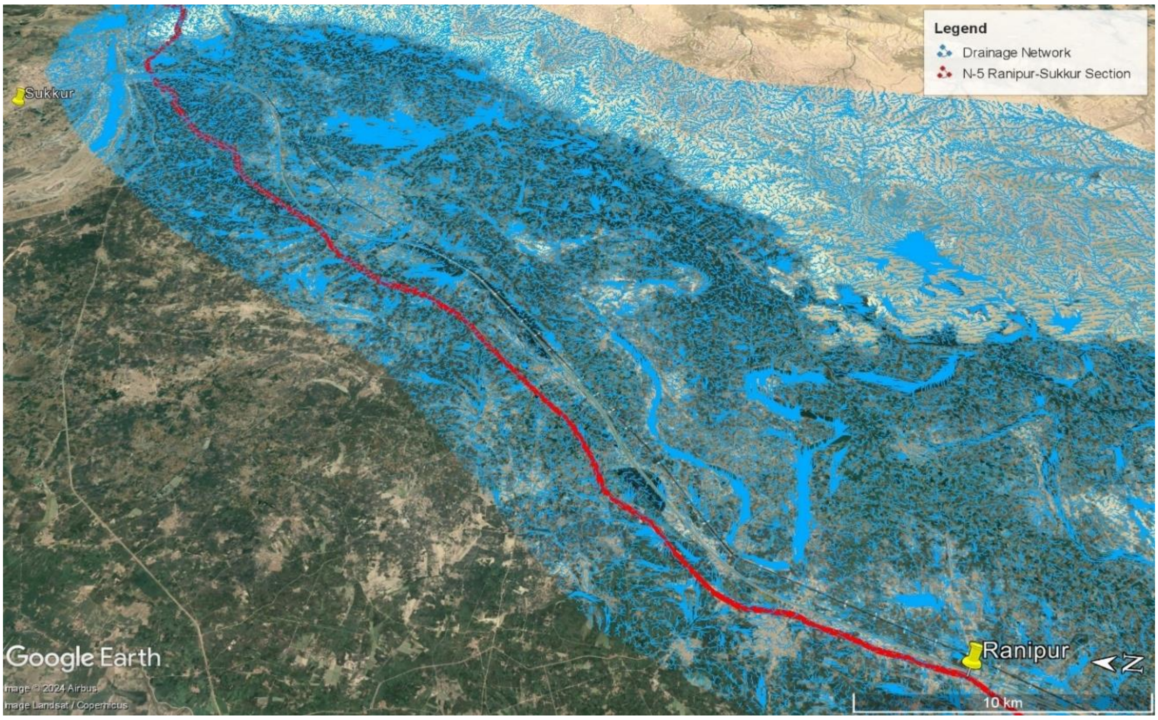

Figure 2.12: Stream Network Generation Using Arc-Hydro Tool

2.9 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 Sukkur station has been collected from Pakistan Metrological Department and its inventory is given in **Table 2.5**.

Table 2.5: Inventory of Gauging Stations

S. No.	Station	Data Type	Data Period (Years)	Agency
Rainfall Gauging Station				
1	Sukkur	One Day Annual Maximum Rainfall	1997-2023	PMD

2.9.1 Analysis of Rainfall Data

Sukkur Station

The one-day annual maximum rainfall data for Sukkur is available for the period 1997 - 2023 (27 years) and is provided in **Table 2.6**.

Table 2.6: 1-Day Annual Maximum Rainfall in Sukkur

Year	Rainfall (mm)	Year	Rainfall (mm)
1997	36.5	2011	37.5
1998	13.5	2012	164.2
1999	47.0	2013	59.0
2000	6.5	2014	8.0
2001	51.0	2015	64.0
2002	6.6	2016	42.0
2003	44.5	2017	16.0
2004	19.0	2018	31.0
2005	29.5	2019	71.0
2006	9.5	2020	30.0
2007	31.2	2021	20.0
2008	92.0	2022	82.0
2009	13.0	2023	90.0
2010	18.0		

Historic data since 1997 suggest an average value of 41.9 mm, the maximum magnitude of rainfall witnessed till date is 164.2 mm in year 2012. **Figure 2.13** shows the trends of annual maximum rainfalls observed at Sukkur station.

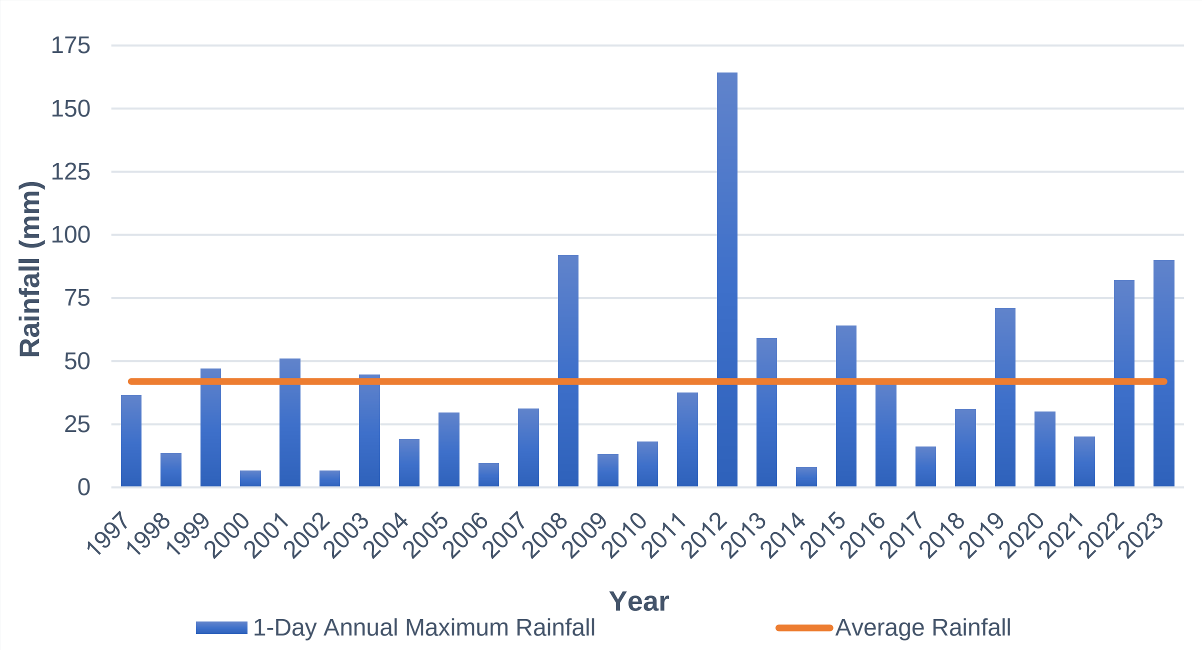

Figure 2.13: One-Day Annual Maximum Rainfall in Sukkur

2.9.2 Frequency Analysis of Rainfall Data

Frequency analysis for 1-day annual maximum rainfall data of Sukkur station has been carried out using Gumble's Extreme Value Type-1 Distribution. The plotting positions have been computed by Weibull's formula. Gumbel distribution is a member of family of extreme value distributions. It is a two-parameter distribution and is widely used in hydrology. Different return periods to be computed for frequency analysis have been approached using Weibull formula. For annual maximum series, Weibull formula has been adopted as the standard plotting position method by the U. S. Water Resources Council (1981).

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

Table 2.7: Results of Rainfall Frequency Analysis at Sukkur

Return Period (Years)	**Rainfall Depth** (mm)
2.33	46.2
5	73.5
10	95.7
25	123.8
50	144.6
100	165.3
500	213.1

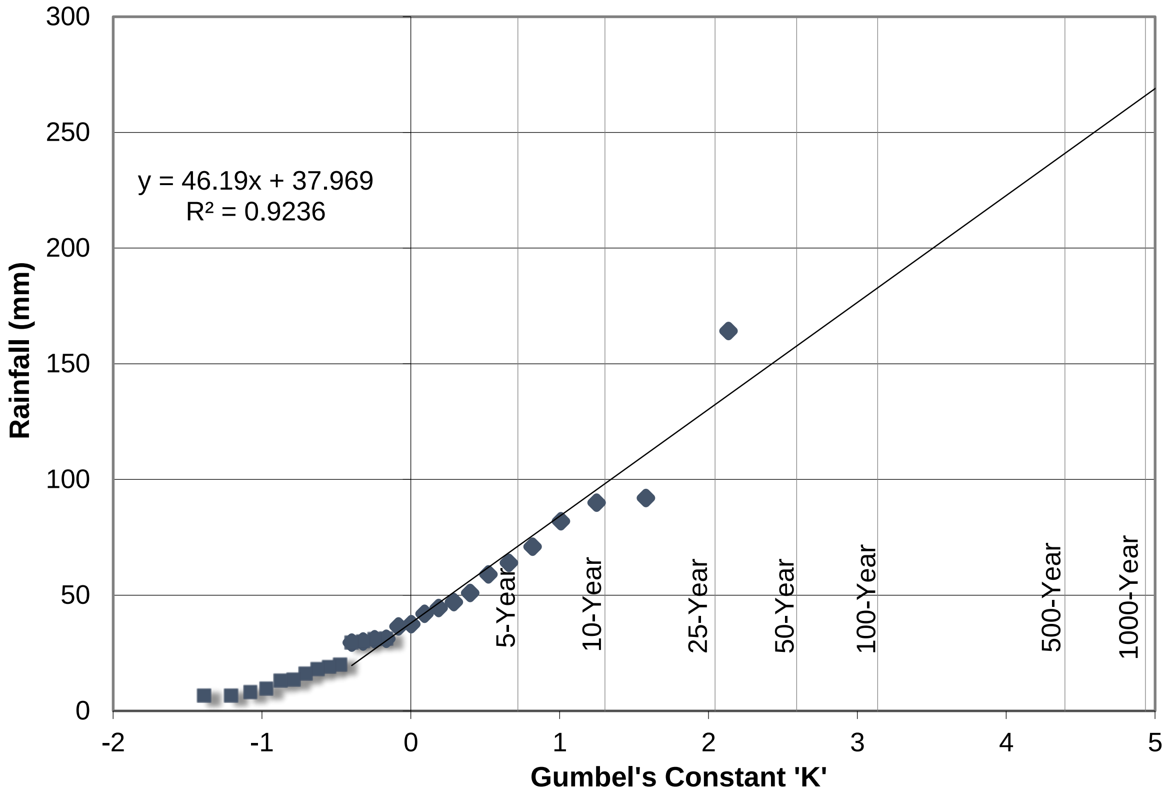

Figure 2.14: Frequency Fitting of 1-Day Annual Maximum Rainfall at Sukkur

2.10 DESIGN FLOOD ESTIMATION

All catchments of Ranipur-Sukkur Road section have area less than 1 km^2, hence design flood for the streams crossing the road has been estimated by using rational method.

2.10.1 Rational Method

As the catchments have area less than 1km^2 hence 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 Sukkur rain gauging station and is shown in **Figure 2.15**. The rainfall distribution with time is then re-oriented to have a centrally loaded rainfall pattern.

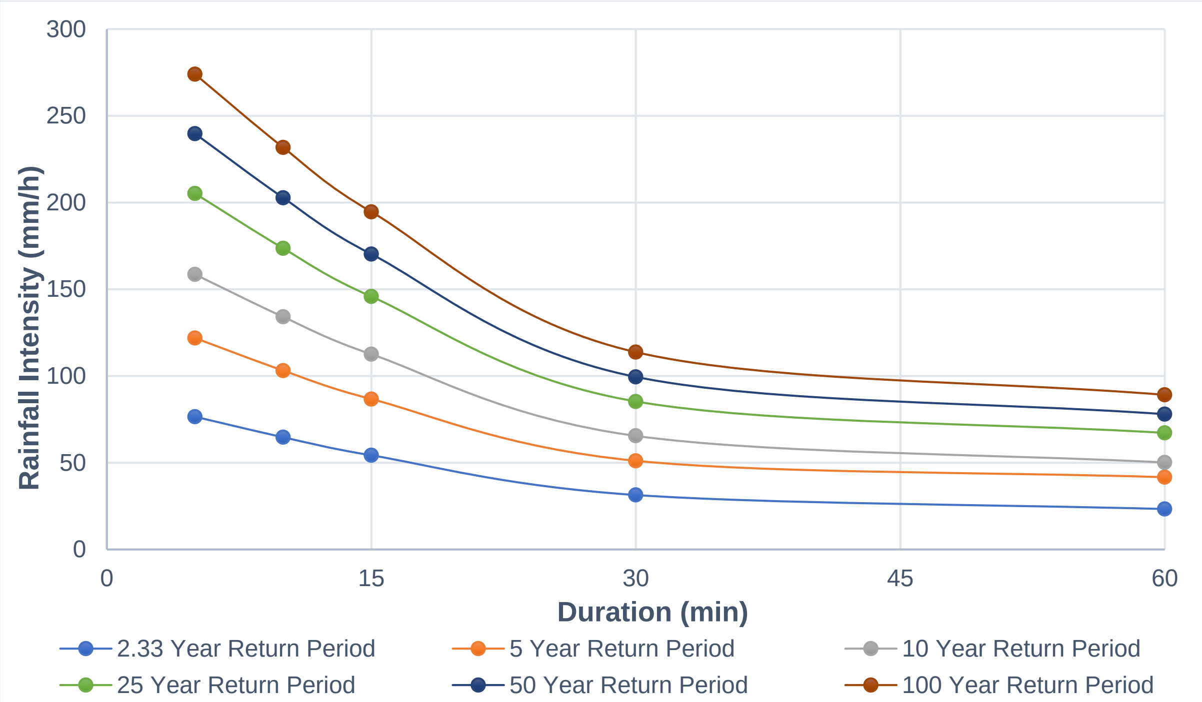

Figure 2.15: Intensity-Duration-Frequency Curve for Sukkur

2.11 ESTIMATED FLOOD DISCHARGES

The floods estimated against various return periods for the natural streams crossing the Ranipur - Sukkur Road Section are given in **Table *2.8***.

Table 2.8: Discharges against Various Return Periods

Sr. No	Structure RD's	Flow Direction	Catchment Area	Peak Flood Discharges		
				25 yrs	50 yrs	100 yrs
			(km^2)	(m^3/sec)		
1	2+210	Left	0.005	0.10	0.12	0.14
2	5+555	Right	0.084	1.03	1.20	1.37
3	7+585	Left	0.033	0.65	0.75	0.86

Sr. No	Structure RD's	Flow Direction	Catchment Area (km²)	Peak Flood Discharges (m³/sec)		
				25 yrs	50 yrs	100 yrs
4	8+275	Left	0.056	1.00	1.16	1.33
5	9+421	Right	0.173	2.60	3.04	3.47
6	13+200	Left	0.039	0.75	0.87	1.00
7	13+950	Right	0.049	0.97	1.13	1.29
8	14+410	Left	0.042	0.82	0.95	1.09
9	15+375	Right	0.031	0.61	0.72	0.82
10	15+650	Right	0.071	1.01	1.18	1.34
11	18+045	Right	0.009	0.17	0.20	0.23
12	18+361	Left	0.078	1.54	1.80	2.06
13	19+416	Left	0.021	0.41	0.47	0.54
14	25+519	Right	0.067	1.32	1.54	1.76
15	34+296	Right	0.046	0.91	1.07	1.22
16	35+229	Right	0.073	1.32	1.55	1.77
17	35+900	Right	0.011	0.22	0.26	0.29
18	37+067	Right	0.104	1.94	2.26	2.59
19	38+025	Right	0.017	0.33	0.39	0.44
20	38+058	Left	0.012	0.23	0.27	0.31
21	40+350	Left	0.006	0.12	0.14	0.16
22	41+160	Right	0.047	0.92	1.07	1.22
23	41+835	Right	0.018	0.36	0.42	0.48
24	45+720	Left	0.086	1.61	1.88	2.15
25	55+770	Right	0.346	5.14	6.00	6.86
26	58+160	Right	0.039	0.77	0.90	1.03
27	62+065	Left	0.575	4.36	5.09	5.81
28	64+104	Left	0.013	0.25	0.29	0.33
29	64+520	Left	0.235	4.61	5.39	6.16
30	64+820	Left	0.024	0.47	0.55	0.63
31	65+530	Left	0.222	3.96	4.62	5.29
32	65+810	Left	0.120	2.35	2.75	3.14
33	66+262	Right	0.398	6.05	7.07	8.08
34	66+610	Right	0.395	6.87	8.02	9.17

2.12 FLOOD DISCHARGES WITH CLIMATE IMPACT

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	Structure RD's	Flow Direction	Catchment Area (km²)	Peak Flood Discharges (m³/sec)		
				25 yrs	50 yrs	100 yrs
1	2+210	Left	0.005	0.11	0.13	0.14
2	5+555	Right	0.084	1.08	1.25	1.39
3	7+585	Left	0.033	0.69	0.79	0.88
4	8+275	Left	0.056	1.06	1.21	1.36
5	9+421	Right	0.173	2.76	3.16	3.53
6	13+200	Left	0.039	0.80	0.91	1.02

Sr. No	Structure RD's	Flow Direction	Catchment Area (km²)	Peak Flood Discharges (m³/sec)		
				25 yrs	50 yrs	100 yrs
7	13+950	Right	0.049	1.03	1.18	1.32
8	14+410	Left	0.042	0.87	0.99	1.11
9	15+375	Right	0.031	0.65	0.75	0.83
10	15+650	Right	0.071	1.07	1.22	1.37
11	18+045	Right	0.009	0.19	0.21	0.24
12	18+361	Left	0.078	1.64	1.88	2.10
13	19+416	Left	0.021	0.43	0.49	0.55
14	25+519	Right	0.067	1.40	1.60	1.79
15	34+296	Right	0.046	0.97	1.11	1.24
16	35+229	Right	0.073	1.41	1.61	1.80
17	35+900	Right	0.011	0.23	0.27	0.30
18	37+067	Right	0.104	2.07	2.36	2.64
19	38+025	Right	0.017	0.35	0.40	0.45
20	38+058	Left	0.012	0.25	0.29	0.32
21	40+350	Left	0.006	0.13	0.14	0.16
22	41+160	Right	0.047	0.98	1.12	1.25
23	41+835	Right	0.018	0.38	0.44	0.49
24	45+720	Left	0.086	1.72	1.96	2.20
25	55+770	Right	0.346	5.46	6.25	6.98
26	58+160	Right	0.039	0.83	0.94	1.05
27	62+065	Left	0.575	4.43	5.23	5.68
28	64+104	Left	0.013	0.26	0.30	0.34
29	64+520	Left	0.235	4.92	5.62	6.28
30	64+820	Left	0.024	0.51	0.58	0.65
31	65+530	Left	0.222	4.22	4.82	5.39
32	65+810	Left	0.120	2.51	2.87	3.21
33	66+262	Right	0.398	6.43	7.36	8.21
34	66+610	Right	0.395	7.31	8.36	9.34

3. HYDRAULIC DESIGN OF CROSS DRAINAGE STRUCTURES

3.1 SCOPE OF HYDRAULIC STUDIES

The scope of hydraulics studies includes assessment of flow capacity and to check the adequacy of cross drainage structures present on this road i.e. Ranipur to Sukkur section for safely pass the design floods with climate change effect under SSP 5-8.5 for 6.8%, 4.3% and 2.2% increase on rainfall for 25-, 50- and 100-year return period floods respectively.

3.1.1 Design Approach of Proposed Culverts And Bridges

Culverts and bridges are provided as cross drainage structures on this roadway where irrigation channels, natural drains and nullahs cross the road. Here, in the reach from 0+000 to 70+000, cross drainage structures comprising culverts and bridges are provided at 127 locations in order to pass the irrigation and flood discharges.

Considering the floods estimated through hydrologic studies, hydraulic design review of existing twenty-four (24) box culverts, four (04) pipe culverts and one (01) bridge have been carried out by adopting comprehensive methodology which described in the subsequent sections. A schematic flow chart for hydraulic studies is shown in **Figure 3.1.**

3.1.2 Evaluation of Existing Bridges

3.1.2.1 HEC-RAS Model

HEC-RAS computer model developed by US Army Corps of Engineers has been used to compute the flow parameters and the water surface profile of nullah at bridge location along the reach under study. Following procedure has been adopted to conduct the hydraulic analysis of nullah to check the adequacy of the existing bridge.

River Geometry

Geometric data consists of the nullah schematic layout diagram, cross sectional survey data, hydraulic structure data (bridge) and cross section interpolation (where needed). Cross sections have been selected at suitable intervals along the nullah to determine the hydraulic design parameters at structure location. Model have been developed with and without hydraulic structure to carry out the hydraulic analysis of nullah. Number of cross sections obtained from topographic survey at upstream and downstream of hydraulic structure have been used to develop the model to compute the Highest Flood Level (HFL) along the stretch of the road under consideration.

Roughness Coefficient

The value of roughness coefficient ‘n’ depends upon the morphology, bed material, vegetation and manmade interventions in and along the flood plain of the nullah. The basic factors affect the ‘n’ value include surface roughness, the size and shape of the grains of the materials forming the wetted parameter, vegetation type and cover, channel alignment and obstructions. Keeping in view the above factors, roughness coefficient of 0.030 for main nullah and 0.035 for left and right over bank have been chosen for the structure.

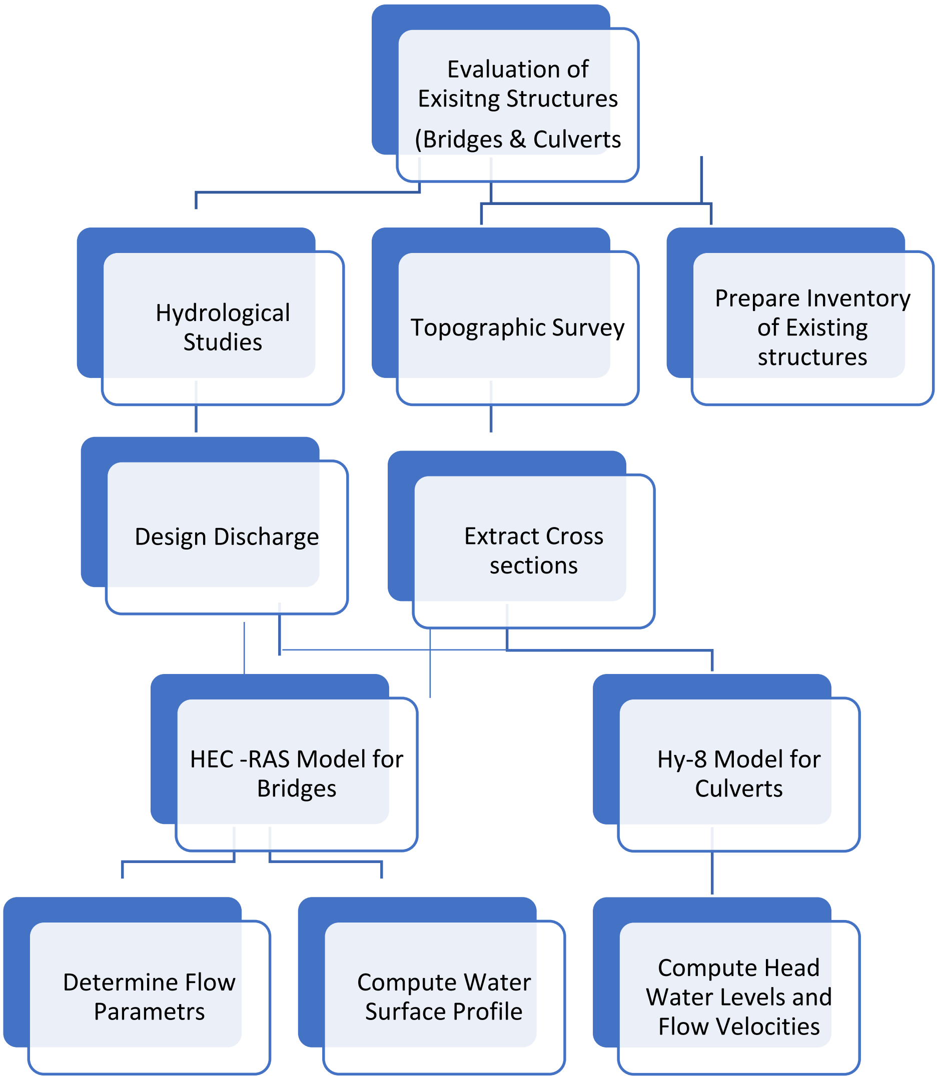

Figure 3.1: Schematic Flow Chart Showing Hydraulic Analysis of Bridge and Culverts

<u>Boundary Condition</u>

The model is run under steady state flow condition for subcritical or supercritical flow regimes and normal depth at downstream or upstream ends of the study reach has been taken as boundary condition depending on the prevalent regime of the nullah.

<u>Hydraulic Design Parameters</u>

The hydraulic design parameters like flow depth and flow velocity have been determined by using the cross-sectional data along with hydrological data as input in the HEC-RAS computer model.

Typical cross section and longitudinal profile of bridge in HEC-RAS model is given in **Figure 3.2** and **Figure 3.3**.

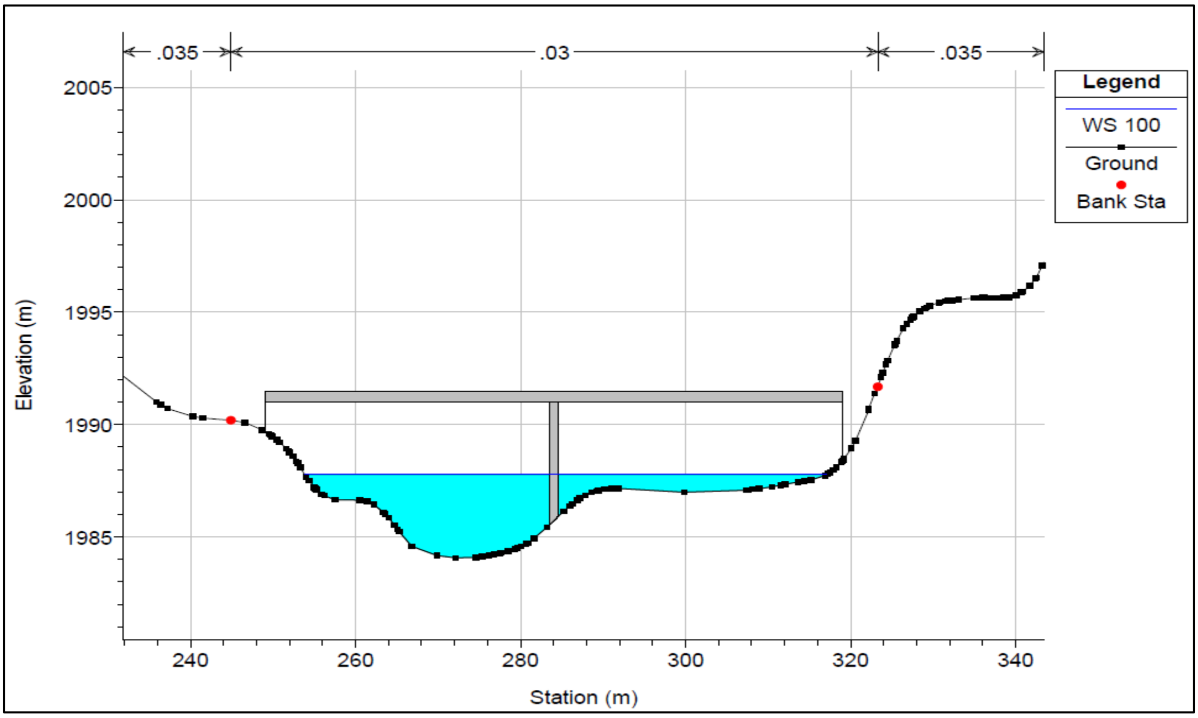

Figure 3.2: Typical Cross Section of Bridge in HEC-RAS Model

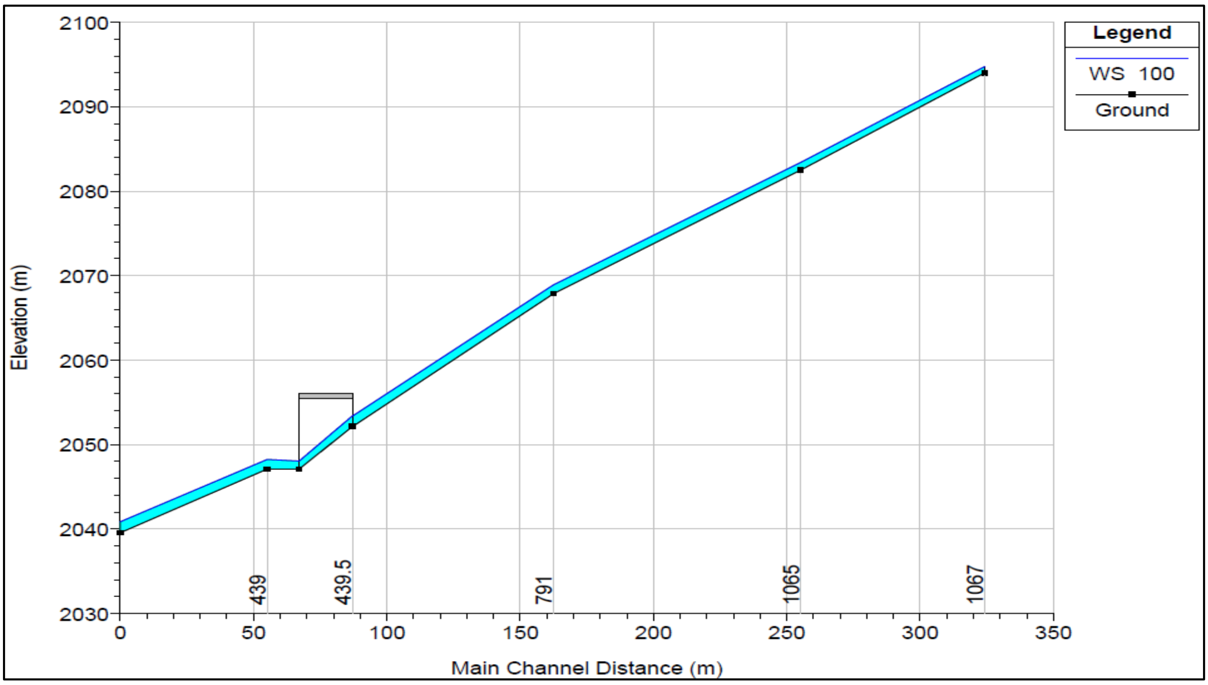

Figure 3.3: Typical Longitudinal Profile of nullah with Bridge in HEC-RAS Model

3.1.2.2 Freeboard

The freeboard for the bridge is adopted as 1m here in case of nullah.

3.1.3 Evaluation of Existing Culverts

The Culvert structures have been analysed on HY-8 software to confirm the existing conveyance capacity against the design discharge i.e., 25-year return period. Followings are the input parameters for the Hy-8 model:

3.1.3.1 Design Discharge

The existing culverts have been analysed on design discharge of 25 years return period flood, whereas minimum discharge is assumed as nil, and the maximum discharge is taken as 50 years return period flood.

3.1.3.2 Tail Water Data

The model requires manning's roughness coefficient (n), average bed slope and one cross section on the downstream, for the computation of tail water level. The average bed slope of the nullah on the downstream side of culvert is taken from the topographic survey data.

3.1.3.3 Roadway Data

The roadway data is required as input in the model, which comprises width of widened roads, road crown elevation and total carriage width. The size of each culvert has been checked for safe capacity under conditions that the head water level will not approach the roadway.

3.1.3.4 Culvert Data

Concrete box and pipe culverts are analysed with manning's roughness coefficient of 0.016. The data required for the model comprised of type, invert levels, culvert length, shape and size of culvert barrels along with inlet and outlet wing wall configurations.

Typical longitudinal profile of a culvert in HY-8 computer model is given as **Figure 3.4.**

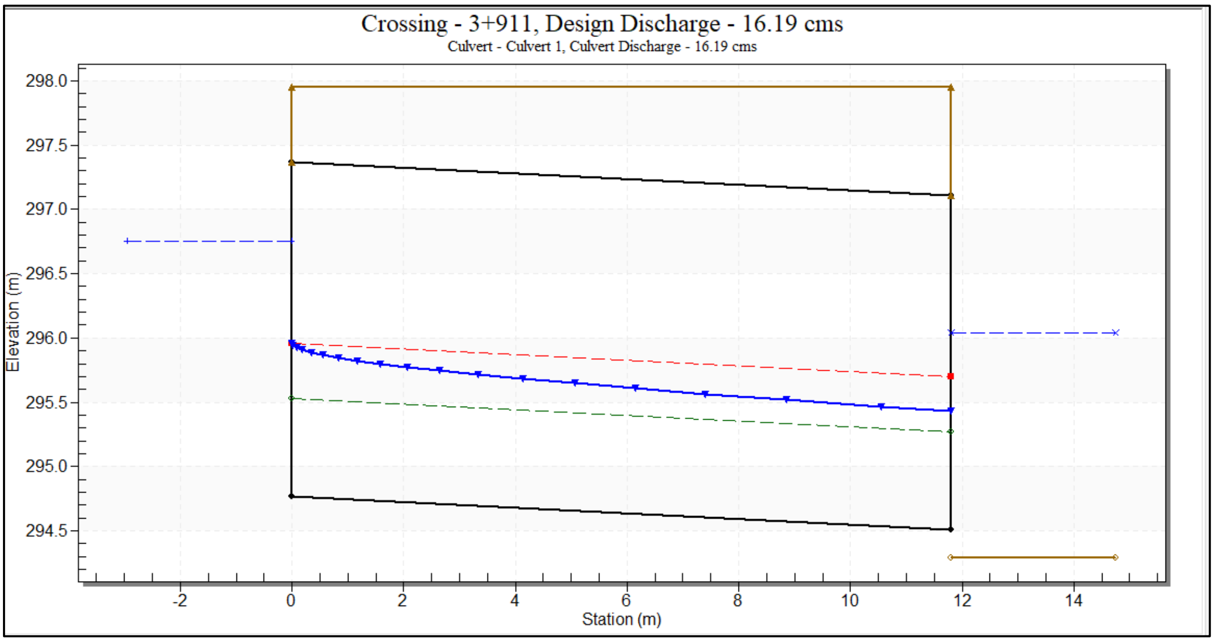

Figure 3.4: Typical Longitudinal Profile of Culvert in HY-8 Model

A typical summary table of culvert in HY-8 Computer Model is given as **Table 3.1**.

Table 3.1: Hydraulic Parameters of Culvert

Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth(m)	Outlet Control Depth(m)	Flow Type	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Tailwater Velocity (m/s)
0.00	0.00	294.77	0.00	0.0	0-NF	0.00	0.00	0.00	0.00	0.00	0.00
2.33	2.33	295.32	**0.55**	0.36	1-JS1t	0.20	0.33	0.62	0.84	0.94	0.80
4.67	4.67	295.64	**0.87**	0.63	1-JS1t	0.32	0.52	0.87	1.09	1.34	0.96
7.00	7.00	295.91	**1.14**	0.83	1-JS1t	0.42	0.68	1.05	1.27	1.66	1.06
9.33	9.33	296.15	**1.38**	1.00	1-JS1t	0.51	0.82	1.20	1.42	1.95	1.14
11.67	11.67	296.37	**1.60**	1.17	1-JS1t	0.60	0.95	1.32	1.54	2.20	1.21
14.00	14.00	296.57	**1.80**	1.33	1-S2n	0.69	1.08	0.82	1.66	4.25	1.27
16.19	16.19	296.75	**1.98**	1.47	1-S2n	0.76	1.19	0.92	1.75	4.41	1.31
18.66	18.66	296.95	**2.18**	1.63	1-S2n	0.84	1.30	1.02	1.85	4.57	1.36
21.00	21.00	297.13	**2.36**	1.79	1-S2n	0.92	1.41	1.12	1.93	4.70	1.40
23.33	23.33	297.31	**2.54**	1.95	1-S2n	1.00	1.51	1.21	2.01	4.83	1.44

3.1.4 Analysis and Results

The hydraulic design review parameters of the existing culverts and bridge along with suggested remarks to be adopted for each structure for the project are shown in **Table 3.2**.

3.2 CONCLUSION AND RECOMMENDATIONS

Hydraulic design review of the culverts and bridge have been carried, by extracting required input parameters from available road layout plans, condition survey, natural topographic and google earth maps to check the adequacy for safely pass the design floods with climate change effect under SSP 5-8.5. It is observed that existing box culverts are present on small drain/ nullahs, and bridge exist on some bigger nullah at Ranipur-Sukkur section. Considering the topography of the project area, some development and huge agricultural land on the sides of the road at different locations the hydraulic analyses for the cross-drainage structures have been taken up. Here, in this reach the structures with individual design discharge have been reviewed as individual for capacity check as shown in Table-1 and some briefed below.

- The results of the hydraulic analyses show that culverts at RD. 45+772 and 55+770 (both sides) are not capable of passing design floods. Hence, these culverts required to increase number of cells/barrels to achieve adequate capacity as shown in summary table.
- Some culverts are moderately choked, minor damaged and filled with mud. Hence, required cleaning, repair and periodic maintenance for the proper drainage of the design floods. Some culverts with poor conditions are also suggested to replace with new box culverts as mentioned in remarks.
- In this reach of road only one bridge existed at RD. 68+275 with a capacity of about 600 m^3/s as indicated in the summary table. Here, one side (R-S) of bridge is filled with mud that require cleaning.

Table 3.2: Hydraulic Design Review Parameters of Existing Culverts and Bridge

Sr. No.	Structure Code	RD	Structure Type	Roadside	Estimated SSP 5-8.5 Discharge	No. of Span	Span / Dia.	Span Height	Estimated Capacity (m^3/sec)		Capacity Check	Remarks
					(m^3/sec)		(m)	(m)	Individual	Combined		
1	-	0+175	-	-	-	-	-	-	-	-	-	Irrigation Channel
2	-	0+900	-	-	-	-	-	-	-	-	-	Irrigation Channel
3	-	1+500	-	-	-	-	-	-	-	-	-	Irrigation Channel
4	PC-1	2+210	Pipe Culvert	-	0.11	1	0.9	-	1.32	1.32	Capacity OK	-
5	BC-1	7+585	Box Culvert	-	0.69	1	1	0.8	2.51	2.51	-	Poor Condition . Replace by 1x1.5 box culvert.
6	BC-2	8+275	Box Culvert	-	1.06	1	1	1	2.63	2.63	Capacity OK	-
7	BC-3	13+200	Box Culvert	-	0.8	1	1	1	3.89	3.89	Capacity OK	-
8	BC-4	13+950	Box Culvert	-	1.03	1	0.9	0.7	-	-	-	Choked & Poor Condition . Replace by 1x1.5 box culvert.
9	BC-5	14+410	Box Culvert	-	0.87	-	-	-	-	-	-	Choked . Replace by 1x1.5 box culvert.
10	-	15+125	-	-	-	-	-	-	-	-	-	Irrigation Channel
11	-	15+280	-	-	-	-	-	-	-	-	-	Irrigation Channel
12	-	15+375	-	-	-	-	-	-	-	-	-	Irrigation Channel
13	-	16+500	-	-	-	-	-	-	-	-	-	Irrigation Channel
14	BC-6	16+700	Box Culvert	-	-	1	0.95	0.95	2.79	2.79	-	Local Flow
15	-	17+200	-	-	-	-	-	-	-	-	-	Irrigation Channel
16	-	17+970	-	-	-	-	-	-	-	-	-	Irrigation Channel
17	-	18+750	-	-	-	-	-	-	-	-	-	Irrigation Channel
18	-	19+800	-	-	-	-	-	-	-	-	-	Irrigation Channel
19	-	20+115	-	-	-	-	-	-	-	-	-	Irrigation Channel
20	-	20+855	-	-	-	-	-	-	-	-	-	Irrigation Channel
21	-	21+325	-	-	-	-	-	-	-	-	-	Irrigation Channel
22	-	21+680	-	-	-	-	-	-	-	-	-	Irrigation Channel
23	-	21+920	-	-	-	-	-	-	-	-	-	Irrigation Channel
24	PC-2	22+225	Pipe Culvert	-	-	1	0.6	-	0.69	0.69	-	Poor Condition. Replace by 1x1.5 box culvert.
25	-	22+345	-	-	-	-	-	-	-	-	-	Irrigation Channel
26	-	22+935	-	-	-	-	-	-	-	-	-	Irrigation Channel
27	-	23+500	-	-	-	-	-	-	-	-	-	Irrigation Channel
28	-	23+800	-	-	-	-	-	-	-	-	-	Irrigation Channel
29	-	24+650	-	-	-	-	-	-	-	-	-	Irrigation Channel
30	-	24+940	-	-	-	-	-	-	-	-	-	Irrigation Channel
31	-	25+135	-	-	-	-	-	-	-	-	-	Irrigation Channel

Sr. No.	Structure Code	RD	Structure Type	Roadside	Estimated SSP 5-8.5 Discharge	No. of Span	Span / Dia.	Span Height	Estimated Capacity (m^3/sec)		Capacity Check	Remarks
					(m^3/sec)		(m)	(m)	Individual	Combined		
32	BC-7	25+520	Box Culvert	-	1.4	1	1	1	3.03	3.03	Capacity OK	-
33	-	25+780	-	-	-	-	-	-	-	-	-	Irrigation Channel
34	-	26+080	-	-	-	-	-	-	-	-	-	Irrigation Channel
35	-	26+280	-	-	-	-	-	-	-	-	-	Irrigation Channel
36	-	26+450	-	-	-	-	-	-	-	-	-	Irrigation Channel
37	-	26+920	-	-	-	-	-	-	-	-	-	Irrigation Channel
38	-	27+600	-	-	-	-	-	-	-	-	-	Irrigation Channel
39	-	27+990	-	-	-	-	-	-	-	-	-	Irrigation Channel
40	-	28+435	-	-	-	-	-	-	-	-	-	Irrigation Channel
41	-	28+600	-	-	-	-	-	-	-	-	-	Irrigation Channel
42	-	28+925	-	-	-	-	-	-	-	-	-	Irrigation Channel
43	-	29+650	-	-	-	-	-	-	-	-	-	Irrigation Channel
44	-	30+060	-	-	-	-	-	-	-	-	-	Irrigation Channel
45	-	30+480	-	-	-	-	-	-	-	-	-	Irrigation Channel
46	-	30+775	-	-	-	-	-	-	-	-	-	Irrigation Channel
47	-	30+800	-	-	-	-	-	-	-	-	-	Irrigation Channel
48	-	31+000	-	-	-	-	-	-	-	-	-	Irrigation Channel
49	-	31+625	-	-	-	-	-	-	-	-	-	Irrigation Channel
50	-	32+045	-	-	-	-	-	-	-	-	-	Irrigation Channel
51	-	32+080	-	-	-	-	-	-	-	-	-	Irrigation Channel
52	-	32+460	-	-	-	-	-	-	-	-	-	Irrigation Channel
53	-	32+860	-	-	-	-	-	-	-	-	-	Irrigation Channel
54	-	33+040	-	-	-	-	-	-	-	-	-	Irrigation Channel
55	-	33+175	-	-	-	-	-	-	-	-	-	Irrigation Channel
56	-	33+445	-	-	-	-	-	-	-	-	-	Irrigation Channel
57	-	34+550	-	-	-	-	-	-	-	-	-	Irrigation Channel
58	-	34+720	-	-	-	-	-	-	-	-	-	Irrigation Channel
59	-	35+545	-	-	-	-	-	-	-	-	-	Irrigation Channel
60	-	35+690	-	-	-	-	-	-	-	-	-	Irrigation Channel
61	BC-8	35+900	Box Culvert	-	0.23	1	1	1	3.15	3.15	Capacity OK	-
62	-	36+480	-	-	-	-	-	-	-	-	-	Irrigation Channel
63	-	36+690	-	-	-	-	-	-	-	-	-	Irrigation Channel
64	-	37+165	-	-	-	-	-	-	-	-	-	Irrigation Channel
65	-	37+810	-	-	-	-	-	-	-	-	-	Irrigation Channel
66	BC-9	38+025	Box Culvert	-	0.35	1	1	1	2.89	2.89	Capacity OK	-
67	BC-10	38+285	Box Culvert	-	-	1	1	1	2.95	2.95	-	Local Flow
68	-	38+545	-	-	-	-	-	-	-	-	-	Irrigation Channel

Sr. No.	Structure Code	RD	Structure Type	Roadside	Estimated SSP 5-8.5 Discharge	No. of Span	Span / Dia.	Span Height	Estimated Capacity (m^3/sec)		Capacity Check	Remarks
					(m^3/sec)		(m)	(m)	Individual	Combined		
69	-	38+750	-	-	-	-	-	-	-	-	-	Irrigation Channel
70	-	39+615	-	-	-	-	-	-	-	-	-	Irrigation Channel
71	-	40+270	-	-	-	-	-	-	-	-	-	Irrigation Channel
72	BC-11	40+350	Box Culvert Pipe Culvert	*R-S* *S-R*	0.13	1 1	1 0.9	1 -	1.34	1.34	-	Poor Condition, Replace by 1x1.5 Box Culvert
73	-	40+800	-	-	-	-	-	-	-	-	-	Irrigation Channel
74	PC-3	41+160	Pipe Culvert	-	0.98	1	0.9	-	1.37	1.37	Capacity OK	Choked, Cleaning & Maintenance Required
75	-	41+415	-	-	-	-	-	-	-	-	-	Irrigation Channel
76	BC-12	41+835	Box Culvert	-	0.38	1	0.8	0.5	1.36	1.36	Capacity OK	Choked, Cleaning & Maintenance Required
77	-	42+480	-	-	-	-	-	-	-	-	-	Irrigation Channel
78	-	42+990	-	-	-	-	-	-	-	-	-	Irrigation Channel
79	-	43+250	-	-	-	-	-	-	-	-	-	Irrigation Channel
80	-	43+490	-	-	-	-	-	-	-	-	-	Irrigation Channel
81	-	43+810	-	-	-	-	-	-	-	-	-	Irrigation Channel
82	-	44+260	-	-	-	-	-	-	-	-	-	Irrigation Channel
83	BC-13	45+010	Box Culvert	-	-	1	1	1	3.11	3.11	-	Local Flow
84	-	45+290	-	-	-	-	-	-	-	-	-	Irrigation Channel
85	-	45+575	-	-	-	-	-	-	-	-	-	Irrigation Channel
86	PC-4	45+720	Pipe Culvert	-	1.72	1	0.9	-	1.35	1.35	Less Capacity	Replace by 1x1.5 Box Culvert
87	-	45+985	-	-	-	-	-	-	-	-	-	Irrigation Channel
88	-	46+545	-	-	-	-	-	-	-	-	-	Irrigation Channel
89	-	47+045	-	-	-	-	-	-	-	-	-	Irrigation Channel
90	-	47+700	-	-	-	-	-	-	-	-	-	Irrigation Channel
91	-	48+135	-	-	-	-	-	-	-	-	-	Irrigation Channel
92	-	48+250	-	-	-	-	-	-	-	-	-	Irrigation Channel
93	-	48+655	-	-	-	-	-	-	-	-	-	Irrigation Channel
94	-	48+820	-	-	-	-	-	-	-	-	-	Irrigation Channel
95	-	49+110	-	-	-	-	-	-	-	-	-	Irrigation Channel
96	-	49+565	-	-	-	-	-	-	-	-	-	Irrigation Channel
97	BC-14	50+080	Box Culvert	-	-	1	1	1	3.21	3.21	-	Local Flow
98	BC-15	50+430	Box Culvert	-	-	1	1	1	3.05	3.05	-	Local Flow
99	-	51+285	-	-	-	-	-	-	-	-	-	Irrigation Channel
100	-	51+620	-	-	-	-	-	-	-	-	-	Irrigation Channel
101	-	52+330	-	-	-	-	-	-	-	-	-	Irrigation Channel
102	-	54+350	-	-	-	-	-	-	-	-	-	Irrigation Channel

Sr. No.	Structure Code	RD	Structure Type	Roadside	Estimated SSP 5-8.5 Discharge	No. of Span	Span / Dia.	Span Height	Estimated Capacity (m^3/sec)		Capacity Check	Remarks
					(m^3/sec)		(m)	(m)	Individual	Combined		
103	-	55+485	-	-	-	-	-	-	-	-	-	Irrigation Channel
104	BC-16	55+770	Box Culvert	-	5.46	1	1	1	2.98	2.98	Less Capacity	Increase 1 barrel of 1x1 to cater the Climate Resilience flood
105	-	56+080	-	-	-	-	-	-	-	-	-	Irrigation Channel
106	-	56+580	-	-	-	-	-	-	-	-	-	Irrigation Channel
107	-	57+050	-	-	-	-	-	-	-	-	-	Irrigation Channel
108	-	57+320	-	-	-	-	-	-	-	-	-	Irrigation Channel
109	-	57+570	-	-	-	-	-	-	-	-	-	Irrigation Channel
110	-	57+970	-	-	-	-	-	-	-	-	-	Irrigation Channel
111	BC-17	58+160	Box Culvert	-	0.83	1	1	1	2.95	2.95	-	Choked, Cleaning & Maintenance Required
112	-	58+535	-	-	-	-	-	-	-	-	-	Irrigation Channel
113	-	58+800	-	-	-	-	-	-	-	-	-	Irrigation Channel
114	-	59+850	-	-	-	-	-	-	-	-	-	Irrigation Channel
115	-	59+975	-	-	-	-	-	-	-	-	-	Irrigation Channel
116	-	60+020	-	-	-	-	-	-	-	-	-	Irrigation Channel
117	-	60+100	-	-	-	-	-	-	-	-	-	Irrigation Channel
118	BC-18	60+235	Box Culvert	-	-	1	1.2	1	3.45	3.45	-	Local Flow
119	BC-19	62+065	Box Culvert	-	4.43	2	1.5	0.8	8.28	8.28	Capacity OK	-
120	-	63+135	-	-	-	-	-	-	-	-	-	Irrigation Channel
121	-	63+305	-	-	-	-	-	-	-	-	-	Irrigation Channel
122	BC-20	64+520	Box Culvert	-	4.92	1	2.2	1	-	-	-	Choked & Poor Condition, Replace by 2x1.5 Box Culvert
123	BC-21	64+820	Box Culvert	-	0.51	1	1.5	1	4.82	4.82	Capacity OK	-
124	BC-22	65+530	Box Culvert	-	4.22	1	1.5	1	4.78	4.78	Capacity OK	-
125	BC-23	65+810	Box Culvert	-	2.51	1	1.5	1	4.85	4.85	Capacity OK	-
126	BC-24	66+610	Box Culvert	-	7.31	2	2.5	2.5	21.47	21.47	Capacity OK	-
127	BR-1	68+275	Bridge	-	-	3	22	4.5	600	600	-	One side (R-S) filled with mud. Required Cleaning.

Note- PC = Pipe Culvert
BC = Box Culvert
BR = Bridge
R-S = Ranipur to Sukkur Side
S-R = Sukkur to Ranipur Side
Capacity of structure is estimated of smaller one in case of difference in size of structures on same RD of P-N & N-P roadways

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