USAID | PAKISTAN
FROM THE AMERICAN PEOPLE

Kurram Tangi Dam Construction

Supplemental Report on Climate Change
Final Report

December 2013
This publication was produced for review by the
United States Agency for International Development.
It was prepared by MWH-NESPAK-ACE under contract AID-391-C-13-00002

This page intentionally left blank

Map to Kurram Tangi Dam Project Documents

Shown below is the suite of documents submitted to USAID under Contract AID-391-C-13-00002 for the KTDP. This report is shaded in red in order to show its relationship to the full set of documentation.

ENVIRONMENTAL ASSESSMENT	
	VOLUME I: MAIN REPORT
	VOLUME II: PROJECT ECONOMIC BENEFITS
	VOLUME III: MAPS
ENVIRONMENTAL MITIGATION AND MONITORING PLAN	
	MAIN REPORT
	ANNEX I: HEALTH AND SAFETY PLAN FRAMEWORK
	ANNEX II: WATERSHED MANAGEMENT PLAN
	ANNEX III: WASTE MANAGEMENT PLAN
	ANNEX IV: FISHERIES MANAGEMENT PLAN
	ANNEX V: EMERGENCY PREPAREDNESS PLAN
	ANNEX VI: INSTRUMENTATION AND MONITORING PLAN
LAND ACQUISITION AND RESETTLEMENT	
	RESETTLEMENT POLICY FRAMEWORK
	RESETTLEMENT ACTION PLAN (COMPONENT I)
CULTURAL HERITAGE PRESERVATION PLAN	
VULNERABLE TRIBES PLAN	
GENDER PLAN	
KEY SUPPORTING TECHNICAL REPORTS	
	SUPPLEMENTAL REPORT ON GEOLOGY
	SUPPLEMENTAL REPORT ON GEOTECHNICAL ASPECTS
	SUPPLEMENTAL REPORT ON SEISMIC HAZARD
	SUPPLEMENTAL REPORT ON HYDROLOGY
	SUPPLEMENTAL REPORT ON CLIMATE CHANGE

All documents may be read as stand-alone documents, but the reader should be aware of the full set of documents available. Any one document may reference other documents in the suite in order to avoid duplication.

This page intentionally left blank

Kurram Tangi Dam Construction
Supplemental Report on Climate Change

USAID Environmental Assessment of Kurram Tangi Dam Construction
Contract Number: AID-391-C-13-00002
From MWH Americas, Inc.
To USAID/Pakistan Energy Office
December 2013
Author: MWH Americas, Inc.

The author's views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government
.

This page intentionally left blank

List of Acronyms

Acronym	Term
ac-ft	Acre Feet
CDM	Clean Development Mechanism
FATA	Federally Administered Tribal Areas
GCISC	Global Change Impact Study Center
GCM	Global Circulation Model
GHG	Greenhouse Gas
GoP	Government of Pakistan
ICOLD	International Commission on Large Dams
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
km	Kilometers
KP or KPK	Khyber Pakhtunkhwa
KTDC	Kurram Tangi Dam Construction
KTMDP	Kurram Tangi Multipurpose Dam Project
MCM	Million Cubic Meter
MWH	MWH Global, Inc. or MWH, Inc.
NESPAK	National Engineering Services Pakistan
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
PMD	Pakistan Meteorological Department
RCM	Regional Climate Model
TGP	Towards Gender Party
UET	University of Engineering and Technology
UN	United Nations
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USAID/Pak	United States Agency for International Development/Pakistan
WAPDA	Water and Power Development Authority
°C	Degree Celsius

This page intentionally left blank

Climate Change

Table of Contents

EXECUTIVE SUMMARY 1
1 INTRODUCTION 1-1
2 CLIMATE CHANGE STUDIES AT WAZIRISTAN AND KURRAM AGENCY (KURRAM TANGI DAM) 2-1
2.1 Geographic Background of the Project 2-1
2.2 Paleoclimatology of the Region 2-1
2.3 Climate and Bio-Climates of the Project Area 2-3
2.4 Climate Perception in Kurram Tangi Region 2-3
2.5 River Flow Parameters 2-5
2.5.1 The Catchment Area 2-5
2.5.2 Land Use of the Catchment Area 2-6
2.5.3 Historical River Flow Data 2-7
2.6 Historical Temperature Data 2-10
2.7 Historical Precipitation Data 2-12
2.8 Historical Seasonal Analysis of the Kurram Tangi Region for use as Baseline in the GCM Analysis 2-14
2.8.1 Historic Seasonal Averages 2-15
3 USING GCMS TO PROJECT SEASON AND OVERALL CLIMATE CHANGE IN THE KURRAM TANGI REGION 3-1
3.1 Introduction 3-1
3.2 GCM Analysis of Precipitation Data 3-1
3.3 GCM Projections of Temperature Data 3-3
4 GREENHOUSE GASES AND THE KURRAM TANGI DAM PROJECT 4-1
4.1 Options for the KTMDP to Reduce GHGs and Capture Carbon Financing Opportunities 4-1
4.2 GHG Emissions Offset by the KTMDP 4-1
5 CLIMATE CHANGE IMPACTS 5-1
5.1 Climate Change Implications – Socio-Economics 5-1
5.2 Sectors at Risk in the Kurram Tangi Region 5-1
6 FINDINGS AND RECOMMENDATIONS 6-1
7 BIBLIOGRAPHY 7-1

List of Tables

Table 2-1: Precipitation Variation with Altitude in Kosi Valley, Nepal (Source: Dhar and Bhattacharya, 1976) .. 2-4
Table 2-2: Catchment Areas 2-6
Table 3-1: GCM Correlation Table for Bannu 3-2
Table 3-2: Parachinar Historic and Projected Decadal Temperatures 3-4

This page intentionally left blank

List of Figures

Figure 1-1: Comparison of Annual Mean Temperature Change in Pakistan with Global Temperature Variations from 1860 to 2000 1-1
Figure 2-1: The Koppen-Geiger Climate Classification: CTRL and TORT 2-2
Figure 2-2: NOAA Parachinar Data, Presented in both Metric and English Units 2-5
Figure 2-3: Map Indicating the Weather Stations Location in Kurram Tangi Dam Catchment Area 2-6
Figure 2-4: Historical Monthly and Annual Discharge of Kurram River at Thal 2-8
Figure 2-5: Graph Showing the Flow of Kurram River at Kurram Tangi Dam Site 2-9
Figure 2-6: Graph Showing the Flow of Kaitu River at Spinwan Site 2-9
Figure 2-7: Annual Mean Temperature Graph of Bannu for the Period from 1948 to 2012 2-10
Figure 2-8: Annual Mean Temperature Graph of Parachinar for the Period from 1948 to 2012 2-11
Figure 2-9: Annual Mean Temperature Graph of Kohat for the Period from 1948 to 2012 2-11
Figure 2-10: Annual Mean Temperature Graph of Gardez for the Period from 1964 to 1982 2-12
Figure 2-11: Historical Precipitation Record of Bannu, KP 2-12
Figure 2-12: Historical Precipitation Record of Parachinar, Kurram Agency, FATA 2-13
Figure 2-13: Historical Precipitation Graph at Kohat, KP 2-13
Figure 2-14: Historical Precipitation Record at Gardez, Afghanistan, from 1964 to 1983 2-14
Figure 2-15: Locations of Meteorological Stations in the Project Area 2-14
Figure 2-16: Historical Average Precipitation and Temperatures 2-15
Figure 2-17: Precipitation and Temperature Historical Decadal Averages 2-15
Figure 2-18: Historical Monthly Average Temperatures 2-16
Figure 2-19: Historical Monthly Average Precipitation ..... +2-16
Figure 2-20: Average Monthly Precipitation at Bannu 2-17
Figure 2-21: Average Monthly Precipitation at Kohat 2-17
Figure 3-1: Average GCM Ensemble Projection vs. Historical Precipitation Data 3-2
Figure 3-2: Parachinar GCM Projection for Temperature vs. Historical Temperature for Five Decadal Periods 3-3
Figure 3-3: Bannu GCM Projection for Temperature vs. Historical Temperature for Five Decadal Periods 3-3
Figure 3-4: Average GCM Ensemble Projection vs. Historical Temperature Data 3-4

List of Annexures (Bound Separately)

Annexure 1: List of Data Tables
Annexure 2: Review of Existing Literature and Research on GCM and RCM
Annexure 3: Global Climate Change Perspective
Annexure 4: National Climate Change Perspective

This page intentionally left blank

EXECUTIVE SUMMARY

Predicting the weather is a challenging science at best. "Only the weather man gets paid for being wrong" is a familiar phrase. This is even more the case when it comes to predicting the weather 20, 50 and 100 years from now, let alone for the rest of this week.

Changes in climate can have a significant impact on infrastructure viability and operation, as well as on the surrounding communities. For water-based infrastructure this is particularly the case, as the impacts of climate change are not just on temperature but also on overall precipitation and storm frequency and intensity. Though global circulation models (GCMs) and regional climate models (RCMs) can predict changes in temperature and precipitation, they do not predict short-duration extreme weather events.

In recent years, temperatures have been rising at above record levels and erratic and extreme weather patterns are occurring with greater frequency. Both global and regional models used to predict future meteorological data show varying degrees of precision. In regions where there are high amounts of terrain changes within short distances, the models tend to not perform as well as in regions with little change.

An analysis was conducted to determine what changes may be likely over the lifetime of the Kurram Tangi Dam. To do this we looked at historical data, the existing body of research and literature available, and conducted an analysis of 18 GCMs. Our research looked at climate changes over seasons, years, and decades, assessing the relative change over time of temperature and precipitation. We also assessed the carbon impacts of the project, and reviewed the socio-economic impacts of climate change.

Our findings show that the Kurram Tangi region is likely to experience hotter summers and shorter winters. The Kurram Tangi drainage area is likely to show a slightly higher average annual precipitation of 4% by 2099. This is well within the historic decadal range of variation, which has gone from as much as +10% to -10% of the historical average. There appears to be no overall seasonal shift in projected scenarios: the spring rains and fall/winter rains are likely to begin and end at approximately the same time as they have historically. The impact to the overall project operation is a possible slight increase in flow rates and volumes in the early spring months than have historically been the case.

The average projected air temperature increase is between 3-4°C above the 1990 base by 2065, and 5°C by 2099. The increase in temperatures appears to be relatively uniform across the seasons. As such, we may see a lengthening of the summer season and shortening of winters. At higher elevations this may lead to an earlier snow and glacier melt, but this is not critical to the Kurram Tangi project as the area with glaciers is very limited and less than 1% of the total watershed area.

The operation of Kurram Tangi Dam will produce minimal greenhouse gas emissions. Comparing this project to the equivalent amount of power and greenhouse gases (GHG's) that would be generated using the mix of generation on the Pakistani grid, we see that the project will reduce GHG emissions by 149,732 metric tons of carbon dioxide per year. This is the equivalent of taking over 30,870 cars off the road for a year.

The local socio-economic impacts are likely to be around adjusting to longer summers and higher summer temperatures. If water resources are not properly managed, this could result in a decrease in summer productivity through the warmest months. However, a longer summer season, if coupled with well managed irrigation waters, could extend the growing season and result in higher agricultural productivity and a boost to the local economy. If not managed properly, it is likely that climate change will result in a decrease in the overall agricultural productivity, and a negative socio-economic impact on the region.

The national impact of increasing temperatures will be an increase in summer electrical demands to meet cooling needs. It is likely that summer production from the Kurram Tangi project will only make a marginal impact on the increased summer power needs nationwide. Unless significant storage

capacity is built to allow for longer retention of the spring flows behind this and other dams, it is likely that Pakistan will need to turn to other, non-hydro sources of power to meet increasing summer power demands, which could have negative economic impacts given the fact that much of the fuel to run Pakistan's non-hydro fossil fuel units is imported. Additionally, the combustion of those fossil fuels will produce additional GHGs, further exacerbating the climate change problems.

Our report concludes with recommendations on how to manage the anticipated climate changes at the Kurram Tangi Dam project and within the region impacted by the project. These include:

- Assess possible shifts in hydrology by the 2040-2065 time period. Based on outcomes account for increased siltation in reservoir management planning, and assess the possible changes in the power curves to account for any reduction in power output during peak summer months.
- Assess possible shifts in future hydrology on the river flood plain levels. Based on outcomes assess any resultant
- Resettlement needs, crop pattern considerations, livestock grazing patterns, and education campaigns about flash flooding.
- Ensure that irrigation planning accounts for possible future decreases in summer water availability, drier soils, and shifts in agricultural practices.
- Assess existing crop and livestock tolerances to increased temperatures and any necessary changes in future management practices.
- Conduct agricultural outreach to assist in adaptive changes which may be necessary in the future.
- Assess whether agricultural outreach may offset possible human induced stresses to the natural rangeland habitats.
- Assess local health practices and needs to determine if climate induced human illnesses are likely, and if measures can be taken to counteract these.
- Prepare emergency plans for extreme climate events.

1 INTRODUCTION

The most general definition of climate change is a change in the statistical properties of the climate system when considered over long periods of time, regardless of cause. Accordingly, fluctuations over periods shorter than a few decades, such as El Niño, do not represent climate change. The term sometimes is used to refer specifically to climate change caused by human activity, as opposed to changes in climate that may have resulted as part of Earth's natural processes. In this sense, especially in the context of environmental policy, the term climate change has become synonymous with anthropogenic global warming. Within scientific journals, global warming refers to surface temperature increases while climate change includes global warming and everything else that increasing greenhouse gas levels will affect. On the broadest scale, the rate at which energy is received from the sun and the rate at which it is lost to space determine the equilibrium temperature and climate of Earth. This energy is distributed around the globe by winds, ocean currents, and other mechanisms to affect the climates of different regions.

Development of the Tribal Areas in North West Pakistan is a high priority. The area is rugged and generally arid. The population is mostly illiterate and lives off the land, taking benefit from whatever opportunity presents itself in this remote area. A prerequisite for development is the availability of water and electricity so commercial activities can grow and create opportunities for jobs. Constructing a dam to produce cheap electricity and supply reliable irrigation water is an ideal activity to spur development by encouraging private sector investment in the area, thereby attracting people to the area and improving lives. Kurram Tangi Dam is proposed to be constructed on the boundary of North Waziristan Agency and F.R. Bannu about 15 km upstream of Kurram Garhi Headworks and 30 km north of Bannu city. Kurram Tangi Dam will regulate the flows of Kurram River where water will be released according to the irrigation requirements and excess water will be stored for use during low flow periods.

Agriculture is both vulnerable to climate shifts and a source of the greenhouse gases driving changes. Climate change related threats to agriculture represent threats to society, and calls for adaptation and mitigation strategies are increasing. Adjustment to potential natural hazards depends on perceptions of the risks. **Figure 1-1** gives a comparison of annual mean temperature change in Pakistan as calculated by the Pakistan Meteorological Department, with global temperature variations from Year 1860 to Year 2000.

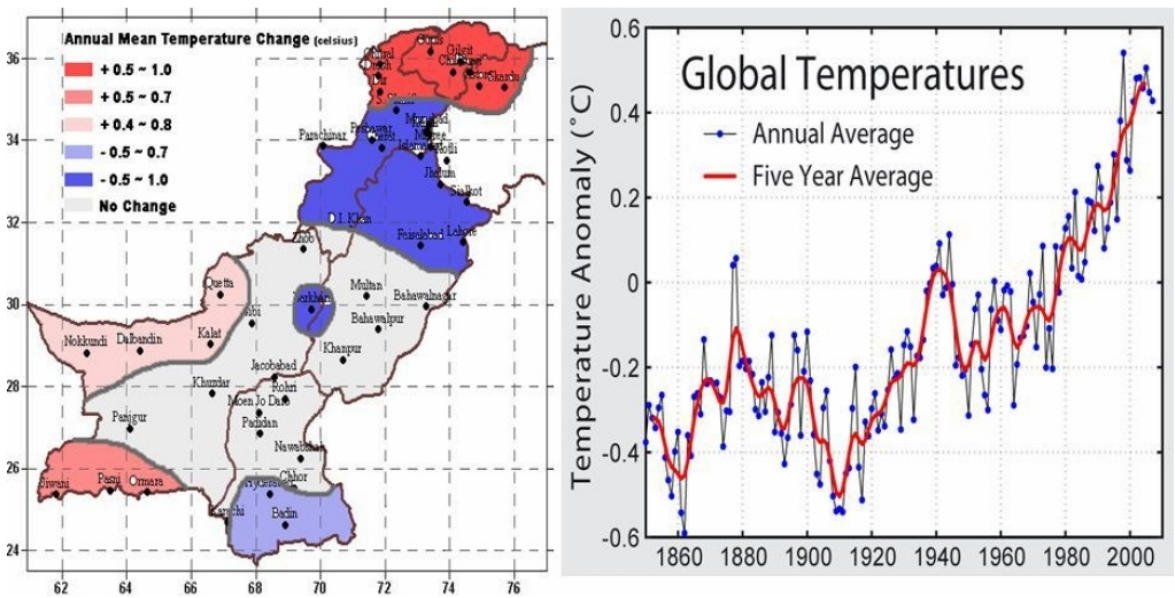


Figure 1-1: Comparison of Annual Mean Temperature Change in Pakistan with Global Temperature Variations from 1860 to 2000

USAID require that the impacts of the Kurram Tangi Multipurpose Dam Project (KTMDP) construction and operation must be seen within the context of global climate change, which might significantly affect the physical (and socio-economic) environment of the project. In the scenario the consultants were asked to quantify processes and factors such as:

- Temperature impact change on water balance models of mountainous regions, on glacial melting, water generation from fossil ice vs. annual replenishment by precipitation, water storage in glacial systems, timescale of balance of deposition and depletion
- Changes in amount, type and seasonal/annual distribution of precipitation in the project area and the upstream/downstream watershed of KTMDP.
- Changes in reservoir temperature and resulting stratification/mixing behavior due to change of average ambient temperature as well as water temperature of Kurram and Kaitu River and other direct inflows, impacts on reservoir water chemistry, fauna and flora
- Changes of upstream/downstream hydrological parameters, notably flow rates and sedimentary load and their seasonal/annual distribution. They might be controlled by underlying phenomena such as glacial melting and subsequent release of water/sediment trapped in ice, glacial retreat and exposition of additional areas to erosion, changes in vegetation and resulting impact on erosion/sediment generation and microclimate
- Changes in seasonal/annual demand patterns for water and electricity, shifts in peak demands for energy (heating/cooling) and water (agriculture, irrigation) in the annual cycle, and interaction of these changes with operational requirements and hydrological parameters, such as seasonal flow rates.

Changes in the climate can have significant impact on infrastructure viability and operation, as well as on the surrounding communities. Against this background, an important challenge is to estimate the impacts of climate change on temperature, precipitation, and storm frequency and intensity for a water-based infrastructure project like the KTMDP. Global Circulation Models (GCMs) are one of the most popular tools used to simulate the long term impacts of increased greenhouse gases on climatic variables such as precipitation and temperature within a particular river basin. This report presents an analysis to determine what changes may be likely over the possible lifetime of the KTMDP. This was accomplished with a review of the existing body of research and literature, historical precipitation and temperature data for the Kurram Tangi region, and use of GCMs for the long term forecast of precipitation and temperature under climate change. This report also presents an assessment of the carbon impacts of the project, and a discussion on socio-economic impacts due to climate change.

This report has four Annexures that are bound separately. Annexure 1 includes ten different data tables (Tables A-1 through A-10). Annexure 2 presents a detailed review of existing literature and research on GCMs and RCMs, and Annexures 3 and 4 present a discussion of the existing body of research on climate change from global and national perspectives, respectively.

2 CLIMATE CHANGE STUDIES AT WAZIRISTAN AND KURRAM AGENCY (KURRAM TANGI DAM)

This chapter presents a review of climate and the historical data required to establish a baseline to assess the impact of climate change on the precipitation and temperature of the Kurram Tangi region. Additional discussion of the existing body of research on climate change from the global and national perspectives, respectively, is provided in Annexures 3 and 4.

2.1 Geographic Background of the Project

The name Kurram comes from the river Kurram, which flows along the valley. The valley in the north is surrounded by snow-covered or "white" mountains, the Safaid Koh, locally known in Pashto as Speen Ghar, which also forms the natural border with Afghanistan. The Safaid Koh Mountains rise from Terimangal pass and stretch eastward, reaching an elevation of 3,600 m. The Sikaram, at 4,760 m, is the tallest peak in this range. The Kurram River flows northwest to southeast, entering North Waziristan below the town of Thal in the Hangu district of KP, and eventually joining the Indus River.

In Lower Kurram Agency, Makhizai is a scenic place where tribes such as the Chamkani, Orakzai and Makhizai have natural richness depended upon hills and mountain with evergreen forests and fields for growing crops like rice and wheat etc. Kurram River drains the southern flanks of the Safed Koh mountain range, and enters the Indus Plains north of Bannu. It flows west to east and crosses the Paktia Province, Afghan-Pakistan border at Coordinates: 33°49′N 69°58′E about 80 km southwest of Jalalabad, and joins the Indus near Isa Khel after a course of more than 320 km (200 mi).

Geographically, the whole of Waziristan is a single unit; however for administrative convenience it has been split into two agencies – North and South Waziristan. The area has been described as a land of high and difficult hills with deep and rugged defiles. The mountains of North Waziristan are geographically separate from the larger mountain systems of Koh-e-Sufaid in the north and Sulaiman in the south. The mountains and hills form a rampart between Pakistan and Afghanistan. The average height of the Waziristan hills is 1,500–2,500 m (4,900–8,200 ft) above sea level. The important ranges in the Waziristan hills are Derwesta, Laran, Vezda, Ingame, Shoidar, Shawal, Eblunkai, Alexandra, Muzdak and Zakha.

The Tochi River flowing through the agency has formed the Tochi Pass, through which armies, people and cultures have moved in and out of this region. The Tochi Pass connects Ghazni, Afghanistan with Bannu, Pakistan. The Tochi River has carved a large and important valley which is bounded by hills and mountains on all sides except the eastern side. It is about 100 km (60 mi) in length and opens up into the Indus Valley near Bannu. The Tochi valley is fertile and cultivable. Kaitu and Kurram are the two minor rivers which flow in the northern part of the agency.

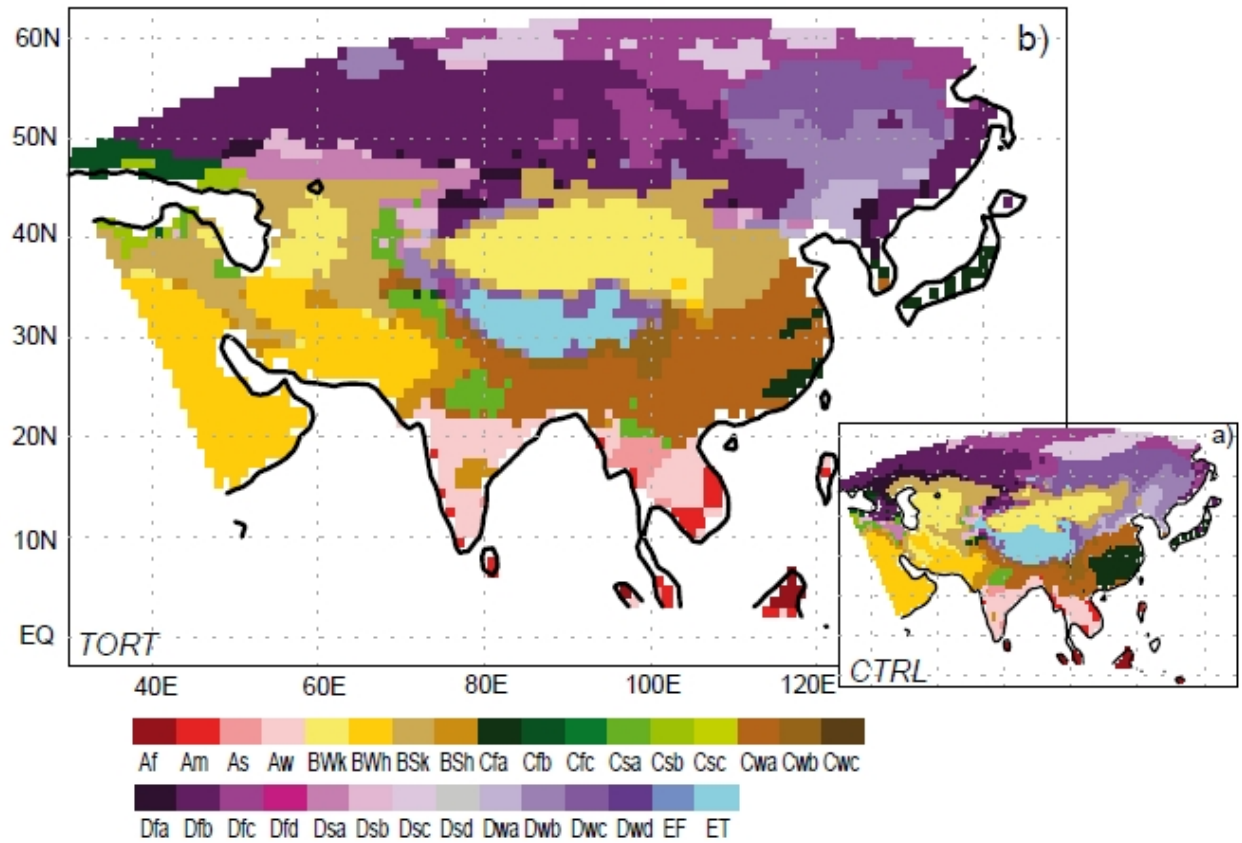
2.2 Paleoclimatology of the Region

The Late Miocene (11.6–5.3 Ma-Million Years ago) is an important stage for the Asian monsoon. Early evidence indicates the inception or a marked strengthening of the monsoon system in both South and East Asia at 8–7 Ma (million years ago). This is attributed to the surface uplift of the Tibetan Plateau. More recent studies, however, challenge this idea, proposing the establishment of the monsoon climate in East Asia and South Asia much earlier than the Late Miocene. Instead of the weaker-than-present monsoon in the Late Miocene suggested by earlier studies, a monsoon climate similar to or even stronger than present is documented in recent studies. While the former studies emphasize the dominant influence of regional tectonics such as the Tibetan Plateau uplift on the monsoon changes in the Late Miocene, the latter stresses the predominant impact of the global climate. For instance, it is suggested that the less-than-present global ice volume and prevailing warmer global condition in the Miocene would have led to a strong summer monsoon at that time.

In a study made by H. Tang and his colleagues (2011), the regional climate model CCLM3.2, nested in one-way mode within a fully-coupled atmosphere-ocean general circulation model (AOGCM), was employed to simulate the average state of the Asian monsoon climate in the Tortonian (11–7 Ma).

This page intentionally left blank

They first compare their regional model results with the driving global model and the monsoon proxies to demonstrate the regional pattern of the monsoon climate in the Tortonian and the adding values of their regional model results. Then, the effect of the Tortonian global forcing and regional boundary conditions is analyzed to further evaluate the contribution of different mechanisms to the Asian monsoon evolution in the Late Miocene. The result are shown in **Figure 2-1**, and Kurram Tangi catchment area falls in three sub categories, namely CWA (warm Temperature, Winter Dry, Hot Summers), CFC (Warm Temperature, Fully Humid, Cool summers) and DWC (Snow, Desert, Cool Summers). In general, a drier condition is found in the Northern Indian sub-continent, which is confirmed by the presence of pedogenic carbonates from Northern Pakistan. It further implies that monsoonal climate may not have been fully established in the Tortonian times (11 to 7 million years ago).



Main climates	Precipitation	Temperature
A: equatorial	W: desert	h: hot arid F: frost
B: arid	S: steppe	k: cold arid T: tundra
C: warm temperate	f: fully humid	a: hot summer
D: snow	s: summer dry	b: warm summer
E: polar	w: winter dry	c: cool summer
	m: monsoonal	d:cold summer

Figure 2-1: The Koppen-Geiger Climate Classification: CTRL and TORT

For the present-day classification, the temperature fields are derived from CRU TS 2.1 data set (Mitchell and Jones, 2005). The precipitation fields are derived from GPCC VASClimOv1.1 data set (Beck et al., 2005). To generate a similar data set for the Tortonian classification, the anomalies of the temperature and precipitation between the regional model experiments TORT and CTRL are added to the present-day observation data set.

2.3 Climate and Bio-Climates of the Project Area

Besides latitude, the climate of Kurram River watershed is directly related to its altitude. The altitude varies from north to south and east to west and so does the climate. Firstly, the temperature changes from subtropical in the south to temperate-cool, cold and very cold (Tundra) in the north and northeast. Secondly, the rainfall varies from semi-arid (330 mm at Bannu) in the south to sub-humid (850 mm at Fort Lockhart) in the east and (810 mm at Parachinar) in the north.

Thirdly, the rainfall pattern also gradually shifts from monsoonal (August to September) in the south to Mediterranean (winter-spring) in the north. The winter-spring precipitations are extremely important, as their effectiveness is much greater under the prevailing low temperatures in this season. The summer rains are received under high temperature conditions and in torrential form. Thus, they are subject to high evapotranspiration, as well as high erosivity, more runoff and soil erosion / sedimentation. The snow-melt water in this season when combines with rain runoff, the accumulative water in most rivers, causes pack floods damaging property and infrastructures and sometimes loss of humans and livestock. It snows on Kohi-Sufaid and valleys in the north frequently during the winter season. Above 14,000 ft (4,267 m) the mountains remain under permanent snow. The snows melt in summer season and generate flash floods.

Seasons are hot in the low altitudinal zones; June, July and August being the hottest months when temperatures vary between 39°C and 41°C. In the higher altitudinal zones, summers are pleasant with temperatures variation from 25°C to 31°C.

Potential evaporation at the various meteorological stations within the Kurram watershed area is high during the summer season when the temperatures are high and humidity is low. Total annual evaporation vs. mean annual rainfall at Bannu is 1752 mm vs. 331 mm; at Fort Lockhart 1114 mm vs. 850 mm and at Parachinar 900 mm vs. 810 mm.

Based on rainfall-amount and seasonal distribution, temperature, continentality and vegetation, the latter indicator of the climate, the following bio-climates have been distinguished in the watershed.

- Tundra – snow desert (above 14,000 ft) zone.
- Dry very cold – alpine (between 12,000 and 14,000 ft) zone
- Dry cold – sub-alpine forests cum pastures zone (between 10,500 and 12,000 ft)
- Dry temperature monsoonal/Mediterranean mixed forest zone (between 7,500 and 10,500 ft)
- Sub-humid Subtropical/ Sub-temperate/ broad – leaded forest zone (between 4,000 and 7,500 ft)
- Sub-humid, sub-tropical monsoonal/Mediterranean, broad-leaded forest zone (between 2,000 and 4,000 ft)
- Arid Sub-tropical monsoonal scrub forest zone (<2,000 ft)

2.4 Climate Perception in Kurram Tangi Region

The analysis of climate change impact on the hydrology of high altitude snowy catchments in this area is complex due to the high variability in climate, lack of data, large uncertainties in climate change projection and uncertainty about the response of snow. However, it is inferred that both temperature and precipitation are projected to increase which results in a steady decline of the snow area of Kohi Safaid. The river flow is projected to increase significantly due to the increased precipitation and ice melt and the transition towards a rain river. Rain runoff and base flow will increase at the expense of snow runoff. However, as the melt water peak coincides with the monsoon peak, no shifts in the hydrograph are expected. Just for correlation and to understand the precipitation pattern, data regarding precipitation variation with altitude is presented in Table 2-1.

Table 2-1: Precipitation Variation with Altitude in Kosi Valley, Nepal (Source: Dhar and Bhattacharya, 1976)

Height above the plains (m)	Average Rainfall ratio Plain to Hill station (summer)
50-500	1.05
500-1,000	0.73
1,000-1,500	1.00
1,500-2,000	1.33
2,000-2,500	1.65
>2,500	0.83

The majority of the Kurram River catchment area, 75%, has an elevation greater than 1,500 m and hence receives precipitation about 1.5 times of the precipitation falling in the Bannu area (Plains). The south facing slopes of mountains receive maximum tropical sunshine and heat up early in the day and stay warm till late in the evening. Sunshine comes to the western slopes after midday. Since the northern slopes are in the shadow of high peaks, they receive sunshine at an oblique angle, often only for few hours, when the sun is high in the sky. Eastern slopes receive sunshine from early morning to the time, sun goes towards west. In these hours much heat is not transferred to the snow surface, because the air is cool and sun rays fall at an oblique angle. So on southern and eastern slopes rate and volume of daily snow melt is less than the southern and western slopes. Snow covered Kohi Safaid Mountains southern and western slopes fall in Pakistan territory.

The following Figure 2-2 represents the mean values of different climate parameters for different months at Parachinar, headquarter of Kurram Agency (http://www.climate-charts.com/Locations/p/PK41560.php).

This page intentionally left blank

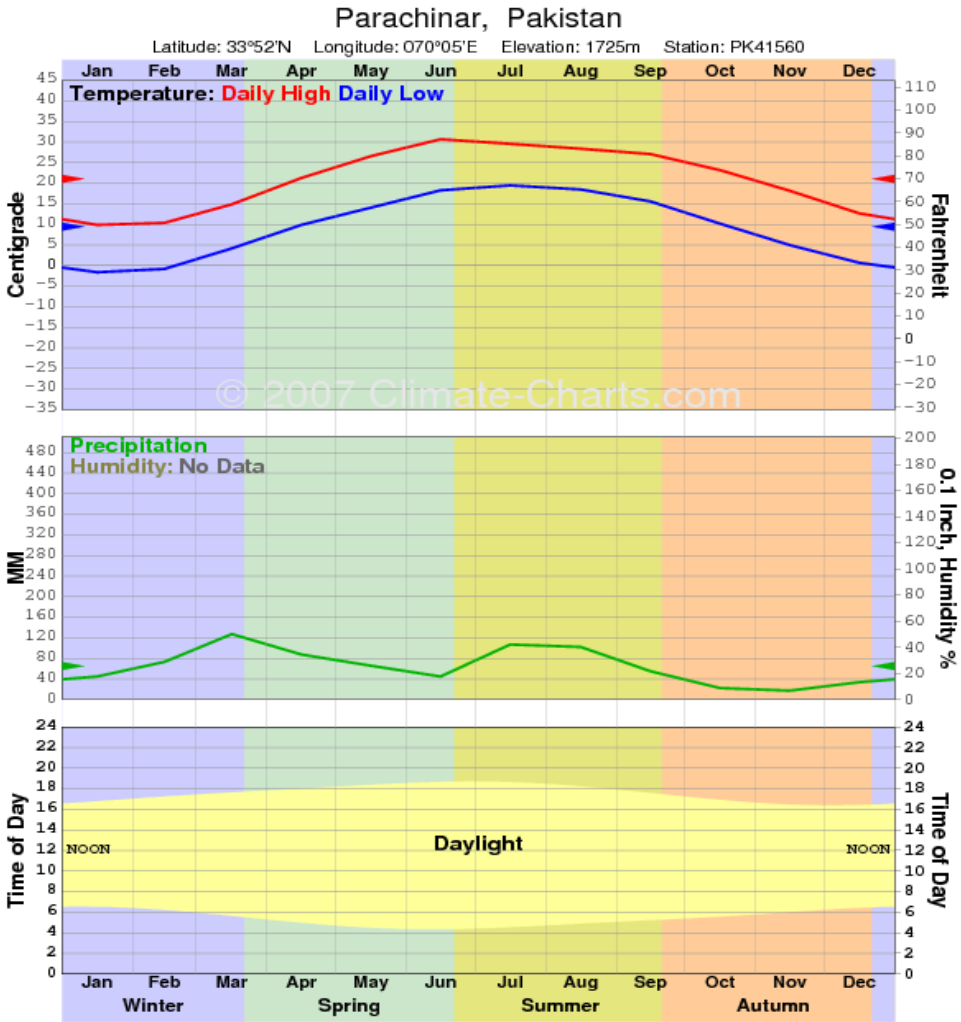


Figure 2-2: NOAA Parachinar Data, Presented in both Metric and English Units

2.5 River Flow Parameters

There are five notable rivers: Tochi, Kaitu, Kurram, Khaisor, and Shaktue. Some notable streams are Khoni Aigad, Chashma Aigad, Saidgi Algad, Kanungo Aigad, Sagga Aigad, Tauda China Aigad, Damoma Aigad, Tarkhobi Aigad, and Suedar Aigad.

2.5.1 The Catchment Area

The Kurram River and Kaitu River are the major rivers draining the area. These rivers take their flows from frequent rainfall and from the snowmelt. The main source of moisture that feeds the snow of Kohi Safaid of the water shed area of Kurram River is from three sources.

1. Southeastern monsoon which comes from Bay of Bengal between the months of June to October.
2. Northwest disturbances, which comes from the north-west between the months of November and February and move towards the east.
3. Local convection currents, which are most active between the two monsoons and especially on very warm sunny days. Convection currents drive all the humidity from the evaporation from the snow and ice surface.

The catchment area of Kurram and Kaitu Rivers lies partly in Afghanistan and partially in Pakistan between longitude 69° 03' E to 70° 52' E and latitude 33° 0' N to 34° 05' N. The catchment boundary was determined from GT Sheets of the area (scale 1:63360) from surface elevation

This page intentionally left blank

contour map, and drainage channel layout. The catchment areas at vital locations along Kurram and Kaitu Rivers are given below in Table 2-2.

Table 2-2: Catchment Areas

Kurram River at Kharalachi post (catchment area within Afghanistan)	=	1857 sq. km		
Kurram River at Thal	=	5160 sq. km		
Kurram River at Kurram Tangi Dam Site	=	6382 sq. miles		
Kaitu River at entry in Pakistan	=	4636 sq. km		
Kaitu River at Spinwam	=	5082 sq. km		
Kurram River at Kurram Garhi Headworks	=	11997 sq. km		
Distributaries of Catchment area in Pakistan and Afghanistan				
Kurram River area in Afghanistan	=	2080 sq.km	=	33%
Kurram River area in Pakistan (at Kurram Tangi Dam site)	=	4820 sq.km	=	67%
Kaitu River area in Afghanistan	=	4636 sq.km	=	91%
Kaitu River area in Pakistan (at Spinwam)	=	445 sq.km	=	9%

For purposes of this study, climate data from four weather stations was evaluated, which roughly form a boundary about the catchment zone. These weather stations that are shown in Figure 2-3 include:

- Gardez: Latitude 33.569434° N, Longitude 69.335432° E
- Parachinar: Latitude 33.899167° N, Longitude 70.100833° E
- Bannu: Latitude 32.98889° N, Longitude 70.605556° E
- Kohat: Latitude 33.583333° N, Longitude 71.43333° E

Figure 2-3: Map Indicating the Weather Stations Location in Kurram Tangi Dam Catchment Area

2.5.2 Land Use of the Catchment Area

The catchment area is a mix of bare mountain rock surface, coniferous/thorn/deciduous/evergreen trees of varying density, scrub forests, rangeland and cultivated depending upon the topography. The elevation of catchment boundary varies between 1,524 m in the south and southeast to as much as 4,572 m in the northeast, north, west, and southwest. The Kurram River carries perennial flows from snowmelt of Koh-e-Sufaid, which forms the northern and west catchment boundary. The catchment area has a steep slope towards the river and any rainfall brings flash floods in various tributaries and the main river.

The valley area along the Kaitu River is narrower. The area lying within Pakistan has experienced extensive development of irrigated and rain fed agriculture. It is also considered that the valley lying

in Afghanistan has some level of agriculture activities. The catchment of Kaitu River is arid in character with higher elevations composed of bare rock surface. The area is highly undulating.

2.5.3 Historical River Flow Data

WAPDA has measuring gauges at three sites along Kurram River, namely Thal, Kurram Garhi and Kurram Tangi, and one site along Kaitu River at Spinwan. The data for Kurram River at Thal is given in Annexure 1, Table A-1. On average the Kurram River, at Thal, shows a flow of 668,000 ac-ft (82.4 MCM) with a maximum flow of 1,384,000 ac-ft and minimum flow of 229,000 ac-ft. The upper graph of **Figure 2-4** represents the annual river flow in Kurram River at Thal. A flow cycle of 10 year is noticeable at this site. Just for comparison sake, monthly flow graphs are also shown on Figure 2-4; the center graph shows 12 months (one year), 48 months (4 years), 84 months (7 years) and 120 months (10 years) moving average; the bottom figure shows a moving average ribbon (similar to that used in stock price movement) and a 120 months cyclic variation is observed. Also noticeable is that cyclic variation is expanding with time, meaning that high and low flows in successive decades is widening.

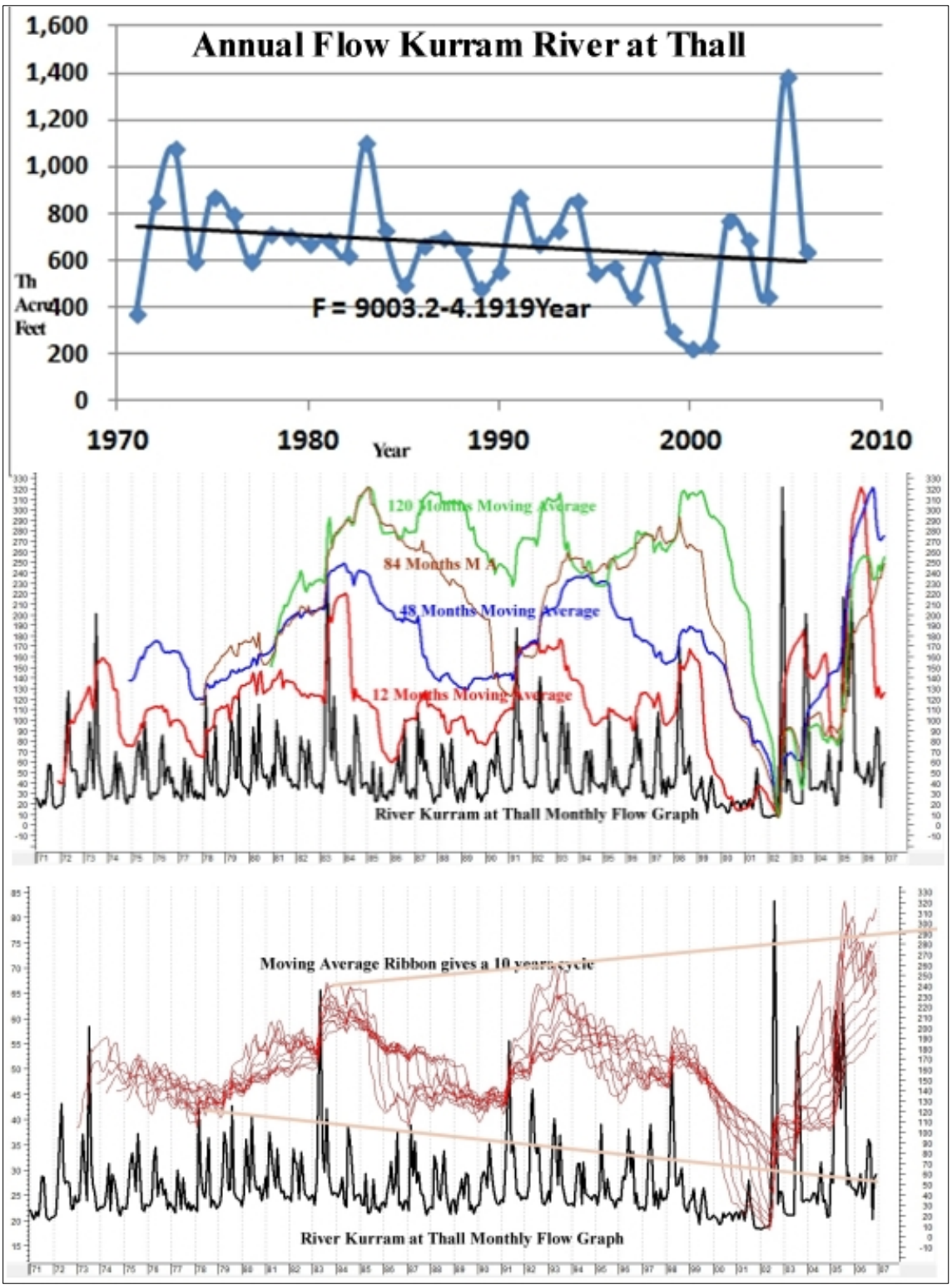


Figure 2-4: Historical Monthly and Annual Discharge of Kurram River at Thal

The trend line of annual discharge of Kurram River at Thal is represented by the following equation:

Annual Flow of River at Thal = 9003 - 4.192 x Year

It shows a decreasing trend in flow. In 2020, a flow of 535,000 ac-ft is expected, whereas in 2050 we can expect a flow of 409,000 ac-ft in the Kurram River at Thal.

This page intentionally left blank

Similarly at the Kurram Tangi Dam site (Annexure 1, Table A-2), the Kurram River again shows a cyclic variation of 10 years (**Figure 2-5**), but here the trend line shows a rising trend. An average annual flow of 412,000 ac-ft has been noted with a maximum discharge of 2,350,000 ac-ft and minimum discharge of 370,000 ac-ft.

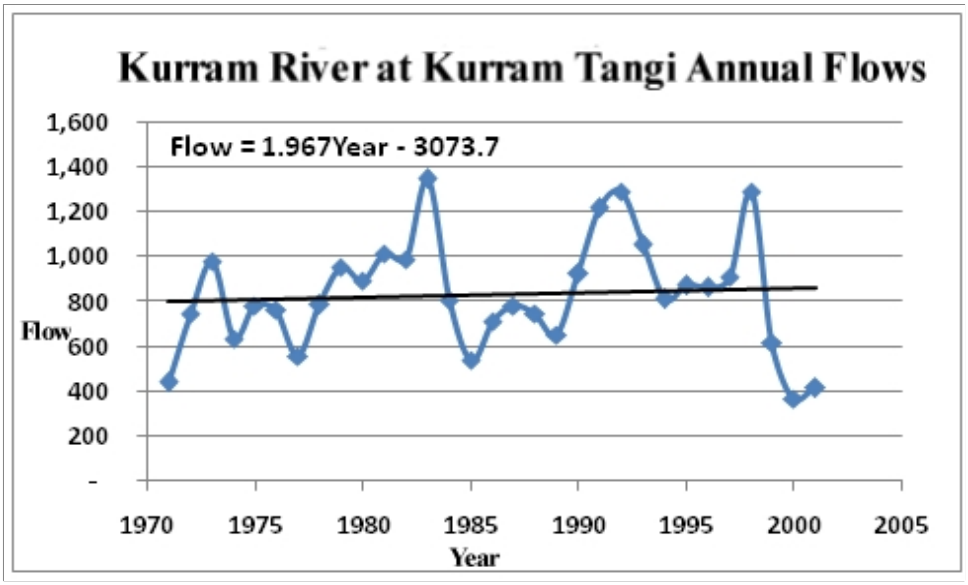


Figure 2-5: Graph Showing the Flow of Kurram River at Kurram Tangi Dam Site

The trend line of annual discharge of Kurram River at the Kurram Tangi Dam site is given by the following equation:

Annual Average River Flow at Kurram Tangi = 1.967 x Year - 3073.7

So, based on this equation we can expect an average flow of 885,000 ac-ft in 2020, and by 2050 we can expect 944,000 ac-ft in Kurram River at the Kurram Tangi Dam site.

Kaitu River at Spinwan shows an average discharge 361,000 ac-ft, with a maximum discharge of 746,000 ac-ft and minimum discharge of 154,000 ac-ft during the recording period (Annexure 1, Table A-3). The annual river flow of Kaitu River at Spinwan is shown in Figure 2-6.

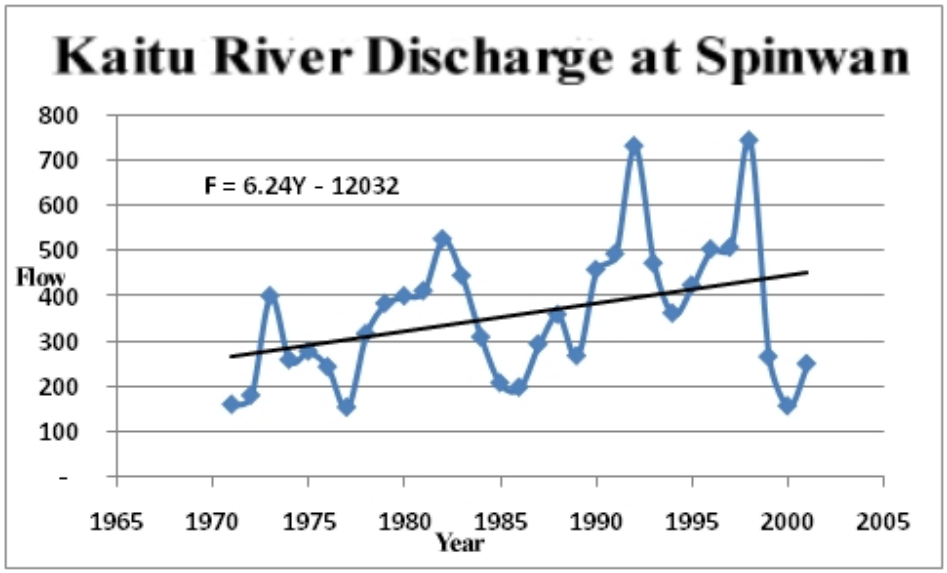


Figure 2-6: Graph Showing the Flow of Kaitu River at Spinwan Site

The equation of the trend line for Kurram River discharges at Spinwam is given as:

This page intentionally left blank

Annual Average River Flow at Spinwan = 6.24 x Year – 12,032

So, based on this equation we can expect an average flow of 936,000 ac-ft in 2020, and in 2050 we can expect 1,129,000 ac-ft in Kaitu River at Spinwan site.

2.6 Historical Temperature Data

The Pakistan Meteorology Department has Parachinar station within the project area to record temperature and precipitation data, whereas Kohat, Bannu and Gardez recording stations are on the outer periphery of the project area.

Annual mean temperature data of Bannu from 1948 to 2012 with a data gap from 1964 to 1969 is shown on **Figure 2-7** (See Annexure 1, Table A-4 for supporting data). The annual trend line for temperature shows a rising trend of about 0.05 to 0.06^0 C per decade.

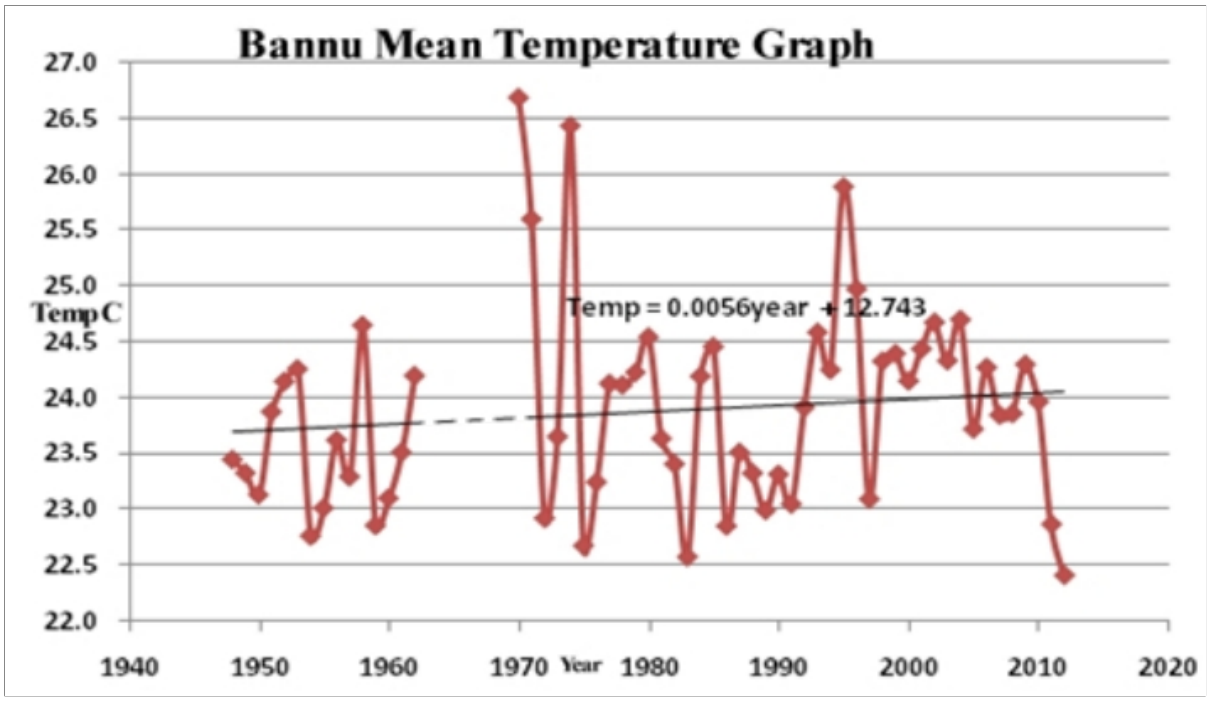


Figure 2-7: Annual Mean Temperature Graph of Bannu for the Period from 1948 to 2012

Annual mean temperature data of Parachinar from 1948 to 2012 with a data gap from 1957, 1958, 1963 and 1964 is shown in Figure 2-8 (See Annexure 1, Table A-5 for supporting data). The temperature annual trend line shows a declining trend with a decline of about 0.02^0 C per decade. As compared to common concept of rising temperature, this station is showing a declining trend in temperature with the passage of time.

This page intentionally left blank

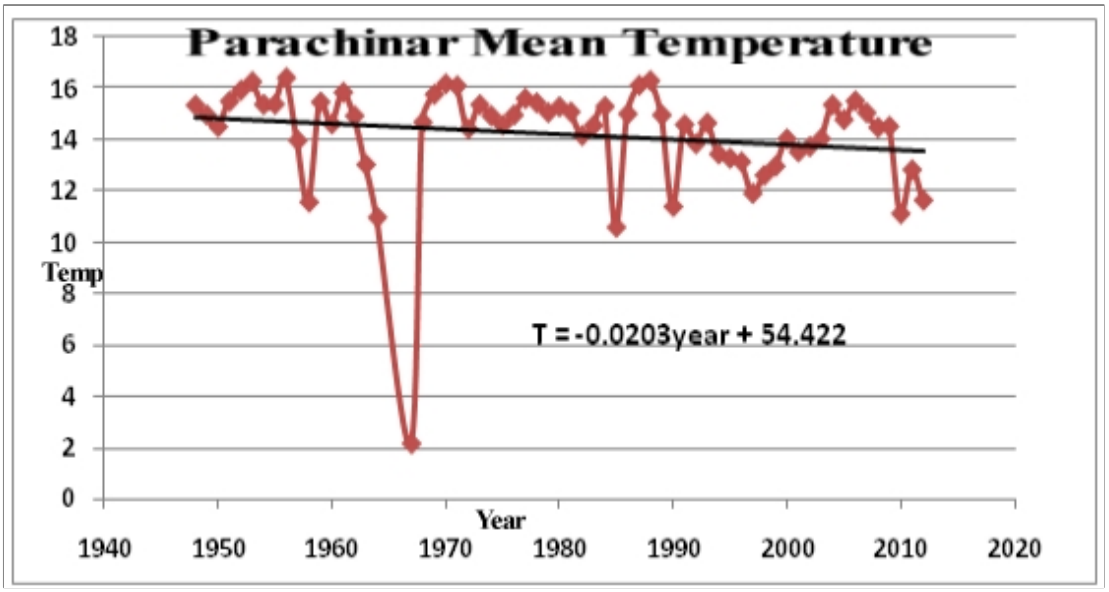


Figure 2-8: Annual Mean Temperature Graph of Parachinar for the Period from 1948 to 2012

Annual mean temperature data of Kohat from 1955 to 2012 is shown on Figure 2-9 (See Annexure1, Table A-6 for supporting data). The temperature annual trend line shows an ascending trend of about 0.01^0 C per decade in conformity with the temperature increasing trend.

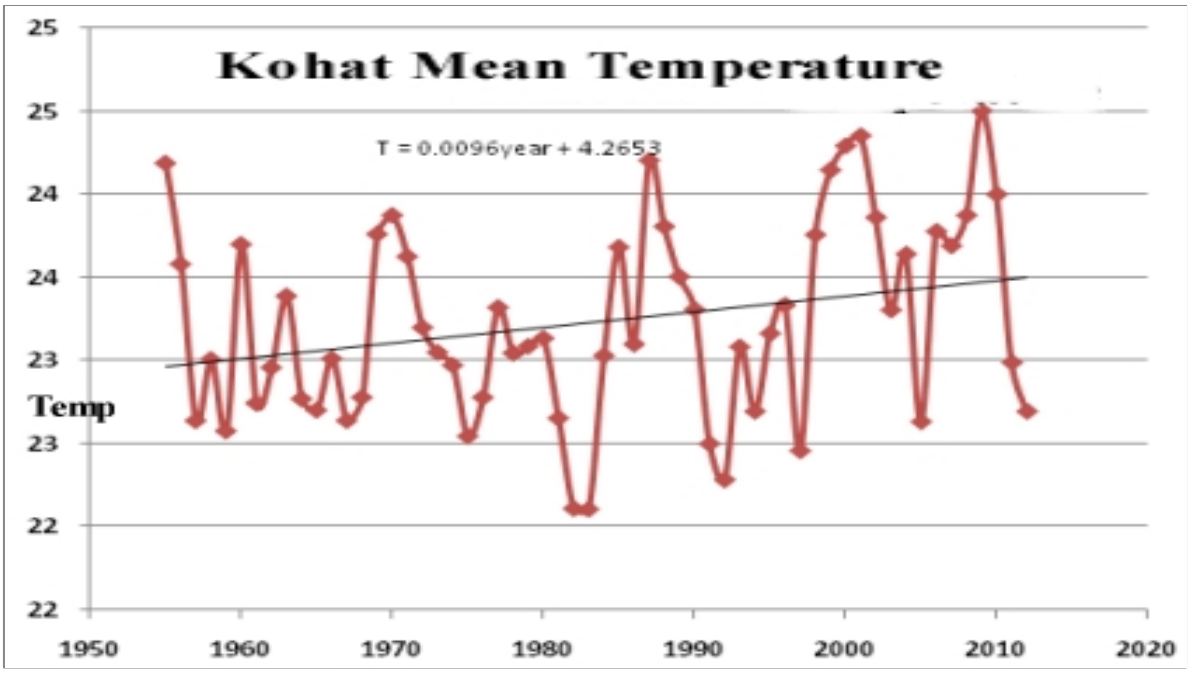


Figure 2-9: Annual Mean Temperature Graph of Kohat for the Period from 1948 to 2012

At Gardez the annual mean temperature (See Annex 1, Table A-10 for supporting data) graph is shown in **Figure 2-10**. The temperature annual trend line shows an ascending trend of about 0.02^0 C per decade in conformity with the temperature increasing trend with other weather stations. Data from 1964 to 1982 was available for this station due to some government policy prevalent after 1983.

This page intentionally left blank

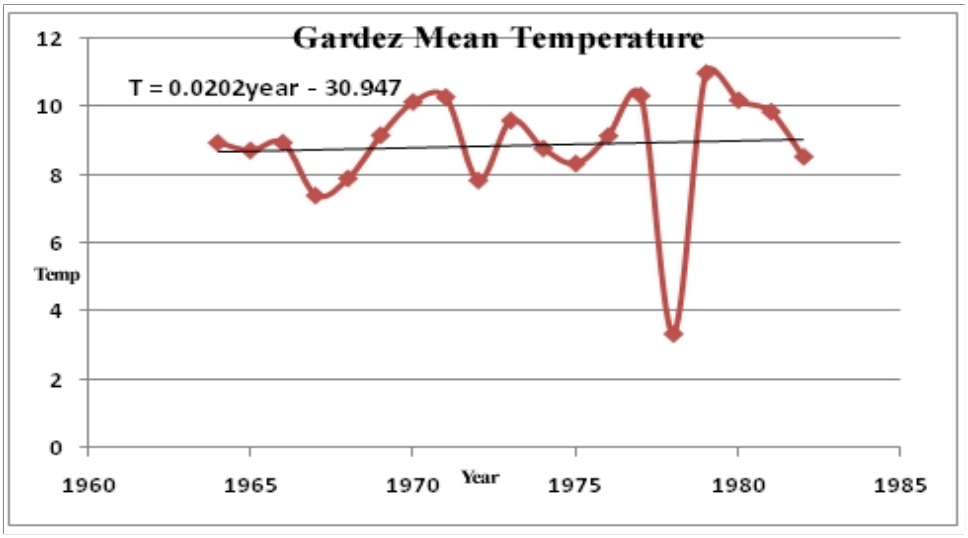


Figure 2-10: Annual Mean Temperature Graph of Gardez for the Period from 1964 to 1982

After analysing temperature data from the four stations in the project area, it appears that in conformity with the global trend of temperature increase, Bannu and Kohat (lies in plain area) are showing an increase in temperature with the passage of time. Similarly, Gardez lying in Afghanistan is also showing a rise in temperature trend, although the data set is too small to give any true picture for Gradez. Parachinar is an exception, as it shows a decrease in temperature with the passage of time. This anomaly needed further investigation.

2.7 Historical Precipitation Data

The main forms of precipitation include drizzle, rain, sleet, snow and hail. Precipitation is a major component of the water cycle and hence for water storage dams. As mentioned prior, the Pakistan Meteorological Department has three measuring stations in the project area, namely Parachinar, Bannu and Kohat.

At Bannu historical record for precipitation are available from 1862 to 2012, with a large gap from 1901 to 1947. Precipitation records are presented on **Figure 2-11**, and supporting data is provided in Annexure 1, Table A-7.

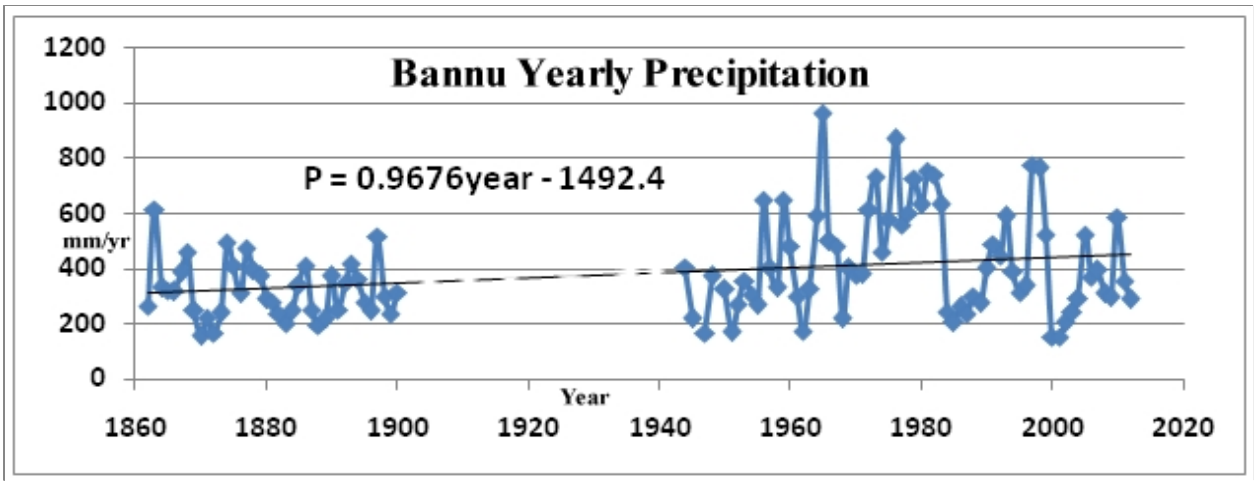


Figure 2-11: Historical Precipitation Record of Bannu, KP

The trend line of this data set steady upward trend, indicating that yearly precipitation is increasing over time. Based on the trend line, on average, 460 mm of precipitation is projected for 2020, 470 mm in 2030, 480 mm in 2040, 490 mm in 2050, and so forth.

This page intentionally left blank

At Parachinar historical record for precipitation are available from 1950 to 2012, with a gap from 1964 to 1969. Two entrees (1960 and 1961) appeared to be anomalous, hence in the graph they have been eliminated to get a rational curve. The supporting data is given in Annexure 1, Table A-8, and precipitation values are presented on Figure 2-12.

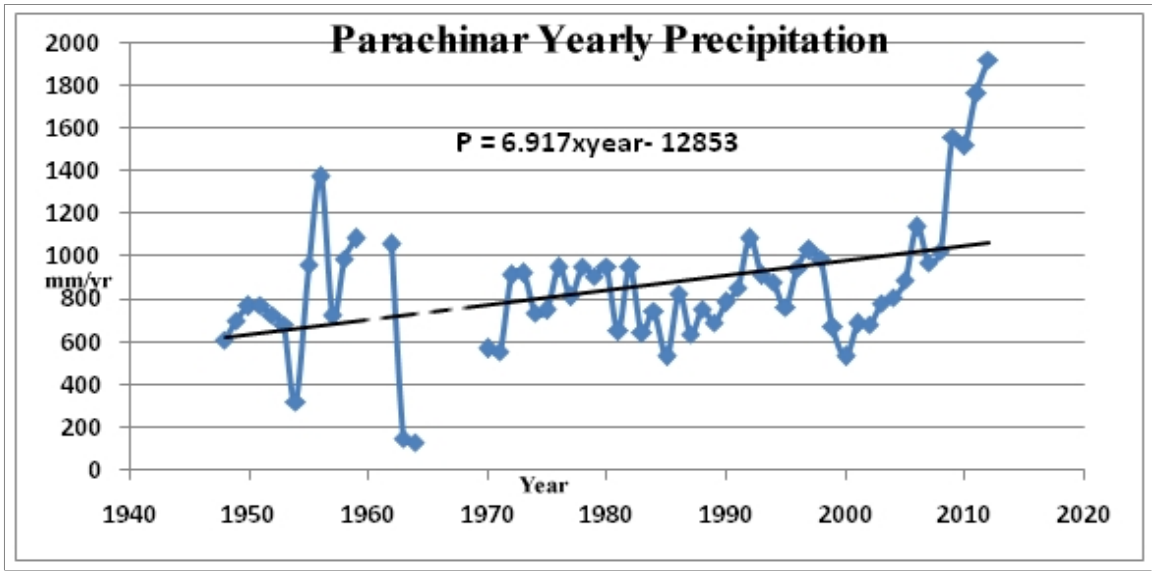


Figure 2-12: Historical Precipitation Record of Parachinar, Kurram Agency, FATA

The straight trend line of this curve shows a steady upward trend, indicating higher precipitation in coming years. It calculates 1119 mm precipitation in 2020, 1188 mm precipitation in 2030, 1258 mm precipitation in 2040, and 1327 mm precipitation in 2050 on the average.

At Kohat historical record for precipitation is available from 1863 to 1900 and 1955-2012 (there is a gap from 1901 to 1954). The data is given in Annexure 1, Table A-9, and presented on **Figure 2-13**. In 1961 abnormally high precipitation of 2161 mm has been observed, otherwise data set is quite normal.

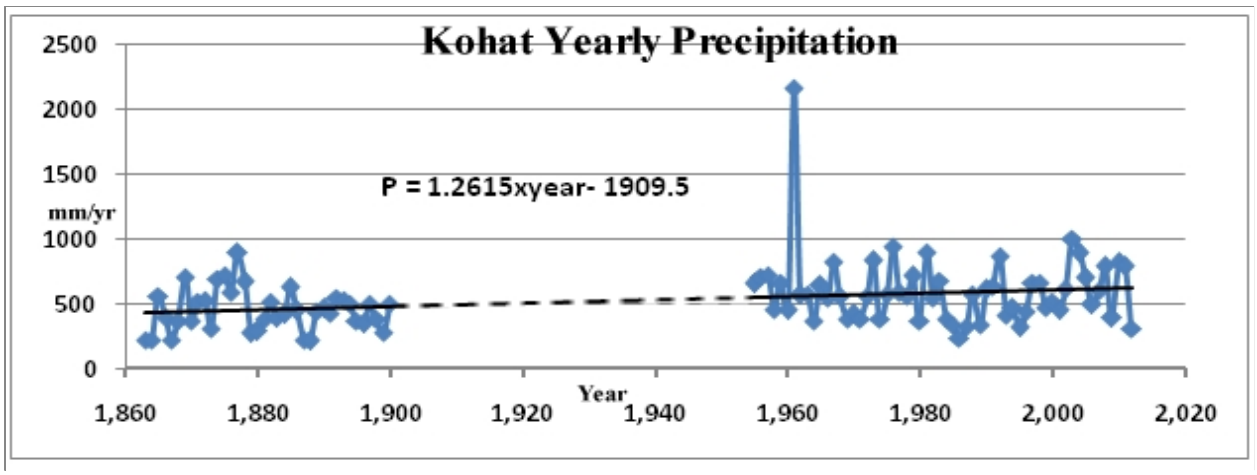


Figure 2-13: Historical Precipitation Graph at Kohat, KP

Here again, the trend line for this data set shows a steady upward trend, indicating slightly higher precipitation in coming years. It estimates, on average, 638 mm precipitation in 2020, 650 mm precipitation in 2030, 663 mm precipitation in 2040, and 676 mm precipitation in 2050.

At Gardez, Afghanistan historical records for precipitation are available from 1964 to 1983 (See Annexure 1, Table A-10 for supporting data), and are shown on Figure 2-14. The data is not sufficient to draw any decadal trend results; however a decrease in precipitation trend is observed from this scanty data.

This page intentionally left blank

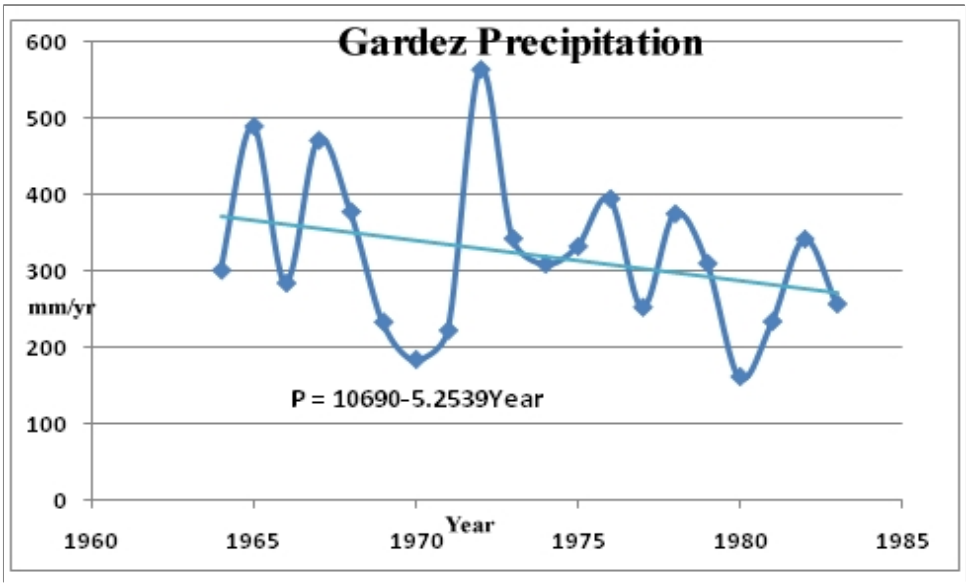


Figure 2-14: Historical Precipitation Record at Gardez, Afghanistan, from 1964 to 1983

2.8 Historical Seasonal Analysis of the Kurram Tangi Region for use as Baseline in the GCM Analysis

Historic precipitation and temperature data was assessed based on the meteorological data from the nearest stations. These are shown on Figure 2-15, and though four stations were chosen only three have sufficient data to allow for analysis. The selected stations were: Parachinar, Bannu and Kohat. Figure 2-15 also provides the elevation of each of these stations, it should be noted that Parachinar is at a much higher elevation than Bannu or Kohat.

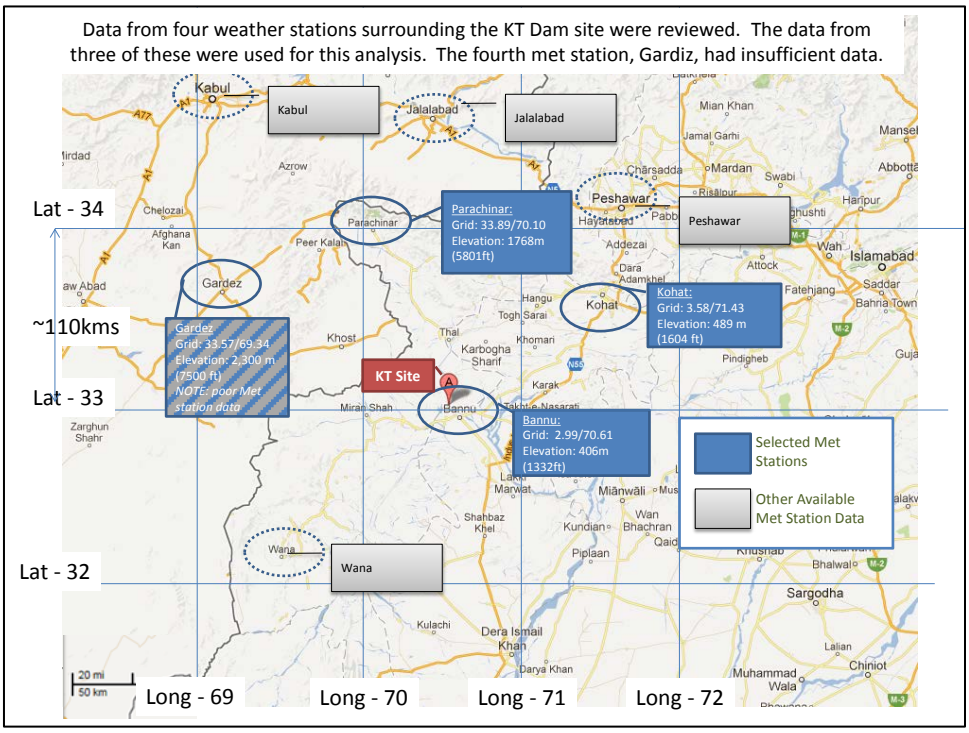


Figure 2-15: Locations of Meteorological Stations in the Project Area

The historic precipitation and temperatures for each station were averaged as shown below. It must be noted that none of the stations had full and continuous data, there are gaps of years and seasons that periodically have occurred.

This page intentionally left blank

2.8.1 Historic Seasonal Averages

In order to prepare for comparison of the historic data against the projected GCM modeled data, a decadal analysis of the met station precipitation and temperatures was conducted (Figure 2-16). The decadal periods selected are as close to the GCM past decadal data as possible. For all of the met stations there is a gap in data that extends from the early 1900's to around 1948.

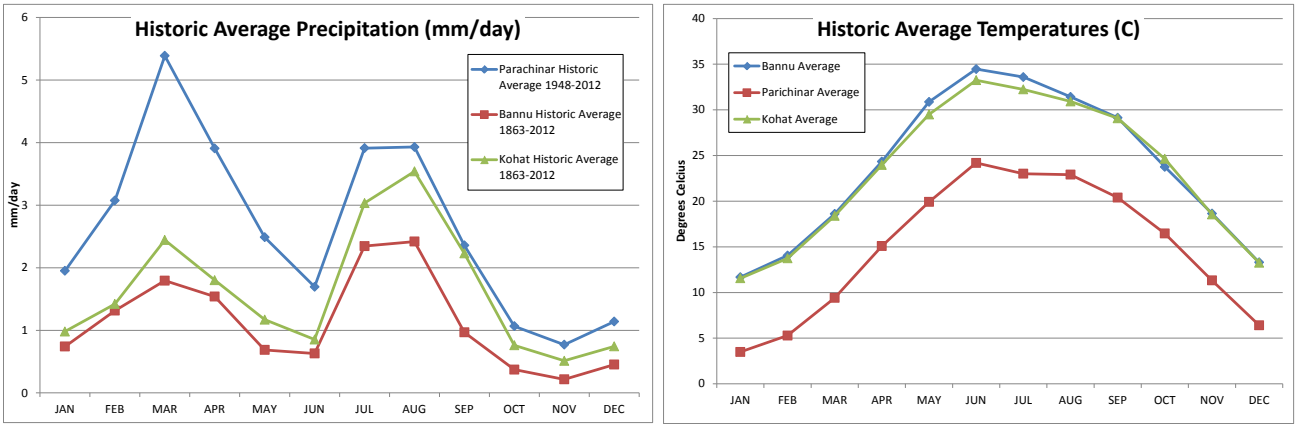


Figure 2-16: Historical Average Precipitation and Temperatures

The seasonal data for precipitation shows relatively consistent seasons across the Kurram Tangi zone, with:

1) Early Spring rainy season (Feb-Apr)
2) Spring dry season (May-Jun)
3) Summer rainy seasons (Jul-Sept)
4) Winter dry season (Oct-Jan)

It is significant to note the timing of the start and end of both the rainy and the hot seasons, because these have a direct impact on the growing season of the region, especially at high elevations.

Figure 2-17 looks at the overall trend in decadal data. The decadal historic precipitation shows little significant deviation over time. The average temperature for the two lower elevation met stations show a 0.4°C increase from the 1940-1960 period to 2012. While the one mountain station shows a nearly 2°C drop in temperature over the same period.

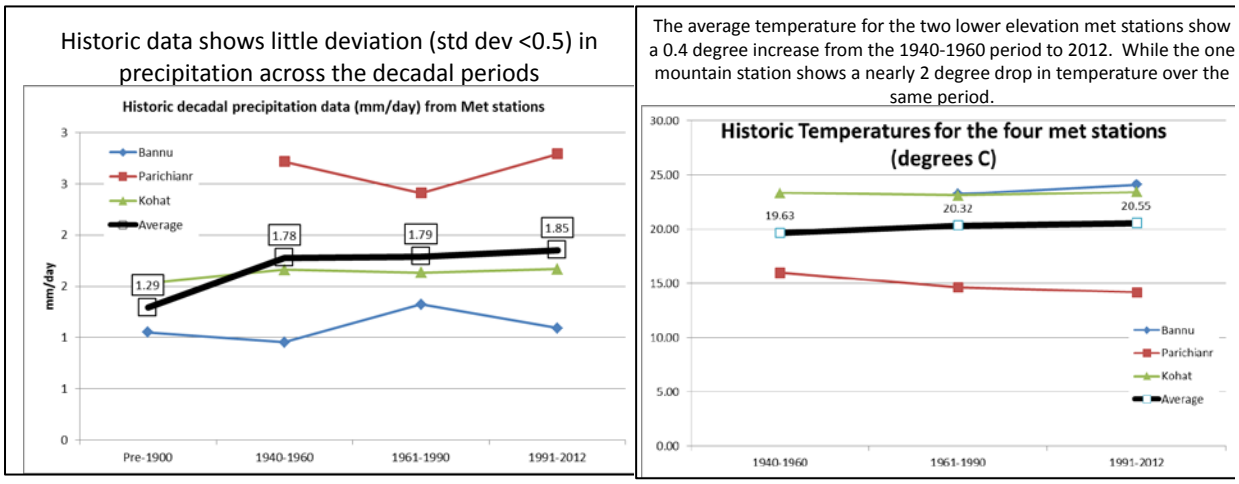


Figure 2-17: Precipitation and Temperature Historical Decadal Averages

The three graphs of Figure 2-18 show the seasonal temperature data for each of the met stations. Historic temperatures for Kohat are stable. Bannu shows some warming in summer months over

This page intentionally left blank

the two decadal periods of time available. Parachinar's decreasing temperature appears to occur primarily in the summer, fall and early winter months.

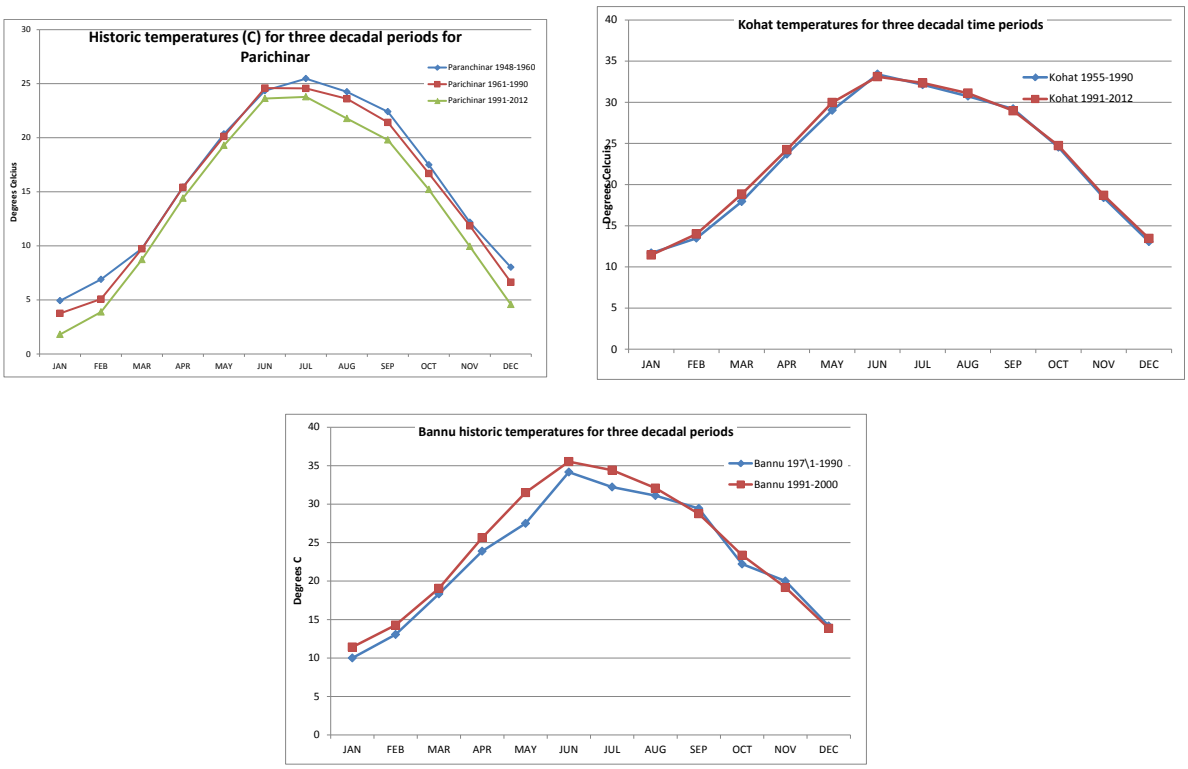


Figure 2-18: Historical Monthly Average Temperatures

Figure 2-19, **Figure 2-20**, and **Figure 2-21** show additional seasonal data about the specific metrological stations.

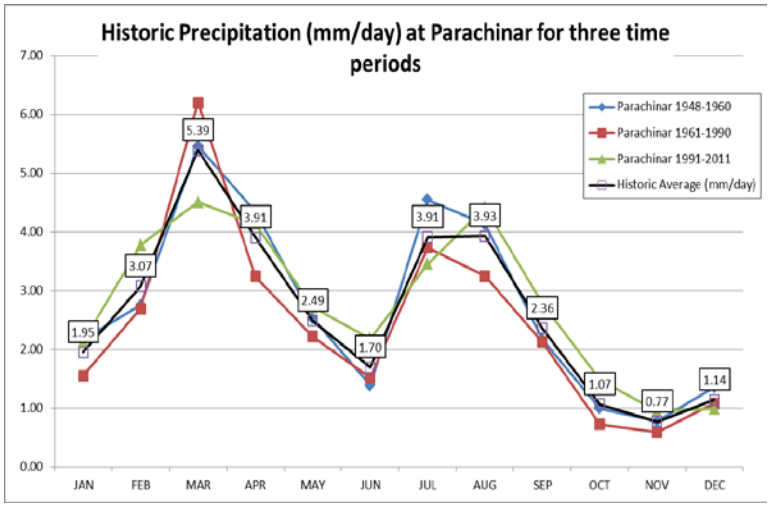


Figure 2-19: Historical Monthly Average Precipitation

Parachinar historic data shows relatively consistent seasons, with a slightly decreased spring rainy season in the 1961-1990 decades. Deviation from the overall historic average during the rainy seasons is typically less than +/- 0.5 mm/day, and less during the dry seasons.

This page intentionally left blank

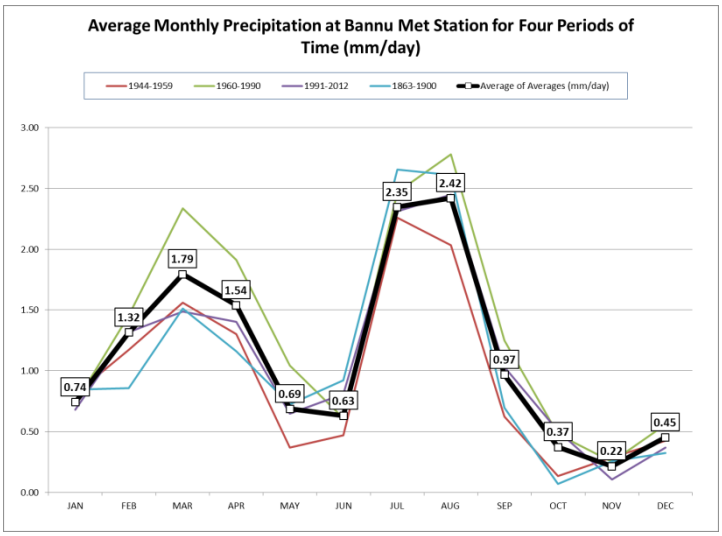


Figure 2-20: Average Monthly Precipitation at Bannu

Bannu historic metrological station data shows that 1961-1990 was a period of higher precipitation in the rainy seasons. 1893-1900 had higher precipitation in the second rainy season, and 1944-1959 had a drier second rainy season. The max/min variations from the average of the decadal data is within a +/- 0.5 mm/day tolerance.

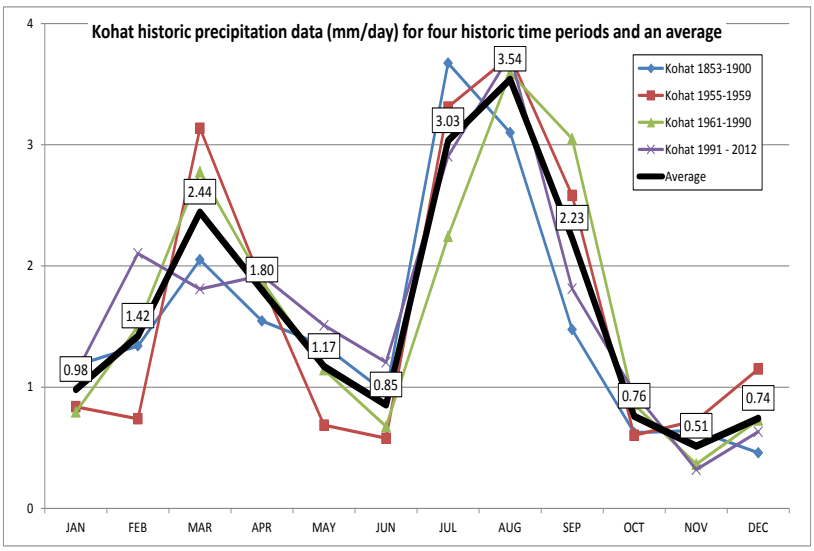


Figure 2-21: Average Monthly Precipitation at Kohat

Kohat historic precipitation shows similar deviations, with a higher range around the spring rainy season

This page intentionally left balnk

3 USING GCMS TO PROJECT SEASON AND OVERALL CLIMATE CHANGE IN THE KURRAM TANGI REGION

3.1 Introduction

GCMs are one of the most popular tools used to simulate the impacts of increased greenhouse gases on climatic variables such as precipitation within a particular river basin. Annexure 2 presents a review of the existing body of research and literature on GCMs and RCMs. This Chapter presents the results of our evaluation of the impact of climate change on the temperature and precipitation of the Kurram Tangi region using GCMs.

Data from 18 Global GCMs were analyzed to assess possible changes in precipitation and temperature in the future, both on a seasonal and decadal basis. Climate change can impact overall precipitation and temperature in such a manner that seasonal shifts occur. In order to understand climate impacts, particularly in mountain regions, it is important to understand if and how seasons may shift. The GCM data for this analysis was pulled from the IPCC Fourth Assessment Report (AR4) for the GHG emissions scenario A1B. Scenario A1B represents a median value for future emissions, and is described as "A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies, with the development balanced across energy sources". The AR4 report was produced in 2007 and represents the latest IPCC comprehensive documentation on climate change, the Fifth Assessment Report will be released in 2014.

The AR4 GCM data was extracted for the closest available latitude and longitude to the two meteorological stations selected for analysis: Parachinar and Bannu. These two stations were selected because they represent the two extremes of the meteorological stations: the plain station and the mountain station. Bannu has the best historic data volume and quantity of the two plains stations against which to compare the GCMs.

Each GCM produces historic decadal temperature and precipitation data as well as projected future decadal data. The historic GCM data for each model was compared to the actual historical data for the relevant met station, and analyzed for best fit correlation. An ensemble of three of these GCMs was then used to represent the possible future decades.

3.2 GCM Analysis of Precipitation Data

The historical correlation for most of the models was not good, with many missing one of the two rainy seasons. Correlation values, r^2, were also poor the highest of which is 0.72. **Table 3-1** provides the correlation values for Bannu, and **Figure 3-1** shows the GMC projects versus historical records available at Bannu. At Parachinar the correlation was slightly lower with a correlation value, r^2 of 0.59.

Table 3-1: GCM Correlation Table for Bannu

GCM correlation table for Bannu			
	R2 to Bannu thru 1990	Lat	Long
Bannu weather station		32.99	70.61
MPIM: ECHAM5	0.18	32.63	71.25
BCCR BCM2	0.10	32.08	70.31
CCCMA GCM3_1-T47	0.56	31.53	71.25
CNRM CM3	0.01	32.08	70.31
CONS ECHO-G	0.04	31.53	71.25
CSIRO MK3	0.25	32.63	71.25
LASG FGOALS-G1_0	0.34	32.03	70.31
GFDL CM2	0.59	31.00	71.25
NASA GISS AOM	-0.60	31.50	70.00
UKMO: HADCM3	0.72	32.50	71.25
UKMO HADGEM1	0.37	31.25	71.25
INM CM3	-0.43	32.00	70.00
IPSL CM4	-0.32	31.69	71.25
NIES MROC3_2HI	0.69	31.96	70.88
NIES MROC3_2-MED	0.40	31.96	70.88
MRI CGCM2_3_2	-0.18	32.08	70.31
NCAR CCSM3	0.52	32.91	71.72
NCAR PCM	0.59	32.08	70.31

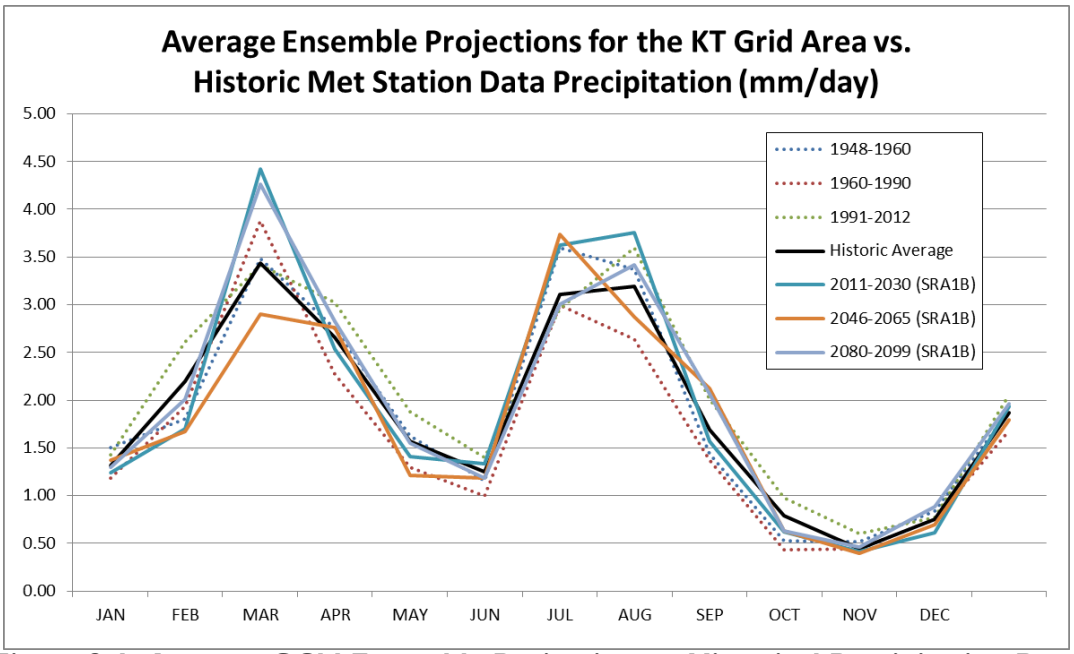


Figure 3-1: Average GCM Ensemble Projection vs. Historical Precipitation Data

GCM's tend to have much less precision in their data around areas with a significant amount of terrain, or variation, within the grids of analysis. For this reason, the most reliable projections are for plains areas, and mountainous regions can be less reliable.

Three GCM models were then selected for further analysis. Two of these, HADCM3 and MROC3_2Hi, were selected based on having the highest r^2 value. The third GCM, ECHAM5, was selected because it was used by PMD for the downscale effort that they conducted. Because the GCM data did not correlate well, an analysis of the relative change in precipitation forecast by the GCMs was conducted. In other words, instead of looking at the absolute precipitation numbers forecast for the future, we looked at how the future numbers were projected to change – either increasing or decreasing – when compared to the historic baseline. This percent change for each GCM was then used as a multiplier on the actual historic data for each met station. The result is a representation of the possible relative change that might be likely in the future. The average of the GCMs was then taken as an ensemble value for each decadal projection period. After each station

was calculated, an average was taken to represent possible precipitation changes across the Kurram Tangi region.

The final combined averages for the GCM predictions across the area show little projected future change in precipitation. The percent difference by 2099 of 4% is well within the historic decadal range of variation, which has gone from as much as +10% to -10% of the historical average. The only exception is the spring rainy season, which may experience additional precipitation in future decades. In addition, there is no real seasonal shift in future time periods when compared to historic data – rainy seasons will not begin or end at significantly different times of the year than they have in the past.

3.3 GCM Projections of Temperature Data

The GCM correlation of historic temperature data with the actual meteorological station data are very close, at with an r^2 of 0.99 for most of the models. The same three GCMs, ECHAM5, HADCM3 and MROC3_2Hi, were used to evaluate temperature projection into the future. The results are shown in the Figure 3-2 and Figure 3-3.

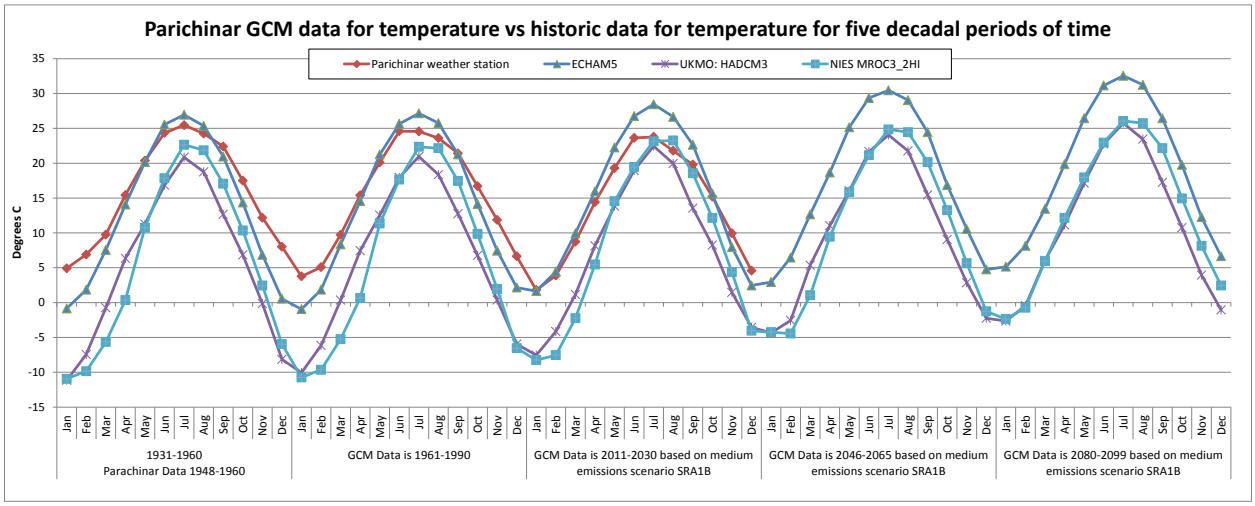


Figure 3-2: Parachinar GCM Projection for Temperature vs. Historical Temperature for Five Decadal Periods

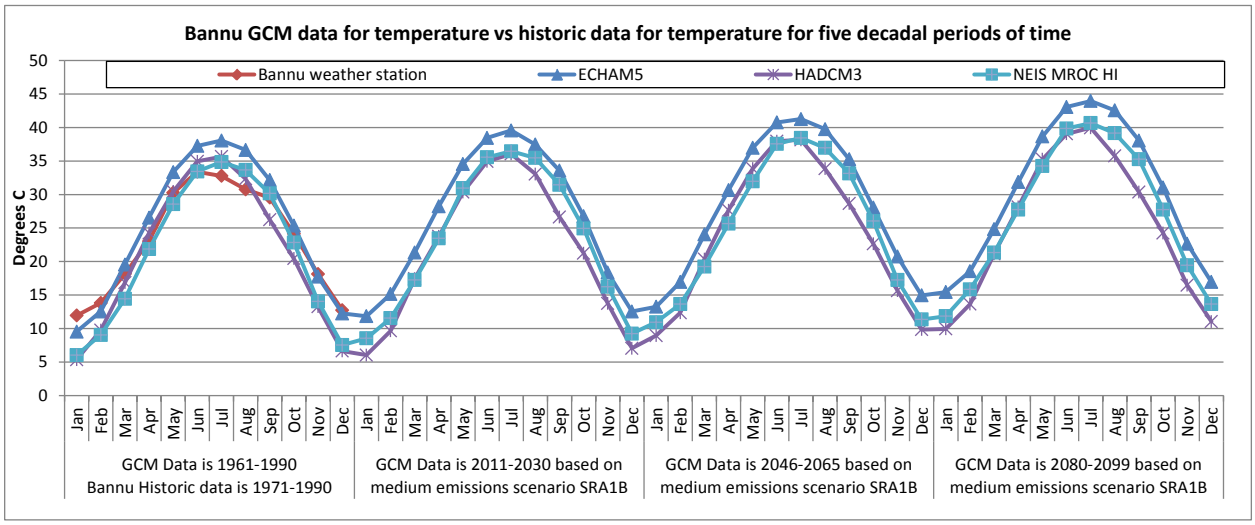


Figure 3-3: Bannu GCM Projection for Temperature vs. Historical Temperature for Five Decadal Periods

A comparison of the temperature seasonal data for each decadal period in the future as well as the past decadal periods is shown on **Figure 3-4**.

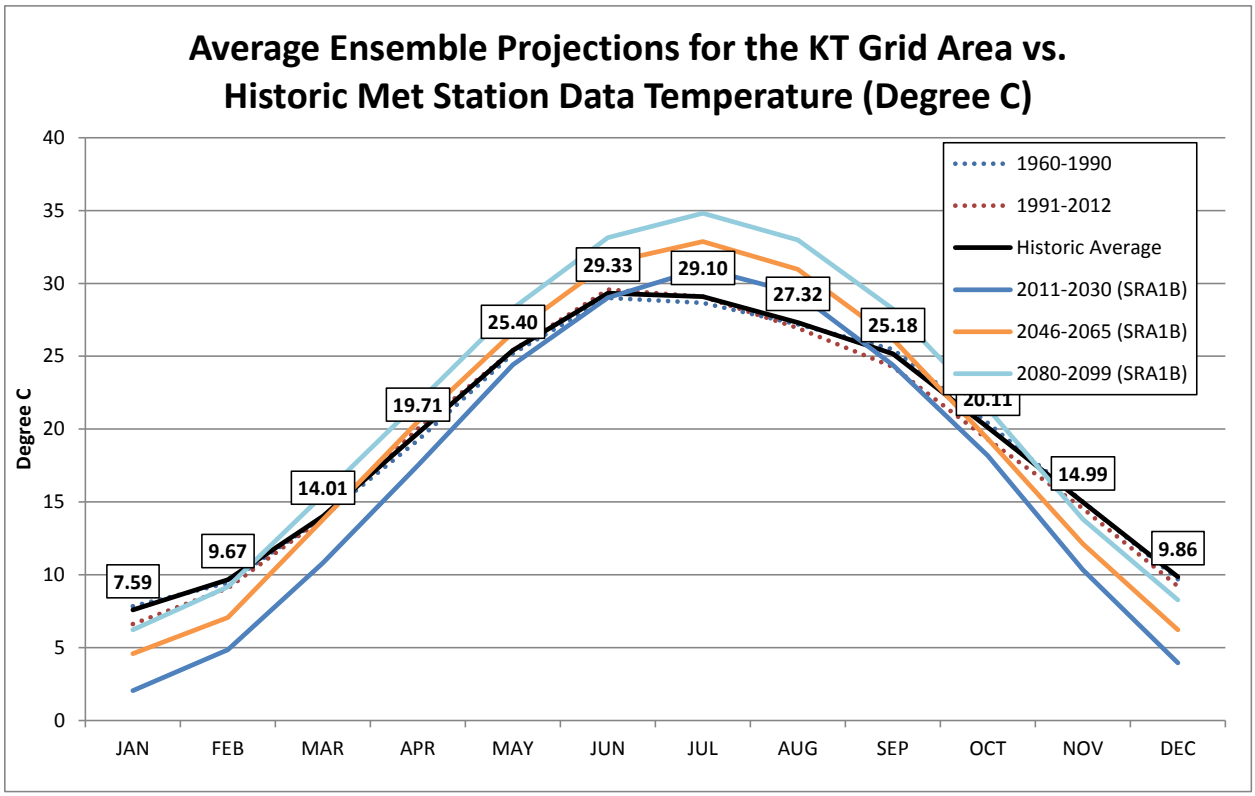


Figure 3-4: Average GCM Ensemble Projection vs. Historical Temperature Data

The projections for Parachinar, provided in **Table 3-2**, show that winters may be cooler in the future, while summer may be warmer. However, a table of the GCM projections for Parachinar shows that the historic GCM data have significantly lower temperatures than actually occurred at Parachinar; therefore it may be more representative to look at the relative change from the historic baseline, which is fairly significant at 3.9°C by 2065 and 5.8°C by 2099. The temperature projections for Bannu, provided in Table 3-3, show that warming occurs mostly in the summer months. This appears to extend the summer season by as much as a month by 2099. Similar to Parachinar, two of the GCM models for Bannu show lower temperatures for past decade than were recorded; therefore it is important to look at the change in degrees Celsius, which is 3.4 by 2065 and 5.2 by 2099.

Table 3-2: Parachinar Historic and Projected Decadal Temperatures

Parichinar Historic and Projected Decadal Temperatures (C)						Average %
	1931-1960	1961-1990	2011-2030	2046-2065	2080-2099	Change
Parichinar weather station	15.96	15.29	13.90			
% decadal Change			-9%			
ECHAM5	**13.61**	14.05	15.40	17.61	19.43	
% decadal Change			10%	14%	10%	11%
% diff from Met data		-8%	11%			
% decadal Change from 1961-1990 base			10%	25%	38%	24%
HADCM3	**5.49**	6.28	7.71	9.84	11.18	
% decadal Change			23%	28%	14%	21%
% diff from Met data		-59%	-45%			
% decadal Change from 1961-1990 base			10%	25%	35%	23%
NEIS MROC HI	**5.91**	5.93	8.23	10.49	12.95	
% decadal Change			39%	27%	23%	30%
% diff from Met data		-61%	-41%			
% decadal Change from 1961-1990 base			16%	32%	50%	33%
Average Change from 1961-1990 Base			12%	**28%**	**41%**	
Average Degree Change			1.7	3.9	5.8	
Average Decade on Decade Change			24%	23%	16%	21%

Table 3-3: Bannu Historic and Projected Decadal Temperatures

Bannu Historic and Projected Decadal Temperatures (C)					
	1961-1990	2011-2030	2046-2065	2080-2099	Average % Change
Bannu weather station	23.23	24.09			
% decadal Change		4%			
ECHAM5	25.08	26.48	28.55	30.63	
% decadal Change		6%	8%	7%	7%
% diff from Met data	8%	10%			
% decadal Change from 1961-1990 base		6%	14%	22%	14%
HADCM3	21.35	21.67	24.16	25.42	
% decadal Change		1%	12%	5%	6%
% diff from Met data	-8%	-10%			
% decadal Change from 1961-1990 base		1%	11%	16%	10%
NEIS MROC HI	21.38	23.43	25.18	27.23	
% decadal Change		10%	8%	8%	8%
% diff from Met data	-8%	-3%			
% decadal Change from 1961-1990 base		8%	15%	23%	16%
Average Change from 1961-1990 Base		5%	**13%**	**21%**	
Average Degree Change		1.3	3.4	5.2	
Average Decade on Decade Change		6%	9%	7%	7%

The average projected air temperature increase is between 3-4°C above the 1990 base by 2065, and 5°C by 2099. The increase in temperatures is projected to occur primarily in the summer season, but since the modeled historic data is biased toward lower values in winter months than actually occurred it is likely that future temperature changes may actually be relatively uniform across the seasons, peaking in the summer month. As such, we may see a lengthening of the summer season and shortening of winters by 2065. At higher elevations this may lead to an earlier snow melt. Since snowpack serves as an effective water storage mechanism, this may ultimately impact late spring or summer water availability. Additionally the spring stream hydrology may change, with earlier and increased water levels and a higher probability of flash flooding. With the most dramatic temperature increases in summer, this could result in higher evapo-transpiration rates in soils and water bodies and a resultant reduction in agricultural productivity.

This page intentionally left blank

4 GREENHOUSE GASES AND THE KURRAM TANGI DAM PROJECT

4.1 Options for the KTMDP to Reduce GHGs and Capture Carbon Financing Opportunities

Hydropower operation of the KTMDP will produce minimal GHG emission, and therefore may qualify for carbon credits. There has been some historic controversy over the qualification of medium to large hydropower facilities for carbon credits because of the tremendous release of carbon emissions during the construction phase of the activity. As a result, the initial rules employed by the IFI's and the UNFCCC were that only small hydropower facilities of under 20 MW could qualify for carbon credits; however this has changed in recent years.

There also remains some debate over the release of GHGs from reservoirs in hot climates where significant amounts of vegetation are present and may be subject to eutrophication. For the KTMDP, it is expected that the reservoir will be cleared of vegetation so potential GHG emissions from the reservoir will be greatly minimized.

The power produced while a hydropower dam is in operation yields minimal GHGs. This is due to the fact that the primary mover is water; there is no combustion or other processes which would yield GHGs. As a result, in recent years several medium to large sized hydropower projects have been able to qualify for carbon credits using the UNFCCC CDM methodology. A variety of carbon finance instruments are available through the large IFI's, in particular the World Bank.

The price of carbon has varied dramatically over the years, going from an average of above $20/MTCO2e to as low as $1-2/MTCO2e. The recent failures to put in place an agreement to take the place of the Kyoto Protocol means that 2012 is the last year, technically speaking, that carbon credits can be traded under the UNFCCC CDM and JI mechanisms. As a result of this, and of the poor design of the EU carbon market, the price of carbon has gone through a dramatic devaluation. None-the-less, carbon credits continue to be financed and purchased by certain funds which are largely backed by IFI's and governments which remain committed to combatting climate change regardless of the status of international agreements. These entities continue to use the methodologies created by the UNFCCC.

4.2 GHG Emissions Offset by the KTMDP

The calculation of GHG emissions reductions involves first setting a baseline, and then calculating the reduction in emissions against that baseline. In this case, the power provided by the powerhouses will be going to the national grid. This means that the hydropower would be displacing other potential sources of power which may have been built instead. In the case of Pakistan, most of the current power generation comes from natural gas (48%), imported fuel oil (32%), or distributed non-grid connected diesel generator sets. All three of these sources are very carbon intensive, varying from 0.5 $kgCO_2/kWh$ for natural gas to 0.75 $kgCO_2/kWh$ for diesel and fuel oil[1]. It is reasonable to expect that any alternative power would likely be some combination of these more conventional power sources.

The International Energy Agency (IEA) produces an average carbon emissions factor for every country in the world. This emissions factor is based on the mix of energy sources currently in use by that country. For Pakistan that emissions factor is 0.451 $kgCO_2/kWh$. This reflects the fact that the remaining portion of Pakistan's power comes from lower carbon intensity sources such as hydropower and nuclear.

For the purposes of this analysis we will conservatively assume that the baseline power displaced by the KTMDP would be some mix of the current grid, and therefore utilize the IEA value for carbon intensity. Since this value is lower than the value for the more likely natural gas or diesel sources of generation, it represents a more conservative calculation. The carbon baseline is then calculated for each year of operation over the anticipated life of the project, as follows:

[1] UNEP/OECD/IEA/IPCC 1995

(kWh displaced by the KTMDP for each year) * (0.451 $kgCO_2/kWh$) = $kgCO_2$/year

The projected power production is 332,000 MWh/year, based on a total installed capacity of 83.3 MW capacity and 45.5% capacity factor.

This then results in a possible carbon offset of 149,732 metric tons of carbon dioxide per year (MT CO_2/year). If we assume a valuation of \$5/MT CO_2, the annual value of that carbon offset would be \$748,660. This is the equivalent of taking over 30,870 motor vehicles off the road for a year.

5 CLIMATE CHANGE IMPACTS

Climate changes for the Kurram Tangi region, based on a literature review and analysis of GCM data, show a steady increase in temperature of 3-4°C by 2065, and 5°C by 2099, with precipitation over the same period increasing, potentially, by as much as 4%. The seasonal analysis shows that these changes could result in shorter winters and longer more intense summers.

The increase in rainfall of 4% is not significant in an historic perspective, where rainfall has varied by +/- 10% from decade to decade. However, a shorter winter could result in earlier and faster melting of the high altitude snow packs. This could result in altered hydrology, with higher more turbulent flows. Resultant erosion of stream and river banks could cause added siltation at the dam site.

Additionally, the early spring flows could result in a reduction in summer water flows and availability. When combined with higher overall temperatures, this will increase evapo-transpiration rates and could lead to a higher incidence of drought. This may reduce the power availability in the summer months.

An additional impact of climate change is erratic weather patterns with more extreme events. Unfortunately, climate models cannot predict these types of weather behaviors, so it is difficult to say if there will be extreme rainfall, drought or other events that could impact the Kurram Tangi region.

5.1 Climate Change Implications – Socio-Economics

The local socio-economic impacts are likely to be around adjusting to a longer summer, a higher summer temperature, and an earlier spring melt of water in snow packs. The impact of hotter summers and shorter winters to the largely Agrarian surrounding communities is likely to be the most severe during the summer temperature peak, which is also a time of low precipitation. There will be a lengthening of the overall growing season, with more crop rotations possible, but this is likely to be offset by the hotter summer peaks with less summer water availability due to earlier snowmelt, leading to drier soils and lower overall productivity. Higher evapotranspiration rates due to increased temperatures during the summer peak are unlikely to be offset by the slight increase in precipitation in the early spring and late summer rainy periods.

If water resources are not properly managed, the anticipated climate changes could result in a decrease in summer productivity through the hottest months; however a longer summer season, if coupled with well managed irrigation waters, could actually extend the growing season and result in higher agricultural productivity. Thus any design of irrigation from the Kurram Tangi Dam for this region should take into consideration the climate changes discussed in this report. Additionally, any agricultural assistance to the area should assess modified crop and livestock needs due to higher temperatures. If managed properly, these activities might lead to a boost in agricultural productivity and the local economy due to a longer growing season, irrigation, and appropriate crop and livestock management practices. If not managed properly, it is likely that climate change will result in a decrease in the overall agricultural productivity, and a negative socio-economic impact on the region.

The national impact of increasing temperatures is an increase in summer demand of power for cooling needs. Since the Kurram Tangi Dam operation would likely peak in the spring months, it is likely that the summer production will only make a marginal impact on the increased summer power needs nationwide. Unless significant storage capacity was built to allow for longer retention of the spring inflows behind this and other dams, it is likely that Pakistan will need to turn to other, non-hydro sources to meet increasing summer power demands, which could have negative economic impacts given the fact that much of the fuel to run Pakistan's non-hydro fossil fuel units is imported. Additionally, the combustion of those fossil fuels will produce GHGs, further exacerbating the climate change problems.

5.2 Sectors at Risk in the Kurram Tangi Region

Water resources, agricultural productivity, energy demand and production, biodiversity and human health may potentially all be at risk from climate change in Pakistan.

Impacts on water resources include:

- Increased floods in the early spring months.
- Increased drought in the high summer months.
- Increased rates of evapo-transpiration in soils and water bodies.
- Possible increased eutrophication and algae build up in water bodies during summer months due to longer summers.
- Possible increased draw down of aquifers.

Impacts on agriculture and livestock include:

Earlier spring melt of the snow pack may cause reduced summer water availability in streams and reservoirs as well as drier soils. These factors may alter crop rotations, cropping patterns, crop types appropriate to the area, and livestock management needs.

- A longer summer season, if coupled with well managed irrigation waters and appropriate cropping and livestock management, could actually extend the growing season and result in higher agricultural productivity.
- Crop and livestock losses due to extreme weather events.

Impacts on the local environment and biodiversity include:

Unmanaged rangelands are likely to be over-stressed from prolonged droughts and shifting human and livestock populations around riverine areas and in mountainous regions. This may reduce tree and shrub cover, impacting winter fuel heating availability for the local population. This can lead to a vicious cycle where natural vegetation loss results in a much higher percent of the trees and shrubs being harvested for fuel in winter months, further denuding the area. Since much of the area is in unmanaged rangelands, the above impacts will likely result in a loss of habitat for any local fauna, and resulting biodiversity loss across local flora and fauna. However, if agricultural productivity is boosted in the managed areas, these human and livestock pressures may be manageable.

Some other climate change related concerns of Pakistan, in general, and Kurram Tangi catchment area may include increased health risks such as heat strokes, pneumonia, malaria and other vector-borne diseases.

6 FINDINGS AND RECOMMENDATIONS

This report presents both original analysis and a literature review of the anticipated climate changes, as well as the impacts and implications of those changes on the KTMDP and region. These are summarized below. This section concludes with suggested actions to manage the future climate changes expected in the Kurram Tangi region.

The anticipated climate changes in the Kurram Tangi region include the following:

- Temperature increases in the future:
    - +3 to 4°C by 2065
    - + 5°C by 2099
- Precipitation remains relatively static in the future:
    - + 4% by 2099
    - Note that the historic variability has been +/- 10%
- Possible extreme events – such as droughts, storms and floods - though we cannot predict either the timing or the nature of these events.

The impacts of those climate changes are:

- Longer summers by the 2040-2065 period.
- Higher summer peak temperatures, with lower observed increases in temperatures during winter months.
- Increased evapo-transpiration rates.
- Possible severe wet or dry periods.

The implications of those climate impacts include:

- Earlier spring snow pack melt.
- Lower summer river flows, water body levels.
- Drier soils through the summer months.
- High ET water loss from water bodies.
- Increased soil erosion.
- Shifting crop needs.
- Shifting livestock management needs.
- Dramatic loss of crops, livestock and livelihoods due to extreme events.

Further sub-implications include:

- Higher soil erosion leading to increased siltation at the dam.
- Reduced power production due to lower water flows and reservoir levels.
- Spring flooding may cause loss of crops, livestock, property destruction and human life.
- Drier summers may cause further degradation of unmanaged rangelands, resulting in loss of the natural habitat and reductions in biodiversity.

Finally, the possible measures to manage these climate implications include the following:

- Assess possible shifts in hydrology by the 2040-2065 time period. Based on outcomes:
    - Account for increased siltation in reservoir management planning, and
    - Assess the possible changes in the power curves to account for any reduction in power output during peak summer months.
- Assess possible shifts in future hydrology on the river flood plain levels. Based on outcomes assess any resultant resettlement needs, crop pattern considerations, livestock grazing patterns, and education campaigns about flash flooding.
- Ensure that irrigation planning accounts for possible future decreases in summer water availability, drier soils, and shifts in agricultural practices.
- Assess existing crop tolerance to increased temperatures, and any necessary changes in crop types or management practices.

- Assess livestock tolerance to increased temperatures, and any necessary changes livestock management practices.
- Conduct agricultural outreach to assist in adaptive changes which may be necessary in the future.
- Assess if agricultural outreach may offset possible human induced stresses to the natural rangeland habitats.
- Assess local health practices and needs to determine if climate induced human illnesses are likely, and if measures can be taken to counter these.
- Prepare emergency plans for extreme climate events.

Adapting to climate change impacts is and will be an ongoing process. It cannot be thought of simply as a set of actions to be taken right now. Adaptation calls for the development of a management framework for becoming more adaptable over time. The reality is that our knowledge about what climate changes to anticipate in the future will get better over time. Similarly, it is hoped that both national and international frameworks, tools, and management options for adapting to climate change will also improve over time. Thus, over time we suggest a periodic review of the effectiveness of climate based risk-management strategies as we learn more about projected climate changes and impact vulnerabilities.

Adaptation poses enormous challenges across sectors, jurisdictions, and levels of governance. Successful adaptation to climate change involves a multitude of interested partners and decision makers: federal, state, and local governments; the private sector, large and small; NGOs and community groups; and others. The issue is how to create a framework in which all of the parties work together effectively, taking advantage of the strengths of each and assuring that the activities reinforce each other rather than getting in each other's way.

7 BIBLIOGRAPHY

Arshad M. Khan, 2008, Climate Change concerns, Research need and efforts in Pakistan, Technical Advisory Panel on Climate Change, Islamabad.

Barker T, et. Al., 2007: Technical Summery, Fourth Assessment Report of the Intergovernmental panel on Climate Change, Cambridge University Press.

Chadha D.K, 2008, Development, Management and impact of climatic change on transboundary aquifers of Indus Basin. http://www.inweb.gr/twm4/abs/CHADHA%20Devinder.pdf

Courtenay Cabot Venton, May 2007, Climate change and water Resources, ERM for Water Aid.

Falkowski, P.; Scholes, R. J.; Boyle, E.; Canadell, J.; Canfield, D.; Elser, J.; Gruber, N.; Hibbard, K. et al. (2000). "The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System". *Science* 290 (5490): 291–296

Fata, Physical features and climate, http://fata.gov.pk/index.php?option=com_content&view=article&id=51&Itemid=85

Federally Administrated Tribal Area, http://www.globalsecurity.org/military/world/pakistan/fata.htm

IPCC, 2010, Inter Government Panel on Climate Change report.

Islam-Ul-Haque, Anum and Ruhmma,2007, Effects Of Climate Change On Planning And Manging Water Services In The Potohar Region Of Pakistan, http://wasa.rda.gov.pk/MD_Papers/climate_change_paper.pdf

James P. Verdon et al. July 2013, Comparison of Geochemical deformation induced by megatonne-scale CO_2 storage at Sleipner, Wayburn, and in Salah, Proceedings of National Academy of Sciences of the United States of America, Published online before print July8, 2013.

Kaleem A.M, & Tahira Munir, 2011, Status Methodology and Results of recent GHG inventory preparation efforts in Pakistan, Second Global Workshop on CD-REDD-II Dublin, South Africa.

Khan A. N. et al, 2011, Climate Change: Emission and Sinks of Greenhouse Gases in Pakistan, Paper No. 293, *Symposium on "Changing Environmental Pattern and its impact with Special Focus on Pakistan".*

Kuntala Lahiri-Dutt, 2010, Special Essay, Pakistan Floods, Global Water Forum, http://www.globalwaterforum.org/2010/09/06/special-essay-pakistan-floods/

Mansoor Raza, Climate change and Food (In) security in Pakistan, http://www.scribd.com/doc/49938617/Climate-change-and-Food-Insecurity-in-Pakistan-for-Magazine

OICIC, 2010, A roadmap for Energy Efficiency and Energy Conservation in Pakistan, A position paper prepared by OICCI (Organization of Islamic Chamber of Commerce and Industry) energy subcommittee.

Pauli Paasonen et al, 2013, Warming-induced increase in aerosol number concentration likely to moderate climate change, Nature Geoscience 28 April, 2013.

Mall R. K, et al, 2006, Water Resources and climate Change: An Indian Perspective, Current Science, Vol 90, No. 12, June 25, 2006.

SIDA, 2010, Preparation of Regional Plan for The Left Bank Of Indus, Delta And Coastal Zone, Sindh Water Sector Improvement Phase-1 Project (Wsip-1), Volume I & IV

Siraj ul Islam et al, 2009, Climate Change Projections for Pakistan, Nepal and Bangladesh for SERS A2 and A1B scenarios using output of 17 GCMs used in IPCC-AR4, Research Report GCISC-RR=03, Global Change Impact Study Center, Islamabad, Pakistan.

Task Force Report on Climate Change, 2010, Planning Commission, Government of Pakistan, Islamabad.

WMO, 2013, A summary of current climate change finding and figures.

Zektser, S, Loaiciga, HA & Wolf, JT (2005) 'Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States', Environmental Geology, vol. 47, pp. 396-404.

USAID | PAKISTAN
FROM THE AMERICAN PEOPLE

Kurram Tangi Dam Construction

Supplemental Report on Climate Change

Annexure 1: Data Tables

December 2013
This publication was produced for review by the
United States Agency for International Development.
It was prepared by MWH-NESPAK-ACE under contract AID-391-C-13-00002

This page intentionally left balnk

List of Acronyms

Acronym	Term
FATA	Federally Administered Tribal Areas
GCM	Global Circulation Model
GoP	Government of Pakistan
KP or KPK	Khyber Pakhtunkhwa
MWH	MWH Global, Inc. or MWH, Inc.
NESPAK	National Engineering Services Pakistan
SWHP	Surface Water Hydrology Project
WAPDA	Water and Power Development Authority
°C	Degree Celsius

This page intentionally left balnk

Table of Contents

List of Data Tables

Table A-1: Kurram River Historic Monthly and Annual Flows at Thal (in Thousand Acre Feet) 1
Table A-2: Kurram River Historic Monthly and Annual Flows at Kurram Tangi (in Thousand Acre Feet) 3
Table A-3: Kaitu River Historic Monthly and Annual Flows at Spinwan (in Thousand Acre Feet) 4
Table A-4: Annual Mean Observed Temperature at Bannu (in °C) 5
Table A-5: Annual Maximum and Mean Observed Temperature at Parachinar, FATA (in °C) 7
Table A-6: Annual Maximum and Mean Observed Temperature at Kohat, KP (in °C) 9
Table A-7: Annual Precipitation Record of Bannu, PK (in mm) 11
Table A-8: Annual Precipitation Record of Parachinar, Kurram Agency, FATA (in mm) 13
Table A-9: Historical Annual Precipitation Record of Kohat, KP (in mm) 15
Table A-10: Historical Annual Mean Temperature and Precipitation Record of Gardez, Afghanistan 18
Table A-11: Future Temperature Projections of Project Area Using GCM Data (in mm). 20
Table A-12: Future Precipitation Projections of Project Area Using GCM Data (in mm). 23

This page intentionally left balnk

Table A-1: Kurram River Historic Monthly and Annual Flows at Thal (in Thousand Acre Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Monsoon total	Non-monsoon total
1971	28	24	25	32	30	40	57	53	31	18	16	19	373	**243**	**130**
1972	23	22	71	129	180	77	70	88	60	48	38	49	854	**604**	**250**
1973	45	43	95	174	139	77	171	67	78	86	64	41	1,079	**706**	**374**
1974	69	93	78	61	48	28	55	36	41	30	24	35	596	**268**	**328**
1975	38	34	49	127	192	89	69	89	61	39	45	46	877	**628**	**249**
1976	38	29	37	63	176	72	64	63	50	95	53	58	798	**488**	**310**
1977	53	54	44	73	53	54	37	38	41	44	49	56	596	**297**	**299**
1978	38	28	50	76	143	52	104	62	39	50	41	30	713	**476**	**237**
1979	30	41	65	123	96	59	41	86	45	39	44	44	711	**448**	**263**
1980	32	30	59	104	61	67	51	42	43	76	56	53	674	**369**	**305**
1981	66	44	107	72	52	55	78	48	42	47	38	40	689	**347**	**342**
1982	38	34	47	54	70	48	55	84	44	39	57	57	626	**356**	**271**
1983	44	35	54	141	293	135	69	123	61	51	47	49	1,102	**823**	**280**
1984	50	45	51	81	57	39	105	91	65	46	47	53	729	**437**	**292**
1985	49	33	30	86	55	35	27	57	27	34	32	38	503	**287**	**216**
1986	35	32	45	57	105	77	51	124	32	42	26	38	665	**447**	**218**
1987	34	30	107	106	98	52	74	52	61	28	21	36	698	**443**	**256**
1988	40	34	78	119	55	41	65	55	44	45	30	39	646	**379**	**266**
1989	39	30	35	42	56	46	57	47	34	39	30	31	484	**281**	**203**
1990	32	33	37	44	60	66	74	50	61	38	33	33	562	**355**	**207**
1991	36	36	48	96	210	97	120	71	35	43	41	42	877	**630**	**246**
1992	37	36	44	41	98	92	90	84	49	33	30	35	671	**455**	**216**
1993	59	51	57	141	90	49	107	52	34	34	30	31	734	**473**	**261**
1994	32	29	47	79	131	290	54	42	44	37	36	40	860	**640**	**219**
1995	40	36	41	85	42	36	58	39	35	36	48	54	552	**297**	**256**
1996	54	49	62	63	83	53	41	38	34	40	30	31	578	**312**	**265**
1997	29	26	32	51	64	43	29	42	31	31	35	38	451	**260**	**191**
1998	35	32	48	93	89	69	44	61	59	31	25	24	613	**416**	**197**
1999	33	28	49	25	21	15	20	21	47	14	14	17	303	**148**	**155**
2000	20	17	17	12	10	14	19	16	20	27	27	28	229	**92**	**137**
2001	28	25	34	27	26	38	23	15	9	8	6	6	243	**137**	**106**
2002	7	8	9	9	9	13	100	321	185	31	43	42	777	**637**	**141**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Monsoon total	Non-monsoon total
2003	23	22	21	20	20	21	117	201	143	35	33	35	692	**523**	**169**
2004	35	34	37	42	41	31	55	72	34	35	19	20	454	**274**	**180**
2005	61	52	217	147	193	122	223	163	49	61	49	46	1,384	**898**	**486**
2006	45	39	47	61	37	43	57	93	88	16	56	60	642	**378**	**264**
Average	39	35	55	77	88	62	70	75	52	40	36	39	668	**405**	**243**
Max	69	93	217	174	293	290	223	321	185	95	64	60	1384	**898**	**486**
Min	7	8	9	9	9	13	19	15	9	8	6	6	229	**92**	**106**

(Source: SWHP/WAPDA)

Table A-2: Kurram River Historic Monthly and Annual Flows at Kurram Tangi (in Thousand Acre Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1971	29.4	22.3	17.5	31.1	25.0	34.6	92.7	89.1	25.1	17.7	20.7	35.6	**441**
1972	21.8	21.9	48.3	111.6	167.7	74.4	71.9	65.7	61.7	28.0	29.2	46.2	**748**
1973	38.9	39.7	84.1	125.2	83.1	40.7	273.9	126.8	59.4	49.1	27.1	31.5	**979**
1974	34.2	31.0	32.8	55.2	130.2	28.6	104.0	88.5	50.8	27.8	20.7	34.4	**638**
1975	31.6	29.9	49.8	83.5	101.7	80.3	49.5	166.4	95.6	28.8	25.6	38.3	**781**
1976	36.3	40.6	56.2	135.3	109.6	47.1	66.5	96.0	55.2	52.3	29.0	40.6	**765**
1977	37.0	30.1	23.9	93.0	55.5	30.3	98.3	54.7	34.9	37.4	27.9	36.3	**559**
1978	31.2	26.4	178.2	79.8	52.3	50.4	73.7	147.9	31.9	40.2	38.9	35.1	**786**
1979	34.2	50.5	85.4	135.7	110.6	55.0	85.5	205.3	57.4	52.8	41.1	41.6	**955**
1980	42.0	58.6	123.8	98.9	57.3	142.0	98.4	74.0	51.4	56.9	41.1	52.0	**897**
1981	73.2	43.1	145.1	144.8	131.5	56.5	134.4	91.4	55.5	51.8	41.3	47.9	**1,017**
1982	73.3	43.2	134.4	139.0	134.5	57.4	126.8	89.2	56.1	51.6	40.9	46.9	**993**
1983	48.2	35.7	100.1	272.7	299.8	104.6	75.6	169.6	84.2	60.3	46.9	52.6	**1,350**
1984	50.7	44.0	50.3	70.1	38.9	38.4	150.6	137.4	94.5	39.7	44.3	49.3	**808**
1985	48.9	34.7	34.4	91.4	26.4	25.8	53.6	92.1	33.7	35.3	24.7	39.9	**541**
1986	40.1	32.2	55.9	87.4	92.1	48.8	86.4	123.0	34.7	37.0	28.2	48.7	**715**
1987	39.7	30.1	152.6	73.8	132.3	68.2	83.7	51.9	46.1	41.1	27.4	34.5	**781**
1988	33.9	29.4	107.8	88.6	48.5	59.4	94.0	128.5	60.1	31.8	21.9	45.4	**749**
1989	42.4	23.8	62.9	90.7	70.3	43.2	97.3	96.5	35.7	33.8	23.3	34.0	**654**
1990	36.3	35.7	94.9	144.8	101.4	61.6	156.5	120.2	55.6	45.3	37.4	36.9	**927**
1991	43.6	44.7	107.2	206.3	259.1	115.4	119.8	111.2	73.9	50.1	40.3	47.2	**1,219**
1992	50.4	54.5	83.2	215.6	245.5	140.3	116.6	142.2	85.1	59.4	47.3	54.9	**1,295**
1993	54.0	39.5	153.4	152.5	122.1	90.8	148.7	81.0	75.7	53.5	39.1	46.2	**1,056**
1994	48.0	51.4	73.5	102.8	88.2	36.2	122.4	63.0	68.2	66.7	41.3	51.8	**813**
1995	51.2	35.1	79.3	188.9	127.5	58.6	85.4	74.4	42.1	56.5	30.9	44.3	**874**
1996	44.5	40.4	70.8	69.7	110.0	146.7	82.8	129.3	38.9	69.3	29.0	33.2	**865**
1997	33.7	29.9	49.8	160.6	179.8	124.8	55.0	64.8	29.6	87.2	48.0	47.2	**910**
1998	51.7	86.4	215.2	265.1	159.6	60.4	97.4	94.3	110.9	64.4	40.5	48.4	**1,294**
1999	63.5	81.9	59.6	33.5	29.7	16.7	71.4	99.9	57.5	38.7	35.5	33.2	**621**
2000	41.0	35.9	31.6	21.7	23.5	39.9	29.9	41.1	41.8	24.2	14.1	25.7	**370**
2001	27.2	17.2	30.4	37.9	16.9	55.8	81.3	60.8	40.4	15.1	13.2	17.9	**414**
Average	43.0	39.3	83.6	116.4	107.4	65.6	99.5	102.5	56.3	45.3	32.8	41.2	**833**
Max	73.3	86.4	215.2	272.7	299.8	146.7	273.9	205.3	110.9	87.2	48.0	54.9	**1,350**
Min	21.8	17.2	17.5	21.7	16.9	16.7	29.9	41.1	25.1	15.1	13.2	17.9	**370**

Table A-3: Kaitu River Historic Monthly and Annual Flows at Spinwan (in Thousand Acre Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1971	8.3	5.9	8.5	9.1	5.1	8.7	25.6	38.3	11.2	6.5	12.5	20.4	**160**
1972	4.8	6.0	8.0	13.9	72.0	13.9	17.7	14.7	9.4	8.8	7.0	4.0	**180**
1973	8.9	5.5	14.3	28.9	13.2	9.2	200.8	74.3	13.4	15.0	9.8	7.5	**401**
1974	9.3	5.8	8.2	10.6	76.3	6.0	46.7	64.2	8.1	10.2	8.8	5.3	**259**
1975	9.8	4.7	7.5	13.3	20.0	34.0	12.0	101.6	44.9	10.1	9.5	10.7	**278**
1976	11.4	7.1	19.0	79.0	20.3	12.0	12.7	37.0	12.3	10.9	10.3	11.3	**243**
1977	8.2	9.8	8.4	22.1	11.2	6.6	34.2	21.7	9.5	7.7	6.4	8.2	**154**
1978	5.7	6.3	118.6	15.7	14.3	11.1	13.4	89.3	9.8	12.6	8.4	12.0	**317**
1979	6.9	14.9	38.8	40.7	22.8	13.9	35.3	157.8	14.3	20.9	9.6	8.6	**384**
1980	15.2	27.0	34.6	27.3	11.7	138.3	74.2	26.4	11.4	13.2	9.6	11.8	**401**
1981	17.0	5.4	77.3	80.1	81.6	10.1	59.7	23.2	19.0	12.5	13.0	13.3	**412**
1982	37.7	11.7	104.7	88.0	69.4	24.6	93.5	38.0	23.3	17.2	9.2	10.0	**527**
1983	9.5	8.1	41.4	170.9	62.3	26.4	15.6	41.3	23.0	18.1	14.8	14.4	**446**
1984	14.6	9.3	9.4	10.3	10.8	12.3	68.9	80.8	56.6	13.2	11.2	12.1	**309**
1985	10.4	11.2	9.7	27.9	7.0	8.5	40.9	49.2	15.8	12.2	9.3	5.6	**208**
1986	11.9	7.4	7.5	37.7	23.5	9.3	31.6	17.2	14.5	12.2	9.0	16.3	**198**
1987	12.0	11.9	51.1	20.0	56.4	21.5	40.8	18.7	14.4	21.0	14.3	11.8	**294**
1988	7.8	8.5	34.4	22.6	13.1	34.8	72.6	101.1	36.2	9.0	8.6	10.8	**360**
1989	7.4	8.2	28.6	47.5	18.5	9.4	45.2	60.9	15.5	11.7	8.6	6.4	**268**
1990	7.7	7.5	67.1	90.2	48.6	17.6	108.1	52.0	24.3	14.8	13.5	7.6	**459**
1991	10.9	13.4	61.1	133.1	86.0	40.0	31.3	47.4	37.6	15.2	7.9	10.5	**494**
1992	11.4	14.8	39.4	163.6	192.0	49.7	51.5	101.5	32.9	34.4	23.4	18.9	**734**
1993	11.7	9.6	72.8	33.7	48.1	49.2	88.0	38.2	55.8	30.7	16.6	19.1	**473**
1994	20.1	19.1	31.5	30.2	18.4	8.8	98.7	30.3	42.2	37.2	14.3	11.9	**363**
1995	14.7	4.9	28.1	121.6	81.4	25.8	49.8	41.9	7.6	25.9	10.7	12.3	**425**
1996	10.7	6.1	11.3	18.9	80.6	136.6	68.0	96.1	13.5	42.9	10.4	9.7	**505**
1997	8.9	10.1	24.0	106.3	131.1	86.2	28.6	40.3	6.3	38.0	20.6	8.2	**509**
1998	11.6	20.9	133.4	243.4	75.3	16.8	57.5	34.1	63.4	40.4	21.7	27.7	**746**
1999	18.1	49.6	11.0	13.3	8.7	6.0	34.1	30.4	25.1	25.2	24.6	19.8	**266**
2000	16.4	19.9	19.6	13.1	10.5	17.4	12.0	12.0	15.7	7.5	6.2	6.6	**157**
2001	8.5	5.9	8.7	10.6	4.5	26.9	74.0	41.5	29.0	14.4	13.2	13.2	**250**
Average	11.9	11.5	36.7	56.2	45.0	28.8	53.0	52.3	23.1	18.4	12.0	11.8	**361**
Max	38	50	133	243	192	138	201	158	63	43	25	28	**746**
Min	5	5	8	9	5	6	12	12	6	6	6	4	**154**

Table A-4: Annual Mean Observed Temperature at Bannu (in °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1948	19.5	19.2	24.5	32.2	40.1	39.4	38.9	36.2	36.6	32.9	25.7	18.8	30.3
1949	19.3	19.7	24.8	33.9	39.8	35.5	37.8	36.6	37.9	16.7	25.6	20.5	29
1950	17.3	18.3	23.1	28	37.2	41.1	38.3	36.9	34.6	31.7	26.2	20.6	29.4
1951	18.4	20.7	24.6	28.1	36.3	39.7	38.9	35.7	37.3	35.3	27.6	22.3	30.4
1952	20.8	21.1	24.1	33.7	37.2	40.4	37.1	36.4	36.6	33	26.6	20.8	30.7
1953	17.4	21.4	28.9	32.5	36.9	40.6	37.9	35.8	34.1	31.7		22.6	30.9
1954		18.1		31.8				37.9	35.7	28.6	25.4		29.6
1955	19.6	23.7	26.2	30.9	33.3	41.1	38.7	35.8	34.9	31.2	27.3	14.7	29.8
1956	19.8	21.9	23.1	30.5	41.3	39.4	36.4	35.7	36.7	29.8	26.1	20.9	30.1
1957	16.3	19.5	23.5	27.8	33.2	38.7	39.3	36.7	35.7	31.3	24.7	19.3	28.8
1958		21.9	25.6	33.8	35.7	40.6	38.6	36.2	34.3	31.3	26.3	19.6	31.3
1959	17.3	17.7	26.3	31.4	36	41.4	35.7	37.3	35.4	32.5	22.9	19.6	29.5
1960	17.8	24.6	22.2	28.3	37.9	41.9	38.2	38.3	36.4	32.7	26.3	21.7	30.5
1961	18.7	17.7	26.1	28.4	37.1	40.3	38.1	37.7	36.7	32.7	22.3		30.5
1962		20.4	24.7	31.1	36.7	40.6	39.1	37.6	34.4		23.3		32
1963								99.7	96.1				
1964													
1965						**Not on Record**							
1966													
1967													
1968													
1969													
1970		21.1	23.3	33.9	38.9	41.1	38.3	37.2					33.4
1971				33.3	37.2	40	37.2	36.7	35	32.8	26.1	23.9	33.6
1972	20	18.3	21.1	32.2	39.4	41.7	40	37.2	35	32.2	26.7	20	30.3
1973	18.3	18.9	23.3	34.4	40	39.4	37.2	36.1	35.6	31.7	26.7	21.7	30.3
1974			33.3		36.1	38.9	38.3	37.2	36.1	32.2			36
1975	18.3	20.6	23.9	30.6	38.9	38.9	38.3	35	33.9	33.3	25.6	21.1	29.9
1976	19	19	23	30	37	38	39	35	35	33	29	22	29.9
1977	18	24	31	31	35	40	39	37	35	33	29	23	31.3
1978	19	23	23	33	42	43	35	36	36	34	26	24	31.2
1979	21.1	20.6	23.9	33.3	36.1	41.7	38.9	36.7	33.9	33.9	28.9	23.3	31
1980	20	22	23	35	40	41	38	38	36	34	29	24	31.7
1981	20	22	24	33	38	41	37	26	36	32	27	23	29.9
1982	20.6	20.6	21.1	31.7	35	41.7	40	37.8	36.7	32.2	25.6	20.6	30.3
1983	18.9	21.7	23.9	27.2	32.2	37.2	38.9	35.6	35.6	29.4	27.2	21.7	29.1
1984	20.6	20	29.4	30.6	41.1	43.9	38.3	36.1	35	32.8	26.7	20.6	31.3
1985	19.4	25	29.4	31.7	37.8	44.4	41.7	36.7	35	31.7	26.7	20.6	31.7
1986	19.4	19.4	21.1	29.4	35	38.3	36.1	35	34.4	29.4	24.4	16.7	28.2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1987	17.2	20.6	22.2	31.1	31.1	38.3	38.3	35.6	35.6	29.4	26.7	21.7	29
1988	20.6	21.7	22.8	32.2	37.8	38.3	36.1	32.8	32.8	28.9	25.6	20	29.1
1989	17.8	18.9	22.8	26.7	34.4	37.8	35.6	33.9	35	32.8	25	18.9	28.3
1990	17.8	18.3	22.2	27.8	38.9	41.1	38.9	34.4	33.3	27.8	25.6	18.3	28.7
1991	16.7	18.9	23.3	28.3	33.3	40.6	38.9	36.1	34.4	29.4	23.3	20.6	28.7
1992	18.3	20	25.6	30.6	35.6	41.7	38.9	37.8	35.6	32.2	26.1	21.1	30.3
1993	18.3	25	23.3	33.3	39.4	41.1	38.3	38.9	35.6	32.8	27.8	23.3	31.4
1994	20	21.1	28.9	34.4	38.9	42.8	38.3	34.4	30.6	27.8	22.8	20.6	30
1995	21.1	25	26.7	28.9	39.4	44.4	40	38.3	35.6	32.2	26.1	19.4	31.4
1996	18.3	21.7	24.4	33.3	37.8	40.6	40.6	37.2	36.1	31.1	26.7	20.6	30.7
1997	19.4	21.4	23.7	27.8	33.6	38.1	39.3	37	36.2	26.9	24.4	18.3	28.8
1998	18.4	19.8	22.4	31.5	37.1	40.3	39	38.2	35.5	32.4	29.1	23.4	30.6
1999	16.8	21.1	25.5	35.4	39.8	41.3	39.7	35.9	36.5	33	27.1	23.8	31.3
2000	20.1	20.6	26.1	35.7	41.8	41.3	38.2	38	35.9	33.9	26.9	22.9	31.8
2001	19.3	23.3	27.8	33.1	40.7	38.9	38.3	38	35.6	33.4	28	22.8	31.6
2002	20.7	20.3	27.9	34	40.3	41.4	40.9	38.7	34.6	31.8	26.4	21.7	31.6
2003	19.1	20.1	24.6	31.9	37.3	42.6	38.3	36.6	35.7	32.2	26.5	22.6	30.6
2004	18.7	22.8	31.2	35.3	39.2	39.9	39.7	36.4	36.4	29.6	27	22.5	31.6
2005	16.8	16.7	23.7	31.6	34.4	42.4	37.7	37.4	35.6	32.8	27.1	22.7	29.9
2006	19.1	25.4	25.7	34.1	41.1	40.5	38.7	36.1	36	33.3	24.3	20.3	31.2
2007	21	19.6	23.9	35.4	38.8	40.6	38.1	38.9	36.8	33.6	28.2	21	31.3
2008	17.2	21	29.7	30.5	38	40	38.8	36.7	35.2	33.4	28.3	23.7	31
2009	20.9	22	26.4	30.4	38.8	40.2	40.2	38.7	36.7	33.2	26.3	22.7	31.4
2010	20.9	20.9	29.7	35.8	39	40	36.7	34.5	35.5	33.9	29.2	22.3	31.5
2011	18.7	19.4	27	30.7	41.1	41.3	37.2	35.9	35.1	32.6	27.2	23	30.8
2012	18	18.7	25.9	31.3	36.8	42.2	40.8	37.5	33.8	31.9	26.8	22	30.5

Table A-5: Annual Maximum and Mean Observed Temperature at Parachinar, FATA (in °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Min	Max	Avg
TNTN = MONTHLY MEAN MINIMUM TEMPERATURE (°C) [NA Means data not available]															
1948	0.0	0.2	3.7	10.2	13.6	13.7	19.6	18.6	16.2	7.3	3.8	0.6	9.0	21.8	15.4
1949	-1.9	-0.7	4.3	11.3	16.3	16.1	19.8	17.6	17.1	9.4	3.1	0.3	9.4	20.6	15.0
1950	-0.9	-3.3	2.8	6.7	13.5	18.4	19.9	18.1	13.2	9.6	3.5	-1.8	8.3	20.7	14.5
1951	-1.8	-0.6	3.9	7.4	13.2	16.2	18.0	18.3	15.6	12.0	6.2	2.7	9.3	21.8	15.5
1952	-0.3	1.1	3.9	10.7	13.7	18.7	19.1	18.1	15.0			0.7	10.1	21.9	16.0
1953	-2.2	2.8	6.3	10.1	13.5	18.6	19.6	17.8	14.9	9.3	5.1	4.2	10.0	22.6	16.3
1954		-0.1		9.6				18.2	15.8	7.6	3.7		9.1	21.7	15.4
1955	-1.8	1.6	6.2	8.0	11.4	16.9	18.9	19.4	15.5	8.8	4.6	1.6	9.3	21.6	15.4
1956	-2.2	5.2	2.6	9.4	17.0	18.1	18.9	17.9	15.7	8.5		0.9	10.2	22.7	16.4
1957															
1958	-0.3	-0.3	1.4	10.5	12.2									23.2	11.6
1959				9.6	13.0	18.2			17.6	11.6	3.9	-0.4	10.5	20.5	15.5
1960	-2.4	2.5	2.5	6.4	12.4	17.3	19.0	19.1	14.9	9.4	3.3	0.0	8.7	20.6	14.6
1961	-1.1	-3.2	2.9	7.4	14.1	17.8	19.3	18.7	17.4	9.4		0.7	9.4	22.3	15.9
1962	-1.5	1.1	4.7	9.9	12.6	17.3	18.6	18.3	13.9		3.2	-0.5	8.9	21.1	15.0
1963	-0.3	2.8						19.3			5.2		6.8	19.4	13.1
1964	-4.9														
1967	-3.1	1.2	3.1	7.6	12.4	18.6	-100.0	0.0	16.7	9.5	5.3	0.0	-2.4	6.8	2.2
1968	-2.4	-1.8	4.9	9.6	11.9	19.4	20.1	18.8	16.1	10.1	4.3	-0.1	9.2	20.2	14.7
1969	-1.9	-0.4	7.8	9.1	12.7	18.7	20.4	19.5	15.7	11.6	4.9	1.9	10.0	21.6	15.8
1970	-0.6	1.1	3.9	11.4	16.2	20.1	18.8	20.2	16.4	11.6	4.7	1.0	10.4	22.0	16.2
1971	-1.7	0.0	5.6	11.6	15.5	19.4	19.2	19.4	15.1	10.6	5.7	2.4	10.2	22.0	16.1
1972	-1.9	-4.5	4.4	9.2	12.7	18.3	19.4	18.0	14.6	9.7	4.3	0.2	8.7	20.2	14.5
1973	-2.8	0.0	4.0	10.5	15.1	20.7	19.5	17.5	17.1	9.6	5.1	-0.9	9.6	21.2	15.4
1974	-2.7	-2.5	6.5	11.5	13.7	17.7	19.6	19.2	15.2	8.8	4.0	-1.4	9.1	20.8	15.0
1975	-2.0	-2.4	3.0	9.1	13.7	17.4	18.5	19.1	15.8	10.5	3.0	0.5	8.9	20.4	14.6
1976	-0.7	-0.7	2.6	8.9	14.4	18.0	20.3	18.2	15.2	10.9	4.7	-0.1	9.3	20.7	15.0
1977	-3.1	-0.7	7.2	10.2	13.5	18.7	20.3	18.5	15.5	11.6	6.5	1.5	10.0	21.3	15.6
1978	-1.5	-0.4	3.4	10.0	16.6	19.0	19.3	19.0	15.8	10.8	4.6	2.0	9.9	21.1	15.5
1979	-0.2	0.1	3.1	11.7	11.2	18.3	20.2	17.3	14.5	11.0	4.5	0.9	9.4	20.8	15.1
1980	-2.5	-0.2	3.3	11.0	15.2	19.0	20.0	18.3	15.2	10.7	5.6	1.4	9.8	20.9	15.3
1981	-1.2	0.4	4.4	10.4	14.5	17.3	19.6	18.7	15.0	9.2	4.4	0.6	9.4	20.8	15.1
1982	-1.4	-2.5	2.8	8.9	12.5	16.5	19.2	18.7	14.3	9.7	4.5	-1.0	8.5	19.9	14.2
1983	-1.9	-0.9	1.6	7.5	12.9	16.6	19.3	19.0	16.3	10.3	6.1	-0.8	8.8	20.4	14.6
1984	-2.5	-3.1	6.4	9.8	15.9	20.7	18.9	19.3	13.9	9.8	5.2	1.2	9.6	21.0	15.3
1985	-0.9	1.1	6.1	10.1	14.6	18.5	19.1	18.4	16.1	9.9	5.5	1.1	10.0	11.3	10.6
1986	-1.9	-0.2	3.3	9.6	13.4	17.9	19.1	18.1	15.3	10.4	5.0	0.1	9.2	20.9	15.0
1987	-0.7	1.4	5.3	9.8	11.9	17.1	19.7	18.9	17.6	10.7	5.9	2.1	10.0	22.3	16.2
1988	0.1	1.0	3.9	11.3	16.6	19.0	20.6	18.4	16.1	10.0	5.6	1.9	10.4	22.3	16.3
1989	-2.2	-1.9	3.2	8.0	12.6	17.7	18.1	17.4	16.0	10.8	5.2	2.3	8.9	21.1	15.0
1990	0.5	-0.2	3.6	7.9	15.9	17.5	19.6	18.7	17.5	9.8		0.2	0.9	21.9	11.4

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Min	Max	Avg
1991	-2.4	-1.2	3.3	7.9	11.5	17.4	18.7	16.7	14.8	8.0	3.5	1.2	8.3	21.0	14.6
1992	-2.5	-2.9	0.4	5.3	10.1	15.4	16.9	16.4	12.8	6.5	3.3	-0.1	6.8	21.0	13.9
1993	-6.2	0.1	0.0	7.6	13.1	16.1	16.0	15.9	13.3	6.2	3.4	-0.2	7.1	22.3	14.7
1994	-2.8	-3.1	2.7	5.3	10.9	15.7	16.6	16.1	7.0	4.8	2.5	-2.2	6.1	20.8	13.5
1995	-6.2	-3.8	-1.0	4.5	9.9	14.8	15.9	14.6	10.6	5.8	0.2	-5.2	5.0	21.6	13.3
1996	-6.5	-3.7	0.2	5.6	7.8	12.9	13.5	13.5	11.6	4.7	-1.6	-5.5	4.4	22.0	13.2
1997	-7.4	-6.8	0.2	3.0	6.8	10.8	14.6	12.7	10.4	3.3	-1.8	-6.4	3.3	20.6	11.9
1998	-8.7	-5.8	-2.8	4.3	8.5	10.2	13.4	12.0	8.9	4.0	-1.9	-6.8	2.9	22.3	12.6
1999	-9.1	-3.5	0.2	6.3	10.5			0.0				-2.9		22.9	
2000	-6.5	-7.5	-1.8	7.5	14.5	12.9	12.3	12.1	12.5	8.5	2.1	-4.7	5.2	23.0	14.1
2001	-7.8	-5.8	-1.2	4.6	10.7	12.5	13.2	11.7	8.0	4.6	1.2	-4.8	3.9	23.2	13.6
2002	-7.6	-7.1	-0.3	3.9	9.5	14.3	16.2	15.3	10.8	8.4	1.6	-5.8	4.9	22.6	13.8
2003	-8.4	-4.5	1.3	8.0	10.5	17.1	17.1	17.6	14.6	6.9	0.6	-2.6	6.5	21.6	14.1
2004	-6.8	-3.6	4.8	8.4	11.3	18.5	19.4	18.3	16.1	9.0	6.4	-0.3	8.5	22.3	15.4
2005	-5.0	-1.7	5.6	9.0	12.0	18.0	19.1	18.1	16.3	10.7	4.4	-0.2	8.9	20.8	14.8
2006	-5.8	3.9	4.8	9.5	16.7	17.0	19.7	17.8	14.6	12.4	4.7	-3.9	9.3	21.8	15.5
2007	-6.2	-0.2	2.9	12.1	14.3	17.7	18.8	18.7	15.5	7.1	4.9	-1.8	8.7	21.5	15.1
2008	-4.8	-3.0	2.6	8.5	18.9	21.9	15.2	13.7	13.4	12.3	2.0	-3.3	8.1	20.9	14.5
2009	-4.7	-2.5	2.4	6.1	16.8	19.6	20.5	22.0	15.8	13.2	0.7	-5.2	8.7	20.4	14.6
2010	-9.5	-0.7	7.4	11.9	9.0	9.2	13.0	10.7	12.5	4.6	0.1	-7.7	5.0	17.3	11.1
2011	-9.7	-5.2	0.8	7.0	12.2	17.5	16.4	14.5	12.8	6.1	2.9	-4.0	5.9	19.8	12.9
2012	-11.6	-9.4	-0.9	6.9	7.6	16.0	19.3	14.7	7.7	3.6	0.0	-7.4	3.9	19.5	11.7

Table A-6: Annual Maximum and Mean Observed Temperature at Kohat, KP (in °C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min	Avg
TXTX = MONTHLY MEAN MAX TEMP. (°C)							[NA Means data not available]								
1955	18.7	23.6	25.8	30.9	33.3	42.0	40.1	35.2	34.9	31.4	27.3	19.9	30.3	18.1	24.2
1956	19.2	22.3	22.3	30.9	41.8	39.5	34.5	34.7	36.6	29.8	25.6	20.3	29.8	17.4	23.6
1957	16.4	19.4	22.8	20.2	31.9	38.8	40.2	36.7	35.9	30.8	23.6	18.9	28.0	17.3	22.6
1958	19.3	15.3	25.1	33.2	35.6	41.3	38.4	36.3	35.3	31.7	26.0	19.3	29.7	16.3	23.0
1959	17.2	17.5	25.7	30.6	34.8	41.4	35.5	36.6	34.6	32.2	23.0	19.4	29.0	16.1	22.6
1960	17.9	24.7	21.3	27.7	36.1	41.4	37.8	37.5	35.7	32.3	24.9	21.1	29.9	17.5	23.7
1961	16.8	16.2	23.9	27.6	36.6	40.1	37.3	36.4	35.3	30.2	22.2	18.6	28.4	17.1	22.7
1962	18.1	19.1	23.9	29.3	35.3	40.0	38.7	36.6	33.8		23.9	18.0	28.8	17.1	23.0
1963	19.3	22.3	22.4	27.8	32.2	41.7	39.8	37.3	35.6	32.4	24.1	20.1	29.6	17.2	23.4
1964	14.3	19.2	25.4	29.4	32.8	38.7	37.2	37.3	35.2	32.2	25.1	18.1	28.7	16.8	22.8
1965	18.5	17.4	23.1	24.3	32.8	39.7	37.7	36.3	36.4	32.1	25.4	19.7	28.6	16.8	22.7
1966	21.0	20.7	22.6	26.6	35.2	39.9	37.8	37.3	33.9	29.0	25.4	19.7	29.1	16.9	23.0
1967	18.2	20.4	22.7	27.4	33.9	40.4	38.2	35.2	35.7	29.1	22.8	17.3	28.4	16.8	22.6
1968	15.3	16.4	23.7	29.8	31.7	40.6	38.4	35.0	37.1	29.0	24.3	18.8	28.3	17.2	22.8
1969	18.3	18.3	29.2	29.3	35.8	40.9	38.6	36.4	35.3	30.9	21.4	21.8	29.7	17.8	23.8
1970	17.8	20.3	22.6	33.3	38.2	40.4	37.8	35.8	34.4	32.5	25.8	20.9	30.0	17.8	23.9
1971	18.0	20.3	26.6	32.6	36.6	39.0	37.1	35.3	34.8	32.3	26.3	21.7	30.1	17.2	23.6
1972	18.1	16.6	24.3	29.1	34.8	40.5	39.2	37.3	35.4	30.7	26.1	18.5	29.2	17.2	23.2
1973	16.2	19.8	22.4	30.9	36.1	41.3	36.1	34.4	33.9	30.3	25.7	19.2	28.9	17.2	23.0
1974	17.3	16.5	26.6	32.1	35.1	38.9	38.1	37.2	34.8	31.1	25.3	16.4	29.1	16.8	23.0
1975	16.8	17.0	22.0	28.9	35.3	39.1	35.7	34.4	34.0	32.9	24.7	20.1	28.4	16.7	22.5
1976	18.2	17.8	21.8	28.5	36.2	39.2	37.3	32.2	33.6	30.5	26.3	19.6	28.4	17.1	22.8
1977	16.4	21.5	28.7	29.6	33.1	38.4	36.6	35.2	34.7	30.9	25.6	19.4	29.2	17.5	23.3
1978	16.0	19.1	20.9	30.4	39.6	40.7	33.6	33.8	35.1	32.1	23.2	21.8	28.9	17.2	23.0
1979	17.9	18.8	22.0	32.4	32.5	40.0	37.4	34.3	34.4	31.7	24.6	19.7	28.8	17.4	23.1
1980	16.8	19.0	20.7	32.2	38.2	39.6	37.0	36.3	34.2	31.1	23.2	19.3	29.0	17.3	23.1
1981	17.1	19.9	22.2	31.2	36.9	40.5	35.8	34.5	34.4	28.5	22.7	19.1	28.6	16.7	22.7
1982	17.4	17.3	19.7	29.0	33.4	38.9	38.5	34.7	33.9	29.1	22.6	16.7	27.6	16.6	22.1
1983	15.8	18.7	20.5	25.0	32.9	37.4	36.5	34.6	33.9	28.4	25.2	18.2	27.3	16.9	22.1
1984	17.6	17.2	26.3	28.9	38.6	42.3	34.8	33.8	32.4	30.5	23.1	18.0	28.6	17.4	23.0
1985	16.9	22.6	27.3	31.2	35.8	40.8	37.0	36.6	37.0	30.8	24.8	19.4	30.0	17.3	23.7
1986	18.3	19.7	21.7	30.1	35.8	40.2	38.1	36.7	36.1	27.6	24.9	19.3	29.0	17.2	23.1
1987	21.6	21.7	23.2	32.7	32.7	39.4	40.2	39.0	37.7	31.3	28.2	22.6	30.9	17.5	24.2
1988	20.1	22.1	23.2	32.7	38.9	39.6	35.6	35.8	36.3	32.1	26.7	20.3	30.3	17.3	23.8
1989	17.5	19.3	23.3	30.8	37.2	40.7	38.9	35.8	36.1	32.9	25.8	19.3	29.8	17.2	23.5
1990	20.0	18.9	23.0	28.6	39.2	41.5	39.2	36.0	35.4	30.0	25.7	18.5	29.7	16.9	23.3
1991	16.7	18.3	23.1	26.9	32.8	39.9	39.9	37.5	35.1	31.4	25.7	20.8	29.0	16.0	22.5
1992	16.8	19.4	22.5	28.0	33.2	39.1	37.3	37.2	34.4	31.6	24.7	20.1	28.7	15.9	22.3
1993	16.4	22.3	21.7	31.7	38.2	40.7	37.4	38.9	35.9	32.7	25.8	23.0	30.4	15.8	23.1
1994	18.8	18.0	26.7	29.3	37.4	43.9	37.8	37.0	34.1	29.8	24.4	17.0	29.5	15.9	22.7
1995	18.1	21.3	23.9	26.7	37.7	42.8	39.4	36.3	35.2	30.8	26.7	17.9	29.7	16.6	23.2
1996	17.6	21.3	24.7	32.5	35.4	40.0	40.0	36.8	36.2	30.7	25.5	20.8	30.1	16.5	23.3
1997	18.1	21.8	24.4	27.6	33.5	38.9	38.3	35.9	35.5	26.6	23.4	17.8	28.5	16.4	22.5
1998	17.7	19.6	23.5	32.0	37.2	40.9	39.3	38.4	35.5	32.3	26.7	22.6	30.5	17.0	23.8
1999	17.6	21.5	25.4	34.4	38.9	41.8	39.2	37.6	36.6	33.1	25.4	23.3	31.2	17.1	24.1
2000	18.5	19.8	25.3	34.9	41.3	41.4	38.3	37.8	36.1	33.8	26.7	22.3	31.4	17.2	24.3
2001	19.4	23.3	27.9	31.4	40.6	39.3	37.1	37.1	35.5	32.8	26.5	21.6	31.0	17.7	24.4
2002	19.8	19.6	27.0	32.8	39.4	40.6	41.4	36.2	33.5	31.7	26.3	20.6	30.7	17.0	23.9
2003	19.1	18.9	23.8	30.6	35.6	40.7	36.9	35.7	34.4	32.2	24.9	20.5	29.4	17.2	23.3
2004	17.7	21.7	30.1	33.7	37.6	38.8	38.8	36.7	36.3	29.0	26.0	20.4	30.6	16.7	23.6

2005	15.4	15.0	23.0	30.6	32.5	41.3	36.7	37.3	35.8	32.2	26.1	21.5	29.0	16.3	22.6
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Max**	**Min**	**Avg**
2006	17.9	24.7	25.1	33.2	41.1	40.6	38.3	35.1	35.3	32.3	24.7	19.4	30.6	16.9	23.8
2007	20.1	18.9	23.4	34.6	37.6	40.0	37.1	37.9	35.4	33.2	27.2	20.5	30.5	16.9	23.7
2008	15.7	20.1	30.3	29.5	37.5	39.1	37.7	35.5	35.1	33.4	27.5	22.4	30.3	17.4	23.9
2009	19.7	21.3	25.9	29.7	38.5	40.1	39.1	38.7	37.0	33.1	-	22.1	31.4	17.6	24.5
2010	21.1	20.3	30.4	35.5	38.9	39.4	37.6	34.1	33.9	32.6	27.2	20.2	30.9	17.1	24.0
2011	17.0	18.0	26.5	29.0	39.8	38.8	36.5	35.0	33.1	31.0	25.5	21.4	29.3	16.7	23.0
2012	18.4	17.9	23.6	30.0	-	41.1	39.6	36.5	33.5	30.5	24.9	20.2	28.7	16.6	22.7

Table A-7: Annual Precipitation Record of Bannu, PK (in mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1862	0.0	0.0	0.0	63.5	0.0	0.0	20.3	58.4	27.9	66.0	25.4	0.0	261.6
1863	33.0	0.0	17.8	5.1	0.0	124.5	134.6	271.8	0.0	0.0	7.6	17.8	612.1
1864	10.2	0.0	12.7	106.7	48.3	12.7	0.0	76.2	35.6	0.0	0.0	27.9	330.2
1865	12.7	68.6	20.3	15.2	2.5	7.6	43.2	58.4	45.7	0.0	15.2	27.9	317.5
1866	0.0	68.6	55.9	0.0	5.1	0.0	10.2	142.2	33.0	0.0	0.0	0.0	315.0
1867	5.1	30.5	33.0	63.5	40.6	0.0	27.9	185.4	0.0	0.0	0.0	0.0	386.1
1868	27.9	35.6	134.6	127.0	10.2	17.8	30.5	20.3	20.3	0.0	0.0	33.0	457.2
1869	27.9	22.9	33.0	0.0	0.0	7.6	99.1	33.0	17.8	0.0	0.0	5.1	246.4
1870	0.0	0.0	27.9	5.1	0.0	5.1	38.1	78.7	0.0	0.0	0.0	0.0	154.9
1871	0.0	66.0	0.0	7.6	0.0	124.5	22.9	0.0	0.0	0.0	0.0	0.0	221.0
1872	17.8	20.3	17.8	66.0	27.9	0.0	0.0	0.0	7.6	7.6	0.0	0.0	165.1
1873	43.2	10.2	17.8	0.0	43.2	0.0	38.1	86.4	0.0	0.0	0.0	0.0	238.8
1874	53.3	10.2	43.2	25.4	0.0	17.8	83.8	259.1	0.0	0.0	0.0	0.0	492.8
1875	0.0	76.2	30.5	0.0	5.1	10.2	86.4	58.4	99.1	2.5	12.7	30.5	411.5
1876	15.2	15.2	76.2	10.2	7.6	25.4	68.6	53.3	20.3	7.6	5.1	5.1	309.9
1877	48.3	43.2	10.2	76.2	58.4	63.5	17.8	25.4	2.5	2.5	73.7	53.3	475.0
1878	33.0	45.7	5.1	83.8	91.4	15.2	12.7	91.4	15.2	0.0	0.0	0.0	393.7
1879	0.0	5.1	149.9	0.0	45.7	25.4	22.9	119.4	0.0	0.0	0.0	2.5	370.8
1880	0.0	5.1	0.0	25.4	7.6	38.1	109.2	5.1	78.7	0.0	0.0	17.8	287.0
1881	0.0	0.0	0.0	76.2	0.0	66.0	45.7	53.3	35.6	0.0	0.0	0.0	276.9
1882	0.0	0.0	17.8	30.5	7.6	30.5	121.9	25.4	2.5	0.0	0.0	0.0	236.2
1883	17.8	0.0	15.2	5.1	2.5	25.4	88.9	35.6	5.1	0.0	5.1	0.0	200.7
1884	58.4	10.2	15.2	5.1	0.0	27.9	58.4	0.0	52.1	17.8	0.0	0.0	245.1
1885	66.0	0.3	53.3	50.8	63.5	2.5	2.5	91.4	0.0	7.6	0.0	0.0	338.1
1886	58.4	22.9	114.3	20.3	38.1	0.0	86.4	55.9	0.0	0.0	12.7	2.5	411.5
1887	10.2	0.0	20.3	30.5	0.0	7.6	109.2	71.6	1.0	0.0	0.0	0.0	250.4
1888	20.3	19.1	11.4	0.0	1.3	2.5	63.8	41.1	0.0	17.0	17.8	0.0	194.3
1889	27.9	12.7	10.2	20.3	12.7	43.2	38.1	53.3	0.0	0.0	0.0	0.0	218.4
1890	25.4	3.3	78.2	57.4	0.0	8.4	47.2	72.4	0.0	0.0	68.8	10.7	371.9
1891	50.8	34.3	26.4	0.0	36.8	6.6	58.2	29.5	8.9	0.0	0.0	0.0	251.5
1892	0.0	8.4	5.3	0.0	0.0	16.5	210.6	91.4	5.3	4.3	0.0	3.6	345.4
1893	31.5	16.0	25.7	21.8	48.0	55.1	145.8	6.1	46.5	0.0	0.0	22.9	419.4
1894	14.0	8.4	77.5	46.7	0.0	8.9	150.6	33.0	14.2	0.0	1.0	7.1	361.4
1895	1.8	2.3	83.8	24.4	0.0	49.8	74.9	35.6	3.8	0.0	0.0	1.5	277.9
1896	28.7	24.4	23.9	3.6	6.1	4.1	41.7	80.8	12.4	0.0	20.1	0.0	245.6
1897	48.8	27.9	51.8	84.1	12.4	5.3	90.9	155.7	15.2	0.0	0.0	21.6	513.8
1898	1.0	61.0	29.7	2.8	20.1	1.8	170.9	0.0	8.4	0.0	0.0	1.8	297.4
1899	0.0	36.1	77.0	6.1	2.5	19.8	78.0	10.4	0.0	0.0	2.5	2.5	235.0
1900	26.9	18.0	35.8	17.0	53.8	10.9	31.8	11.9	83.3	0.0	4.8	17.3	311.7
				Not on Record									
1944	16.8	114.6	16.0	32.5	10.4	1.3	82.6	74.2	52.6	1.0	0.0	0.0	402.0
1945	29.2	0.0	10.4	37.1	13.5	42.7	37.3	31.0	13.7	3.1	0.3	0.5	218.8
1946	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1947	7.6	33.3	70.9	0.0	1.8	0.0	0.0	32.5	0.0	0.0	0.0	17.3	163.4
1948	19.1	38.1	25.7	25.7	0.0	0.0	108.0	134.1	0.0	0.0	0.0	21.1	371.8
1949	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1950	46.5	11.7	30.2	120.9	16.8	1.5	5.6	84.8	5.8	0.0	0.0	0.0	323.8
1951	3.8	9.9	51.1	34.0	25.2	0.0	30.5	4.8	0.0	0.0	11.4	-1.0	169.7
1952	-1.0	59.9	26.2	20.3	6.9	66.0	44.5	29.7	2.3	0.0	0.8	16.2	271.8
1953	45.0	38.1	4.6	7.6	10.7	16.3	66.0	91.4	67.3	0.0	1.3	7.6	355.9
1954	67.3	91.4	38.6	25.7	9.4	0.0	19.8	25.4	24.1	2.5	2.5	0.0	306.7
1955	0.0	0.0	21.6	10.9	18.3	21.1	74.2	92.7	4.3	0.0	0.0	23.4	266.5

1956	8.4	13.2	211.6	82.6	3.3	2.0	187.7	110.2	0.0	28.2	-1.0	0.0	646.2
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1957	58.4	0.0	46.0	58.9	16.8	5.6	82.0	75.2	5.6	2.3	37.1	16.3	404.2
1958	10.9	6.4	70.6	25.9	2.5	7.1	32.0	81.3	32.0	-1.0	0.0	61.5	329.2
1959	39.9	42.9	52.8	64.5	24.9	34.0	210.3	14.0	54.4	21.1	67.1	21.6	647.5
1960	8.4	35.6	93.7	121.7	5.8	1.5	116.8	32.5	35.8	0.0	0.0	29.5	481.3
1961	37.1	5.3	12.7	68.3	6.6	2.0	140.5	19.3	3.8	0.0	3.6	-1.0	298.2
1962	1.3	28.2	23.6	10.2	3.8	8.6	10.4	40.1	15.8	0.0	17.3	11.9	171.2
1963	0.0	19.8	37.1	77.5	71.6	0.0	50.9	14.5	43.2	0.0	5.1	4.1	323.8
1964	72.5	14.0	43.6	46.2	32.5	40.0	117.6	94.8	91.4	15.2	1.3	25.1	594.2
1965	71.0	120.5	66.4	208.4	136.4	43.2	99.6	115.7	36.9	13.4	23.6	26.9	962.0
1966	0.2	101.7	90.3	98.0	38.5	17.0	30.0	47.1	28.7	45.1	0.0	0.6	497.2
1967	0.0	32.8	108.5	88.7	10.2	1.3	8.6	35.6	28.6	28.9	25.4	110.5	479.1
1968	7.0	14.7	32.5	47.2	17.5	0.0	63.5	15.2	0.0	15.8	0.0	4.6	218.0
1969	8.2	43.1	51.2	47.2	39.6	10.0	68.7	41.9	25.3	56.7	7.0	0.0	398.9
1970	23.6	40.9	53.3	23.3	16.2	23.9	63.2	78.3	36.3	6.2	0.0	11.2	376.4
1971	5.0	35.4	21.4	50.2	21.6	30.1	122.5	60.5	28.7	1.8	1.2	1.2	379.6
1972	73.4	54.4	59.5	81.2	47.6	35.1	45.0	104.8	36.3	16.1	11.1	50.4	614.9
1973	20.1	71.3	78.0	43.4	37.6	16.7	196.5	190.7	62.5	6.3	0.0	7.5	730.6
1974	15.6	55.7	29.9	56.4	45.9	25.2	60.8	63.6	71.6	0.0	0.0	34.3	459.0
1975	10.0	51.1	80.6	73.2	44.5	27.2	139.4	95.3	43.9	1.3	0.3	12.7	579.5
1976	18.1	81.3	64.0	72.4	49.1	27.4	148.1	303.1	75.4	26.9	0.6	3.0	869.4
1977	74.0	8.5	16.6	92.9	42.2	21.8	82.1	96.3	53.6	38.4	20.7	11.2	558.3
1978	30.1	20.5	140.7	47.5	9.1	36.3	125.3	102.2	62.5	9.0	13.5	2.2	598.9
1979	45.5	54.8	90.5	39.0	69.5	40.9	71.2	199.5	55.3	16.7	23.9	17.3	724.1
1980	38.3	67.6	109.7	22.7	20.2	47.2	116.8	88.8	56.7	35.1	17.4	11.1	631.6
1981	32.5	45.1	192.0	47.0	39.4	3.9	146.8	165.5	30.8	38.1	3.9	7.8	752.8
1982	37.5	55.7	162.8	54.4	74.9	22.9	53.4	121.6	36.0	44.2	43.5	31.0	737.9
1983	26.3	37.1	98.1	116.3	53.1	15.9	23.6	148.3	91.2	14.9	0.9	5.7	631.4
1984	-1.0	0.0	61.3	16.7	0.0	0.0	15.3	80.4	60.9	1.4	-1.0	7.5	241.5
1985	2.5	1.5	28.3	63.4	14.2	-1.0	10.3	40.2	1.4	18.4	0.0	25.0	204.2
1986	-1.0	39.6	79.6	8.8	16.3	3.8	76.7	17.0	-1.0	0.0	15.0	4.5	259.3
1987	0.0	40.6	114.5	-1.0	30.7	6.8	0.0	37.0	7.9	0.0	0.0	0.0	236.5
1988	14.6	0.0	128.6	0.0	0.0	15.5	60.5	27.5	5.8	2.8	1.2	42.8	299.3
1989	14.7	2.2	43.0	8.5	5.5	18.8	68.3	83.2	9.6	5.3	0.5	14.0	273.6
1990	16.2	82.8	32.5	46.6	0.6	24.0	38.2	109.9	26.3	0.0	-1.0	22.9	399.0
1991	7.1	25.0	95.2	86.3	82.4	0.2	97.7	83.7	3.3	0.0	0.0	4.5	485.4
1992	63.1	43.5	74.2	98.4	40.9	1.2	6.8	60.1	33.4	0.0	1.9	23.9	447.4
1993	11.5	24.0	136.0	61.6	56.3	0.3	215.3	19.2	65.7	-1.0	-1.0	0.0	587.9
1994	6.6	46.3	29.5	17.0	6.6	16.0	104.3	96.8	12.0	19.2	0.0	33.4	387.7
1995	5.0	13.3	86.7	71.4	-1.0	0.0	33.6	58.1	26.4	20.0	-1.0	2.2	314.7
1996	8.0	20.2	59.7	5.9	34.6	38.7	32.2	112.0	-1.0	21.6	5.8	0.0	337.7
1997	20.2	19.7	67.3	157.9	61.6	70.5	72.7	102.7	34.9	125.2	11.6	30.1	774.4
1998	41.0	144.2	92.0	100.0	47.4	41.2	111.8	90.2	61.6	32.3	1.5	0.0	763.2
1999	75.3	65.0	52.4	0.0	-1.0	37.0	32.7	155.2	98.6	6.7	2.3	0.0	524.2
2000	14.0	1.5	2.0	5.0	0.0	30.0	26.2	42.9	21.8	2.2	0.0	6.0	151.6
2001	0.0	-1.0	5.1	0.0	1.0	65.0	30.2	35.8	14.0	0.0	0.0	0.2	150.3
2002	0.0	29.7	11.2	18.7	26.0	1.2	79.4	7.6	3.0	11.5	5.0	10.4	203.7
2003	15.0	31.7	47.9	32.0	12.2	0.0	17.7	60.6	15.6	0.0	2.6	4.6	239.9
2004	22.9	18.8	0.0	3.2	12.5	-1.0	71.7	71.6	57.7	9.2	-1.0	22.2	287.8
2005	84.3	63.7	63.4	21.3	20.7	2.4	88.4	98.0	77.6	0.0	3.0	0.0	522.8
2006	21.0	8.8	21.9	3.7	2.5	5.5	51.0	126.9	19.0	40.4	13.5	53.4	367.6
2007	-1.0	150.4	46.3	18.3	0.1	127.8	25.8	10.4	2.2	0.0	13.0	0.7	394.0
2008	22.4	11.3	19.5	70.0	11.0	63.3	19.8	48.9	22.7	11.8	0.0	7.3	308.0
2009	11.7	28.2	72.6	78.1	10.9	0.6	8.0	54.3	32.3	1.5	-1.0	-1.0	296.2
2010	14.2	18.6	15.0	4.1	2.3	14.0	312.6	179.6	12.0	0.0	0.0	11.0	583.4

2011	0.0	46.7	16.0	41.3	-1.0	19.9	108.6	55.9	21.1	41.4	5.5	0.0	355.4
2012	19.4	2.0	-1.0	31.8	12.4	-1.0	30.4	99.0	44.8	3.2	4.0	43.0	288.0

Table A-8: Annual Precipitation Record of Parachinar, Kurram Agency, FATA (in mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1948	13.5	63.5	113.8	74.4	32.8	48.8	41.9	86.4	10.2	3.0	0.0	117.3	1303.0
1949	86.4	83.6	111.8	56.9	73.7	21.1	103.1	106.9	38.4	0.3	0.0	15.5	1463.5
1950	143.3	43.7	69.6	111.0	75.9	29.2	137.9	124.2	23.9	0.0	7.4	0.0	1536.2
1951	59.9	36.8	161.8	89.9	108.5	14.7	91.2	121.4	13.2	40.9	23.4	8.4	1495.8
1952	25.9	114.8	150.4	82.6	49.5	27.2	95.5	88.9	38.1			52.8	1409.4
1953	65.3	74.2	35.1	69.3	67.8	49.5	128.5	102.4	44.7	22.6	9.7	14.7	1001.8
1954		115.8		70.4				66.8	25.4	35.8	3.8		1279.1
1955	16.0	14.0	197.4	40.6	150.9	23.9	137.2	218.7	127.0	2.5	0.0	33.0	2334.8
1956	94.0	8.9	199.4	283.2	0.0	99.1	360.7	154.9	72.4	101.1	0.0	0.0	2095.5
1957	50.8	167.4	245.4	258.3									1708.4
1958	22.9	53.3	215.9	104.1	66.3	36.8	102.9	176.5	110.5	22.6	1.3	73.4	2070.4
1959	72.6	90.2		182.4	145.0	53.1		132.1	171.5	7.9	166.4	62.7	2858.5
1960	156.2	135.9	360.4	272.5	92.7	54.6	209.6	157.5	106.7	101.6	44.5	82.6	4760.2
1961	120.4	217.2	1686.6	281.7	93.7	51.8	289.6	95.3	86.6	30.5	23.6	8.6	4040.9
1962	4.8	41.7	118.9	151.6	143.5	67.1	114.3	124.5	223.5		7.6	57.9	1200.2
1963	0.0	28.4						73.7			42.7		
1964	128.5												
1965													
1966				**Not on Record**									
1967													
1968													
1969													
1970	49.0	55.0	70.0	48.0	28.0	31.0	118.0	73.0	53.0	15.0	0.0	29.0	**569.0**
1971	3.0	66.0	32.0	71.0	39.0	43.0	193.0	51.0	52.0	2.0	1.0	2.0	**555.0**
1972	157.0	70.0	130.0	102.0	114.0	72.0	38.0	57.0	64.0	11.0	16.0	80.0	**911.0**
1973	47.0	136.0	98.0	115.0	44.0	32.0	337.0	48.0	51.0	11.0	0.0	1.0	**920.0**
1974	30.0	97.0	55.0	86.0	87.0	58.0	96.0	102.0	76.0	0.0	0.0	50.0	**737.0**
1975	21.0	84.0	121.0	142.0	60.0	49.0	82.0	79.0	77.0	4.0	1.0	30.0	**750.0**
1976	39.0	122.0	112.0	122.0	81.0	17.0	259.0	72.0	87.0	27.0	2.0	9.0	**949.0**
1977	129.0	9.0	41.0	176.0	55.0	64.0	64.0	94.0	65.0	43.0	50.0	22.0	**812.0**
1978	52.0	56.0	185.0	118.0	23.0	88.0	95.0	184.0	95.0	23.0	33.0	2.0	**954.0**
1979	39.0	107.0	132.0	98.0	136.0	69.0	67.0	121.0	79.0	8.0	21.0	29.0	**906.0**
1980	44.0	94.0	175.0	50.0	58.0	47.0	170.0	167.0	20.0	70.0	27.0	29.0	**951.0**
1981	49.0	76.0	129.0	53.0	45.0	8.0	106.0	37.0	68.0	45.0	7.0	25.0	**648.0**
1982	19.0	127.0	113.0	67.0	114.0	21.0	11.0	196.0	36.0	106.0	79.0	58.0	**947.0**
1983	42.0	36.0	168.0	61.0	107.0	18.0	5.0	115.0	69.0	6.0	0.0	14.0	**641.0**
1984	4.0	44.0	85.0	97.0	8.0	80.0	167.0	146.0	43.0	0.0	28.0	42.0	**744.0**
1985	49.0	16.0	31.0	108.0	58.0	8.0	80.0	88.0	15.0	25.0	9.0	46.0	**533.0**
1986	11.0	61.0	205.0	93.0	108.0	37.0	77.0	113.0	17.0	13.0	48.0	43.0	**826.0**
1987	2.0	45.0	260.0	48.0	118.0	39.0	29.0	65.0	15.0	11.0	0.0	2.0	**634.0**
1988	59.0	40.0	212.0	28.0	7.0	86.0	58.0	110.0	58.0	11.0	4.0	79.0	**752.0**
1989	48.0	76.0	172.0	34.0	31.0	20.0	104.0	84.0	52.0	13.0	17.0	38.0	**689.0**
1990	56.0	105.0	88.0	84.0	23.0	42.0	104.0	119.0	64.0	19.0	7.0	74.0	**785.0**
1991	63.0	112.0	185.0	114.0	167.0	27.0	66.0	38.0	55.0	8.0	13.0	7.0	**855.0**
1992	120.0	74.0	114.0	197.0	116.0	44.0	89.0	134.0	78.0	64.0	15.0	38.0	**1083.0**
1993	62.0	32.0	390.0	95.0	66.0	58.0	74.0	82.0	35.0	6.0	11.0	1.0	**912.0**
1994	40.0	79.0	113.0	141.0	85.0	49.0	110.0	74.0	77.0	51.0	13.0	48.0	**880.0**
1995	3.0	84.0	97.0	170.0	43.0	51.0	106.0	110.0	26.0	54.0	3.0	14.0	**761.0**
1996	34.0	79.0	209.0	54.0	192.0	54.0	46.0	142.0	36.0	73.0	18.0	7.0	**944.0**
1997	28.0	37.0	174.0	187.0	76.0	137.0	54.0	91.0	48.0	143.0	12.0	42.0	**1029.0**
1998	75.0	179.0	130.0	167.0	86.0	55.0	117.0	60.0	88.0	28.0	5.0	0.0	**990.0**

1999	66.0	115.0	78.0	10.0	45.0	37.0	111.0	77.0	84.0	9.0	35.0	0.0	**667.0**
2000	41.0	39.0	62.0	10.0	15.0	72.0	68.0	71.0	34.0	71.0	23.0	24.0	**530.0**
2001	32.5	37.3	96.6	47.1	62.5	92.4	156.5	66.0	58.2	19.0	9.4	7.0	**684.5**
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
2002	49.9	110.1	95.7	73.2	28.0	58.2	26.7	111.4	31.2	6.9	61.5	27.2	**680.0**
2003	18.6	138.4	117.2	86.4	14.5	19.2	73.9	120.3	116.2	18.0	29.8	26.2	**778.7**
2004	77.2	55.4	24.6	89.7	61.1	94.9	85.4	194.7	28.0	22.8	9.8	63.4	**807.0**
2005	140.6	149.8	90.8	36.0	171.3	38.0	82.6	102.3	34.9	27.4	12.8	0.0	**886.5**
2006	81.8	68.7	124.3	72.6	31.9	59.1	120.2	198.3	100.7	54.0	98.2	128.2	**1138.0**
2007	9.5	177.4	236.7	30.0	55.2	80.4	117.4	158.2	44.5	12.5	0.0	48.9	**970.7**
2008	82.7	36.5	14.0	207.3	84.1	84.9	95.3	199.3	99.2	36.0	25.5	58.0	**1022.8**
2009	260.6	190.2	186.9	195.0	89.1	87.7	140.0	101.7	243.2	17.0	23.0	26.2	**1560.6**
2010	28.8	197.3	100.7	103.9	98.5	134.5	287.5	345.0	148.1	45.0	18.0	10.6	**1517.9**
2011	28.7	100.7	191.6	217.5	145.5	71.1	175.7	304.8	214.6	170.0	141.0	0.0	**1761.2**
2012	111.0	233.8	242.9	424.8	118.7	35.4	153.6	230.6	151.6	75.6	46.8	96.4	**1921.2**

Table A-9: Historical Annual Precipitation Record of Kohat, KP (in mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1853			4.5										
1854							Not on Record						
1855							13.7	4.9	0.6	6.1	0.0	0.0	
1856			1.1	3.7	0.3	1.8	10.8	3.6	3.3	0.6	0.0	0.0	
1857	0.0	1.0	0.3	1.0	0.7	0.1	2.1						
1858													
1859													
1860							**Not on Record**						
1861													
1862													
1863	0.0	0.0	0.0	58.4	15.2	15.2	17.8	22.9	33.0	27.9	30.5	0.0	**221.0**
1864	0.0	0.0	0.0	109.2	12.7	50.8	0.0	20.3	20.3	0.0	0.0	5.1	**218.4**
1865	20.3	88.9	88.9	63.5	10.2	0.0	78.7	58.4	71.1	22.9	0.0	58.4	**561.3**
1866	0.0	22.9	30.5	12.7	149.9	2.5	40.6	58.4	86.4	0.0	0.0	0.0	**403.9**
1867	0.0	35.6	20.3	76.2	22.9	0.0	0.0	48.3	2.5	0.0	0.0	17.8	**223.5**
1868	17.8	86.4	73.7	86.4	10.2	17.8	30.5	5.1	22.9	2.5	0.0	20.3	**373.4**
1869	20.3	25.4	261.6	45.7	5.1	2.5	76.2	88.9	152.4	27.9	0.0	0.0	**706.1**
1870	20.3	0.0	53.3	12.7	0.0	22.9	160.0	66.0	35.6	0.0	0.0	0.0	**370.8**
1871	2.5	149.9	17.8	15.2	40.6	101.6	83.8	63.5	22.9	0.0	0.0	15.2	**513.1**
1872	55.9	30.5	0.0	53.3	88.9	0.0	264.2	0.0	12.7	20.3	5.1	0.0	**530.9**
1873	12.7	15.2	27.9	2.5	50.8	0.0	55.9	68.6	50.8	7.6	0.0	15.2	**307.3**
1874	152.4	5.1	27.9	7.6	0.0	25.4	198.1	261.6	15.2	0.0	0.0	0.0	**693.4**
1875	0.0	76.2	35.6	0.0	86.4	0.0	99.1	119.4	231.1	33.0	30.5	10.2	**721.4**
1876	50.8	15.2	94.0	38.1	5.1	30.5	121.9	53.3	30.5	76.2	53.3	22.9	**591.8**
1877	45.7	83.8	50.8	12.7	66.0	86.4	17.8	25.4	20.3	48.3	330.2	104.1	**891.5**
1878	48.3	40.6	2.5	50.8	55.9	2.5	177.8	223.5	2.5	66.0	0.0	0.0	**670.6**
1879	0.0	10.2	58.4	0.0	0.0	20.3	61.0	71.1	38.1	0.0	0.0	15.2	**274.3**
1880	0.0	12.7	0.0	0.0	58.4	53.3	55.9	40.6	48.3	0.0	0.0	17.8	**287.0**
1881	5.1	12.7	78.7	99.1	20.3	40.6	45.7	50.8	15.2	20.3	0.0	0.0	**388.6**
1882	33.0	1.3	27.9	55.9	30.5	27.9	259.1	38.1	40.6	0.0	0.0	0.0	**514.4**
1883	30.5	5.1	38.1	33.0	2.5	10.2	144.8	68.6	0.0	15.2	45.7	0.0	**393.7**
1884	48.3	33.0	55.9	10.2	10.2	33.0	84.3	65.8	54.9	19.8	8.4	0.0	**423.7**
1885	82.8	19.1	70.1	164.6	147.3	5.3	40.6	73.2	9.7	0.0	2.5	13.2	**628.4**
1886	70.4	41.7	98.0	45.7	66.5	13.7	27.7	45.0	27.9	0.0	6.1	6.4	**449.1**
1887	1.5	0.0	27.9	24.9	6.6	24.4	52.6	38.1	32.8	11.9	0.0	0.0	**220.7**
1888	18.3	29.0	17.8	20.8	0.0	4.6	14.2	52.8	0.0	6.9	50.8	0.0	**215.1**
1889	28.4	72.9	20.3	40.6	43.4	38.1	79.8	96.0	21.3	0.0	0.0	0.0	**440.9**
1890	19.8	7.4	58.7	56.4	41.9	23.9	19.8	127.3	0.0	5.3	66.0	38.9	**465.3**
1891	118.4	70.4	95.0	27.4	41.1	3.8	12.2	14.2	41.7	9.4	0.0	0.0	**433.6**
1892	0.0	3.0	18.3	0.0	19.8	4.6	95.3	380.7	0.0	20.6	0.0	2.5	**544.8**
1893	52.6	8.4	66.8	17.8	80.5	6.1	157.7	28.4	75.7	8.9	0.0	33.3	**536.2**
1894	23.4	24.1	39.6	15.5	8.1	74.9	231.4	42.7	33.5	0.0	0.0	4.8	**498.1**
1895	0.0	1.3	192.5	20.1	0.0	21.1	47.8	82.8	3.8	0.0	0.0	0.0	**369.3**
1896	29.5	46.5	32.8	0.0	8.6	36.3	63.0	51.1	48.3	9.4	21.8	0.0	**347.2**
1897	58.4	46.5	35.1	104.4	41.9	32.3	39.1	106.4	6.9	4.1	0.0	24.6	**499.6**
1898	2.5	97.8	39.6	0.0	51.8	10.9	57.9	72.4	32.3	0.0	0.0	15.5	**380.7**
1899	0.0	45.2	53.6	21.3	1.8	36.6	72.4	20.6	31.2	0.0	0.8	0.0	**283.5**
1900	68.6	38.4	74.9	49.0	37.6	14.5	64.8	104.1	27.2	0.3	1.0	24.9	**505.2**
							Not on Record						

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1955	0.0	0.0	76.7	3.0	38.9	7.6	49.0	392.7	73.9	5.1	0.0	10.4	**657.4**
1956	2.3	8.9	178.6	31.5	0.0	59.2	246.9	51.1	99.3	25.1	1.3	1.3	**705.4**
1957	50.8	0.8	112.8	216.2	52.1	9.4	45.7	76.5	40.6	37.8	53.1	26.7	**722.4**
1958	18.0	18.3	67.6	18.8	5.1	7.6	85.3	59.2	60.5	1.5	4.6	115.6	**462.0**
1959	69.9	95.3	33.0	65.3	31.8	2.3	79.0	46.2	110.0	41.4	71.6	15.2	**660.9**
1960	15.0	1.0	114.6	0.0	0.0	18.0	109.7	68.1	80.3	1.3	0.0	44.7	**452.6**
1961	110.0	26.2	16.5	94.7	28.2	46.7	73.7	68.3	1577.3	84.3	33.0	2.5	**2161.5**
1962	13.2	37.6	61.7	36.8	55.6	37.1	74.2	95.3	60.2		19.3	75.4	**566.4**
1963	0.0	38.9	130.0	114.3	64.5	9.1	25.1	28.2	50.8	57.9	23.4	32.8	**575.0**
1964	45.2	17.3	47.2	46.0	31.0	54.6	38.9	20.1	35.3	8.1	0.0	23.9	**367.6**
1965	21.1	76.7	48.5	201.2	80.8	28.7	56.1	46.7	38.6	13.0	28.2	5.1	**644.7**
1966	0.0	98.8	101.3	126.7	37.3	19.0	33.8	21.6	24.1	81.0	0.0	0.0	**543.6**
1967	0.0	50.5	239.5	38.6	18.0	15.2	119.9	92.5	11.9	61.0	22.1	154.7	**823.9**
1968	44.7	22.1	92.7	37.6	49.8	39.6	32.8	136.1	7.1	79.8	10.9	7.4	**560.6**
1969	0.0	52.8	38.1	36.1	43.7	18.3	59.7	58.9	30.0	46.0	0.0	0.0	**383.6**
1970	16.3	38.6	59.7	23.6	18.5	36.1	67.6	122.9	33.8	0.5	0.0	6.3	**423.9**
1971	4.8	29.5	21.1	84.1	18.0	38.1	106.2	55.9	19.8	3.6	0.3	2.5	**383.9**
1972	42.9	82.8	48.3	59.4	26.9	11.4	30.0	141.7	34.0	40.1	13.7	34.8	**566.0**
1973	7.4	66.0	115.3	14.0	66.3	6.6	115.3	308.1	109.2	9.1	0.0	15.2	**832.5**
1974	5.3	36.6	25.6	61.4	30.7	0.0	25.4	42.0	112.0	0.0	0.0	42.4	**381.4**
1975	4.9	59.0	88.4	65.2	73.7	14.5	134.0	116.8	21.1	0.0	0.0	3.3	**580.9**
1976	14.9	93.6	38.1	67.2	50.2	20.9	102.1	419.6	78.8	56.3	0.0	0.0	**941.7**
1977	56.3	14.2	8.0	70.3	65.6	4.9	81.9	103.5	91.1	70.0	12.8	13.5	**592.1**
1978	21.4	6.1	216.3	23.5	1.3	6.4	156.2	87.1	31.2	6.3	7.6	2.8	**566.2**
1979	41.3	41.9	34.4	14.5	69.8	8.7	94.0	356.2	14.8	13.2	17.7	11.2	**717.7**
1980	53.2	79.8	67.1	9.9	4.4	9.2	26.7	14.0	63.4	8.4	26.7	4.6	**367.4**
1981	29.7	35.4	364.9	36.8	21.2	0.8	100.8	249.9	19.9	30.2	5.8	0.0	**895.4**
1982	55.4	25.0	200.7	28.4	28.4	18.0	41.3	56.0	30.1	8.9	38.6	11.8	**542.6**
1983	36.3	46.9	91.5	195.2	42.9	14.0	19.5	146.8	36.5	42.8	3.0	1.0	**676.4**
1984	1.3	14.8	43.0	16.8	16.0	10.0	71.4	158.1	14.9	1.3	25.6	7.7	**380.9**
1985	34.5	1.5	31.7	51.2	29.0	24.2	17.7	76.9	5.1	5.8	10.5	48.8	**336.9**
1986	8.8	29.1	38.3	18.7	3.9	21.1	25.4	40.5	6.4	8.2	18.2	15.1	**233.7**
1987	0.0	23.5	64.1	5.2	39.2	36.3	67.0	57.0	23.0	7.0	0.0	1.0	**323.3**
1988	16.8	16.6	131.0	33.0	34.0	34.0	124.0	61.0	59.0	13.5	0.0	49.0	**571.9**
1989	16.3	8.0	42.1	10.0	9.2	19.2	61.0	90.0	52.0	1.0	2.0	30.0	**340.8**
1990	38.0	92.0	77.5	68.0	6.0	6.0	105.0	69.0	53.0	13.0	9.0	76.0	**612.5**
1991	20.0	77.0	125.0	128.2	117.0	35.0	51.0	55.0	17.4	7.0	-1.0	1.0	**633.6**
1992	68.0	59.0	113.0	102.0	113.0	19.0	44.0	231.0	83.0	18.0	9.0	14.0	**873.0**
1993	11.0	7.0	139.5	34.0	15.0	18.0	134.0	22.0	17.0	7.0	12.5	0.0	**417.0**
1994	5.0	46.0	52.0	60.0	35.0	7.0	92.0	20.0	48.0	32.0	12.0	57.0	**466.0**
1995	8.0	32.0	49.0	61.0	5.0	14.0	52.0	41.0	24.0	18.0	5.0	9.0	**318.0**
1996	35.0	43.0	60.0	17.0	31.0	50.0	34.0	107.0	9.0	55.0	1.0	-1.0	**442.0**
1997	7.0	18.0	19.0	129.0	92.0	24.0	88.0	102.0	31.0	100.0	9.0	42.0	**661.0**
1998	27.0	163.5	72.5	71.0	52.6	10.5	89.5	69.5	79.5	33.0	0.0	0.0	**668.6**
1999	122.0	27.0	67.0	4.0	30.5	14.0	84.0	66.0	29.0	8.0	24.0	0.0	**475.5**
2000	45.5	23.5	33.0	12.5	69.0	32.0	85.0	104.0	51.5	49.0	-1.0	12.0	**517.0**
2001	0.0	-1.0	36.5	64.5	19.6	66.2	98.0	71.5	61.5	29.0	-1.0	3.5	**450.3**
2002	1.6	56.0	34.0	21.5	8.2	85.0	13.5	241.0	63.0	53.0	2.0	45.0	**623.8**
2003	46.0	134.5	102.5	85.0	13.0	54.5	210.0	181.5	107.5	10.0	31.0	24.5	**1000.0**
2004	76.5	59.0	18.0	52.0	56.0	82.0	154.0	140.0	117.0	47.0	37.0	56.0	**894.5**
2005	133.0	143.0	115.0	15.0	65.0	13.0	42.0	44.0	119.0	10.0	0.0	4.0	**703.0**
2006	62.0	17.0	23.0	6.0	13.0	5.0	62.0	143.0	33.0	25.0	27.0	79.0	**495.0**
2007	0.0	196.0	82.5	31.0	55.0	89.5	29.0	18.0	84.0	-1.0	25.0	-1.0	**608.0**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2008	68.0	12.0	8.0	147.0	126.0	82.0	115.0	173.0	16.0	12.0	-1.0	34.0	**792.0**
2009	14.0	37.0	45.0	119.0	23.0	20.0	29.0	28.0	27.0	48.0	-.-	0.0	**390.0**
2010	6.0	64.0	14.0	21.0	26.0	47.0	357.0	237.0	36.0	3.0	0.0	8.0	**819.0**
2011	2.0	77.0	23.0	49.0	18.0	21.0	80.0	373.0	68.0	70.0	9.0	0.0	**790.0**
2012	1.0	5.0	3.0	39.0	-	7.0	38.0	83.0	74.0	19.0	2.0	44.0	**315.0**

Table A-10: Historical Annual Mean Temperature and Precipitation Record of Gardez, Afghanistan

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gardiz Meam Temperature (°C)												
1964		-4.50	4.70	9.30	15.00		21.40	22.50	16.50	8.10	1.60	-5.10
1965	-3.50	-4.50	2.60	7.30	13.90	19.30	21.00	19.60	15.90	12.30	4.80	-4.00
1966	-8.50	1.00	4.00	8.50	14.90	20.80	21.10	21.00	16.40	9.80	1.10	-2.70
1967	-13.50	-2.20	0.10	1.70	13.10	20.10	22.00	21.00	17.40	8.90	3.80	-3.50
1968	-9.20	-8.50	3.00	9.90	12.30	20.60	22.10	20.70	17.00	9.50	3.30	-5.80
1969	-7.90	-4.60	7.00	8.90	14.20	19.70	22.70	21.00	15.00	11.30	3.10	-0.40
1970	-3.10	-3.50	3.70	12.50	17.90	21.60	21.70	22.00	17.40	10.80	3.30	-2.60
1971	-4.30	-3.70	3.90	12.10	17.50	22.50	22.00	21.60	15.70	10.00	4.90	1.20
1972	-4.30	-12.00	0.30	9.40	14.00	19.50	21.10	19.30	15.90	9.50	5.30	-3.80
1973	-9.20	-3.00	3.40	10.90	15.90	22.60	22.00	21.80	17.90	10.40	4.30	-1.80
1974	-4.60	-8.30	5.60	11.10	15.10	19.90	22.40	21.40	16.70	8.70	2.90	-5.50
1975	-8.10	-8.10	0.20	9.20	15.30	19.80	21.60	21.20	17.50	10.60	2.40	-1.50
1976	-4.10	-4.30	-0.30	9.20	16.00	20.10	22.90	20.60	17.50	11.50	2.80	-2.10
1977	-6.80	-6.10	7.50	11.50	16.60	20.20	23.50	21.40	17.20	12.90	5.50	0.50
1978	-12.90	-9.90	-2.20	4.50	9.80	13.90	16.30	14.80	9.10	2.40	-0.70	-4.70
1979	-1.0	-0.5	2.3	12.8	12.8	21.0	23.1	29.9	16.5	11.9	4.1	-1.1
1980	-8.70	-3.90	1.90	11.90	16.30	21.30	27.50	21.00	16.10	11.70	6.10	1.10
1981	-7.10	-3.50	4.00	11.80	16.50	19.60	22.20	21.30	10.50	9.20	3.90	
1982	-4.20	-6.50	-0.10	10.60	14.60	20.40	21.80	21.40	15.20	10.80	3.60	-5.10
1983	-6.2	-5.2	-1.6	7.8	15.5							
1984												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Gardiz Precipitation (mm)												
1964		48.40	61.20	99.40	2.10	5.90	23.70	0.00	3.70	0.00	18.90	37.60
1965	73.80	88.90	82.00	148.50	47.40	0.00	9.80	0.60	4.20	0.00	15.90	18.60
1966	11.50	94.90	77.60	65.40	10.60	6.10	8.30	0.00	0.10	2.10	0.00	7.50
1967	5.70	117.90	83.40	149.90	11.00	4.00	23.70	0.00	0.00	18.70	32.10	24.70
1968	29.00	55.90	65.00	65.00	17.50	0.00	0.00	0.00	0.00	15.60	16.00	113.80
1969	24.80	49.90	35.80	46.70	28.70	0.00	5.80	6.20	0.00	12.30	13.80	9.00
1970	30.20	15.00	43.40	36.20	0.00	0.00	5.00	44.60	0.00	0.00	0.00	9.60
1971	6.90	87.50	72.40	17.00	5.40	0.00	6.20	13.00	0.00	0.00	1.90	11.80
1972	85.80	76.00	110.50	103.80	51.70	40.60	0.00	1.70	0.00	1.10	20.50	72.30
1973	31.80	96.00	47.70	54.80	6.60	0.00	80.30	13.70	0.00	0.00	6.10	5.50
1974	51.00	59.20	37.40	68.60	21.30	0.00	9.30	0.00	0.00	0.00	0.00	62.20
1975	22.60	96.70	94.80	49.30	15.20	0.40	8.50	13.90	0.00	0.00	7.30	23.50
1976	52.30	100.70	98.60	78.80	17.00	3.30	15.60	3.10	9.00	2.60	0.60	13.10
1977	83.00	9.20	2.30	54.80	16.10	0.00	8.30	7.60	0.00	0.00	28.80	42.30
1978	37.60	42.60	92.20	34.80	3.40	7.90	92.20	13.80	0.00	0.00	47.70	2.80
1979	18.60	55.50	98.00	45.20	18.90	0.70	25.00	22.50	0.00	0.00	1.90	23.60

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	33.20	16.50	57.90	3.10	0.00	7.30	0.30	0.00	0.00	14.70	9.20	19.30
1981	22.00	34.60	81.50	17.60	27.00	0.00	29.50	0.00	12.30	7.70	0.00	1.60
1982	31.50	80.40	72.40	8.00	18.10	0.00	0.00	2.50	0.00	19.30	66.70	43.00
1983	35.50	52.90	81.40	51.90	29.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	18.00
1984	2.9	21.5	39.6	24.9		0						

Table A-11: Future Temperature Projections of Project Area Using GCM Data (in mm).

Latitude	Longitude	Station Name	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060	2061-2070	2071-2080	2081-2090	2091-99
32.5	69		0.65	1.04	1.09	1.55	2.51	3.13	4.21	4.09	5.16	5.67
32.5	69.25		0.63	1.01	1.07	1.51	2.53	3.11	4.25	4.16	5.25	5.71
32.5	69.5		0.59	0.96	0.99	1.43	2.50	3.06	4.22	4.14	5.24	5.66
32.5	69.75		0.36	0.83	0.78	1.26	2.31	2.84	3.92	3.88	4.98	5.33
32.5	70		0.09	0.65	0.56	1.11	2.13	2.62	3.65	3.67	4.80	5.06
32.5	70.25		-0.02	0.60	0.44	1.05	2.06	2.55	3.64	3.67	4.84	5.08
32.5	70.5		-0.01	0.62	0.42	1.04	2.00	2.51	3.63	3.71	4.84	5.10
32.5	70.75		0.05	0.61	0.46	1.07	1.99	2.54	3.65	3.78	4.85	5.14
32.5	71		0.01	0.57	0.43	1.06	2.02	2.53	3.67	3.79	4.82	5.13
32.5	71.25		0.00	0.57	0.40	1.00	2.02	2.47	3.67	3.77	4.80	5.12
32.5	71.5	Mianwali	0.00	0.56	0.38	0.95	2.04	2.39	3.71	3.74	4.77	5.09
32.5	71.75		-0.06	0.53	0.30	0.93	2.06	2.35	3.73	3.69	4.72	5.02
32.5	72		-0.18	0.48	0.19	0.93	2.14	2.35	3.73	3.63	4.68	4.96
32.75	69		0.66	1.03	1.15	1.54	2.54	3.21	4.25	4.15	5.21	5.74
32.75	69.25		0.69	1.04	1.15	1.54	2.55	3.22	4.29	4.23	5.25	5.79
32.75	69.5		0.66	0.99	1.08	1.47	2.53	3.16	4.27	4.21	5.24	5.75
32.75	69.75		0.45	0.88	0.85	1.31	2.34	2.91	4.01	3.97	5.03	5.44
32.75	70		0.21	0.73	0.65	1.14	2.14	2.69	3.76	3.77	4.88	5.15
32.75	70.25		0.05	0.63	0.53	1.06	2.06	2.60	3.69	3.73	4.88	5.12
32.75	70.5		0.03	0.64	0.48	1.06	2.01	2.54	3.65	3.77	4.85	5.13
32.75	70.75		0.13	0.65	0.53	1.10	2.00	2.57	3.69	3.84	4.87	5.17
32.75	71		0.07	0.62	0.47	1.07	2.02	2.52	3.70	3.82	4.84	5.14
32.75	71.25		0.00	0.59	0.42	0.99	2.03	2.44	3.69	3.74	4.77	5.08
32.75	71.5		0.00	0.61	0.43	0.96	2.06	2.41	3.73	3.71	4.76	5.07
32.75	71.75		0.00	0.64	0.47	1.00	2.08	2.40	3.75	3.69	4.75	5.07
32.75	72		0.06	0.68	0.57	1.09	2.12	2.51	3.81	3.72	4.81	5.14
33	69		0.72	1.05	1.24	1.57	2.59	3.32	4.30	4.31	5.36	5.88
33	69.25		0.71	1.03	1.21	1.51	2.58	3.31	4.30	4.32	5.38	5.90
33	69.5		0.60	0.93	1.06	1.38	2.47	3.14	4.18	4.16	5.25	5.68
33	69.75		0.38	0.81	0.81	1.22	2.25	2.84	3.88	3.91	4.97	5.29
33	70	Bannu	0.19	0.73	0.64	1.10	2.09	2.66	3.72	3.77	4.86	5.12
33	70.25		0.11	0.69	0.57	1.07	2.03	2.59	3.71	3.77	4.88	5.14
33	70.5		0.08	0.69	0.51	1.09	1.99	2.52	3.67	3.79	4.83	5.11
33	70.75		0.07	0.69	0.50	1.06	2.00	2.52	3.67	3.75	4.81	5.07
33	71		0.01	0.65	0.47	1.03	2.02	2.49	3.67	3.71	4.78	5.03
33	71.25		-0.06	0.58	0.43	1.00	2.02	2.46	3.68	3.68	4.75	5.01
33	71.5		-0.01	0.63	0.50	1.01	2.06	2.45	3.73	3.66	4.76	5.04
33	71.75		0.07	0.72	0.60	1.07	2.12	2.46	3.80	3.69	4.80	5.11
33	72		0.19	0.81	0.71	1.16	2.19	2.57	3.89	3.75	4.86	5.20
33.25	69		0.78	1.10	1.30	1.59	2.66	3.40	4.36	4.41	5.48	5.96
33.25	69.25		0.78	1.09	1.30	1.52	2.65	3.38	4.37	4.42	5.50	5.99
33.25	69.5		0.60	0.96	1.06	1.36	2.47	3.12	4.16	4.17	5.28	5.66
33.25	69.75		0.34	0.82	0.72	1.16	2.18	2.75	3.80	3.86	4.95	5.21
33.25	70		0.22	0.77	0.58	1.08	2.02	2.58	3.65	3.72	4.83	5.05
33.25	70.25		0.16	0.75	0.54	1.08	2.00	2.54	3.67	3.73	4.83	5.07
33.25	70.5		0.07	0.72	0.47	1.07	2.02	2.51	3.68	3.74	4.82	5.07
33.25	70.75		0.03	0.70	0.48	1.04	2.05	2.50	3.70	3.70	4.83	5.07
33.25	71		0.04	0.69	0.52	1.04	2.07	2.51	3.71	3.69	4.82	5.07
33.25	71.25		0.06	0.68	0.57	1.08	2.06	2.52	3.74	3.71	4.80	5.08

33.25	**71.5**		0.06	0.72	0.61	1.05	2.08	2.49	3.77	3.68	4.79	5.08
Latitude	**Longitude**	**Station Name**	**2001-2010**	**2011-2020**	**2021-2030**	**2031-2040**	**2041-2050**	**2051-2060**	**2061-2070**	**2071-2080**	**2081-2090**	**2091-99**
33.25	**71.75**		0.06	0.75	0.64	1.03	2.13	2.46	3.82	3.62	4.80	5.08
33.25	**72**		0.11	0.80	0.69	1.08	2.14	2.52	3.85	3.67	4.80	5.12
33.5	**69**		0.74	1.10	1.25	1.56	2.57	3.27	4.27	4.28	5.33	5.83
33.5	**69.25**		0.81	1.15	1.33	1.55	2.63	3.34	4.37	4.38	5.43	5.96
33.5	**69.5**		0.80	1.09	1.25	1.46	2.57	3.22	4.29	4.27	5.32	5.76
33.5	**69.75**		0.53	0.93	0.92	1.27	2.35	2.97	3.98	4.04	5.11	5.44
33.5	**70**		0.29	0.81	0.68	1.12	2.10	2.68	3.76	3.83	4.92	5.18
33.5	**70.25**		0.20	0.73	0.62	1.08	2.03	2.58	3.70	3.73	4.82	5.06
33.5	**70.5**		0.13	0.68	0.58	1.07	2.03	2.59	3.71	3.71	4.83	5.04
33.5	**70.75**		0.10	0.65	0.56	1.07	2.02	2.57	3.70	3.71	4.85	5.04
33.5	**71**		0.15	0.70	0.62	1.10	2.09	2.58	3.73	3.72	4.85	5.11
33.5	**71.25**		0.21	0.81	0.67	1.10	2.17	2.56	3.82	3.71	4.83	5.18
33.5	**71.5**	**Kohat**	0.16	0.79	0.67	1.09	2.11	2.51	3.80	3.67	4.76	5.13
33.5	**71.75**		0.09	0.77	0.65	1.07	2.09	2.55	3.80	3.63	4.80	5.10
33.5	**72**		0.13	0.84	0.69	1.07	2.13	2.58	3.86	3.61	4.85	5.12
33.75	**69**		0.78	1.11	1.28	1.62	2.60	3.30	4.27	4.33	5.35	5.86
33.75	**69.25**		0.84	1.13	1.37	1.61	2.74	3.43	4.46	4.51	5.55	6.05
33.75	**69.5**		0.81	1.10	1.28	1.52	2.65	3.32	4.39	4.40	5.44	5.92
33.75	**69.75**		0.61	1.00	1.05	1.38	2.42	3.06	4.08	4.12	5.12	5.52
33.75	**70**	**Parachinar**	0.39	0.89	0.75	1.20	2.15	2.71	3.80	3.85	4.83	5.13
33.75	**70.25**		0.32	0.81	0.72	1.17	2.07	2.66	3.71	3.78	4.76	5.04
33.75	**70.5**		0.35	0.76	0.77	1.19	2.12	2.74	3.75	3.80	4.77	5.11
33.75	**70.75**		0.36	0.73	0.74	1.17	2.15	2.73	3.81	3.81	4.79	5.14
33.75	**71**		0.32	0.73	0.70	1.12	2.13	2.67	3.80	3.77	4.80	5.13
33.75	**71.25**		0.25	0.81	0.68	1.07	2.10	2.58	3.78	3.70	4.80	5.14
33.75	**71.5**		0.21	0.90	0.71	1.11	2.12	2.56	3.81	3.67	4.80	5.17
33.75	**71.75**		0.18	0.87	0.72	1.11	2.11	2.60	3.81	3.68	4.82	5.16
33.75	**72**	**Cherat**	0.15	0.84	0.71	1.12	2.12	2.68	3.83	3.73	4.90	5.20
34	**69**		0.81	1.12	1.30	1.64	2.61	3.33	4.24	4.29	5.30	5.87
34	**69.25**		0.85	1.14	1.39	1.63	2.75	3.47	4.45	4.45	5.52	6.04
34	**69.5**		0.86	1.11	1.32	1.59	2.71	3.45	4.45	4.45	5.49	6.03
34	**69.75**		0.78	1.04	1.26	1.54	2.61	3.35	4.36	4.35	5.35	5.86
34	**70**		0.69	0.98	1.15	1.47	2.51	3.21	4.23	4.19	5.18	5.67
34	**70.25**		0.59	0.90	1.08	1.41	2.40	3.08	4.09	4.12	5.06	5.48
34	**70.5**		0.54	0.85	1.01	1.36	2.36	3.01	4.07	4.08	5.01	5.42
34	**70.75**		0.49	0.82	0.92	1.30	2.29	2.93	4.01	3.98	4.94	5.33
34	**71**		0.37	0.79	0.81	1.21	2.19	2.81	3.91	3.88	4.88	5.24
34	**71.25**		0.28	0.87	0.72	1.14	2.14	2.67	3.86	3.78	4.82	5.21
34	**71.5**	**Peshawar**	0.30	0.99	0.75	1.15	2.17	2.63	3.89	3.72	4.82	5.26
34	**71.75**		0.30	0.97	0.79	1.18	2.20	2.72	3.93	3.77	4.97	5.34
34	**72**	**Risalpur**	0.24	0.89	0.79	1.14	2.14	2.74	3.85	3.77	4.98	5.26
34.25	**69**		0.87	1.12	1.31	1.69	2.64	3.37	4.25	4.31	5.27	5.88
34.25	**69.25**		0.93	1.18	1.42	1.70	2.74	3.49	4.43	4.41	5.45	6.01
34.25	**69.5**		0.87	1.06	1.25	1.57	2.65	3.40	4.36	4.32	5.35	5.93
34.25	**69.75**		0.75	0.98	1.18	1.50	2.60	3.33	4.31	4.26	5.28	5.83
34.25	**70**		0.59	0.91	1.05	1.38	2.46	3.15	4.15	4.09	5.07	5.59
34.25	**70.25**		0.48	0.88	0.93	1.33	2.32	3.00	3.98	4.03	4.96	5.41
34.25	**70.5**		0.45	0.92	0.90	1.35	2.31	2.93	3.99	4.04	4.98	5.42
34.25	**70.75**		0.40	0.95	0.85	1.29	2.24	2.85	3.95	3.96	4.94	5.35
34.25	**71**		0.35	0.99	0.81	1.25	2.19	2.79	3.94	3.89	4.93	5.30

34.25	**71.25**		0.31	1.00	0.77	1.19	2.14	2.70	3.92	3.81	4.90	5.26
Latitude	**Longitude**	**Station Name**	**2001-2010**	**2011-2020**	**2021-2030**	**2031-2040**	**2041-2050**	**2051-2060**	**2061-2070**	**2071-2080**	**2081-2090**	**2091-99**
34.25	**71.5**		0.25	0.95	0.73	1.10	2.09	2.61	3.85	3.71	4.87	5.19
34.25	**71.75**		0.25	0.93	0.73	1.09	2.12	2.63	3.87	3.70	4.96	5.24
34.25	**72**		0.23	0.91	0.74	1.08	2.10	2.64	3.84	3.68	4.97	5.22
34.5	**69**		0.91	1.16	1.33	1.74	2.74	3.49	4.40	4.39	5.41	5.98
34.5	**69.25**		0.91	1.13	1.35	1.67	2.64	3.43	4.33	4.29	5.31	5.87
34.5	**69.5**		0.81	1.05	1.24	1.60	2.53	3.30	4.20	4.16	5.17	5.73
34.5	**69.75**		0.66	0.98	1.11	1.48	2.49	3.21	4.15	4.11	5.12	5.67
34.5	**70**		0.45	0.92	0.99	1.35	2.36	3.05	4.01	3.96	4.99	5.50
34.5	**70.25**		0.38	0.94	0.97	1.33	2.26	2.94	3.98	3.95	4.95	5.39
34.5	**70.5**		0.38	0.93	0.96	1.32	2.23	2.91	3.94	3.95	4.96	5.34
34.5	**70.75**		0.36	0.93	0.89	1.29	2.19	2.87	3.89	3.89	4.96	5.32
34.5	**71**		0.30	0.95	0.82	1.24	2.14	2.78	3.87	3.84	4.99	5.31
34.5	**71.25**		0.20	0.91	0.76	1.18	2.12	2.71	3.84	3.79	5.01	5.27
34.5	**71.5**		0.14	0.83	0.70	1.10	2.11	2.67	3.78	3.76	4.99	5.22
34.5	**71.75**		0.13	0.78	0.67	1.07	2.12	2.64	3.78	3.74	5.00	5.21
34.5	**72**		0.14	0.78	0.67	1.08	2.13	2.63	3.81	3.71	5.01	5.23

Table A-12: Future Precipitation Projections of Project Area Using GCM Data (in mm).

Latitude	Longitude	Station Name	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060	2061-2070	2071-2080	2081-2090	2091-99	Baseline(1961-1990)
32.5	**69**		0.06	-0.02	0.95	-0.02	0.77	-0.02	0.65	0.23	0.40	0.20	0.77
32.5	**69.25**		0.16	0.02	1.96	-0.01	1.61	-0.01	1.37	0.37	0.95	0.36	1.64
32.5	**69.5**		0.24	-0.02	2.70	-0.10	2.31	-0.05	1.94	0.33	1.51	0.30	2.25
32.5	**69.75**		0.43	-0.06	2.98	-0.30	2.68	-0.02	2.15	0.18	1.88	0.14	2.36
32.5	**70**		0.59	0.01	3.03	-0.31	2.86	0.06	2.31	0.07	2.06	0.18	2.42
32.5	**70.25**		0.39	0.09	2.38	-0.05	2.32	0.06	2.07	0.01	1.74	0.24	2.10
32.5	**70.5**		0.18	0.12	1.75	0.18	1.65	0.12	1.65	0.00	1.33	0.21	1.66
32.5	**70.75**		0.17	0.17	1.78	0.31	1.58	0.24	1.64	0.07	1.34	0.28	1.70
32.5	**71**		0.32	0.21	2.13	0.33	1.84	0.36	1.83	0.17	1.57	0.40	1.98
32.5	**71.25**		0.16	0.08	1.60	0.30	1.35	0.33	1.35	0.21	1.16	0.37	1.54
32.5	**71.5**	**Mianwali**	0.06	0.05	1.25	0.30	1.02	0.39	0.95	0.36	0.78	0.46	1.25
32.5	**71.75**		0.10	0.05	1.37	0.24	1.10	0.43	0.96	0.49	0.75	0.55	1.33
32.5	**72**		0.29	0.07	2.03	0.18	1.63	0.55	1.37	0.68	1.07	0.78	1.85
32.8	**69**		0.10	0.01	1.10	0.04	0.89	0.03	0.76	0.31	0.46	0.29	0.94
32.8	**69.25**		0.11	-0.01	1.28	0.02	1.03	-0.03	0.91	0.20	0.65	0.14	1.07
32.8	**69.5**		0.17	-0.02	1.69	-0.01	1.44	-0.09	1.27	0.13	1.02	0.05	1.43
32.8	**69.75**		0.23	-0.07	1.96	-0.08	1.78	-0.08	1.52	0.07	1.29	0.02	1.66
32.8	**70**		0.30	-0.04	2.05	-0.04	1.94	0.04	1.66	0.07	1.41	0.17	1.81
32.8	**70.25**		0.35	0.08	2.01	0.17	1.87	0.20	1.72	0.13	1.40	0.37	1.88
32.8	**70.5**		0.29	0.13	1.64	0.30	1.46	0.24	1.48	0.10	1.20	0.34	1.58
32.8	**70.75**		0.14	0.11	1.36	0.31	1.20	0.21	1.29	0.07	1.12	0.26	1.34
32.8	**71**		0.21	0.10	1.57	0.27	1.37	0.25	1.42	0.12	1.32	0.28	1.50
32.8	**71.25**		0.21	0.08	1.51	0.24	1.27	0.30	1.23	0.24	1.15	0.38	1.43
32.8	**71.5**		0.13	0.04	1.38	0.21	1.12	0.32	1.03	0.34	0.93	0.43	1.30
32.8	**71.75**		0.20	0.02	1.69	0.16	1.41	0.34	1.21	0.47	1.02	0.54	1.54
32.8	**72**		0.28	0.01	1.96	0.17	1.67	0.41	1.36	0.61	1.11	0.74	1.81
33	**69**		0.15	0.02	1.44	0.18	1.16	0.10	1.02	0.35	0.66	0.35	1.30
33	**69.25**		0.17	0.03	1.53	0.20	1.25	0.08	1.16	0.27	0.82	0.27	1.40
33	**69.5**		0.22	0.04	1.54	0.21	1.29	0.11	1.18	0.24	0.87	0.31	1.41
33	**69.75**		0.34	0.04	1.92	0.17	1.68	0.18	1.47	0.24	1.19	0.38	1.67
33	**70**	**Bannu**	0.34	0.02	1.87	0.13	1.68	0.18	1.42	0.25	1.13	0.43	1.61
33	**70.25**		0.31	0.07	1.62	0.19	1.46	0.20	1.26	0.26	0.95	0.51	1.44
33	**70.5**		0.34	0.11	1.78	0.23	1.60	0.23	1.49	0.23	1.24	0.47	1.56
33	**70.75**		0.30	0.07	1.73	0.19	1.55	0.20	1.51	0.18	1.34	0.34	1.50
33	**71**		0.32	0.09	1.71	0.18	1.51	0.23	1.47	0.23	1.33	0.38	1.51
33	**71.25**		0.40	0.13	2.10	0.19	1.84	0.33	1.68	0.36	1.56	0.52	1.86
33	**71.5**		0.33	0.07	2.08	0.16	1.81	0.33	1.56	0.42	1.43	0.56	1.84
33	**71.75**		0.20	0.00	1.74	0.09	1.50	0.27	1.25	0.43	1.06	0.56	1.56
33	**72**		0.12	-0.07	1.42	0.03	1.25	0.20	0.99	0.40	0.80	0.50	1.30
33.3	**69**		0.19	0.02	1.67	0.22	1.33	0.15	1.15	0.40	0.74	0.44	1.47
33.3	**69.25**		0.22	0.00	1.82	0.28	1.48	0.14	1.32	0.38	0.89	0.43	1.65
33.3	**69.5**		0.25	-0.02	1.70	0.18	1.43	0.08	1.29	0.19	0.92	0.35	1.51
33.3	**69.75**		0.31	-0.03	1.75	0.08	1.56	0.07	1.37	0.12	1.01	0.36	1.43
33.3	**70**		0.29	0.00	1.70	0.10	1.58	0.11	1.36	0.21	1.00	0.49	1.37
33.3	**70.25**		0.32	0.04	1.85	0.09	1.75	0.11	1.52	0.23	1.17	0.54	1.49
33.3	**70.5**		0.40	0.07	2.17	0.02	2.02	0.07	1.76	0.19	1.44	0.47	1.69
33.3	**70.75**		0.38	0.05	2.01	0.01	1.80	0.11	1.59	0.28	1.26	0.46	1.59
33.3	**71**		0.36	0.08	1.84	0.12	1.58	0.26	1.36	0.47	1.05	0.62	1.56
33.3	**71.25**		0.38	0.12	2.16	0.17	1.89	0.39	1.55	0.56	1.31	0.74	1.91

Latitude	Longitude	Station Name	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060	2061-2070	2071-2080	2081-2090	2091-99	Baseline(1961-1990)
33.3	71.5		0.31	0.03	2.10	0.07	1.87	0.32	1.47	0.48	1.29	0.66	1.84
33.3	71.75		0.21	-0.05	1.77	0.06	1.52	0.32	1.16	0.54	0.94	0.73	1.58
33.3	72		0.16	-0.12	1.95	0.03	1.71	0.31	1.33	0.61	1.06	0.78	1.74
33.5	69		0.11	-0.03	1.06	0.08	0.86	0.07	0.68	0.29	0.38	0.34	0.86
33.5	69.25		0.11	-0.08	1.27	0.11	1.04	0.04	0.84	0.26	0.55	0.28	1.08
33.5	69.5		0.20	-0.11	2.06	0.18	1.77	0.07	1.45	0.45	1.01	0.56	1.76
33.5	69.75		0.35	-0.10	2.69	0.09	2.37	0.09	1.99	0.37	1.49	0.66	2.19
33.5	70		0.31	-0.03	2.04	0.04	1.91	0.06	1.58	0.19	1.20	0.49	1.63
33.5	70.25		0.34	0.05	2.08	0.04	2.05	0.03	1.71	0.22	1.33	0.59	1.67
33.5	70.5		0.36	0.06	2.29	-0.03	2.21	-0.06	1.89	0.26	1.43	0.63	1.82
33.5	70.75		0.35	0.05	2.34	-0.05	2.14	0.00	1.79	0.41	1.32	0.58	1.91
33.5	71		0.26	0.00	2.14	0.00	1.86	0.17	1.47	0.55	1.12	0.56	1.80
33.5	71.25		0.07	-0.09	1.43	0.00	1.22	0.24	0.85	0.52	0.67	0.43	1.24
33.5	71.5	Kohat	0.19	-0.09	1.96	0.00	1.76	0.31	1.24	0.62	1.07	0.56	1.70
33.5	71.75		0.27	-0.13	2.44	-0.05	2.23	0.26	1.69	0.66	1.39	0.71	2.10
33.5	72		0.13	-0.18	2.00	-0.08	1.84	0.10	1.48	0.52	1.09	0.63	1.74
33.8	69		0.15	-0.03	1.11	0.07	0.88	0.11	0.68	0.31	0.39	0.36	0.87
33.8	69.25		0.23	-0.06	1.81	0.15	1.47	0.08	1.19	0.38	0.82	0.42	1.49
33.8	69.5		0.22	-0.10	1.88	0.09	1.59	0.00	1.27	0.32	0.91	0.37	1.54
33.8	69.75		0.32	-0.10	2.36	-0.01	2.08	0.02	1.74	0.32	1.39	0.53	1.90
33.8	70	Parachinar	0.34	-0.05	2.16	-0.02	2.00	0.03	1.64	0.32	1.28	0.61	1.69
33.8	70.25		0.38	0.07	2.52	0.08	2.38	0.13	1.91	0.50	1.53	0.86	2.01
33.8	70.5		0.38	0.07	2.82	0.11	2.57	0.17	2.06	0.68	1.67	0.94	2.31
33.8	70.75		0.30	-0.03	2.67	0.11	2.29	0.22	1.76	0.82	1.33	0.83	2.23
33.8	71		0.18	-0.14	2.60	0.05	2.19	0.22	1.64	0.80	1.25	0.63	2.18
33.8	71.25		0.08	-0.27	2.41	-0.11	2.11	0.14	1.53	0.62	1.26	0.37	1.98
33.8	71.5		0.10	-0.30	2.24	-0.18	2.02	0.09	1.47	0.52	1.22	0.32	1.84
33.8	71.75		0.17	-0.26	2.53	-0.20	2.34	-0.01	1.87	0.40	1.57	0.30	2.09
33.8	72	Cherat	0.25	-0.24	3.00	-0.19	2.83	-0.07	2.37	0.33	1.97	0.36	2.51
34	69		0.10	-0.04	0.84	0.03	0.68	0.05	0.55	0.20	0.35	0.21	0.63
34	69.25		0.19	-0.03	1.61	0.12	1.33	0.03	1.11	0.33	0.78	0.33	1.30
34	69.5		0.18	-0.07	1.85	0.10	1.53	-0.01	1.27	0.29	0.94	0.28	1.53
34	69.75		0.19	-0.08	1.90	0.07	1.61	-0.03	1.31	0.36	0.95	0.36	1.59
34	70		0.14	-0.09	1.75	0.06	1.55	-0.05	1.24	0.43	0.85	0.43	1.49
34	70.25		0.27	-0.01	2.53	0.08	2.19	0.06	1.76	0.59	1.27	0.68	2.19
34	70.5		0.23	-0.04	2.68	0.08	2.30	0.10	1.84	0.59	1.41	0.65	2.35
34	70.75		0.14	-0.16	2.66	0.02	2.28	0.09	1.81	0.57	1.47	0.51	2.29
34	71		0.12	-0.30	2.85	-0.16	2.50	-0.06	1.98	0.41	1.65	0.31	2.39
34	71.25		0.08	-0.38	2.38	-0.33	2.17	-0.25	1.73	0.13	1.48	-0.04	1.93
34	71.5	Peshawar	0.03	-0.35	1.68	-0.36	1.63	-0.30	1.35	0.02	1.17	-0.18	1.32
34	71.75		0.08	-0.34	2.40	-0.40	2.35	-0.39	2.09	-0.05	1.77	-0.08	1.90
34	72	Risalpur	0.27	-0.32	3.60	-0.36	3.48	-0.39	3.16	-0.06	2.72	0.10	2.91
34.3	69		0.06	-0.05	0.81	-0.02	0.65	-0.02	0.60	0.11	0.40	0.12	0.60
34.3	69.25		0.10	-0.03	1.43	0.04	1.19	-0.07	1.08	0.18	0.78	0.17	1.15
34.3	69.5		0.11	-0.02	1.76	0.07	1.47	-0.07	1.31	0.22	0.99	0.17	1.47
34.3	69.75		0.15	0.00	1.77	0.09	1.46	-0.03	1.25	0.32	0.91	0.27	1.50
34.3	70		0.14	-0.02	1.56	0.11	1.33	-0.02	1.11	0.39	0.79	0.31	1.35
34.3	70.25		0.32	0.02	2.05	-0.01	1.75	-0.01	1.45	0.28	1.12	0.34	1.71
34.3	70.5		0.29	-0.04	1.91	-0.05	1.64	0.02	1.34	0.21	1.04	0.31	1.60
34.3	70.75		0.22	-0.19	1.97	-0.14	1.80	-0.09	1.50	0.10	1.22	0.17	1.61

Latitude	Longitude	Station Name	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050	2051-2060	2061-2070	2071-2080	2081-2090	2091-99	Baseline(1961-1990)
34.3	**71**		0.17	-0.28	1.89	-0.23	1.81	-0.23	1.53	-0.01	1.26	0.04	1.52
34.3	**71.25**		0.17	-0.28	1.89	-0.23	1.85	-0.25	1.58	0.06	1.27	0.05	1.55
34.3	**71.5**		0.26	-0.24	2.45	-0.23	2.37	-0.20	2.08	0.18	1.67	0.18	2.01
34.3	**71.75**		0.21	-0.21	2.43	-0.26	2.35	-0.23	2.14	0.13	1.69	0.19	1.95
34.3	**72**		0.16	-0.18	2.28	-0.23	2.16	-0.22	2.05	0.12	1.55	0.24	1.83
34.5	**69**		0.07	-0.04	1.06	-0.01	0.86	-0.07	0.77	0.12	0.52	0.19	0.83
34.5	**69.25**		0.04	-0.04	0.94	-0.02	0.78	-0.11	0.73	0.08	0.49	0.11	0.73
34.5	**69.5**		0.03	-0.03	0.82	-0.03	0.72	-0.14	0.69	0.06	0.45	0.06	0.64
34.5	**69.75**		0.16	0.01	1.11	0.03	0.96	-0.09	0.87	0.19	0.53	0.22	0.89
34.5	**70**		0.27	-0.02	1.14	0.04	1.02	-0.07	0.90	0.22	0.56	0.23	0.93
34.5	**70.25**		0.26	-0.03	0.96	0.07	0.93	-0.05	0.81	0.20	0.52	0.26	0.83
34.5	**70.5**		0.50	0.02	1.91	0.22	1.85	0.17	1.59	0.38	1.34	0.61	1.64
34.5	**70.75**		0.46	-0.05	2.16	0.07	2.15	-0.02	1.93	0.23	1.59	0.43	1.82
34.5	**71**		0.39	-0.13	2.12	-0.05	2.13	-0.19	1.92	0.19	1.37	0.38	1.79
34.5	**71.25**		0.43	-0.12	2.32	-0.03	2.26	-0.09	1.96	0.40	1.27	0.57	1.99
34.5	**71.5**		0.59	-0.01	2.86	0.06	2.67	0.15	2.22	0.69	1.51	0.82	2.44
34.5	**71.75**		0.62	0.08	2.95	0.08	2.68	0.22	2.20	0.80	1.52	0.88	2.48
34.5	**72**		0.49	0.09	2.60	0.01	2.29	0.11	1.93	0.73	1.22	0.79	2.14

This page intentionally left balnk

USAID | PAKISTAN
FROM THE AMERICAN PEOPLE

Kurram Tangi Dam Construction

Supplemental Report on Climate Change

Annexure 2: Review of Existing Literature and Research on GCM and RCM

December 2013
This publication was produced for review by the
United States Agency for International Development.
It was prepared by MWH-NESPAK-ACE under contract AID-391-C13-00002

This page intentionally left balnk

List of Abbreviations and Acronyms

Abbreviations/Acronym	Term
ac-ft	Acre Feet
CDM	Clean Development Mechanism
FAO	Food and Agriculture Organization
FATA	Federally Administered Tribal Areas
GCISC	Global Change Impact Study Center
GCM	Global Circulation Model
GEBCO	General Bathymetric Chart of the Oceans
GHG	Greenhouse Gas
GIS	Geographic Information System
GoP	Government of Pakistan
ICTP	International Centre for Theoretical Physics
ICOLD	International Commission on Large Dams
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
km	Kilometers
KP or KPK	Khyber Pakhtunkhwa
KTDC	Kurram Tangi Dam Construction
KTMDP	Kurram Tangi Multipurpose Dam Project
MCM	Million Cubic Meter
MWH	MWH Global, Inc. or MWH, Inc.
NESPAK	National Engineering Services Pakistan
NGO	Non-governmental Organization
NPS	National Park Service (USA)
NRCAN	Natural Resources Canada
PMD	Pakistan Meteorological Department
RCM	Regional Climate Model
SDSM	Statistical Downscaling Model
TGP	Towards Gender Party
UET	University of Engineering and Technology
UN	United Nations
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USAID/Pak	United States Agency for International Development/Pakistan
USGS	United States Geological Survey
WAPDA	Water and Power Development Authority
°C	Degree Celsius

This page intentionally left balnk

Table of Contents

1 INTRODUCTION 1-1
2 PAKISTAN METEOROLOGY DEPARTMENT GCM DATA ANALYSIS . 2-1
3 GCM DATA ANALYSIS BY GCISC ISLAMABAD 3-1
4 UNIVERSITY OF WASHINGTON GCMS ANALYSIS 4-1
5 SYNTHESIS OF CLIMATE DATA 5-1
6 REFERENCES 6-1

List of Tables

Table 3-1: Projected Temperature Change ΔT (°C) by Seventeen GCMs over Kabul 3-1
Table 3-2: Projected Precipitation Changes, ΔP (%) by Seventeen GCMs Kabul 3-2
Table 3-3: Projected Monthly Precipitation Changes, ΔP (%) by Seventeen *GCM*s over Kabul and Jhelum River Basins 3-2
Table 4-1: Ensemble Precipitation Average for Different Months of the Year by University of Washington for Kurram Tangi Catchment Area 4-2
Table 4-2: Ensemble Temperature Average for Different Months of the Year by University of Washington for Kurram Tangi Catchment Area 4-3

List of Figures

Figure 2-1: Decadal Total Precipitation Change as per PMD GCM Analysis over Pakistan 2-2
Figure 2-2: Decadal Total temperature Change as per PMD GCM Analysis over Pakistan 2-3
Figure 2-3: GCM Maps of Pakistan Showing Temperature Scenarios 2050 and 2080 2-4
Figure 2-4: Decadal (2011-2050) Precipitation Deviations from Normal and Projections (Annual mm/yr) in Kurram Tangi Catchment Area, FATA, Pakistan 2-6
Figure 2-5: Decadal (2051-2099) Precipitation Deviations from Normal and Projections (Annual mm/yr) in Kurram Tangi Catchment Area, FATA, Pakistan 2-7
Figure 2-6: Decadal Temperature Deviation from Normal and Projections in ^{0}C from 2011-2060 Decades in Kurram Tangi Catchment Area, FATA, Pakistan 2-9
Figure 2-7: Decadal Temperature Deviation from Normal and Projections in 0C from 2061-2099 Decades along with Baseline Map in Kurram Tangi Catchment Area, FATA, Pakistan 2-10
Figure 2-8: Future Precipitation and Temperature Projections of Project Area Cities by Pakistan Metrological Dept GCM and Observed Meteorological Data for 2001-2010 2-11
Figure 2-9: Maximum, Minimum and Mean Temperature Data for Different Months for 2010-2020 Decades for Parachinar, Kurram Agency, Pakistan 2-12
Figure 3-1: River Jhelum and Kabul Catchment Areas 3-1
Figure 3-2: Projected Monthly Precipitation Changes, ΔP (%) by Seventeen *GCM*s over Kabul & Jhelum River Basin, Pakistan 3-3
Figure 4-1: Change in Annual Temperature by 2080 Using Twenty Different GCM Data and Taking Middle Value for Plotting 4-1

Figure 4-2: Change in Annual Precipitation by 2080 Using Twenty Different GCM Data and Taking Middle Values for Plotting....4-2

Figure 4-3: Deviation from the Mean Value of Monthly Precipitation Change in Kurram Tangi Area, Pakistan by University of Washington Analysis....4-3

Figure 4-4: Deviation from the Mean Value of Monthly Temperature Change in Kurram Tangi Area by University of Washington Analysis....4-4

Figure 5-1: Yearly Precipitation, Kurram River Flow at Thal, and Maximum Temperature at Parachinar for the Period from 1971 to 2006....5-2

Figure 5-2: Observed and GCM Precipitation Data for Bannu, Kohat, and Parachinar, and their Correlation for the Period from 2001 to 2012....5-3

Figure 5-3: Observed and GCM Precipitation Data for Bannu, Kohat, and Parachinar, and their Correlation for the Period from 2001 to 2012....5-4

1 INTRODUCTION

Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis. GCMs depict the climate using a three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans.

The global annual mean surface temperature change presents limitations regarding the description and the understanding of the climate response to an external force. Indeed, the regional temperature response to a uniform force (and even more to a vertically or geographically distributed force) is highly inhomogeneous. In addition, climate sensitivity only considers the surface mean temperature and gives no indication of the occurrence of abrupt changes or extreme events. Despite its limitations, however, the climate sensitivity remains a useful concept because many aspects of a climate model scale well with global average temperature (although not necessarily across models), because the global mean temperature of the earth is fairly well measured, and because it provides a simple way to quantify and compare the climate response simulated by different models to a specified perturbation. By focusing on the global scale, climate sensitivity can also help separate the climate response from regional variability.

This page intentionally left balnk

2 PAKISTAN METEOROLOGY DEPARTMENT GCM DATA ANALYSIS

Although the message of "global climate change" is catalyzing international action, it is local and regional changes that directly affect people and ecosystems and are of immediate concern to scientists, managers, and policy makers. A major barrier preventing informed climate-change adaptation planning is the difficulty accessing, analyzing, and interpreting climate-change information. The Pakistan Meteorology Department, Islamabad is doing a great job by taking all these parameters and providing information to the group of people interested in knowing the future scenario.

To produce prediction on extended time scale, however, regional climate models and statistical downscaling models are commonly used. Pakistan Meteorological Department has been using Regional Climate Model (RegCM4) fourth version developed by ICTP, Trieste, Italy and Précis introduced b Hadley Center, UK for climate outlooks. Regional predictions of monthly and seasonal time scales are prepared by downscaling GCM outputs statistically using SDSM. These techniques are being tested against accuracy of models and simultaneously improvements and alterations are adopted to minimize the errors. **Figure 2-1** regarding expected precipitation changes and **Figure 2-2** regarding mean temperature change on decadal basis have been prepared by Pakistan Meteorological Department (PMD) using the above algorithm, and are reproduced below. Temperature will rise and precipitation drop is expected after 2050 in this region.

This page intentionally left balnk

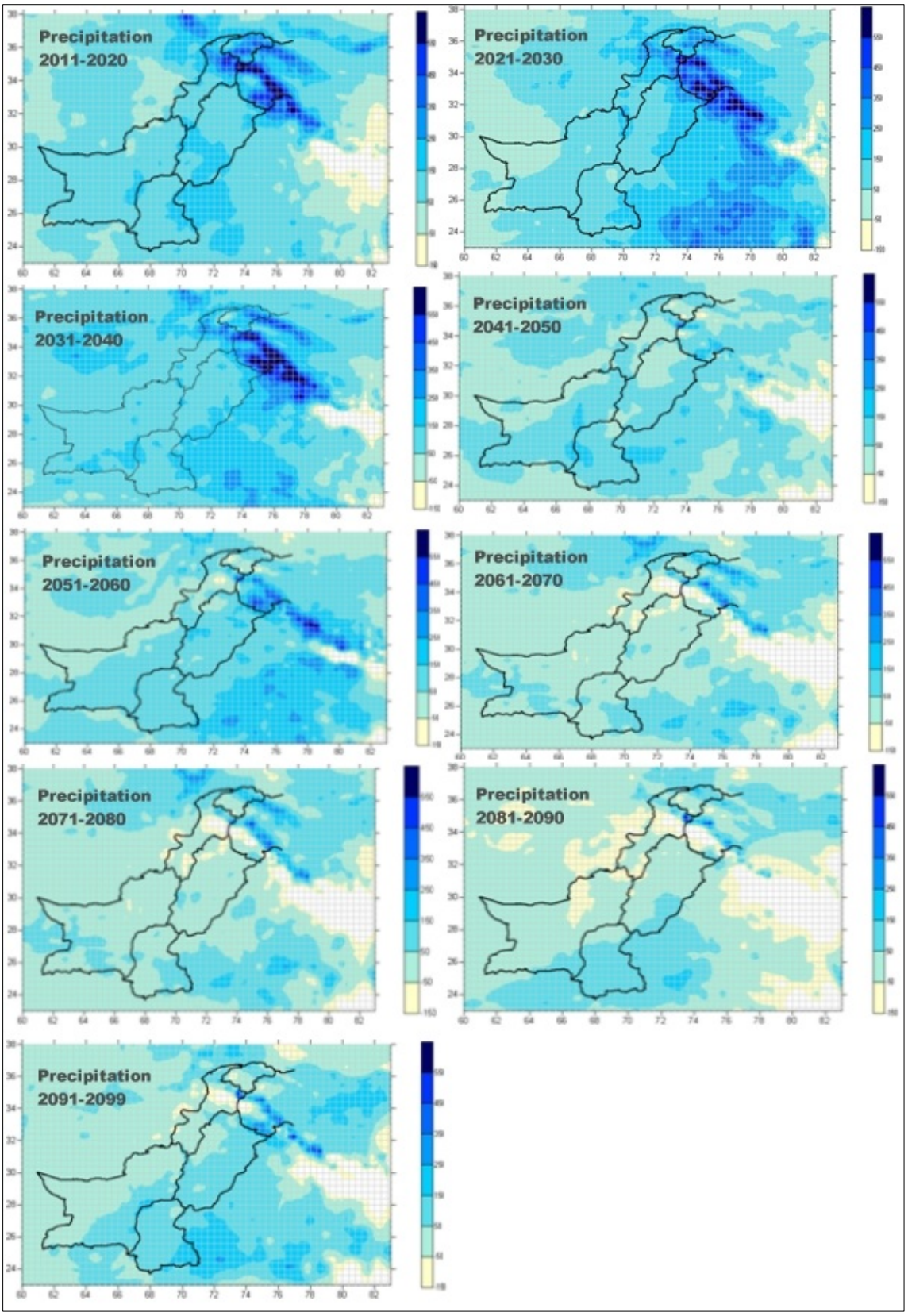


Figure 2-1: Decadal Total Precipitation Change as per PMD GCM Analysis over Pakistan

This page intentionally left balnk

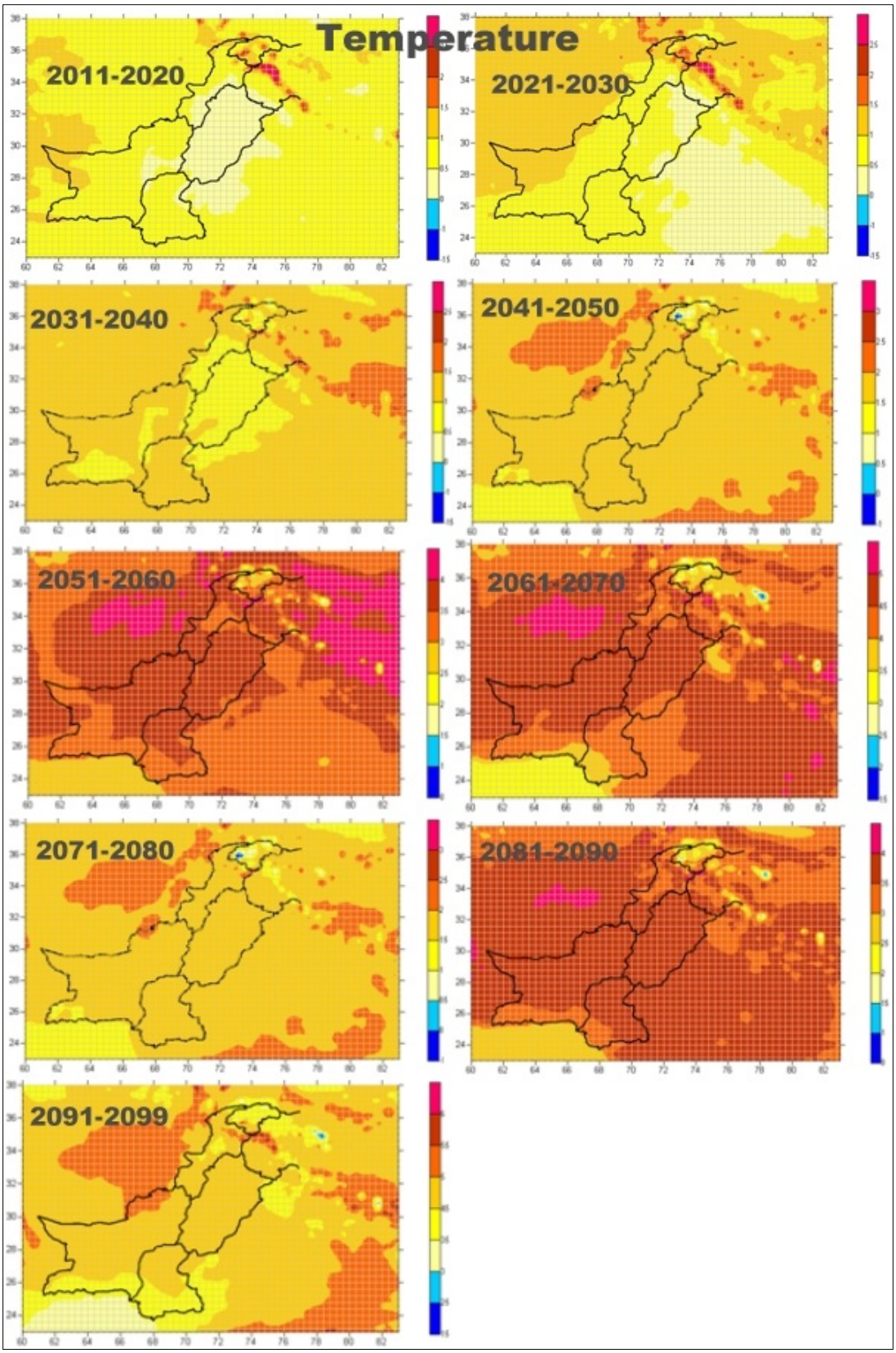


Figure 2-2: Decadal Total temperature Change as per PMD GCM Analysis over Pakistan

The GCM model shown on **Figure 2-3** is taken from http://www.climatewizard.org/ prepared by the University of Washington, USA. Its map data sources are Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL,

This page intentionally left balnk

Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community. The map shows the temperature change by the middle model. That is, half of the models a greater amount of change and half of the models project less change as compared to 1961-1990 baseline. The maps provided on **Figure 2-3** show a good correlation with each other.

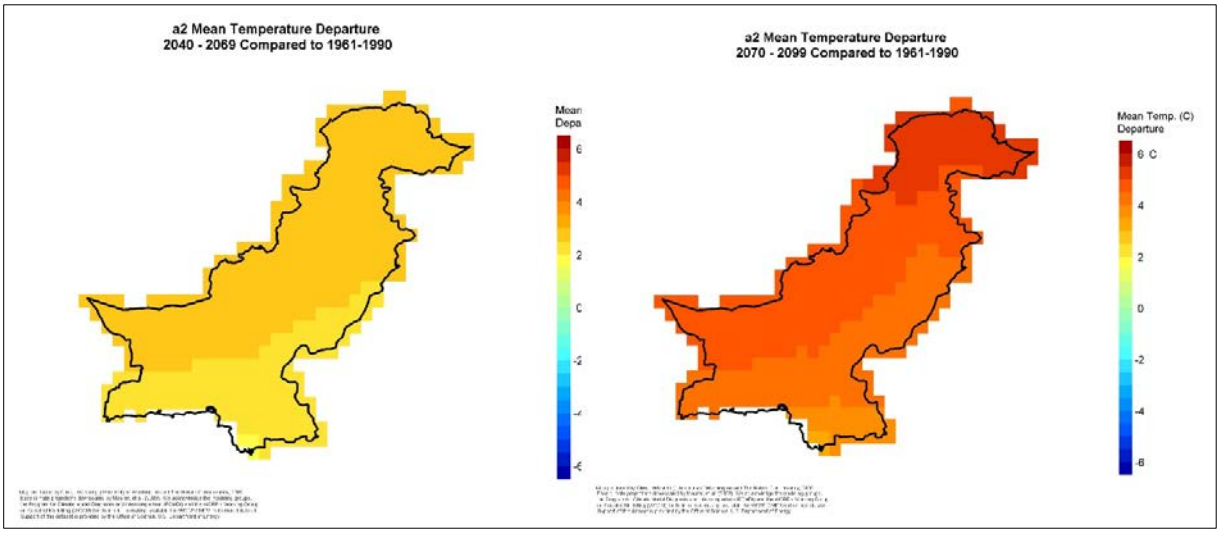


Figure 2-3: GCM Maps of Pakistan Showing Temperature Scenarios 2050 and 2080

All the work in this section has been performed using GCM data provided by the "Numerical Modeling group of Research and Development Division, Pakistan Meteorological Department (PMD), Islamabad, Pakistan" for Regional Climate Model simulations. The parameters of GCM provided are as follows:

PRECIS_25KM-1961-2100:
ECHAM5 data for A1B Scenario downscaled with PRECIS Regional Climate Model.
Grid size 25KM
Baseline (1961-1990)
Future Projections (2010-2100)
Decadal and Monthly Mean Temperature (°C) and Precipitation (mm/day)

RegCM4_25KM-1961-2100:
ECHAM5 data for A1B Scenario downscaled with RegCM4 Regional Climate Model.
Grid size 25KM
Baseline (1961-1990)
Future Projections (2010-2100)
Decadal and Monthly Mean Temperature (°C) and Precipitation (mm/day)

A1B Scenario:
World: market-oriented
Economy: fastest per capita growth
Population: 2050 peak, then decline
Governance: strong regional interactions; income convergence
Technology: balanced across all sources

Both the observed and GCM-derived predictor variables have been normalized with respect to their 1961-1990 means and standard deviations, i.e., the mean and standard deviation for the 1961-1990 period were calculated and the mean subtracted from each daily value before dividing by the standard deviation. Since GCMs do not always perform well at simulating the climate of a particular region this means that there may be large differences between observed and GCM-simulated conditions (i.e., GCM bias or error) which could potentially violate the statistical assumptions associated with SDSM and give poor results if the predictor data were not normalized. The normalization process ensures that the distributions of observed and GCM-derived predictors are in

closer agreement than those of the raw observed and raw GCM data. The predictor variables supplied here have been normalized over the complete 1961-1990 period. Other options include normalization by season and this may improve the performance of SDSM, particularly in regions where there is a distinct seasonal climate pattern. The volume of data involved means that it is not possible to supply a number of predictor data sets which have been prepared using a number of different normalization options. However, by obtaining the raw observed and raw GCM output it is possible for one to construct one's own predictor data sets using different normalization options, if one so wish.

Although the catchment area is not too large, but for having a better understanding decadal data of GCM from longitude 32.25^0 to 34.50^0 and Latitude from 69^0 to 71.75^0 is analyzed. There are two sets of data, one pertaining to precipitation deviation from normal (Annexure 1, Table A-11) and the other pertaining to temperature deviation from the normal (Annexure 1, Table A-12).

Precipitation maps for different decades are prepared and presented on **Figure 2-4** (from 2011-2050) and **Figure 2-5** (from 2051-2099). On left hand side of these maps decadal deviation from the normal (1961-90) with daily precipitation in mm is given. While on the right hand side total future projections in mm/year is given. A close look on these maps indicates that the precipitation will remain highest in the northeast corner, while a smooth gradient is observed in the southeast and southwest corners, while a sharp decrease in precipitation is forecasted in the northwest corner (Afghanistan side). This phenomenon will remain in place till 2070, after 2070 a slight decrease in precipitation is expected in this region as inferred from the GCM precipitation data prepared and downscaled by the Pakistan Meteorological Department. It is further clarified that due to many uncertainties associated with the precipitation data, it is very difficult to get a clear picture for the future.

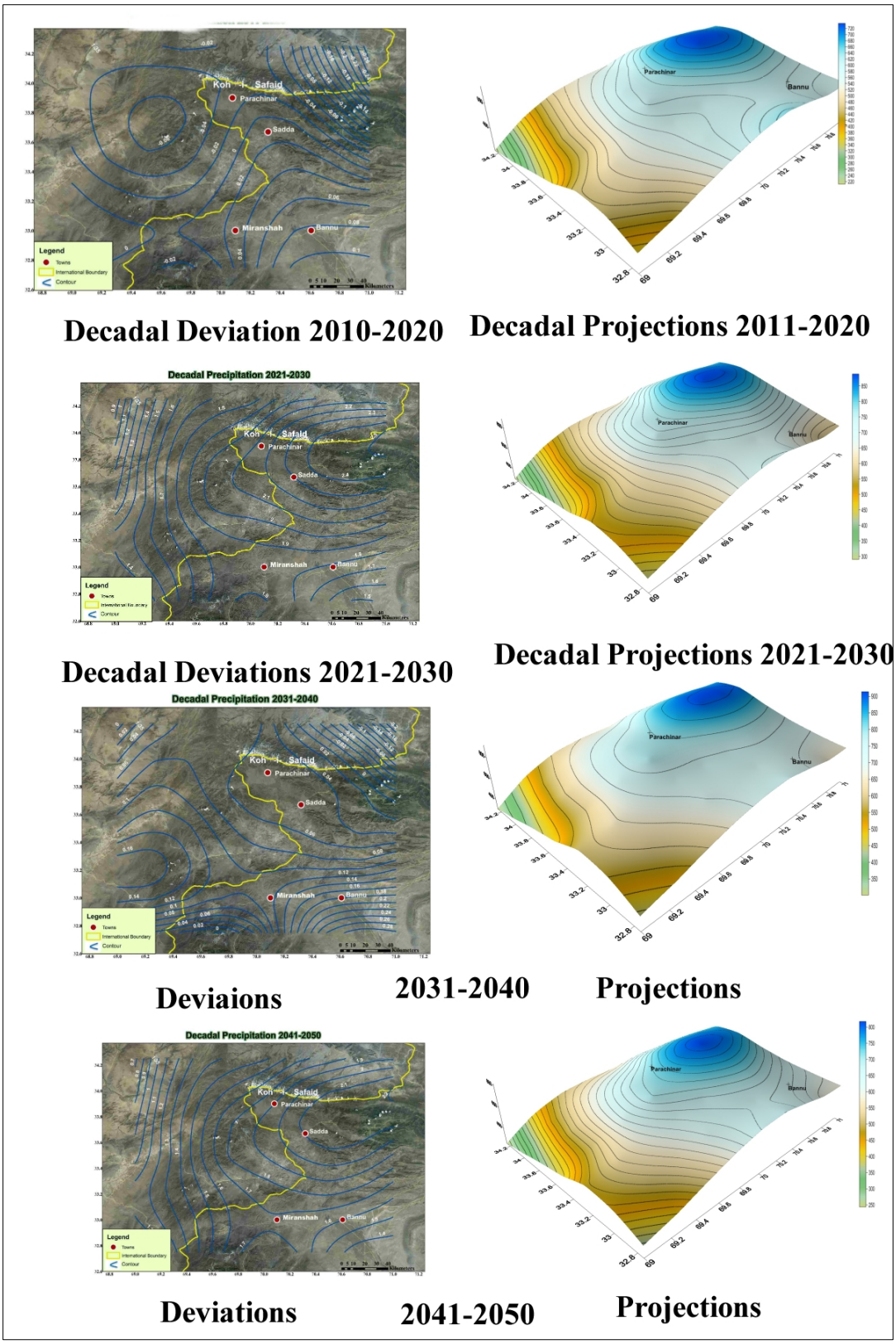


Figure 2-4: Decadal (2011-2050) Precipitation Deviations from Normal and Projections (Annual mm/yr) in Kurram Tangi Catchment Area, FATA, Pakistan

This page intentionally left balnk

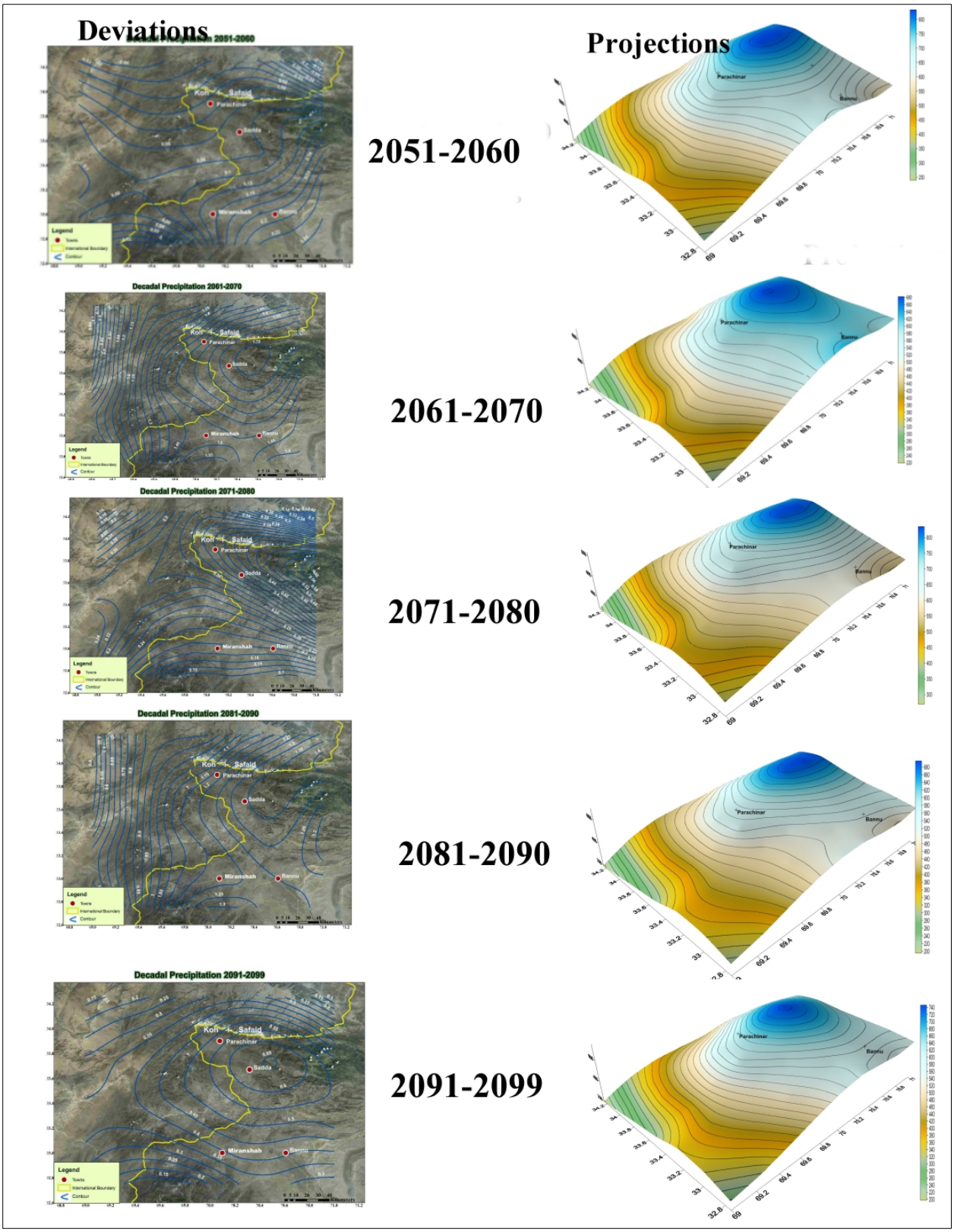


Figure 2-5: Decadal (2051-2099) Precipitation Deviations from Normal and Projections (Annual mm/yr) in Kurram Tangi Catchment Area, FATA, Pakistan

Temperature maps for different decades are prepared and presented on **Figure 2-6** (from 2011-2060) and **Figure 2-7** (from 2061-2099). On left hand side of these maps decadal deviation from the normal (1961-90) with mean annual temperature in degrees centigrade is given. While on the right

hand side total future projections in ^{0}C is given. A close look on these maps indicates that the temperature is and will remain highest in the south east corner of the map near Bannu. This high temperature zone is out of catchment area of Kurram Tangi Dam. While the northwest corner will remain the coolest place, south of Gardez. An interesting feature is noticeable that the baseline temperature (1961-1990) range from 7 °C in the north western corner of the area, while in the south east corner an average temperature of 23 ^{0}C was observed. A decadal temperature increase of ½ °C is inferred from the GCM temperature data prepared and downscaled by the Pakistan Meteorological Department. The temperature is expected to be 13 °C in the north western corner and 28 °C in the south eastern corner during 2090-2099 decade.

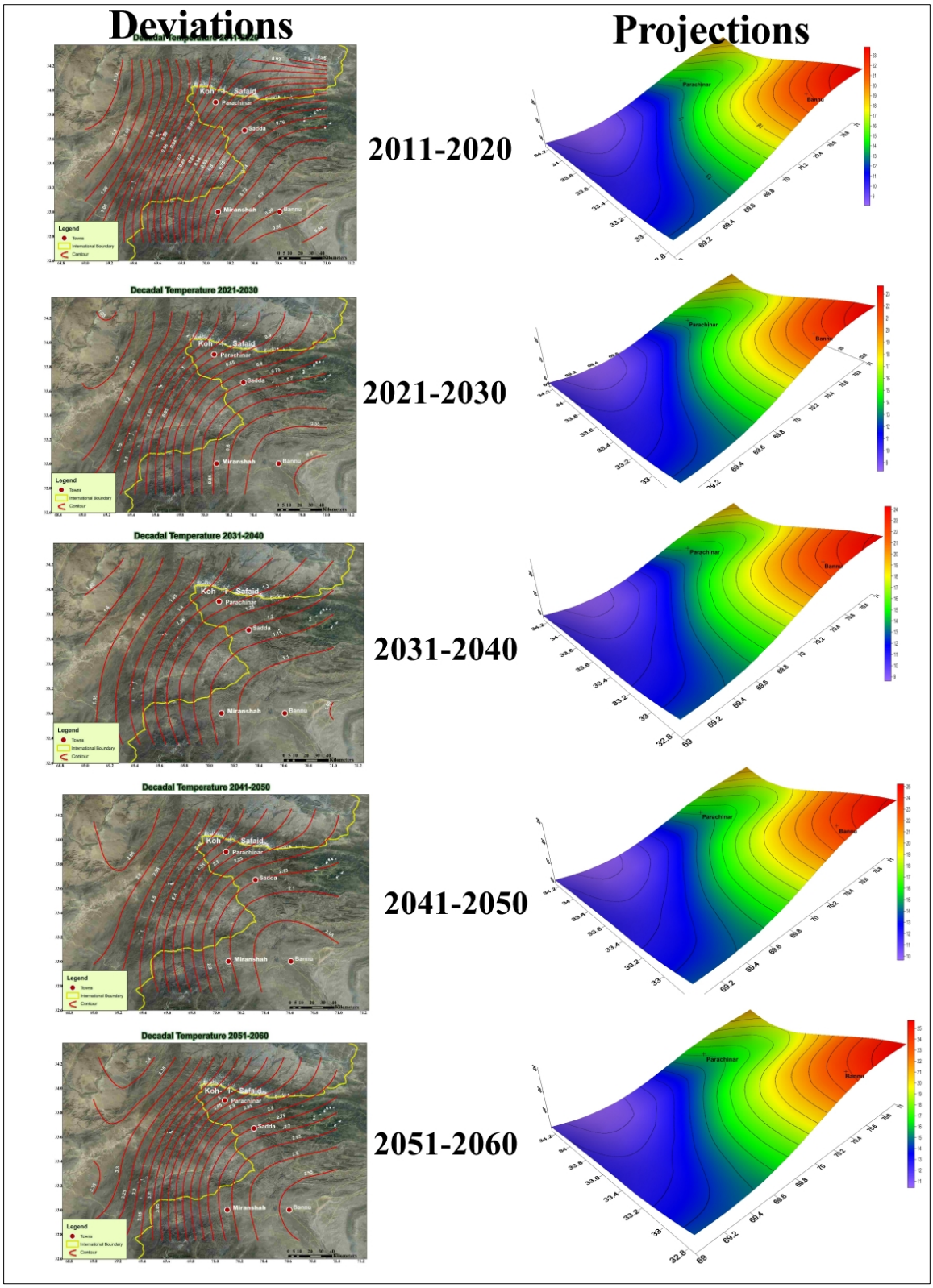


Figure 2-6: Decadal Temperature Deviation from Normal and Projections in ⁰C from 2011-2060 Decades in Kurram Tangi Catchment Area, FATA, Pakistan

This page intentionally left balnk

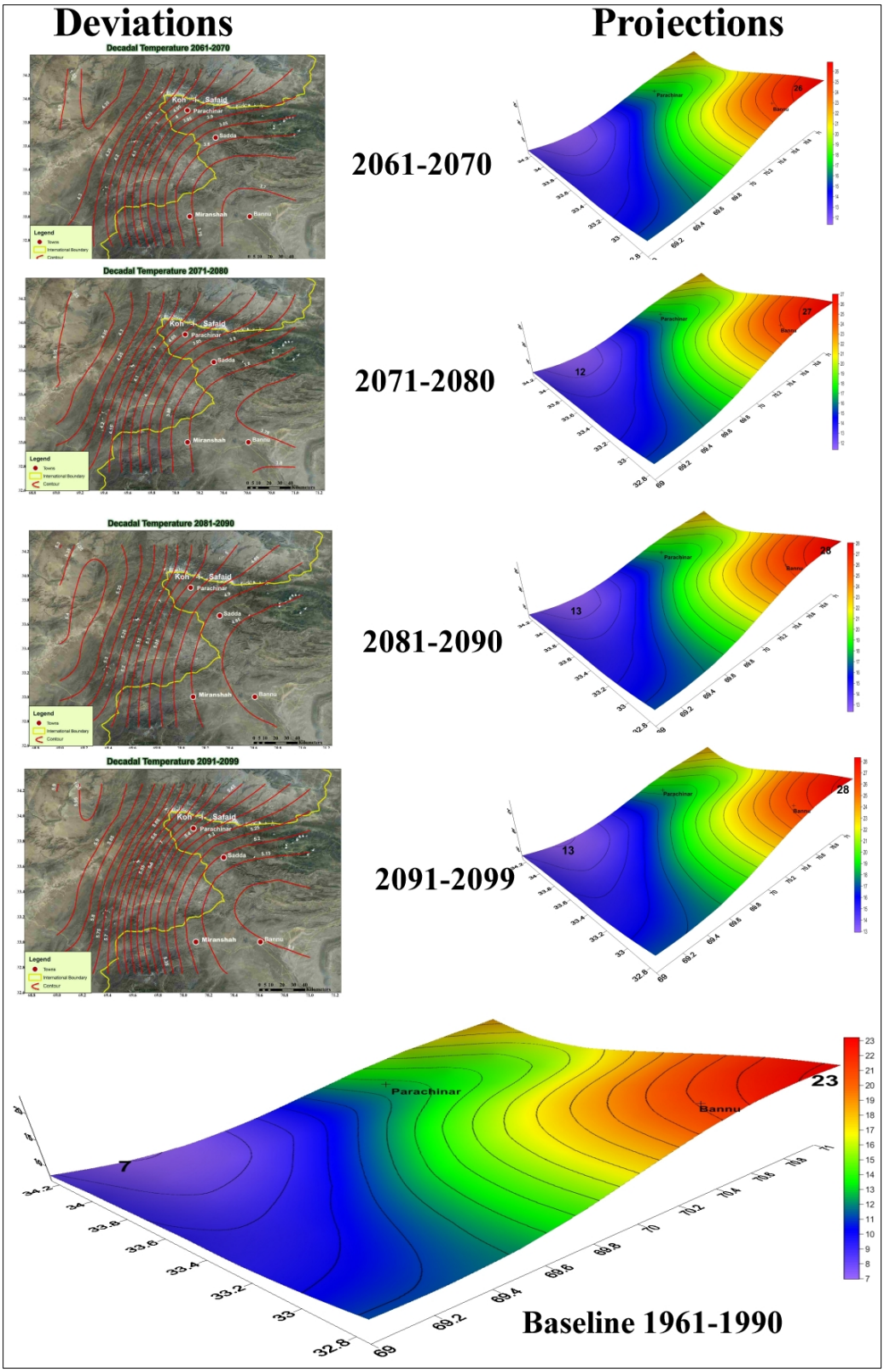


Figure 2-7: Decadal Temperature Deviation from Normal and Projections in 0C from 2061-2099 Decades along with Baseline Map in Kurram Tangi Catchment Area, FATA, Pakistan

From the observed data and GCM projections provided by the Pakistan Meteorological Department, decadal future temperature projections for Parachinar, Kohat and Bannu have been prepared and shown on **Figure 2-8**. For correlation purpose observed meteorological data for 2001 to 2010 is

This page intentionally left balnk

also plotted. In all the cases the temperature is showing a steady increase with time. An average of 4.6 degree increase is expected by the end of the century in the project area; however precipitation projections behavior is quite uncertain due to many parameters involved in precipitation.

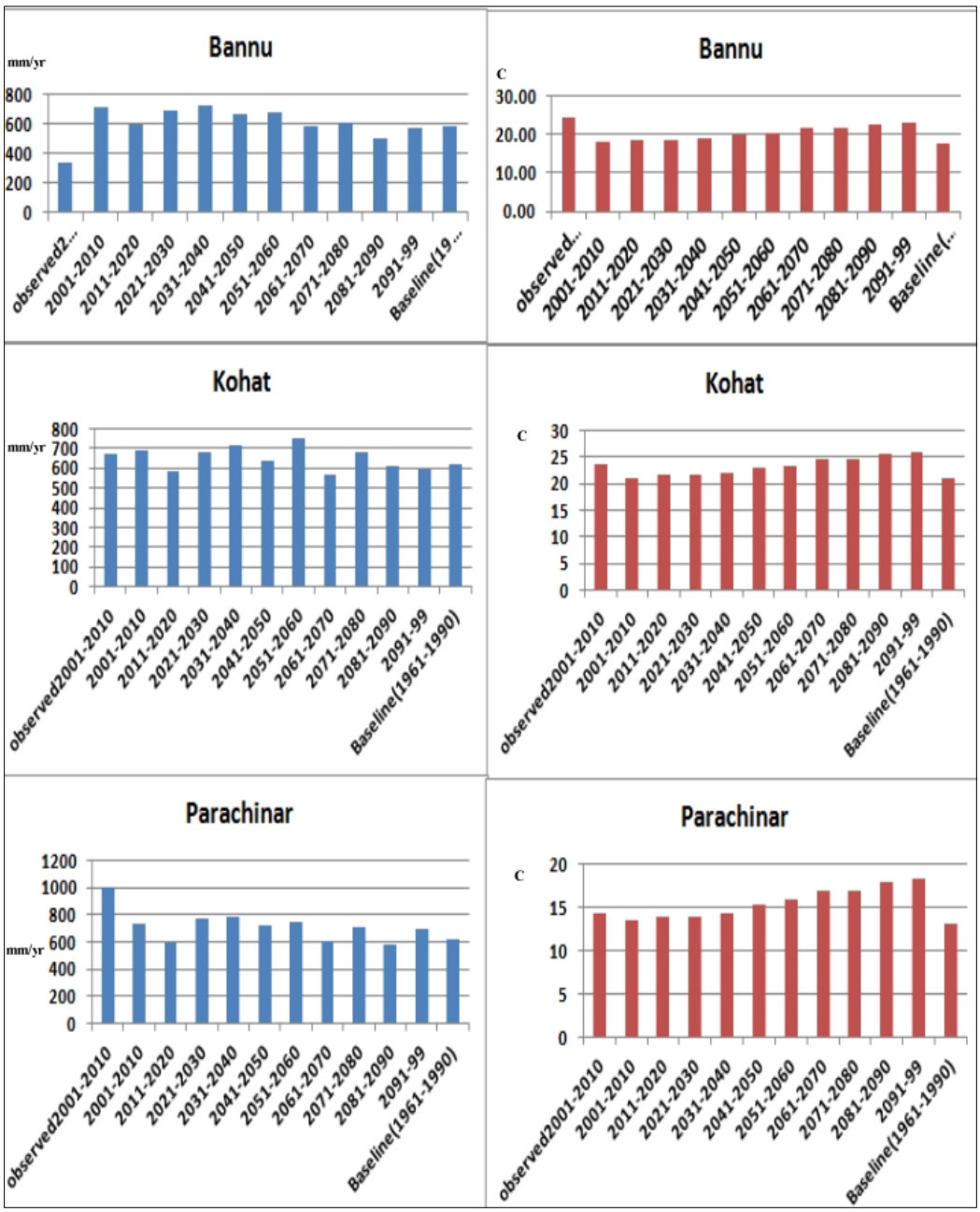


Figure 2-8: Future Precipitation and Temperature Projections of Project Area Cities by Pakistan Metrological Dept GCM and Observed Meteorological Data for 2001-2010

Precipitation is showing an increasing trend until 2040, then a declining trend in Bannu and Parachinar future projections is observed, whereas in Kohat it shows an increasing trend till 2060, and then decreasing trend is postulated after this year.

For 2010-202 decade Parachinar data was further analyzed on monthly basis and following variations were noticed in the GCM data (**Figure 2-9**).

This page intentionally left balnk

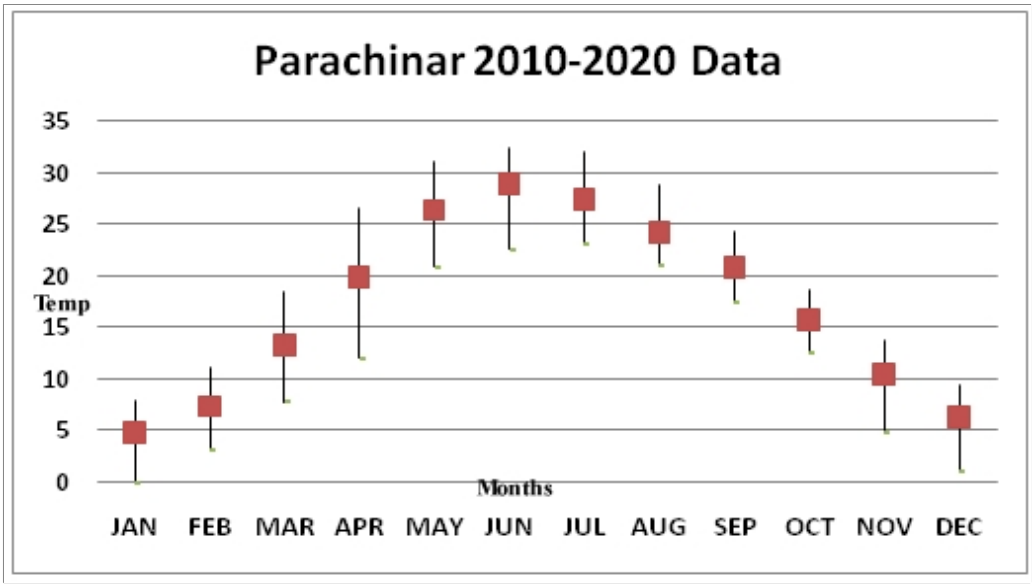


Figure 2-9: Maximum, Minimum and Mean Temperature Data for Different Months for 2010-2020 Decades for Parachinar, Kurram Agency, Pakistan

This page intentionally left balnk

3 GCM DATA ANALYSIS BY GCISC ISLAMABAD

Global Change Impact Study Center Islamabad (Siraj ul Islam et.al) have analyzed seventeen different GCM data for Kabul and Jhelum River watersheds (**Figure 3-1**). Kurram Tangi water shed also falls in Kabul River zone. **Table 3-1** shows the projected temperature change over Kabul basin.

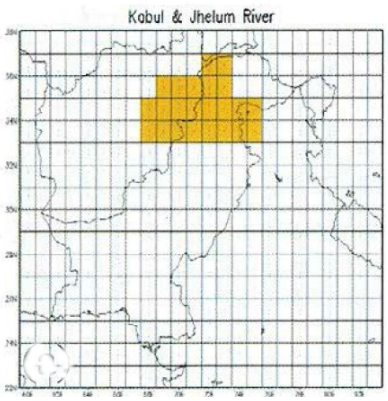


Figure 3-1: River Jhelum and Kabul Catchment Areas

The rise in the temperature of 2.81^0 C for 2050 in A2 scenario, whereas in A1B scenario, the fall of 4.14 °C in 2050s is projected, simulated by ensemble of the seventeen GCMs.

Table 3-1: Projected Temperature Change ΔT (°C) by Seventeen GCMs over Kabul

	A2			AIB		
	2020s	2050s	2080s	2020s	2050s	2080s
UKMO-HadCM3	1.35	2.94	5.22	6.1	-4.69	3.54
PCM-NCAR	0.9	1.68	3.09	-0.99	-0.2	-2.08
CCSM3-NCAR	1.76	2.94	4.79	14.9	14.11	18.95
MRI-CGCM2.3.2	1.17	2.37	3.77	-3.56	6.59	3.69
ECHAM5/MPI-OM	1.22	2.72	5.38	-5.05	-21.79	-18.33
MIROC3.2 (hires)	2.11	3.58	5.4	0.74	13.38	-11.66
IPSL-CM4	1.37	2.82	5.18	1.8	-8.6	-5.39
INM-CM3.0	2.08	3.44	5.07	-13.11	-16.09	-26.33
GISS_ER	1.53	2.77	4.47	-2.85	-5.66	-10.27
GFDL-CM2.1	1.85	3.2	5.4	-9	-11.74	-14.12
GFDL-CM2.0	1.87	3.72	6.12	-5.52	-13.73	-18.06
CSIRO-MK3.0	1.25	2.18	3.83	-3.36	4.55	7.36
CNRM-CM3	1.2	2.62	4.55	-1.75	2.85	3.37
GISS_AOM	---	---	---	0.84	-2.28	3.99
GISS_EH	---	---	---	-6.03	-6.3	-14.65
FGOALS-g1.0	---	---	---	-0.44	0	-11.43
MIROC3.2 (medres)	---	---	---	5.29	6.01	10.44
(X ± ΔX)	1.5 ± 0.11	2.81 ± 0.16	1.79 ± 0.23	1.29 ± 1.54	-4.14 ± 2.29	-4.76 ± 2.95

Table 3-2 shows the precipitation change in different decades. In A2 scenario, up to 2050 no significant change is expected, whereas by 2080s, a reduction of 3.4% in precipitation is expected in

this scenario. Whereas in A1B scenario, a rise in precipitation by over 4% is expected in 2050s and 2080s scenarios. This interpretation is in line with the observed future predictions.

Table 3-2: Projected Precipitation Changes, ΔP (%) by Seventeen GCMs Kabul

GCMS	A2			AIB		
	2020s	2050s	2080s	2020s	2050s	2080s
UKMO-HadCM3	9.91	16.69	-3.11	6.1	-4.69	3.54
PCM-NCAR	4.04	5.09	1.74	-0.99	-0.2	-2.08
CCSM3-NCAR	11.12	18.24	33.82	14.9	14.11	18.95
MRI-CGCM2.3.2	9.47	9.59	9.05	-3.56	6.59	3.69
ECHAM5/MPI-OM	-4.75	-5.49	-5.82	-5.05	-21.79	-18.33
MIROC3.2 (hires)	-0.23	-5.37	4.04	0.74	-13.38	-11.66
IPSL-CM4	4.33	-0.01	-3.54	1.8	-8.6	-5.39
INM-CM3.0	-10.86	13.81	-22.53	-13.11	-16.09	-26.33
GISS_ER	-1.51	-3.99	-16.28	-2.85	-5.66	-10.27
GFDL-CM2.1	-2.3	-4.9	-18.22	-9.9	-11.74	-14.12
GFDL-CM2.0	-8.71	-16.02	-28.84	-5.52	-13.73	-18.06
CSIRO-MK3.0	7.34	0.41	2.44	-3.36	4.55	7.36
CNRM-CM3	3.6	-0.3	3.11	-1.75	2.85	3.37
GISS_AOM	---	---	---	0.84	-2.28	3.99
GISS_EH	---	---	---	-6.03	-6.3	-14.65
FGOALS-g1.0	---	---	---	-0.44	0	-11.43
MIROC3.2 (medres)	---	---	---	5.29	6.01	10.44
(X ± ΔX)	1.65 ± 1.96	0.01 ± 2.86	-3.40 ± 4.46	1.29 ± 1.54	4.14 ± 2.29	4.76 ± 2.95

Table 3-3 shows the 2036-2065 (2050's) projected monthly percentage precipitation change simulated by ensemble of 17 GCMs over River Kabul and Jhelum Basins.

Table 3-3: Projected Monthly Precipitation Changes, ΔP (%) by Seventeen *GCMs* over Kabul and Jhelum River Basins

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.18	-12.2	-12.04	-7.55	-13.74	-6.03	1.32	13.11	-0.39	-1.8	1.72	-2.47
±5.50	±4.18	±3.41	±4.32	±4.35	±5.89	±5.15	±8.61	±7.02	±8.33	±4.15	±3.21

The same monthly precipitation change is reflected on **Figure 3-2** for A1B scenario. No clear cut picture can be drawn because of low percentage change and generally large uncertainties associated with them, as reflected in the table as well as in the figure.

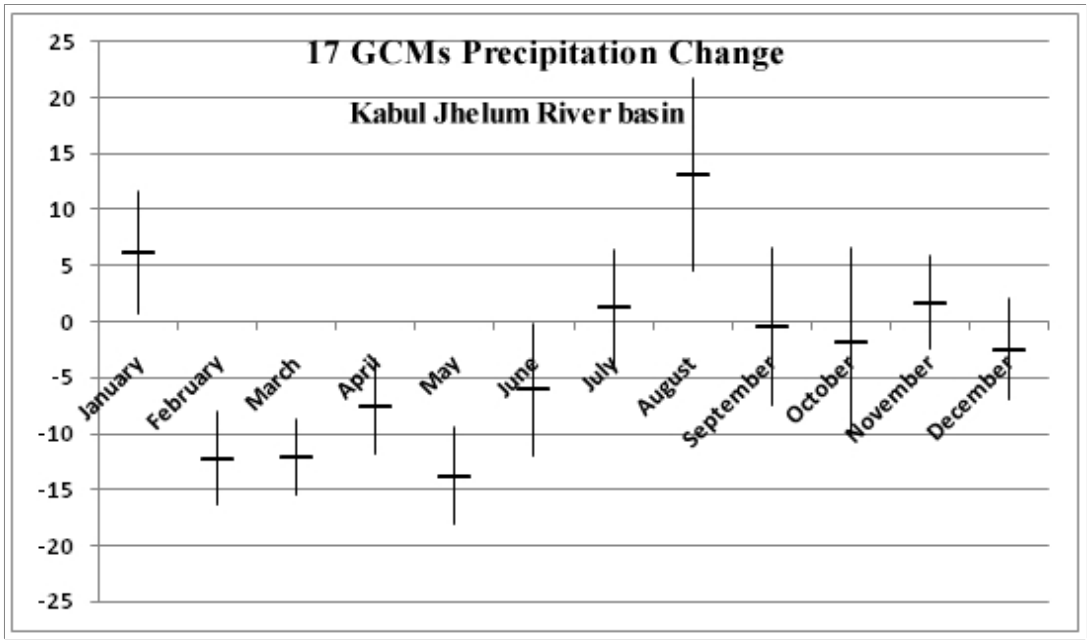


Figure 3-2: Projected Monthly Precipitation Changes, ΔP (%) by Seventeen *GCMs* over Kabul & Jhelum River Basin, Pakistan

This page intentionally left balnk

4 UNIVERSITY OF WASHINGTON GCMS ANALYSIS

The GCM model shown on **Figure 4-1** and **Figure 4-2** are taken from http://www.climatewizard.org/ prepared by the University of Washington, USA. Its map data Sources are Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community. The map shows the temperature change by the middle model. That is, half of the models predict a greater amount of change and half of the models project less change as compared to 1961-1990 baseline. It also reflects that there is 2 to 4 °C change in the temperature till 2080 (2070-2090) with increased precipitation of around 20 mm annually. It is worthy to mention that the parameters used are for A2 scenario, which means slowest and most fragment development, with lowest per capita growth and population is increasing.

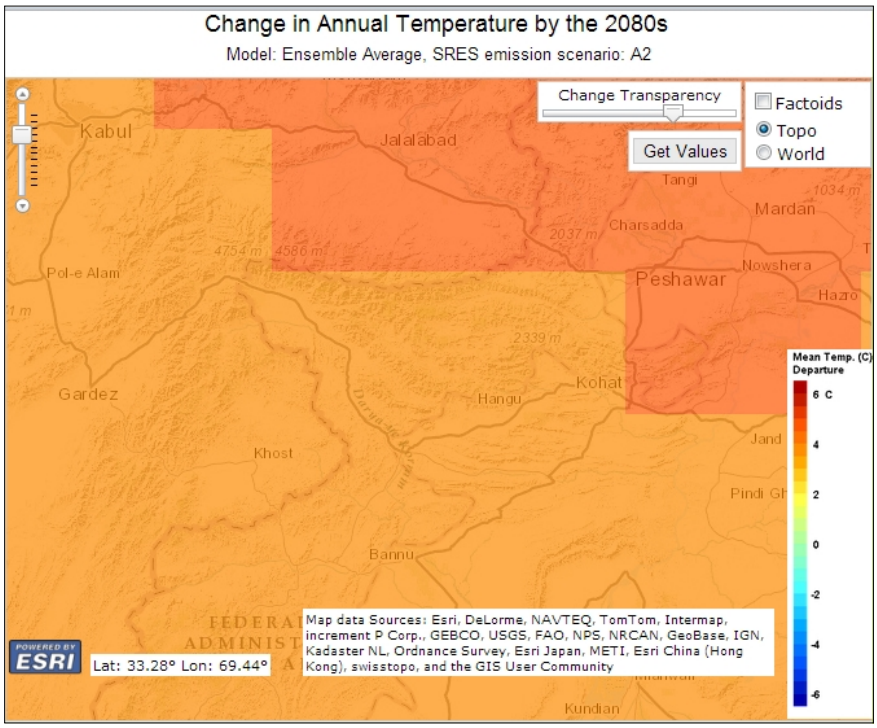


Figure 4-1: Change in Annual Temperature by 2080 Using Twenty Different GCM Data and Taking Middle Value for Plotting

This page intentionally left balnk

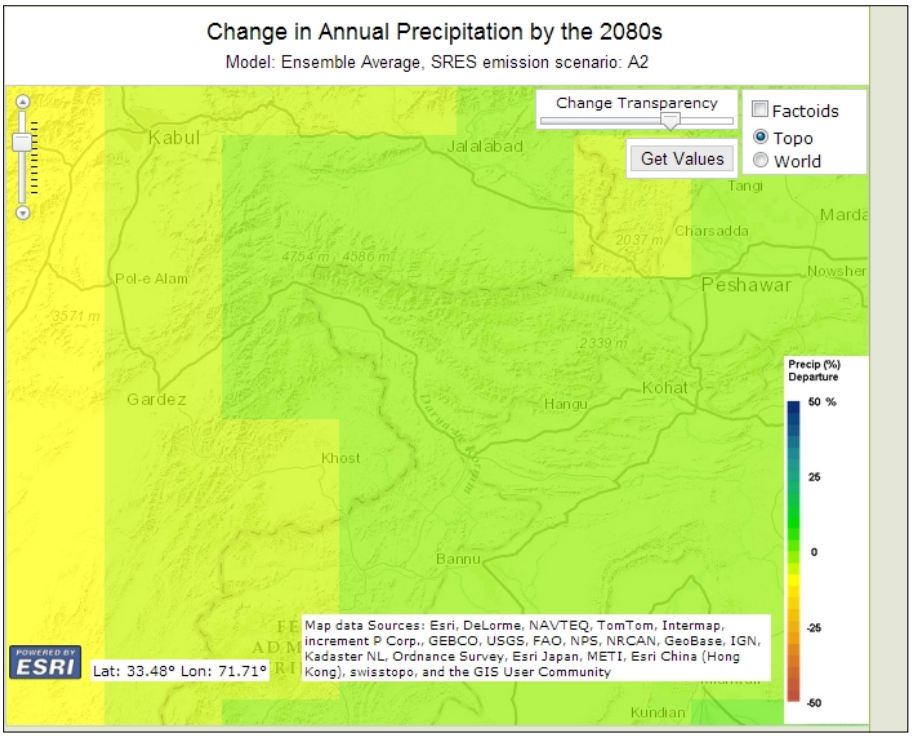


Figure 4-2: Change in Annual Precipitation by 2080 Using Twenty Different GCM Data and Taking Middle Values for Plotting

The precipitation change for A1B scenario for different months by different GCM given by University of Washington for Latitude 33° 45' and Longitude 70° 45' for 2080 is given in **Table 4-1** and is represented on **Figure 4-3**.

Table 4-1: Ensemble Precipitation Average for Different Months of the Year by University of Washington for Kurram Tangi Catchment Area

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
bccr_bcm2_0.1	-26	13	-11	-21	22	3	-14	46	1	-22	-6	-25
cccma_cgcm3_1.1	9	-26	-35	-30	-31	34	21	-3	4	33	18	47
cnrm_cm3.1	-17	-4	0	-6	23	-20	7	38	18	39	40	7
csiro_mk3_0.1	15	8	-20	-12	6	-8	17	27	-7	29	56	27
gfdl_cm2_0.1	-11	-35	-20	-6	-33	-11	-25	-49	-25	1	-64	-15
gfdl_cm2_1.1	-24	-27	-8	-33	-36	-8	13	-22	6	14	-21	-49
giss_model_e_r.1	-10	-31	-12	-35	-6	19	6	-4	-12	0	-47	-26
inmcm3_0.1	-33	-22	-34	-42	-33	-8	-9	6	-1	-5	-50	8
ipsl_cm4.1	69	6	-29	-14	-47	-22	-20	14	-33	-13	13	-10
miroc3_2_medres.1	-34	-23	-24	-28	-27	5	8	1	34	82	0	-16
miub_echo_g.1	-23	-2	-23	-33	-38	-38	-35	-4	-27	-26	27	41
mpi_echam5.1	-27	-33	-14	-12	-6	12	21	33	23	-2	-3	-23
mri_cgcm2_3_2a.1	15	23	-11	-15	-27	-18	-20	72	-12	3	45	26
ncar_ccsm3_0.1	-12	-28	-5	-15	15	65	43	72	68	85	112	-10
ncar_pcm1.1	-3	-34	-19	-12	-7	11	22	95	1	31	30	-15
ukmo_hadcm3.1	-11	3	-3	-10	-36	-15	25	77	44	-16	65	-10
Max	69	23	0	-6	23	65	43	95	68	85	112	47
Mean	-7.7	-13.3	-16.8	-20.3	-16.3	0.1	3.8	24.9	5.1	14.6	13.4	-2.7
Min	-34	-35	-35	-42	-47	-38	-35	-49	-33	-26	-64	-49

This page intentionally left balnk

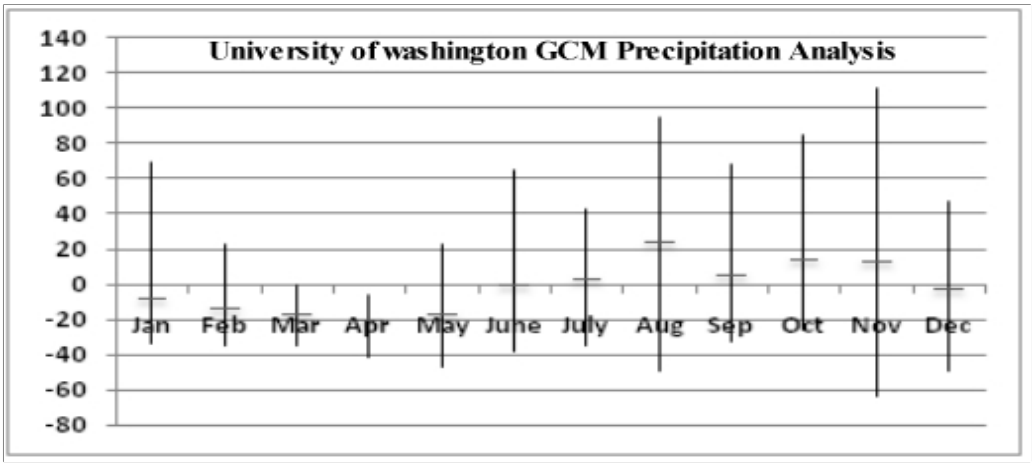


Figure 4-3: Deviation from the Mean Value of Monthly Precipitation Change in Kurram Tangi Area, Pakistan by University of Washington Analysis

The temperature change for A1B scenario for different months by different GCM given by University of Washington for Latitude 33° 45' and Longitude 70° 45' for 2080 is given in **Table 4-2** and is represented on **Figure 4-4**.

Table 4-2: Ensemble Temperature Average for Different Months of the Year by University of Washington for Kurram Tangi Catchment Area

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
bccr_bcm2_0.1	2.99	3.77	2.41	3.41	2.98	3.75	3.32	2.76	3.01	2.72	2.77	2.82
cccma_cgcm3_1.1	5.05	5.65	5.76	5.53	5.56	4.55	3.83	4.01	4.29	4.01	3.99	4.48
cnrm_cm3.1	2.69	3.07	4.16	5.83	4.16	4.35	3.57	3.13	3.86	4.23	2.88	2.03
csiro_mk3_0.1	3.02	2.79	3.47	3.51	2.86	3.37	3.25	3.46	3.56	3.1	2.7	2.22
gfdl_cm2_0.1	4.48	5.08	4.93	4.66	5.11	5.79	4.5	5.62	5.71	5.23	4.55	5.14
gfdl_cm2_1.1	5.17	4.12	3.87	4.08	4.52	4.72	4.45	5.35	4.61	4.27	4	4.5
giss_model_e_r.1	2.98	3.45	4.22	4.12	4.27	3.93	3.89	4.49	4.6	3.8	4.54	4.39
inmcm3_0.1	3.74	4.53	3.04	2.31	3.46	3.53	4.48	4.49	3.82	4.58	3.75	4.16
ipsl_cm4.1	5.51	6.9	5.79	4.35	4.8	4.45	4.69	5.01	4.91	4.33	4.69	4.79
miroc3_2_medres.1	5.78	7	6.16	4.85	4.96	5.51	4.71	4.74	5.33	4.65	4.08	4.53
miub_echo_g.1	5.3	5.5	4.48	5.54	5.29	6.27	5.81	5.26	5.07	4.91	4.25	5.22
mpi_echam5.1	5.58	5.79	5.33	5.22	5.07	5.42	5.28	5.41	5.38	5.46	4.31	4.26
mri_cgcm2_3_2a.1	4.11	3.33	2.89	3.02	3.62	4.28	3.9	4.16	4.34	3.8	3.08	2.82
ncar_ccsm3_0.1	3.88	4.36	3.84	4.99	3.91	2.16	1.83	2.58	3.15	3.16	3.35	3.46
ncar_pcm1.1	3.16	2.26	2.11	2.8	2.9	2.57	2.28	1.94	2.44	2.59	2.97	2.28
ukmo_hadcm3.1	6.08	4.97	4.63	4.21	5.83	4.6	4.28	3.88	4.38	3.8	3.27	5.21
Max	6.08	7	6.16	5.83	5.83	6.27	5.81	5.62	5.71	5.46	4.69	5.22
Mean	4.35	4.54	4.19	4.28	4.33	4.33	4.00	4.14	4.28	4.04	3.70	3.89
Min	2.69	2.26	2.11	2.31	2.86	2.16	1.83	1.94	2.44	2.59	2.7	2.03

This page intentionally left balnk

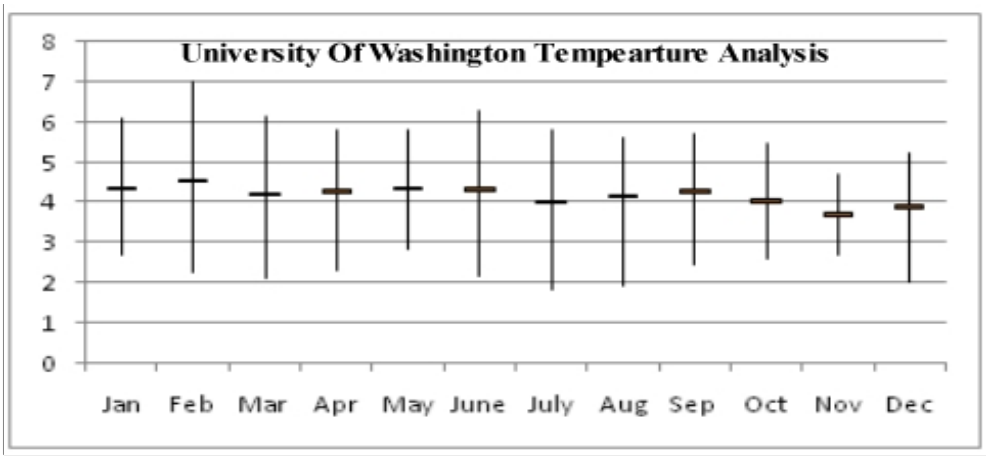


Figure 4-4: Deviation from the Mean Value of Monthly Temperature Change in Kurram Tangi Area by University of Washington Analysis

It is evident that maximum temperature change till the end of the century is expected to be around 4 °C. While the precipitation parameters shows a lot of uncertainty.

This page intentionally left balnk

5 SYNTHESIS OF CLIMATE DATA

The above described analyses represent individual research efforts to understand the possible climate trends which have occurred, and are likely to occur in the future. Each represents a unique set of assumptions and modeling capabilities. In order to assess the possible climate changes for the purposes of this project it is necessary to look across all of this analysis and observe the generalized trends.

An attempt has also been made to correlate River Kurram flow at Thal, with the precipitation and temperature at Parachinar. **Figure 5-1** shows the yearly precipitation in mm/yr at Parachinar vs the annual river flow at Thal in thousand cubic meters, and an acceptable correlation is seen between river flows and precipitation in that area. Just for comparison sake, whether temperature influence river flows, in the same figure, a correlation is attempted between Kurram River flow at Thal with Parachinar annual temperature. In 1985 a very severe cold is felt in Parachinar, but has hardly affected the river flows. Similarly for period 1998-2002 while temperature was high, but river flows were minimal, hence correlation between both parameters, i.e. river flow and temperature of that valley is difficult. It is a known fact that the melting of snow at Koh-i-Safaid do contribute to river flows of Kurram River, but precipitation has more pronounced effect as compared to change in temperature. Probably the snowline in Kurram is at around 3,900 meters, and the seasonal snow below this line is a direct contribution of the precipitation, and its melting by temperature rise has no direct bearing on river flows.

This page intentionally left balnk

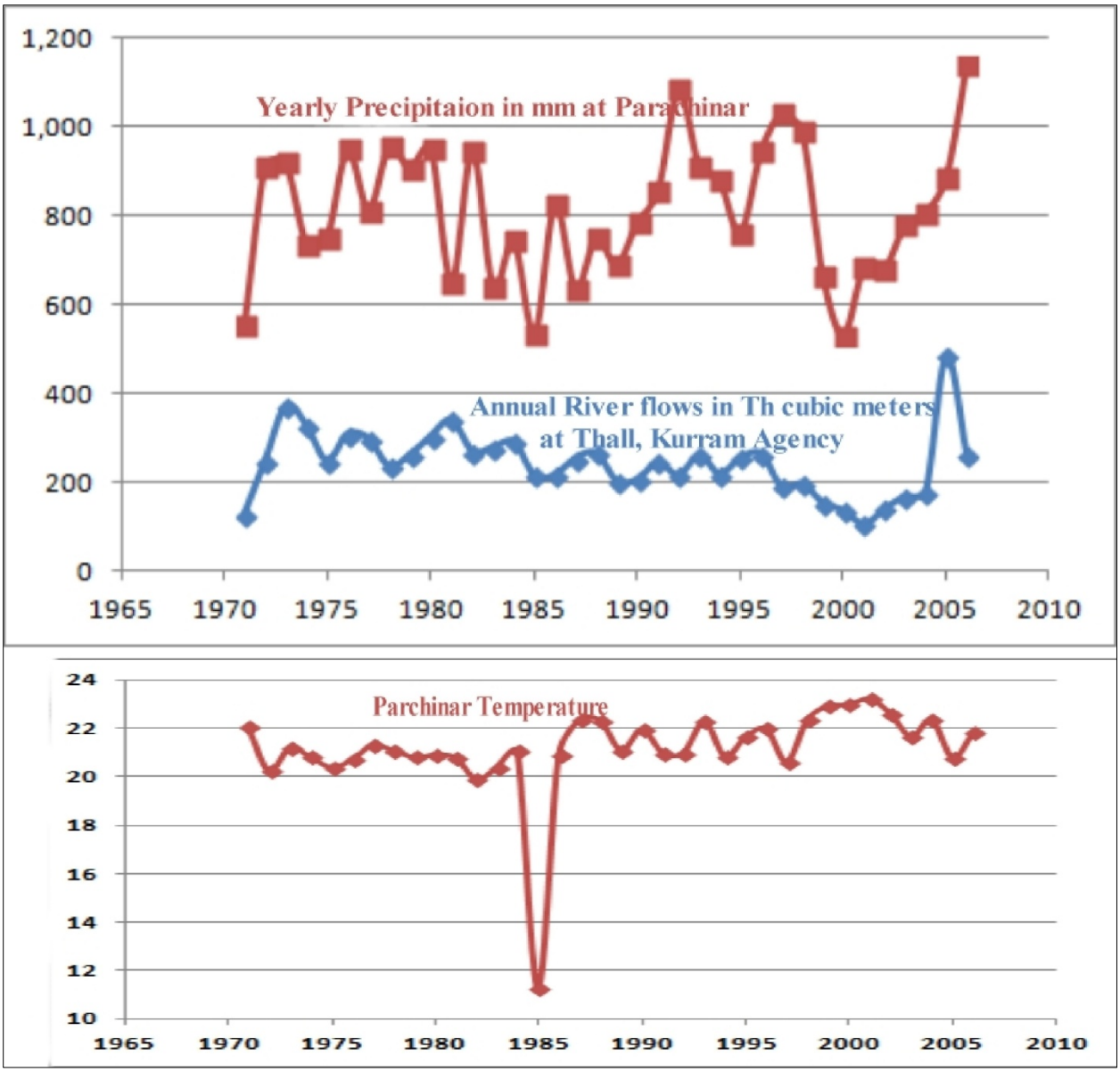


Figure 5-1: Yearly Precipitation, Kurram River Flow at Thal, and Maximum Temperature at Parachinar for the Period from 1971 to 2006.

The projections of PMD GCM PRECIS-25Kms 1961-2100 and ECHM5 data set figures are also presented on **Figure 2-4** to **Figure 2-7**. If we compare the historic trend line from the Meteorological Stations to the PMD GCM Baseline we can observe how close the modeled GCM data is to the actual met station data as discussed above and presented on **Figure 2-8**. This allows us to have some understanding of possible deviations in the GCM projected data.

Figure 5-2 shows a continued graph regarding precipitation's observed and GCM data of Pakistan Meteorology Department and University of Washington data for Bannu, Kohat and Parachinar. A very nice correlation is observed in all these data set for Kohat and Bannu. However, Parachinar is an exception. The precipitation projections for Parachinar by PMD and University of Washington show a straight line meaning little change in future scenario, whereas the observed data trend line shows a slight rising trend in the future. There is a little deviation of Y parameter in observed and projected values, but keeping the fact in mind that the observed stations coordinates don't tally with the GCM grid coordinates for these stations, one is bound to accept this little shift. Gardez data can't be added due to scanty observed data available for that station.

This page intentionally left balnk

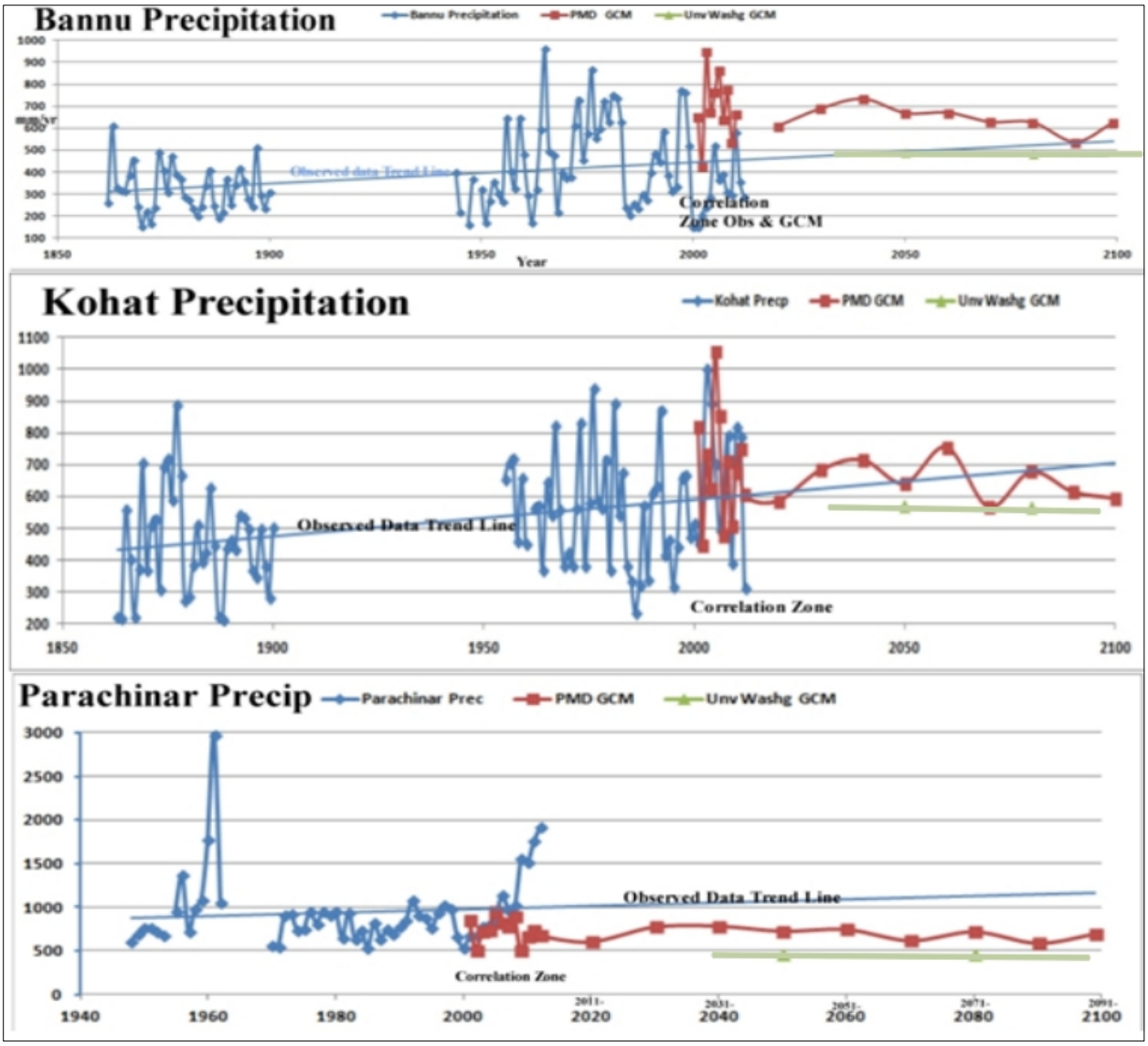


Figure 5-2: Observed and GCM Precipitation Data for Bannu, Kohat, and Parachinar, and their Correlation for the Period from 2001 to 2012

The observed and GCM temperature data of Pakistan Meteorology Department and University of Washington data for Bannu, Kohat and Parachinar is presented on **Figure 5-3**. A very nice correlation is observed in all stations except in Parachinar data for the period from 2001-2012. In Parachinar case, the future projections show an upward trend, whereas Observed shows a downward trend. As an analyst one always rely on the observed data parameters, hence this projection of GCM data may not be true. There is a again little deviation of Y parameter like we observed in precipitation graph, but keeping the fact in mind that the observed stations coordinates don't tally with the GCM grid coordinates for these stations, one is bound to accept this little shift. Gardez data can't be added due to scanty observed data available for that station.

This page intentionally left balnk

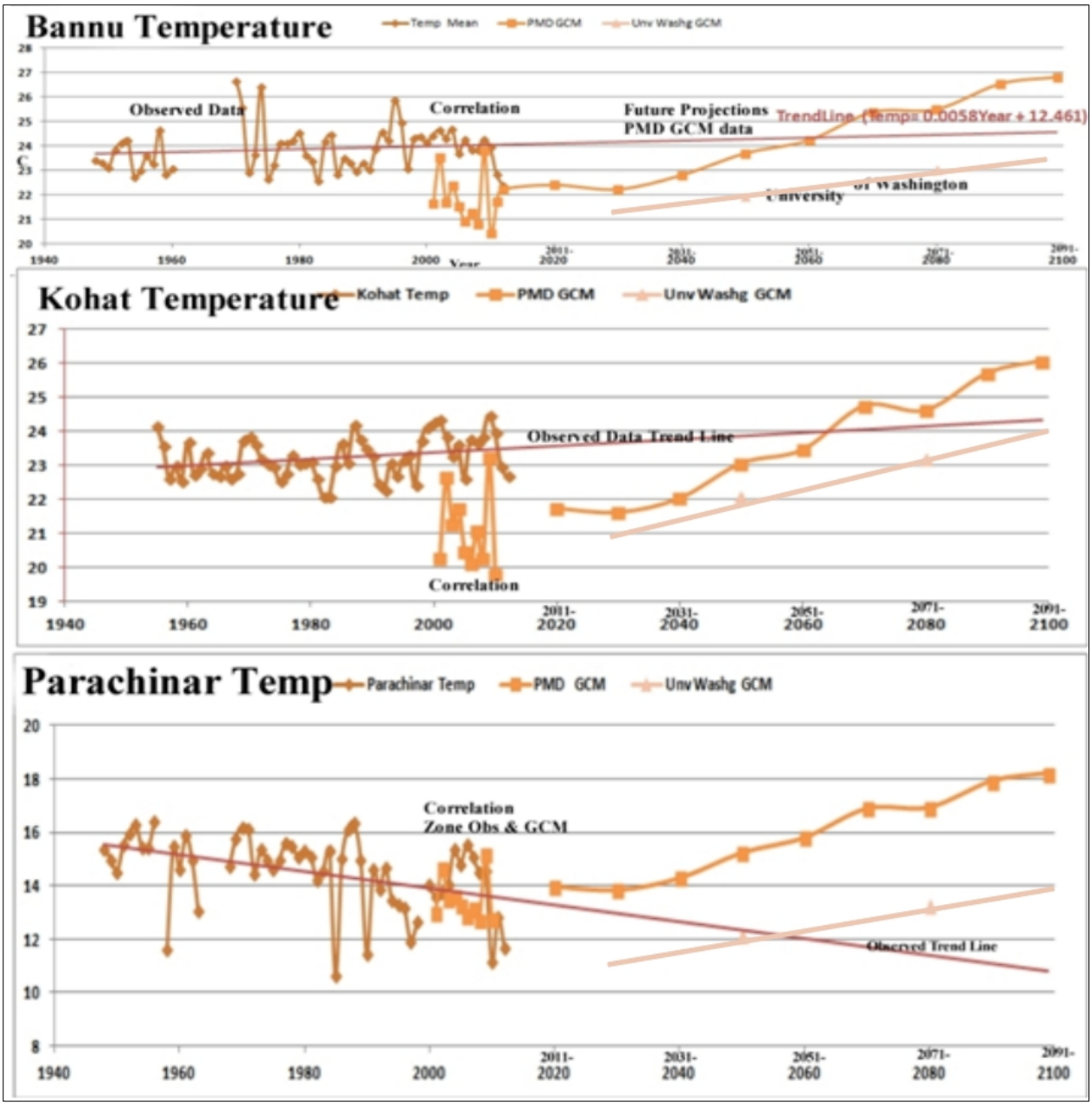


Figure 5-3: Observed and GCM Precipitation Data for Bannu, Kohat, and Parachinar, and their Correlation for the Period from 2001 to 2012

Summing up all the data interpretation, it is noted that like whole of Pakistan, a 4 °C rise in temperature in the project area is expected gradually by the end of the century. However, precipitation shows a mixed trend. Observed data indicates a rising trend in precipitation, 17 GCM data of Kabul River Basin, interpreted by the Global Change Impact Study Centre, shows a 4% increase in precipitation by the end of the century **Table 3-2**, PMD and University of Washington shows a steady behavior of the precipitation (neither decrease nor increase) in the project area by the end of century.

This page intentionally left balnk

6 REFERENCES

See references in the Supplemental Main Report on Climate Change.

This page intentionally left balnk

USAID | PAKISTAN
FROM THE AMERICAN PEOPLE

Kurram Tangi Dam Construction

Supplemental Report on Climate Change

Annexure 3: Global Climate Change Perspective

December 2013
This publication was produced for review by the United States Agency for International Development.
It was prepared by MWH-NESPAK-ACE under contract AID-391-C-13-00002

This page intentionally left balnk

List of Acronyms

Abbreviations/Acronym	Term
ac-ft	Acre Feet
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
FAO	Food and Agriculture Organization
FATA	Federally Administered Tribal Areas
GCM	Global Circulation Model
GCISC	Global Change Impact Study Center
GEBCO	General Bathymetric Chart of the Oceans
GHG	Greenhouse Gas
GIS	Geographic Information System
GoP	Government of Pakistan
ICTP	International Centre for Theoretical Physics
ICOLD	International Commission on Large Dams
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
km	Kilometers
KP or KPK	Khyber Pakhtunkhwa
KTDC	Kurram Tangi Dam Construction
KTMDP	Kurram Tangi Multipurpose Dam Project
MCM	Million Cubic Meter
MWH	MWH Global, Inc. or MWH, Inc.
NESPAK	National Engineering Services Pakistan
NGO	Non-governmental Organization
NPS	National Park Service (USA)
NRCAN	Natural Resources Canada
PMD	Pakistan Meteorological Department
PPM	Parts Per Million
RCM	Regional Climate Model
SDSM	Statistical Downscaling Model
TGP	Towards Gender Party
UET	University of Engineering and Technology
UN	United Nations
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USAID/Pak	United States Agency for International Development/Pakistan
USGS	United States Geological Survey
WAPDA	Water and Power Development Authority
°C	Degree Celsius

This page intentionally left balnk

Table of Contents

1 INTRODUCTION 1-1
2 CLIMATE CHANGE IMPACTS 2-1
3 GLOBAL WARMING 3-1
4 NATURAL FACTORS CONTRIBUTION IN CLIMATE CHANGE 4-1
4.1 Continental Drift 4-1
4.2 Volcanoes 4-1
4.3 Thermohaline Circulation of Sea 4-1
4.4 The Earth's Tilt 4-2
4.5 Solar Radiation 4-2
5 GHG EMISSION/HUMAN CONTRIBUTION IN CLIMATE CHANGE 5-1
5.1 Carbon Cycle 5-2
5.2 Carbon Storage 5-4
5.3 Past, Present and Future: Emission Trends 5-5
6 REFERENCES 6-1

List of Figures

Figure 2-1: Global Warming Leading to Other Changes 2-1
Figure 2-2: Sea Level Rise due to Global Warming (Source: IPCC Report, 2007) 2-2
Figure 3-1: Global Mean Temperature 3-1
Figure 5-1: Level of Carbon Dioxide in the Atmosphere 5-2
Figure 5-2: An Overview of the Geological Carbon Storage Options 5-5
Figure 5-3: Comparison of Historical Carbon Dioxide Concentration with Temperature 5-7
Figure 5-4: Global Trend in Temperature 5-8

List of Tables

Table 3-1: Highlight of Possible Climate Change Impacts 3-3
Table 5-1: Carbon Pools in the Major Reservoirs on Earth 5-3

This page intentionally left balnk

1 INTRODUCTION

Climate change is already taking place, and in South Asian countries, particularly the poorest people living there, are most at risk. Five major risks related to climate change are rise in sea level, glacial retreat, floods, higher average temperatures, and high frequency of droughts. The objective of the Annex is to present a literature review of the climate change and its impact from a global perspective.

This page intentionally left balnk

2 CLIMATE CHANGE IMPACTS

The effects of minor levels of climate change are already being felt, with impacts across many economic sectors. **Figure 2-1** shows a correlation of changes in other sectors by climate change. Some of those effects are described in the following paragraphs.

1. Water: Rising global temperatures will lead to an intensification of the hydrological cycle, resulting in dryer dry seasons and wetter rainy seasons, and subsequently heightened risks of more extreme and frequent floods and drought. Changing climate will also have significant impacts on the availability of water, as well as the quality and quantity of water that is available and accessible. Melting glaciers will increase flood risk during the rainy season, and strongly reduce dry-season water supplies to one-sixth of the World's population.
2. Rising global temperatures lead to other changes around the world, such as stronger hurricanes, melting glaciers, and the loss of wildlife habitats. That's because the earth's air, water, and land are all related to one another and to the climate. This means that a change in one place can lead to other changes somewhere else. For example, when air temperatures rise, the oceans absorb more heat from the atmosphere and become warmer. Warmer oceans, in turn, can cause stronger storms.

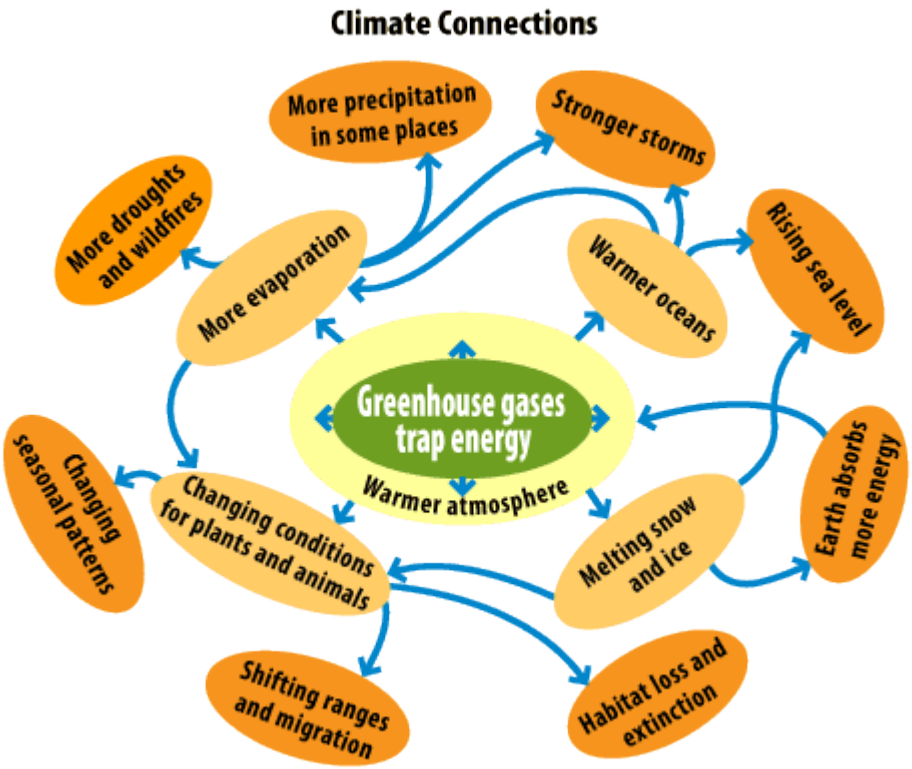


Figure 2-1: Global Warming Leading to Other Changes

3. Agriculture: Declining crop yields are likely to leave hundreds of millions without the ability to produce or purchase sufficient food supplies, especially in Africa. At mid to high latitudes, crop yields may increase for low levels of change in temperature, but will decline at higher levels of temperature change.
4. Ecosystems: Changing temperatures will cause ecosystems to shift – forests, land types and plant species will dieback in some areas as temperatures rise, but increase in other areas. However, in many cases, the pace of change in temperature may be too fast for ecosystems to adjust, resulting in the loss of forests and species.
5. Health: Higher temperatures expand the range of some dangerous vector-borne diseases, such as malaria, which already kills one million people annually, most of whom are children in

This page intentionally left balnk

the developing world. Further, heat waves associated with climate change, and increases in water borne diseases, will result in increased health problems.

6. Coastlines: Melting ice and thermal expansion of oceans are the key factors driving sea level rise. **Figure 2-2** shows a range of projected sea level rise due to global warming. In addition to exposing coastlines, where the majority of the human population lives, to greater erosion and flooding pressures, rising sea levels will also lead to salt water contamination of groundwater supplies, threatening the quality and quantity of freshwater access to large percentages of the population. For example, according to some estimates a 1 meter rise in sea level will displace 80% of the population of Guyana.

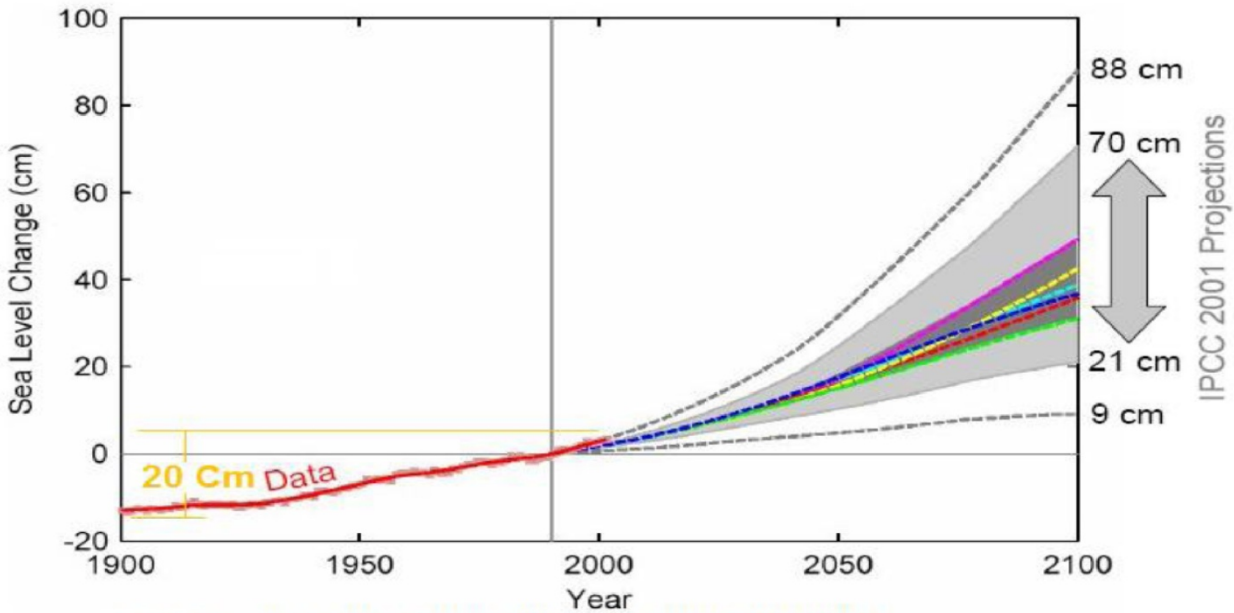


Figure 2-2: Sea Level Rise due to Global Warming (Source: IPCC Report, 2007)

The World Health Organization has identified potential health impacts from global climate change via three pathways:

1. Direct impacts (such as exposure to pollutants);
2. Impacts mediated by ecosystems (such as malnutrition and increased risk of infectious diseases); and
3. Indirect, deferred, and displaced impacts (such as health consequences of livelihood loss).

All of the studies on climate change suggest the worst impacts will be felt by the poorest people. Mary Robinson, the former Irish president, said, "Climate change is already having a domino effect on food and nutritional security for the world's poorest and most vulnerable people. Child malnutrition is predicted to increase by 20% by 2050. Climate change impacts will disproportionately fall on people living in tropical regions, and particularly on the most vulnerable and marginalized population groups. This is the injustice of climate change – the worst of the impacts are felt by those who contributed least to causing the problem."

This page intentionally left balnk

3 GLOBAL WARMING

On a global scale, the following data provides a glimpse for scientists (Arshad, 2008):

- 0.6 °C increase in average global temperature during the last century;
- Warmest twelve years: 2005, 2007, 1998, 2002, 2003, 2006, 2004, 2001, 1997, 1995, 2000, 1999 (Yellow curve, **Figure 3-1**);

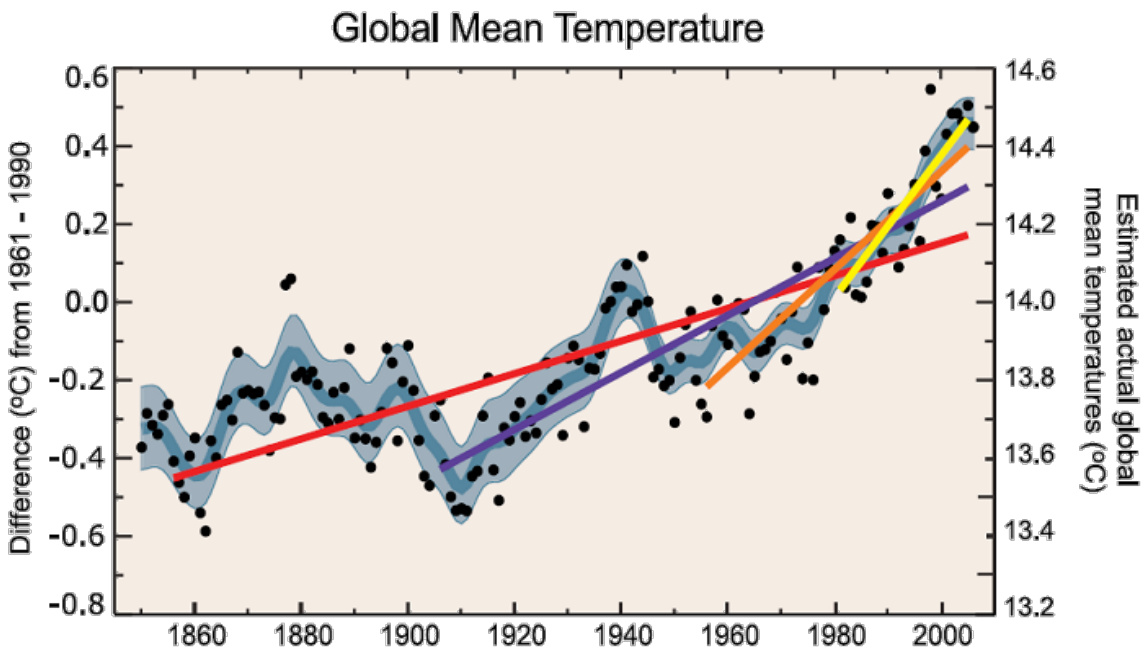


Figure 3-1: Global Mean Temperature

- Further increase by 1.8 – 4 °C projected over the 21st century;
- Associated to the above will be large changes (both, increases and decreases) of temperature and precipitation in different world regions;
- Frequency and intensity of extreme climatic events (severe cyclonic storms, floods, droughts etc.) will increase considerably;
- Large scale melting of mountain glaciers and polar ice caps, particularly the Arctic; and
- Substantial rise in sea level.

The Australian, a broadsheet newspaper published in Australia, in its issue of 22nd April 2013 published that the earth was cooling until the end of the 19th century and a hundred years later the planet's surface was on average warmer than at any time in the previous 1,400 years, according to climate records. In a study spanning two millennia published in Nature Geoscience, scientists say a "long-term cooling trend" around the world swung into reverse in the late 19th century. In the 20th century, the average global temperature was 0.4 °C higher than that of the previous 500 years, with only Antarctica bucking the trend. From 1971-2000, the planet was warmer than at any other time in nearly 1,400 years. This measure is a global average, and some regions did experience warmer periods than that - but only for a time. Europe, for instance, was probably warmer in the first century AD than at the end of the 20th century. The investigation is the first attempt to reconstruct temperatures over the past 2,000 years for individual continents. US Paleoclimatologist Professor Michael Mann in his book 'The hockey stick and climate wars' has advocated his stance in the 2001 report on global climate, the Intergovernmental Panel on Climate Change of the United Nations prominently featured the "Hockey Stick," a chart showing global temperature data over the past one thousand years. The Hockey Stick demonstrated that temperature had risen with the increase in industrialization and use of fossil fuels. The inescapable conclusion was that worldwide human activity since the industrial age had raised CO_2 levels, trapping greenhouse gases in the atmosphere and warming the planet.

The world was warmer, by around 2-3 °C. The tropics were wetter, sea levels were higher, there is less ice and CO_2 levels are rising above present levels. It happened just over 3.2 million years ago, in a period of our planet's history known as the Pliocene. All this happened in a narrow time frame of 10,000 years at that time (http://www.bbc.com/future/story/20130424-a-vision-of-our-future-climate). Understanding how the planet reacted to higher CO_2 levels in the past is an important step. Throughout its history, the earth's climate and the amount of carbon dioxide in the atmosphere has changed naturally. "Changes in the levels of CO_2 are caused by several unrelated processes," says Dr. James Riding at the British Geological Survey. "Volcanoes, plants and animals, destabilization of the oceans, methane in the sea floor, these are all natural mechanisms for altering CO_2." However, the increase since the industrial revolution has been larger than it should by these natural causes alone. So, the narrower the timeframe in the past, the better the information to put into climate models. "What we had was a shopping list of criteria that needed to be met," says Professor Alan Haywood, a palaeoclimate modeler of the University of Leeds, who led the research. "By looking at sediment records we are able to understand how the earth's climate has changed," adds Dr. Erin McClymont, a physical geographer at the University of Durham, also part of the research team. "To narrow down on the interval, we look at oxygen isotopes in the chemistry of shells." This is because carbonate built by organisms use the sea to make shells and the chemistry of the sea changes in response to changes in our environment. All this information then had to be combined with models of the earth's orbit and things such as stomata in leaves (which react to changes in CO_2 levels), to create a more complete global inventory. "It all became a bit of a detective story," says Haywood. **Table 3-1** provides more detail on the kinds of impacts that are predicted to occur at different increases in global average temperatures.

Table 3-1: Highlight of Possible Climate Change Impacts

Temp rise (°C)	Water	Food	Health	Land	Environment	Abrupt and Large-Scale Impacts
1°C	Small glaciers in the Andes disappear completely, threatening water supplies for 50 million people	Modest increases in cereal yields in temperate regions	At least 300,000 people each year die from climate related diseases (predominantly diarrhoea, malaria, and malnutrition) Reduction in winter mortality in higher latitudes (Northern Europe, USA)	Permafrost thawing damages buildings and roads in parts of Canada and Russia	At least 10 percent of land species facing extinction (according to one estimate) 80 percent bleaching of coral reefs, including Great Barrier Reef	Atlantic Thermohaline Circulation starts to weaken
2°C	Potentially 20 - 30 percent decrease in water availability in some vulnerable regions, e.g. Southern Africa and Mediterranean	Sharp declines in crop yield in tropical regions (5 - 10 percent in Africa)	40 – 60 million more people exposed to malaria in Africa	Up to 10 million more people affected by coastal flooding each year	15 – 40 percent of species facing extinction (according to one estimate). High risk of extinction of Arctic species, including polar bear and caribou	Potential for Greenland ice sheet to begin melting irreversibly, accelerating sea level rise and committing world to an eventual 7m sea level rise. Rising risk of abrupt changes to atmospheric circulations, e.g. the monsoon.
3°C	In Southern Europe, serious droughts occur once every 10 years 1 – 4 billion more people suffer water shortages, while 1 – 5 billion gain water, which may increase flood risk	150 - 550 additional millions at risk of hunger (if carbon fertilisation weak) Agricultural yields in higher latitudes likely to peak	1 – 3 million more people die from malnutrition (if carbon fertilisation weak)	1 – 170 million more people affected by coastal flooding each year	20 – 50 percent of species facing extinction (according to one estimate), including 25 – 60 percent mammals, 30 – 40 percent birds and 15 – 70 percent butterflies in South Africa. Onset of Amazon forest collapse (some models only)	
4°C	Potentially 30 -50 percent decrease in water availability in Southern Africa and Mediterranean	Agricultural yields decline by 15- 35 percent in Africa, and entire regions out of production (e.g. parts of Australia)	Up to 80 million more people exposed to malaria in Africa	7 – 300 million more people affected by coastal flooding each year	Loss of around half Arctic tundra. Around half of all the world's nature reserves cannot fulfil objectives	
5°C	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India	Continued increase in ocean acidity seriously disrupting marine ecosystems and possibly fish stocks		Sea level rise threatens small islands, low-lying coastal areas (Florida) and major world cities such as New York, London, and Tokyo		
More than 5°C	The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if emissions continue to grow and positive feedbacks amplify the warming effect of greenhouse gases (e.g. release of carbon dioxide from soils or methane from permafrost). This level of global temperature rise would be equivalent to the amount of warming that occurred between the last age and today – and is likely to lead to major disruption and large-scale movement of population. Such "socially contingent" effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience.					

Notes:
As colours move from yellow to red, they indicate increasing severity of impacts.
This table shows illustrative impacts at different degrees of warming. Some of the uncertainty is captured in the ranges shown, but there will be additional uncertainties about the exact size of impacts (more detail in Box 3.2). Temperatures represent increases relative to pre-industrial levels. At each temperature, the impacts are expressed for a 1°C band around the central temperature, e.g. 1°C represents the range 0.5 – 1.5°C etc. Numbers of people affected at different temperatures assume population and GDP scenarios for the 2080s from the Intergovernmental Panel on Climate Change (IPCC). Figures generally assume adaptation at the level of an individual or firm, but not economy-wide adaptations due to policy intervention (covered in Part V).
Source: Stern Review, Chapter 3.

The earth's climate is dynamic and always changing through a natural cycle. What the world is more worried about is that the changes that are occurring today have been speeded up because of human activities. These changes are being studied by scientists all over the world who are finding evidence from tree rings, pollen samples, ice cores, and sea sediments. The causes of climate change can be divided into two categories - those that are due to natural causes and those that are created by man.

This page intentionally left balnk

4 NATURAL FACTORS CONTRIBUTION IN CLIMATE CHANGE

There are a number of natural factors responsible for climate change. Some of the more prominent ones are continental drift, volcanoes, ocean currents, the earth's tilt, and comets and meteorites. The major is sun energy entering and leaving the earth atmosphere. Let's look at them in a little detail.

4.1 Continental Drift

The movement of continents and the building and eroding of mountains have greatly changed the climate of earth over the course of millions and billions of years. About 200 million years ago they were joined together. Scientists believe that back then, the earth was not as we see it today, but the continents were all part of one large landmass. Proof of this comes from the similarity between plant and animal fossils and broad belts of rocks found on the eastern coastline of South America and western coastline of Africa, which are now widely separated by the Atlantic Ocean. The discovery of fossils of tropical plants (in the form of coal deposits) in Antarctica has led to the conclusion that this frozen land at some time in the past, must have been situated closer to the equator, where the climate was tropical, with swamps and plenty of lush vegetation. The continents that we are familiar with today were formed when the landmass began gradually drifting apart, millions of years back. This drift also had an impact on the climate because it changed the physical features of the landmass, their position and the position of water bodies. The separation of the landmasses changed the flow of ocean currents and winds, which affected the climate. This drift of the continents continues even today; the Himalayan range is rising by about 1 mm (millimeter) every year because the Indian land mass is moving towards the Asian land mass, slowly but steadily.

4.2 Volcanoes

When a volcano erupts it throws out large volumes of sulphur dioxide (SO2), water vapour, dust, and ash into the atmosphere. Although the volcanic activity may last only a few days, yet the large volumes of gases and ash can influence climatic patterns for years. Millions of tonnes of sulphur dioxide gas can reach the upper levels of the atmosphere (called the stratosphere) from a major eruption. The gases and dust particles partially block the incoming rays of the sun, leading to cooling. Sulphur dioxide combines with water to form tiny droplets of sulphuric acid. These droplets are so small that many of them can stay aloft for several years. They are efficient reflectors of sunlight, and screen the ground from some of the energy that it would ordinarily receive from the sun. Winds in the upper levels of the atmosphere, called the stratosphere, carry the aerosols rapidly around the globe in either an easterly or westerly direction. Movement of aerosols north and south is always much slower. This should give you some idea of the ways by which cooling can be brought about for a few years after a major volcanic eruption.

Mount Pinatoba, in the Philippine islands erupted in April 1991 emitting thousands of tonnes of gases into the atmosphere. Volcanic eruptions of this magnitude can reduce the amount of solar radiation reaching the earth's surface, lowering temperatures in the lower levels of the atmosphere (called the troposphere), and changing atmospheric circulation patterns. The extent to which this occurs is an ongoing debate.

Another striking example was in the year 1816, often referred to as "the year without a summer." Significant weather-related disruptions occurred in New England and in Western Europe with killing summer frosts in the United States and Canada. These strange phenomena were attributed to a major eruption of the Tambora volcano in Indonesia, in 1815

4.3 Thermohaline Circulation of Sea

The term thermohaline circulation (THC) refers to a part of the large-scale ocean circulation that is driven by global density gradients created by surface heat and freshwater fluxes.The adjective thermohaline derives from thermo- referring to temperature and haline referring to salt content, factors which together determine the density of sea water. Wind-driven surface currents (such as

the Gulf Stream) travel polewards from the equatorial Atlantic Ocean, cooling en route, and eventually sinking at high latitudes (forming North Atlantic Deep Water). This dense water then flows into the ocean basins. While the bulk of it upwells in the Southern Ocean, the oldest waters (with a transit time of around 1600 years) upwell in the North Pacific (http://en.wikipedia.org/wiki/Thermohaline_circulation - cite_note-3). Extensive mixing therefore takes place between the ocean basins, reducing differences between them and making the earth's oceans a global system. On their journey, the water masses transport both energy (in the form of heat) and matter (solids, dissolved substances and gases) around the globe. As such, the state of the circulation has a large impact on the earth's climate. The thermohaline circulation is sometimes called the ocean conveyor belt, the great ocean conveyor, or the global conveyor belt. On occasion, it is used to refer to the meridional overturning circulation (often abbreviated as MOC). The term MOC, however, is more accurate and well defined, as it is difficult to separate the part of the circulation which is actually driven by temperature and salinity alone as opposed to other factors such as the wind and tidal forces. Temperature and salinity gradients can also lead to a circulation which does not add to the MOC itself.

The thermohaline circulation plays an important role in supplying heat to the polar regions, and thus in regulating the amount of sea ice in these regions, although poleward heat transport outside the tropics is considerably larger in the atmosphere than in the ocean. Changes in the thermohaline circulation are thought to have significant impacts on the earth's radiation budget. Insofar as the thermohaline circulation governs the rate at which deep waters are exposed to the surface, it may also play an important role in determining the concentration of carbon dioxide in the atmosphere. While it is often stated that the thermohaline circulation is the primary reason that Western Europe is so temperate, it has been suggested that this is largely incorrect, and that Europe is warm mostly because it lies downwind of an ocean basin, and because of the effect of atmospheric waves bringing warm air north from the subtropics. However, the underlying assumptions of this particular analysis have likewise been challenged. Large influxes of low density meltwater from Lake Agassiz and deglaciation in North America are thought to have led to a disruption of deep water formation and subsidence in the extreme North Atlantic and caused the climate period in Europe known as the Younger Dryas (Big Freeze).

4.4 The Earth's Tilt

The earth makes one full orbit around the sun each year. It is tilted at an angle of 23.5° to the perpendicular plane of its orbital path. For one half of the year when it is summer, the northern hemisphere tilts towards the sun. In the other half when it is winter, the earth is tilted away from the sun. If there was no tilt we would not have experienced seasons. Changes in the tilt of the earth can affect the severity of the seasons - more tilt means warmer summers and colder winters; less tilt means cooler summers and milder winters.

4.5 Solar Radiation

Climate is influenced by natural changes that affect how much solar energy reaches Earth. These changes include changes within the sun and changes in the earth's orbit. Changes occurring in the sun itself can affect the intensity of the sunlight that reaches the earth's surface. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity). The sun follows a natural 11-year cycle of small ups and downs in intensity, but the effect on the earth's climate is small. Changes in the shape of the earth's orbit as well as the tilt and position of the earth's axis can also affect the amount of sunlight reaching the earth's surface. Changes in the sun's intensity have influenced the earth's climate in the past. For example, the so-called "Little Ice Age" between the 17th and 19th centuries may have been partially caused by a low solar activity phase from 1645 to 1715, which coincided with cooler temperatures. The "Little Ice Age" refers to a slight cooling of North America, Europe, and probably other areas around the globe. Changes in the earth's orbit have had a big impact on climate over tens of thousands of years. In fact, the amount of summer sunshine on the Northern Hemisphere, which is affected by changes in the planet's orbit, appears to control the advance and retreat of ice sheets. These changes appear to be the primary cause of past cycles of ice ages, in which Earth has

experienced long periods of cold temperatures (ice ages), as well as shorter interglacial periods (periods between ice ages) of relatively warmer temperatures.

Changes in solar energy continue to affect climate. However, solar activity has been relatively constant, aside from the 11-year cycle, since the mid-20th century and therefore does not explain the recent warming of Earth. Similarly, changes in the shape of the earth's orbit as well as the tilt and position of the earth's axis affect temperature on relatively long timescales (tens of thousands of years), and therefore cannot explain the recent warming.
When sunlight reaches Earth, it can be reflected or absorbed. The amount that is reflected or absorbed depends on the earth's surface and atmosphere. Light-colored objects and surfaces, like snow and clouds, tend to reflect most sunlight, while darker objects and surfaces, like the ocean, forests, or soil, tend to absorb more sunlight. The term albedo refers to the amount of solar radiation reflected from an object or surface, often expressed as a percentage. Earth as a whole has an albedo of about 30%, meaning that 70% of the sunlight that reaches the planet is absorbed. Absorbed sunlight warms the earth's land, water, and atmosphere. Reflectivity is also affected by aerosols. Aerosols are small particles or liquid droplets in the atmosphere that can absorb or reflect sunlight. Unlike greenhouse gases (GHGs), the climate effects of aerosols vary depending on what they are made of and where they are emitted. Those aerosols that reflect sunlight, such as particles from volcanic eruptions or sulfur emissions from burning coal, have a cooling effect. Matters that absorb sunlight such as black carbon (a part of soot) have a warming effect.
In another study, its reverse has been inferred. The warming global climate is causing plants to emit chemicals that lead to more climate-cooling clouds, say researcher in a new study. The cooling effect of more clouds could dampen the warming trend a bit in some remote parts of the world where there are not already ample human-made particles in the air already seeding more cloud formation. "It's not that much," said Pauli Paasonen of the University of Helsinki in Finland and one of the authors of the study, published in the April 28 issue of Nature Geoscience. But it's another step towards sorting out the roles of small particles – called aerosols – in future climate change, he said. It's also one of the very few negative feedbacks found in the current warming world.

Most of the feedbacks to climate change have been positive, meaning they tend to exacerbate the warming as, for instance, melting sea ice does when it allows sunlight to warm sea water rather than reflecting that sunlight back into space, or when permafrost melts, it releases carbon dioxide, which adds to the overall greenhouse gas problem.

This page intentionally left balnk

5 GHG EMISSION/HUMAN CONTRIBUTION IN CLIMATE CHANGE

The Clinton Foundation has assessed that in urban areas buildings account for 75% of carbon emission. It is also estimated that 90% of world urban areas are on coastlines. Deforestation, which is another major cause of carbon emission, is going on the globe at a fast pace for human greed of land. Each year 13 million hectares of forest are lost. For example, in Haiti 100 years ago 60% area had forest, presently only 2% area is under forest. The same applies to Pakistan, where forest area is now below sustainability level. Transportation sector (cars, trucks, trains, airplanes, etc.) accounts for 14% of carbon emission globally. Presently, while there will be some gains from climate change, most of the impacts will be negative, and gains and losses will not be evenly distributed (ERM, 2007).

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1997 in Kyoto, Japan, at the Third Session of the Conference of the Parties (COP) to the UNFCCC. It contains legally binding commitments, in addition to those included in the UNFCCC. Most Organization for Economic Cooperation and Development countries and countries with economies in transition agreed to reduce their anthropogenic greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol entered into force on 16 February 2005.

The amount of greenhouse gases in the atmosphere reached a new record high in May 2013, when it crossed the 400 ppm mark. The period 1990 to 2011 saw a 30% increase in radiative forcing – a measure of the warming effect on the climate – because of increased atmospheric concentrations of greenhouse gases. Carbon dioxide, the single most important greenhouse gas emitted by human activities, is responsible for 85% of the increase in radiative forcing over the past decade (water vapor is also a powerful GHG but human activities affect its levels indirectly). The amount of CO_2 in the atmosphere reached 400 parts per million in 2013, or 140% of the pre-industrial level of 280 parts per million.

Methane is the second most important long-lived greenhouse gas. Atmospheric methane reached a new high of about 1813 parts per billion (ppb) in 2011, or 259% of the pre-industrial level, due to increased emissions from man-made sources. Since 2007, atmospheric methane has been increasing again after a period of leveling-off, with a nearly constant rate during the last three years.

Nitrous oxide is emitted into the atmosphere by both natural (about 60%) and man-made sources (approximately 40%), including oceans, soil, biomass burning, fertilizer use, and various industrial processes. Its atmospheric concentration in 2011 was about 324.2 parts per billion, which is 1.0 ppb above the previous year and 120% of the pre-industrial level. Nitrous oxide also plays an important role in the destruction of the stratospheric ozone layer which protects us from the harmful ultraviolet rays of the sun.

In addition to greenhouse gases, other emissions, such as black carbon (which recent research suggests has a greater warming effect than previously understood) and dust (which has a cooling effect) also influence the climate (WMO, March 2013).

Today, the global economy annually consumes at least 80 times more coal than was burned in 1850 at the height of the industrial revolution, and it accounts for 43% of human caused carbon dioxide

This page intentionally left balnk

emission. The International Energy Agency said that global coal use—now close to 8 billion tons a year—could increase by 65% by 2035 if current energy trends continue.

A recent independent analysis reported that 1,200 new coal-fired power plants are being proposed worldwide, three-quarters of them in India and China. The planet still has so much coal underground that if industrial economies mine and burn this fossil fuel at current rates, known reserves would last for more than a century. The Guardian UK in its publication of 10th March, 2013 has reported that Indian power coal plants kill 120,000 people a year, and a cause for 20 million new asthma cases per year.

To find out, let's look at carbon dioxide, the most common greenhouse gas. The top **Figure 5-1** shows the actual amount of carbon dioxide in the atmosphere from the year 1750 until today. The bottom graph of **Figure 5-1** shows how much extra carbon dioxide people around the world have been putting into the atmosphere since 1750. There is a direct connection between these two graphs.

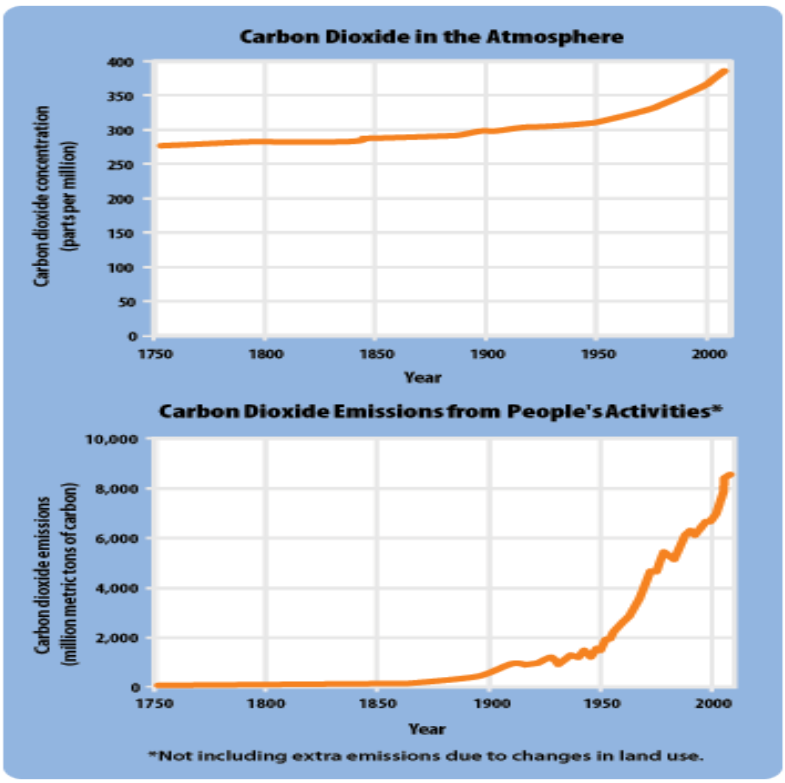


Figure 5-1: Level of Carbon Dioxide in the Atmosphere

The amount of carbon dioxide started to increase a few hundred years ago during the industrial revolution, when people started burning a lot of fossil fuels like coal, oil, and natural gas for energy. You can also see that people are burning even more fossil fuels today, which explains why the amount of carbon dioxide in the atmosphere has continued to rise.

5.1 Carbon Cycle

The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of Earth. Along with the Nitrogen cycle and the water cycle, the carbon cycle comprises a sequence of events that are the key to making Earth capable of sustaining life; it describes the movement of carbon as it is recycled and reused throughout the biosphere.

The global carbon budget is the balance of the exchanges (incomes and losses) of carbon between the carbon reservoirs or between specific loops (e.g., atmosphere ↔ biosphere) of the carbon cycle. An examination of the carbon budget of a pool or reservoir can provide information about whether the pool or reservoir is functioning as a source or sink for carbon dioxide. Carbon-based molecules

are crucial for life on earth, because it is the main component of biological compounds. Carbon is also a major component of many minerals. Carbon also exists in various forms in the atmosphere. Carbon dioxide is partly responsible for the greenhouse effect and is the most important human contributed greenhouse gases.

In the past two centuries, human activities have seriously altered the global carbon cycle, most significantly in the atmosphere. Although carbon dioxide levels have changed naturally over the past several thousand years, human emissions of carbon dioxide into the atmosphere exceed natural fluctuations. Changes in the amount of atmospheric CO_2 are considerably altering weather patterns and indirectly influencing oceanic chemistry. Records from ice cores have shown that, although global temperatures can change without changes in atmospheric CO_2 levels, CO_2 levels cannot change significantly without affecting global temperatures. Current carbon dioxide levels in the atmosphere exceed measurements from the last 420,000 years and levels are rising faster than ever recorded (**Figure 5-1**), making it critically important to understand better how the carbon cycle works and what its effects are on the global climate. The carbon exchanges between reservoirs occur as the result of various chemical, physical, geological, and biological processes. The ocean contains the largest active pool of carbon near the earth's surface (**Table 5-1**). The natural flows of carbon between the atmosphere, ocean, and sediments are fairly balanced, so that carbon levels would be roughly stable without human influence. (Falkowaski et. al., 2000)

Table 5-1: Carbon Pools in the Major Reservoirs on Earth

Pool	Quantity (gigatons)
Atmosphere	720
Oceans (total)	38,400
Total inorganic	*37,400*
Total organic	1,000
Surface layer	670
Deep layer	36,730
Lithosphere	
Sedimentary carbonates	> 60,000,000
Kerogens	15,000,000
Terrestrial biosphere (total)	2,000
Living biomass	600 - 1,000
Dead biomass	1,200
Aquatic biosphere	2-Jan
Fossil fuels (total)	4,130
Coal	3,510
Oil	230
Gas	140
Other (peat)	250

Debate about 're-balancing the carbon cycle' arises from a concern that use of fossil fuels, which has accelerated since the start of the industrial revolution, has caused carbon to accumulate in the atmosphere. Levels of CO_2 in the atmosphere are estimated to have risen from 280 ppm to almost 400 ppm since 1800 and this is linked to global warming. It is therefore argued that the carbon cycle should be re-balanced by reducing the amount of CO_2 in the atmosphere.

'Carbon cycle re-balancing' is a useful name for a group of environmental policies listed below. The name gives a specific reason for adopting these policies. Related names, including pleas for

sustainable development and participation in the green movement are politics-based rather than science-based.

- Carbon offset - for example by photosynthesis (e.g. in new forests).
- Carbon capture and storage - extraction of CO_2 and placing it underground or underwater.
- Carbon capture and transformation - extraction of CO_2 and forcing it to react with hydrogen via renewable energy electrolysis to create methane as an energy store/carrier. Low to neutral CO_2 cycle.
- Sustainable energy - a shift from fossil fuels energy to wind power and solar power.
- Nuclear power - as an alternative to fossil fuels.
- Sustainable design - to reduce inputs and outputs of energy.
- Sustainable transport - to reduce reliance on fossil fuels.

Burning domestic refuse to generate power can be promoted as a recycling, and therefore sustainable, policy. But from a carbon cycle re-balancing standpoint it is better to compost as much domestic refuse as possible.

5.2 Carbon Storage

Carbon capture and storage, or CCS, technology exists and is already a potential amelioration of the greenhouse problem. Energy companies have been condensing carbon dioxide from power station exhausts and gas and oil fields, and finding places to store it, usually deep underground (**Figure 5-2**). But deep burial may not be a permanent solution, which is why James Verdon, an earth scientist at the University of Bristol in the United Kingdom, and colleagues took a more careful look at three cases of long-term disposal. Their study was published in July 2013 in Proceedings of the National Academy of Sciences. Three million tons of carbon dioxide (equivalent to the exhaust from 500,000 cars) have been buried every year since 2000 in an oil and gas reservoir below Weyburn, in Saskatchewan, Canada.

Around a million tons of liquefied CO_2 each year is now stripped from natural gas and pumped back into the Sleipner field under the Norwegian North Sea, and in the last seven years almost four million tons has been put back deep under a natural gas field at In Salah in Algeria. In each case, the gas exerts pressure on the surrounding rocks. What geologists need to know is how the rocks react to this new pressure and whether the gas will migrate. They also need to understand whether there is a history of faulting, and whether the process is likely to trigger earthquakes. The risks also include the opening of existing fractures; damage to the rocks that cap the reservoirs, failures of the wells bored into the storage site and the deformation of the entire geological structure. And since nothing in geology happens in a hurry, the scientists have to calculate probabilities of hazard for thousands of years.

This page intentionally left balnk

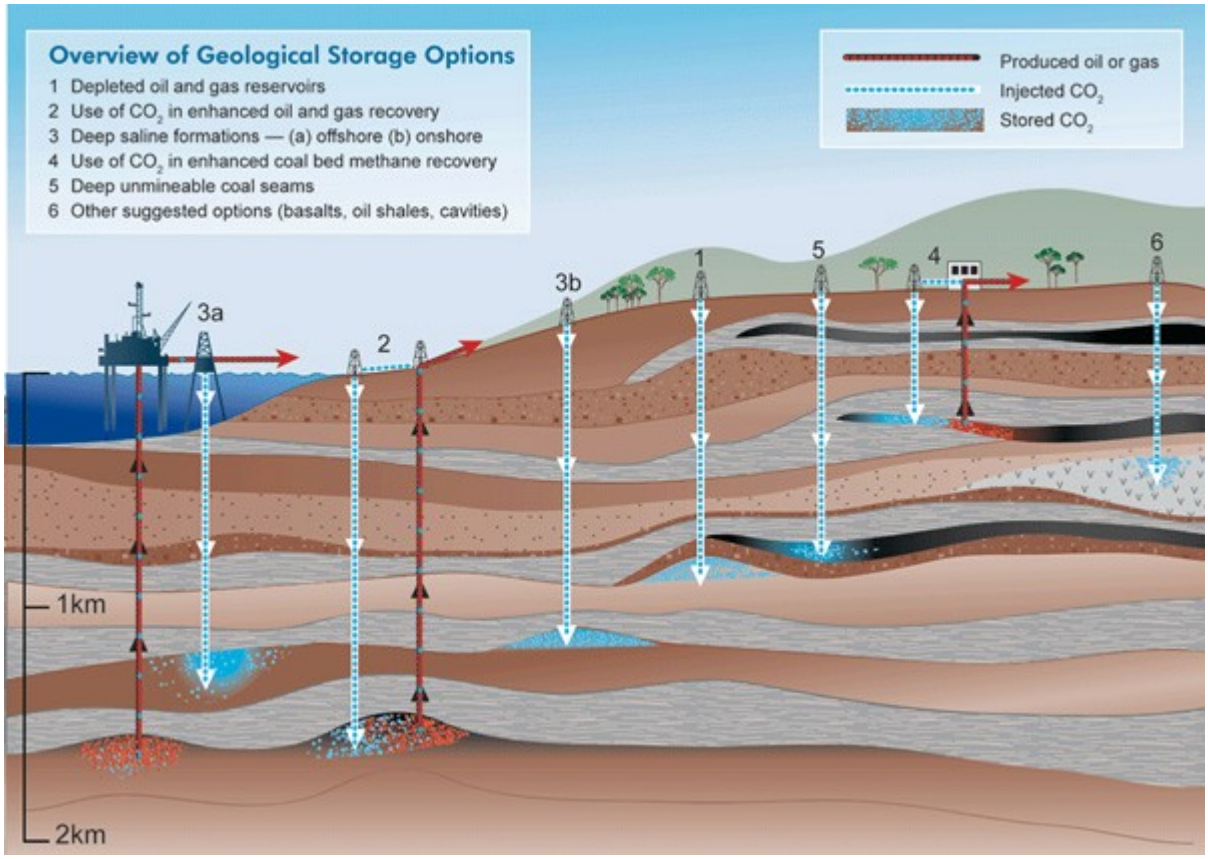


Figure 5-2: An Overview of the Geological Carbon Storage Options

5.3 Past, Present and Future: Emission Trends

Emissions of the GHGs covered by the Kyoto Protocol increased by about 70% (from 28.7 to. 49.0 GtCO2-eq) from 1970–2004 (by 24% from 1990–2004), with carbon dioxide being the largest source, having grown by about 80%. The largest growth in CO_2 emissions has come from power generation and road transport. Methane emissions rose by about 40% from 1970, with an 85% increase from the combustion and use of fossil fuels. Agriculture, however, is the largest source of CH_4 emissions. Nitrous oxide emissions grew by about 50%, due mainly to increased use of fertilizer and the growth of agriculture. Industrial emission of N_2O fell during this period *(*high agreement, much evidence*)*. Emissions of ozone-depleting substances (ODS) controlled under the Montreal Protocol (which includes GHGs chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs)), increased from a low level in 1970 to about 7.5 GtCO2-eq in 1990 (about 20% of total GHG emissions), but then decreased to about 1.5 GtCO2-eq in 2004, and are projected to decrease further due to the phase-out of CFCs in developing countries. Emissions of the fluorinated gases (F-gases), HFCs, perfluorocarbons (PFCs) and SF6 controlled under the Kyoto Protocol grew rapidly (primarily HFCs) during the 1990s as they replaced ODS to a substantial extent and were estimated at about 0.5 GtCO2eq in 2004 (about 1.1% of total emissions on a 100-year global warming potential (GWP) basis) *(*high agreement, much evidence*)*. Atmospheric CO_2 concentrations have increased by almost 100 ppm since their pre-industrial level, reaching 379 ppm in 2005, with mean annual growth rates in the 2000-2005 period higher than in the 1990s, and now stands over 400 ppm. The total CO_2-equivalent (CO_2-eq) concentration of all long-lived GHGs is now about 455 ppm CO_2-eq. Incorporating the cooling effect of aerosols, other air pollutants and gases released from land-use change into the equivalent concentration, leads to an effective 311-435 ppm CO_2-equivalent concentration (high agreement, much evidence*)*. Considerable uncertainties still surround the estimates of anthropogenic aerosol emissions. As regards global sulphur emissions, these appear to have declined from 75 ± 10 MtS in 1990 to 55-62 MtS in 2000. Data on non-sulphur aerosols are sparse and highly speculative. In 2004, energy supply accounted for about 26% of GHG emissions,

industry 19%, gases released from land-use change and forestry 17%, agriculture 14%, transport 13%, residential, commercial and service sectors 8% and waste 3%. These figures should be seen as indicative, as some uncertainty remains, particularly with regards to CH_4 and N_2O emissions (error margin estimated to be in the order of 30-50%) and CO_2 emissions from agriculture and forestry with an even higher error margin *(*Barker et. al, *2007).*

The problem, as the world's climate scientists point out, is that to continue burning coal at the ever-expanding pace of recent years means that there is little hope of holding global temperature increases to 2 °C (3.6 °F). To combust even a third to a half of the world's proven reserves of coal would — barring the widespread adoption of carbon-capture technologies — lead to a climate-destabilizing rise in temperature far in excess of 2 °C, according to recent studies. On the other hand it is also advocated that "Overcoming global poverty is at least as important a priority (as mitigating climate change) and providing affordable fuel is essential to that, all of us share the objective of reducing greenhouse gases in the atmosphere, and some of us want to do that while not forgetting other challenges.

The Guardian UK in its 29th April issue has reported that the concentration of carbon dioxide in the atmosphere has reached 399.72 ppm and is likely to pass the symbolically important 400 ppm level for the first time in the next few days. Readings at the US government's Earth Systems Research laboratory in Hawaii, are not expected to reach their 2013 peak until mid-May, but were recorded at a daily average of 399.72 ppm on 25 April. The weekly average stood at 398.5 on 29th May 2013. Hourly readings above 400 ppm have been recorded six times in the last week, and on occasion, at observatories in the high Arctic. But the Mauna Loa station, sited at 3,400 m and far away from major pollution sources in the Pacific Ocean, has been monitoring levels for more than 50 years and is considered the gold standard.

Earth was formed about 4.5 billion years ago. It's hard to say exactly what the earth's daily weather was like in any particular place on any particular day thousands or millions of years ago. But we know a lot about what the earth's climate was like way back then because of clues that remain in rocks, ice, trees, corals, and fossils. These clues tell us that the earth's climate has changed many times before. There have been times when most of the planet was covered in ice, and there have also been much warmer periods. Over at least the last 650,000 years, temperatures and carbon dioxide levels in the atmosphere have increased and decreased in a cyclical pattern.

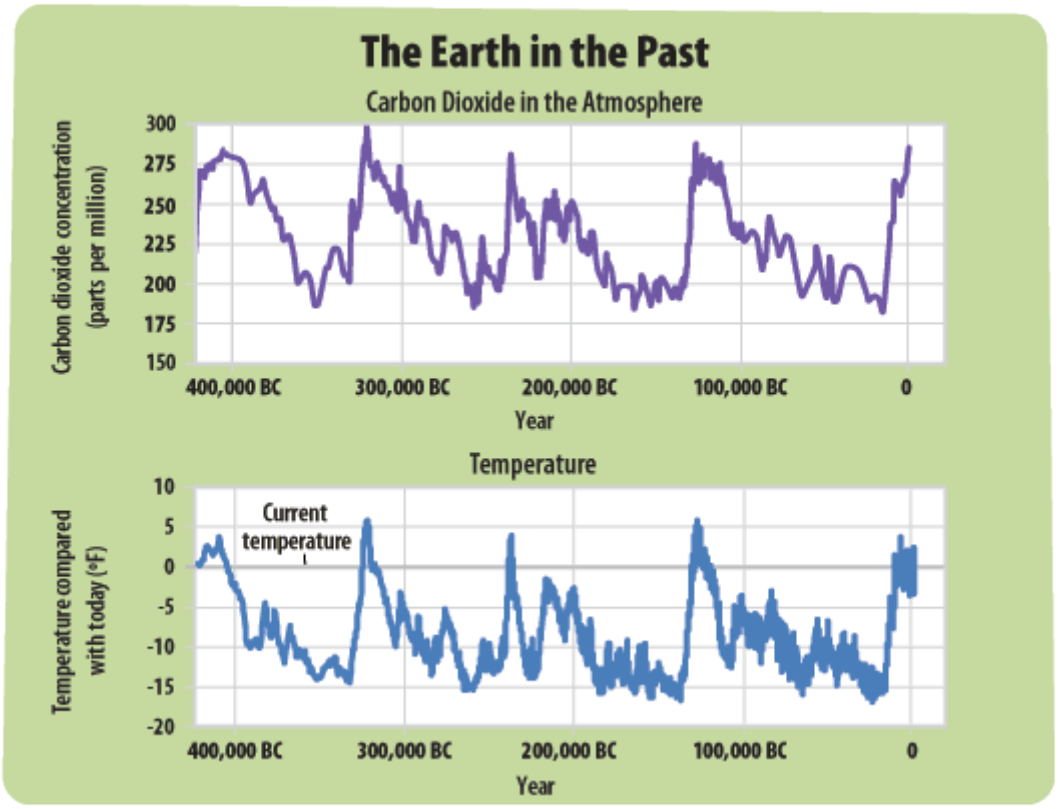


Figure 5-3: Comparison of Historical Carbon Dioxide Concentration with Temperature

These above graphs represented in **Figure 5-3** are based on the Vostok ice core from Antarctica. They do not include the most recent increases in carbon dioxide and temperature caused by humans. Notice the strong connection between carbon dioxide and temperature. People didn't cause the climate change that occurred thousands or millions of years ago, so it must have happened for other natural reasons.

The earth's climate is getting warmer (**Figure 5-4**), and the signs are everywhere. Rain patterns are changing, sea level is rising, and snow and ice are melting sooner in the spring. As global temperatures continue to rise, we'll see more changes in our climate and our environment. These changes will affect people, animals, and ecosystems in many ways.

Less rain can mean less water for some places, while too much rain can cause terrible flooding. More hot days can dry up crops and make people and animals sick. In some places, people will struggle to cope with a changing environment. In other places, people may be able to successfully prepare for these changes. The negative impacts of global climate change will be less severe overall if people reduce the amount of greenhouse gases we're putting into the atmosphere and worse if we continue producing these gases at current or faster rates.

This page intentionally left balnk

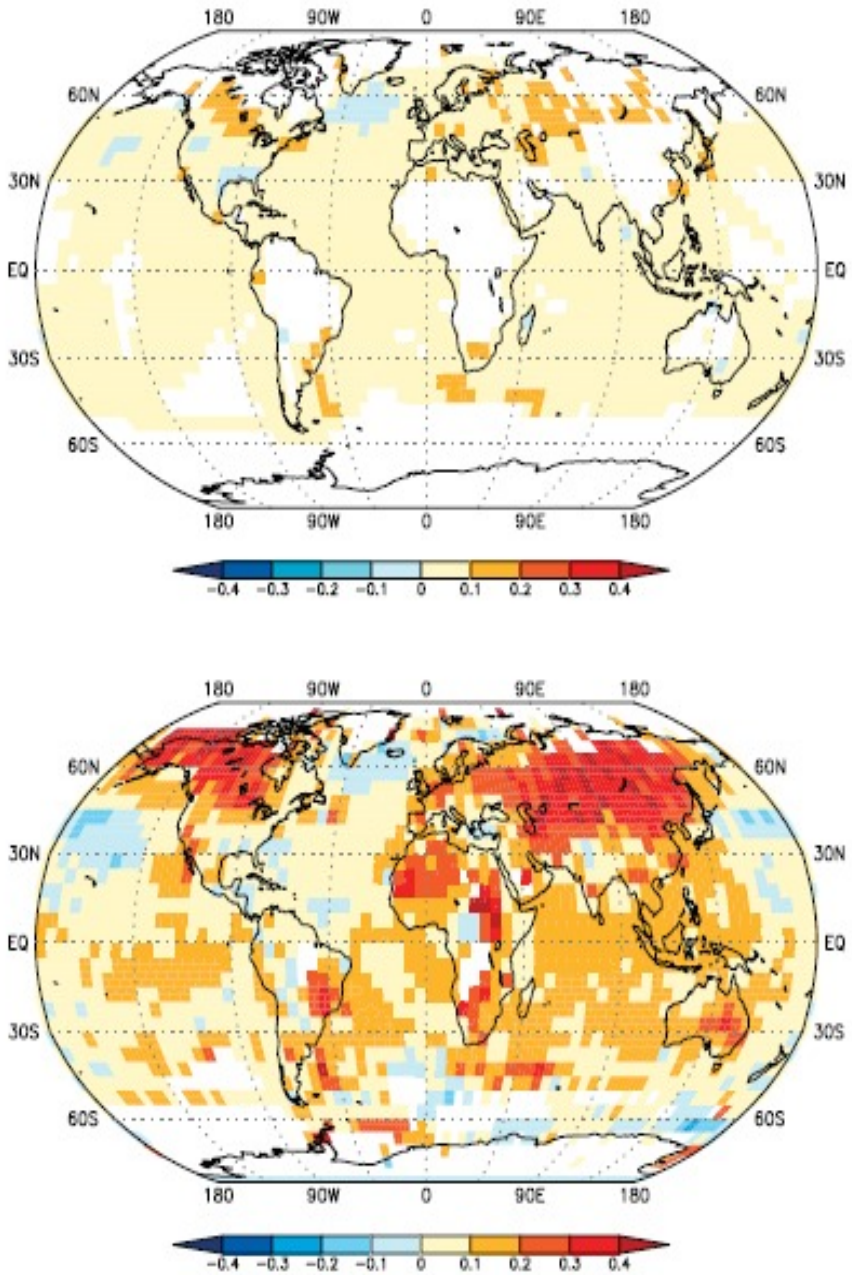


Figure 5-4: Global Trend in Temperature

The upper map shows the average change in temperature per decade from 1870 to 2005. Areas in Orange have seen temperature rise between 0.10 -0.20 °C per decade, so that average 1.350 to 2.70 °C warmer than in 1870. The lower map shows the average change in temperature per decade from 1950 to 2005. (Source: Joint Institute for the study of atmosphere and Ocean, University of Washington).

This page intentionally left balnk

6 REFERENCES

See references in the Supplemental Main Report on Climate Change.

This page intentionally left balnk

USAID | PAKISTAN
FROM THE AMERICAN PEOPLE

Kurram Tangi Dam Construction

Supplemental Report on Climate Change

Annexure 4: National Climate Change Perspective

December 2013
This publication was produced for review by the United States Agency for International Development.
It was prepared by MWH-NESPAK-ACE under contract AID-391-C-13-00002

This page intentionally left balnk

List Acronyms

Abbreviations/Acronym	Term
ac-ft	Acre Feet
bcfd	Billion Cubic Feet Per Day
GCM	Global Circulation Model
GHG	Greenhouse Gas
GIS	Geographic Information System
GoP	Government of Pakistan
HKH	Himalaya-Karakoram-Hindukush
ICIMOD	International Center for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
km	Kilometers
KP or KPK	Khyber Pakhtunkhwa
KTDC	Kurram Tangi Dam Construction
KTMDP	Kurram Tangi Multipurpose Dam Project
LNG	Liquefied Natural Gas
MMTOE	Million Metric Tonne of Oil Equivalent
MWH	MWH Global, Inc. or MWH, Inc.
NESPAK	National Engineering Services Pakistan
OECD	Organization for Economic Cooperation and Development
PMD	Pakistan Meteorological Department
RCM	Regional Climate Model
TFCC	Task Force On Climate Change (GoP)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USAID/Pak	United States Agency for International Development/Pakistan
USGS	United States Geological Survey
WAPDA	Water and Power Development Authority
°C	Degree Celsius

This page intentionally left balnk

Table of Contents

1 INTRODUCTION 1-1

2 MAJOR SOURCES OF GHG IN PAKISTAN AND COMPARISON WITH OTHER COUNTRIES 2-1

3 ENERGY MIX IN PAKISTAN 3-1

4 IMPACT OF CLIMATE CHANGES ANTICIPATED IN PAKISTAN 4-1

4.1 Impact on Glaciers of Pakistan 4-1

4.2 Impact on Other Water Resources of Pakistan 4-3

5 TASK FORCE ON CLIMATE CHANGE (TFCC), GOVERNMENT OF PAKISTAN 5-1

5.1 Effect on Precipitation Pattern noted by TFCC 5-1

5.2 Major Concerns raised by TFCC 5-1

5.3 Recommended Measures by TFCC in Enhancing Water Security 5-2

6 SUMMARY OF PAST AND EXPECTED FUTURE CLIMATE CHANGES IN PAKISTAN 6-1

7 REFERENCES 7-1

List of Figures

Figure 2-1: Sector-wise CO_2 Emission in Pakistan (Total 16.6 Million Tonnes in 2008) 2-2

Figure 2-2: Sectorial Share in GHG Emission in 1993-94 and 2007-08 2-3

Figure 3-1: Total Energy Mix of Pakistan in 2011 3-1

Figure 4-1: Snowmelt Contribution of Water in Subcontinent River Systems 4-2

Figure 4-2: Cumulative Mass Balance for Selected Glaciers System 4-3

Figure 4-3: Correlations between Asian Monsoon Precipitation, Northern Hemisphere Temperature, and Some Events of Human History 4-4

Figure 4-4: All India Summer Rainfall Anomalies (1871-2004). Dark Line Shows 10 Years Moving Average (after Mall R.K. et al) 4-4

Figure 4-5: Cumulative Rainfall (mm) July 11 to August 20, 2010 in Pakistan 4-7

List of Tables

Table 2-1: Carbon Dioxide Emission by Different Countries of the World 2-1

Table 4-1: Rainfall Data for the Last Week of July 2010 of Different Cities of Pakistan 4-6

This page intentionally left balnk

1 INTRODUCTION

Climatologically, most parts of Pakistan are arid to semi-arid with significant spatial and temporal variability in climatic parameters. 59% of the annual rainfall is due to monsoon rains; a dominant hydro-meteorological resource for Pakistan. The greater Himalayan region above latitude 35°N receives winter precipitation mostly in the form of snow and ice. The snowmelt contribution keeps the rivers running throughout the year. The coastal climate is confined to a narrow strip along the coast in the south and southeast of Pakistan, and northern Pakistan is dominated by the mountain climate ranging from humid to arid. In between these regions, the climate is broadly of tropical continental nature. The objective of this annex is to present a literature review of the climate change and its impact in the context of Pakistan.

Around 23% of the Pakistan's land and nearly 50% of the entire population is vulnerable to damage resulting from potential disasters. The impacts of higher temperatures, more variable precipitation, more extreme weather events, and sea level rise are felt in South Asia and will continue to intensify. These changes are already having major impacts on the economic performance of South Asian countries and on the lives and livelihoods of millions of poor people. Major changes include:

- Glacier melting in the Himalayas is projected to increase flooding and will affect water resources within the next two to three decades.
- Climate change will compound the pressures on natural resources and the environment due to rapid urbanization, industrialization, and economic development.
- Crop yields could decrease up to 30% in South Asia by the mid-21st century.
- Mortality due to diarrhea primarily associated with floods and droughts will rise in South Asia.
- Sea-level rise will exacerbate inundation, storm surge, erosion and other coastal hazards.

The fertility of the alluvial plains of Pakistan derives from sediments deposited over geological time by the Indus from the high mountain ranges of the Himalaya-Karakoram-Hindukush (HKH) range. The continuing flow of water across the plains is largely derived from the same source and provides the basis for irrigated agriculture which is the mainstay of Pakistan's economy. Mountain sources of flow in the Indus are vulnerable both to changes in temperature and precipitation as most of the runoff is derived from the melting of seasonally accumulated snow and ice from glaciers. Glacial areas of Pakistan are about 13,680 square kilometers, and on average is 3% of the mountainous region. In the Karakorum Range the total length of glaciers is 160 km. About 37% of the Karakorum area is under glaciers, the Himalayas have 17% glaciers, whereas the Alps have about 22% glaciers.

This page intentionally left balnk

2 MAJOR SOURCES OF GHG IN PAKISTAN AND COMPARISON WITH OTHER COUNTRIES

A relatively small number of countries produce a large majority of global GHG emissions. Many also rank among the most populous countries and have the largest economies. The major emitters include almost an equal number of developed and developing countries, as well as some transition economies of the former Soviet Union. Emission projections at the national level are highly uncertain. Uncertainties are especially acute in developing country economies, which tend to be more volatile and vulnerable to external shocks. Furthermore, past projections are also questionable in respect to their accuracy. This has made it difficult to develop policies that are based on such projections. For instance, fixed emission caps (such as Kyoto Protocol-style targets) are less likely to be viable in developing countries than in industrialized countries (**Table 2-1**).

Table 2-1: Carbon Dioxide Emission by Different Countries of the World

Rank	Country	Carbon Dioxide emissions in megatons	Percentage of global total
1	China	7,225	16.4%
2	USA	6,934	15.7%
3	European Union	5,331	12.1%
4	Brazil	2,855	6.5%
5	Indonesia	2,039	4.6%
6	Russian Federation	2,013	4.6%
7	India	1,875	4.2%
8	Japan	1,390	3.1%
9	Germany	1,005	2.3%
10	Canada	811	1.8%
11	United Kingdom	684	1.5%
13	Korea (South)	608	1.4%
14	Italy	582	1.3%
15	France	575	1.3%
16	Iran	572	1.3%
17	Australia	572	1.3%
33	Pakistan	244	0.5%

The followings activities are considered to be the source of GHG emission in Pakistan, which are in line with the GHG emission sources in the industrialized world:

Energy Related Activities

Energy Sector (fuel combustion and fugitive)

– Energy Industries (i.e., power sector)
– Manufacturing, Agriculture, Construction

Transport, Commercial and Residential sectors

– Fugitive Emissions

Non- Energy Related Activities

Industrial Process

– Cement production
– Steel production
– Soda ash production

This page intentionally left balnk

– Urea production
– Use of Asphalt in construction industry

Agriculture Sector
– Livestock
– Rice cultivation
– Fertilizer application
– Crop residues burning

Land Use, Land Use Changes and Forestry (LULUCF)
– Net carbon change (carbon uptake and carbon release)

Waste
– Solid waste disposal
– Waste water handling

It is estimated that in 2008, CO_2 emission in Pakistan were of the order of 166.6 Million Tonnes. The highest emissions came from power sector, which contributed 27% of the total value, and Industry contributed 25% of total of carbon dioxide emission as shown on **Figure 2-1**.

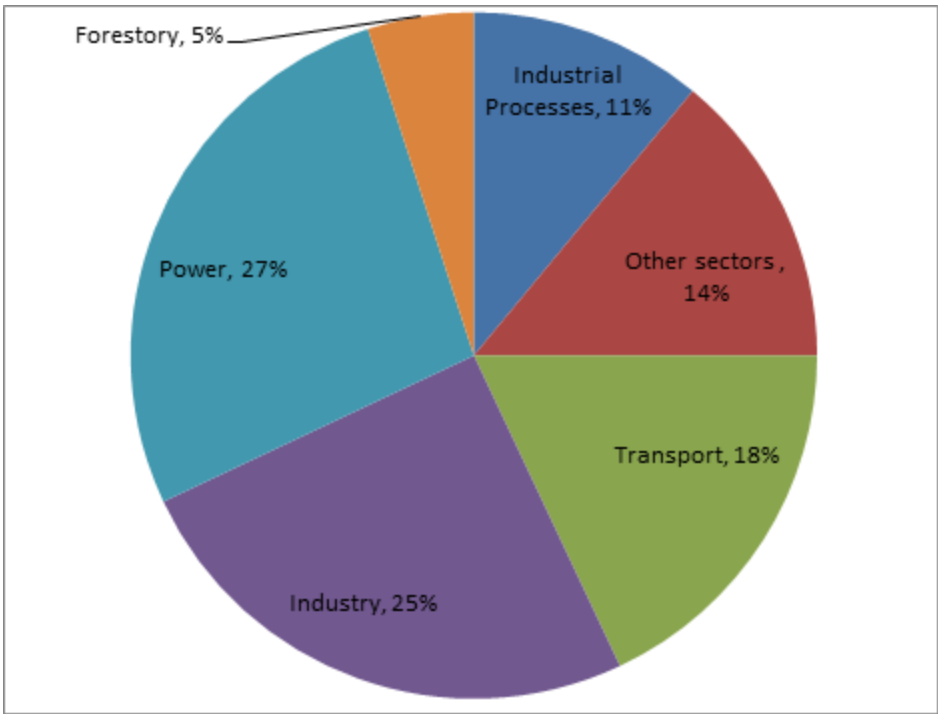


Figure 2-1: Sector-wise CO_2 Emission in Pakistan (Total 16.6 Million Tonnes in 2008)

Methane (CH4) emissions in Pakistan are estimated to be 4.4 million tonnes, with 85% produced due to agriculture and the other sectors contributed the remaining 15%. Nitrous oxide ($NO_{2)}$ emissions are estimated to be 96,000 tonnes and here again the agriculture sector alone contributed the majority, 88%, of the total emissions. It is worthy to mention that the agriculture and livestock sectors are the mainstay of the national economy in Pakistan. It contributes 22% to the counties Gross Domestic Product (GDP), accounts for 60% of country's exports, provides livelihood to about 68% of the country's population living in rural areas, and employs 43% of the national labor force. For comparison sake 1993-94 emissions are correlated with 2007-2008 (Khan A N, 2011) emissions and are shown on **Figure 2-2**.

This page intentionally left balnk

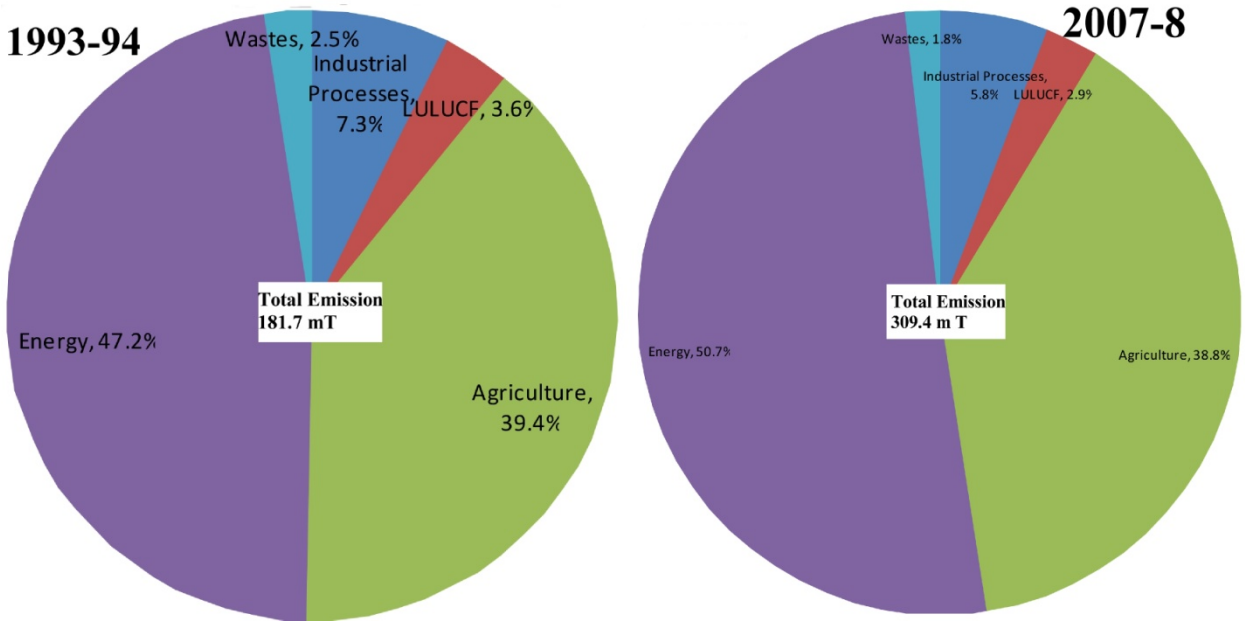


Figure 2-2: Sectorial Share in GHG Emission in 1993-94 and 2007-08

Comparing GHG emission with other nations, Pakistan ranks much lower in GHG emissions relative to its neighbors. China produces 6,534 million Tonnes of GHG, India emits 1,495 million tonnes of GHG, and Iran contributes 511 million tonnes GHG, whereas Pakistan's contribution in GHG emission is only 309 million tonnes, as per 2008 data (Kaleem, 2011).

This page intentionally left balnk

3 ENERGY MIX IN PAKISTAN

Energy makes the economic wheel turn and ensures economic growth. Economic growth is dependent on energy security, sustainability, cost effectiveness and environmental friendliness. Access to sustainable energy sources is one of the challenges Pakistan must overcome for considerable economic development over the next decade. Currently 48% of energy needs are met with indigenous gas, oil imports account for 32%, hydro/nuclear/imported account for 13%, and coal accounts for the remaining 7%, as shown on **Figure 3-1**. Energy supplies in Pakistan grew at a rate of 6% per annum from 2003 to 2008 (47 MMTOE in FY2003 to 63 MMTOE in FY 2008), per WAPDA figures (http://www.wapda.gov.pk/htmls/engymix.htm). Further, energy consumption in 1980 was about 12 MMTOE and around 33 MMTOE in 2000. The current energy mix in Pakistan is imbalanced even on worldwide comparative basis, replying primarily on gas and oil. By 2015 the natural gas supply-demand gap after LNG imports of 1.0 bcfd (if implemented) will increase to 1.7 bcfd, and is unlikely to be covered as IPI cannot be completed in this time frame. There is clearly an essential need for a revised primary energy mix plan along with a revised electricity generation plan categorized by source for the 2010 – 2030 period.

In the residential/commercial sector, the energy used in homes and businesses (residential demand) is around five times greater than commercial demand. Pakistan's domestic sector consumed 8.1 MMTOE energy in 2008 – 2009 compared to commercial consumption of just below 1.5 MMTOE. Industrial consumption was just under 15 MMTOE during the same period with the transport sector making up a further 11.4 MMTOE. Additionally, Pakistan consumed 15.3 MMTOE of fossil fuels (including coal and petroleum products) in the thermal power generation sector and nearly 4 MMTOE in non-energy uses in the fertilizer sector. Looking into the future, Pakistan's growth in energy needs will further exacerbate the mismatch in the consumption of energy and the inefficient implementation of pricing anomalies (subsidies) which in turn have led to large increases in consumption of natural gas and electricity. The beneficiaries of subsidies are generally not the originally intended recipients, and end up causing losses to the public exchequer (OICIC, 2010).

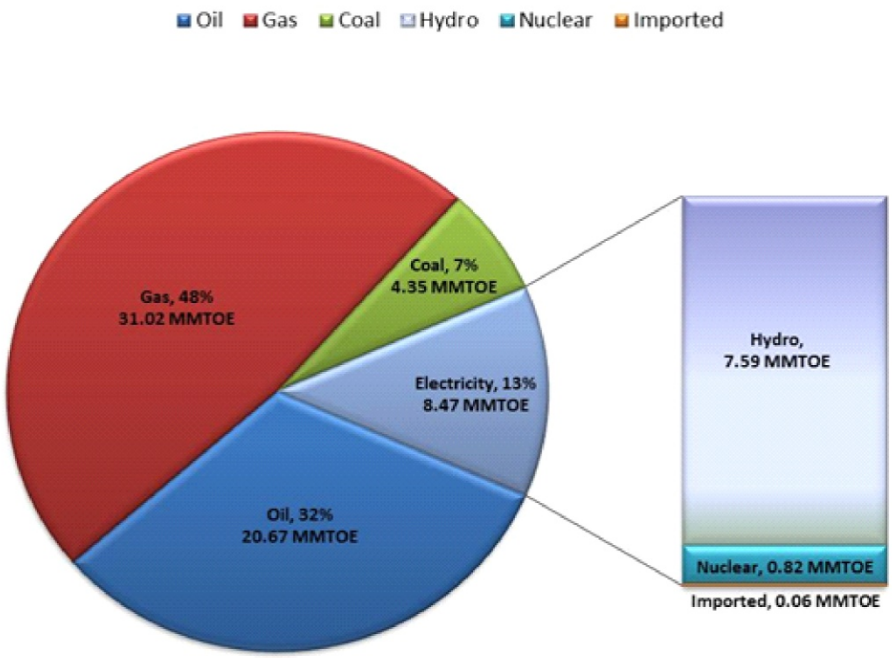


Figure 3-1: Total Energy Mix of Pakistan in 2011

From 1980 until present, the demand for energy in Pakistan has grown almost six-fold. It is estimated that demand would again double by 2015. With a significant dependence on hydrocarbons as its primary energy source, the situation is not sustainable. The state of affairs is further impacted by a growing population with a low median age, low per capita energy consumption yet high energy

intensity, and a recent boom in cheap but energy hungry home appliances. Contrary to as expected, energy demand in developed economies such as those of OECD (Organization for Economic Cooperation and Development) member states is actually expected to be lower in 2030 than in 2005, despite a projected growth of more than 50% in those economies. A possible explanation to this could be significant advancements in energy efficiency in these countries. Pakistan would be expected to benefit from the study of OECD models. With the rising cost of crude oil from $60 in 2005 to $147 in 2008, Pakistan's oil based thermal generation (32%) has become unsustainable and has resulted in a massive energy sector debt ($3.6 billion). Coal utilization is about 9% in the energy mix, and it contributes to only 0.1% for power generation compared to 72% in China, 56% in India, and more than 50% in the USA.

The country has an estimated hydropower potential of about 45,000 MW, of which only 6,500 MW have been installed. Hydropower has only an 11% share in the current energy mix. It is necessary to maintain an optimal hydro/thermal mix in base load operations to mitigate the reduction in output from hydropower plants during low flow periods. To bridge the gap in the energy mix, there is a critical need to maximize the use of coal resources, renewable energy sources, and hydro resources by constructing new dams.

4 IMPACT OF CLIMATE CHANGES ANTICIPATED IN PAKISTAN

A conference was organized by the Ministry of Environment and the International Union for Conservation of Nature (IUCN), Pakistan, and supported by the UK Department for International Development and the Norwegian Embassy in 2009. Dr. Rajendra Kumar Pachauri, Chairman of the Inter-governmental Panel on Climate Change (IPCC), said, "Pakistan was witnessing severe pressures on natural resources, and environment and climatic changes are likely to exacerbate this trend, noting Pakistan as the 12th most vulnerable country. Water supply, already a serious concern in many parts of the country, will decline dramatically, affecting food production. Export industries such as fisheries will also be affected, while coastal areas risk being inundated, flooding the homes of millions of people living in low-lying areas." Pakistan, thus, seems to face potential environmental catastrophe.

Droughts in 1999 and 2000 caused sharp declines in water tables and dried up wetlands, severely degrading ecosystems. Pakistan has been impacted by global warming, for instance temperatures in the country's coastal areas have risen since the early 1900s from 0.6 to 1°C, and precipitation has decreased 10% to 15% in the coastal belt and hyper arid plains over the last 40 years while there is an increase in summer and winter rains in northern Pakistan.

Pakistan produces minimal chlorofluorocarbons and little sulphur dioxide emissions, thus making a negligible contribution to ozone depletion and acid rain. Pakistan will, nevertheless, suffer disproportionately from climate change and other global environmental problems.

It has been recorded that Pakistan's per capita grain area shrunk by 38-56% from 1950 to 1998 and by 2050 this fall will go up to 55-63%. Despite the projected increase in grain area the population of Pakistan is expected to grow to 350 million by 2050 which will reduce its grain land per person from 0.08 hectares at present to 0.03 hectares, roughly equivalent to one strip between 10-yard markers on a football field (Mansoor Raza).

4.1 Impact on Glaciers of Pakistan

The Himalayas are the origin of many glaciers and significant rivers in Asia. The range includes different types of glaciers. The most significant glacier in the area is the Siachen glacier, which is the largest glacier outside the Polar Regions. Some of the important glaciers in the Jammu and Kashmir are as follows:

- Siachen Glacier
- Baltoro Glacier
- Biafo Glacier
- Nubra Glacier
- Hispur Glacier

According to a 1999 report by the International Commission for Snow and Ice, glaciers in the Himalayas are receding faster than in any other part of the world. On the other hand, Hewitt reported widespread evidence of glacial expansion in the late 1990s in central Karakoram, in contrast to a worldwide decline of mountain glaciers. These conflicting findings make the assessment of the impact of climate change on Karakoram glaciers, and by extension the impact on the Indus River flow, more uncertain.

Changes in climate or the resulting accumulation of snow and disappearance of glaciers in the upper reaches of the river basins could have serious consequences for the livelihoods not only of those engaged in the agricultural sector but also for the economy as a whole. Concerns about the impact of climate change on the Indus, based on an assessment of what might happen, given temperature changes in line with global climate change projections (Rees and Collins, 2005; Akhtar et al., 2008), have given rise to projection of dramatic decreases in river flow (Briscoe and Qamar, 2007). Such concerns have been supported by reports of significant retreat and depletion of glacier volume across the HKH range (Eriksson, 2009; Berthier, 2007; Sheathe et al., 2004).

This page intentionally left balnk

Efforts to quantify the contribution of melting glacier ice to the regional hydrology are just beginning. Precipitation and basin runoff generally decrease from the east to west – a direct result of the summer monsoon's weakening. Also, glaciers in the west are a more important source of stream flow volume (**Figure 4-1**). The total runoff in the western mountains is considerably less than that in the east at all altitudes, as expected, given the relative aridity of the western mountains.

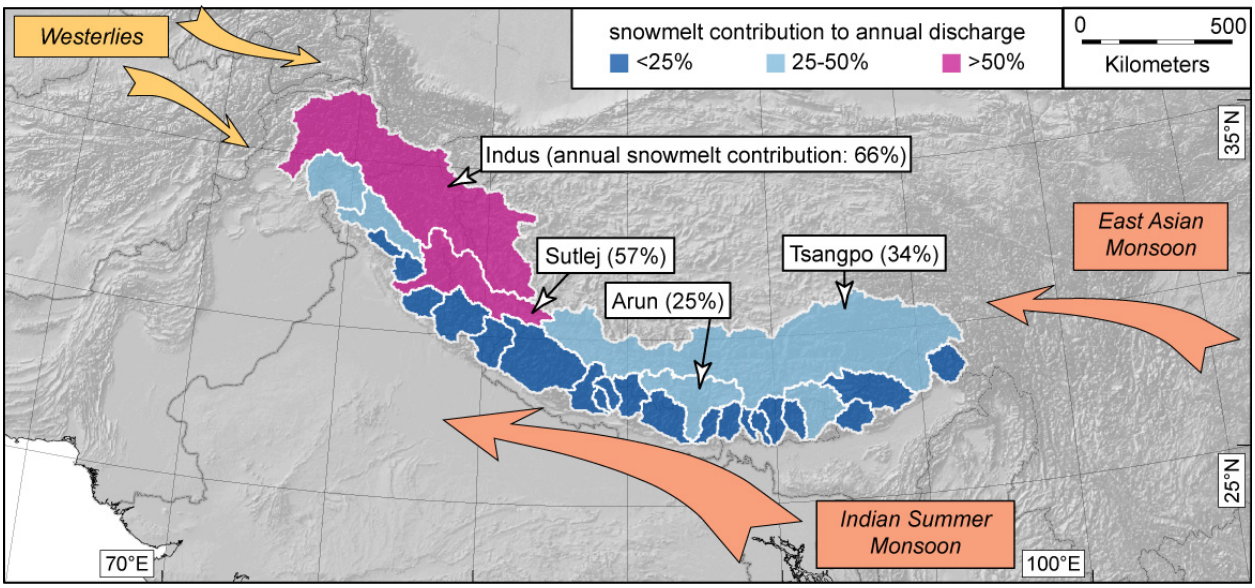


Figure 4-1: Snowmelt Contribution of Water in Subcontinent River Systems

Estimated rates of terminus retreat, typically measured from the point of furthest down-valley extent of a glacier, vary from approximately 2 to 20% over the past 40 years (Kulkarni et al. 2007). International Center for Integrated Mountain Development (ICIMOD), Kathmandu, reports that glaciers are retreating at rates of 10 m to 60 m per year and many small glaciers (<0.2 km^2) have already disappeared (Bajracharya et al., 2007). Upward shifts in the elevation of a terminus as great as 100 m have been recorded during the past 50 years and retreat rates of 30 m per year are common. These rates of retreat do not differ to any significant extent from retreat rates measured at other locations throughout the world. Temperature data from the Hindu Kush and Karakoram Mountains of the Upper Indus Basin show a variable pattern, but one that would support the stability, if not growth, of glaciers in the region. Since 1961, summer mean and minimum temperatures show a consistent decline while winter mean and maximum temperatures show significant increases, although still remaining well below the freezing level at the elevation of the glaciers (Fowler and Archer 2006). Decreases of approximately 20% in summer runoff of the Hunza and Shyok Rivers are estimated to have resulted from the observed 1° C decrease in mean summer temperatures, a pattern consistent with the observed thickening and expansion of some Karakoram glaciers (Fowler and Archer 2006; Hewitt 2005). Yao et al. (2009) describe how the percentage of retreating glaciers within China has increased from about 50% of all glaciers during the period 1950-1970 to more than 90% since 1990. The least amount of retreat has occurred at the higher elevations of the Tibetan Plateau with increasing amounts of retreat toward the lower elevations of the southeast edge of the Plateau and the lower elevations of the Karakoram Mountains. This general situation is reflected in **Figure 4-2**, where the mass of the glaciers at the higher elevations of the "Tibet" region is shown to be decreasing at a slower rate than glacier mass in the more extensive "Himalaya" region, which includes glaciers found at much lower elevations.

This page intentionally left balnk

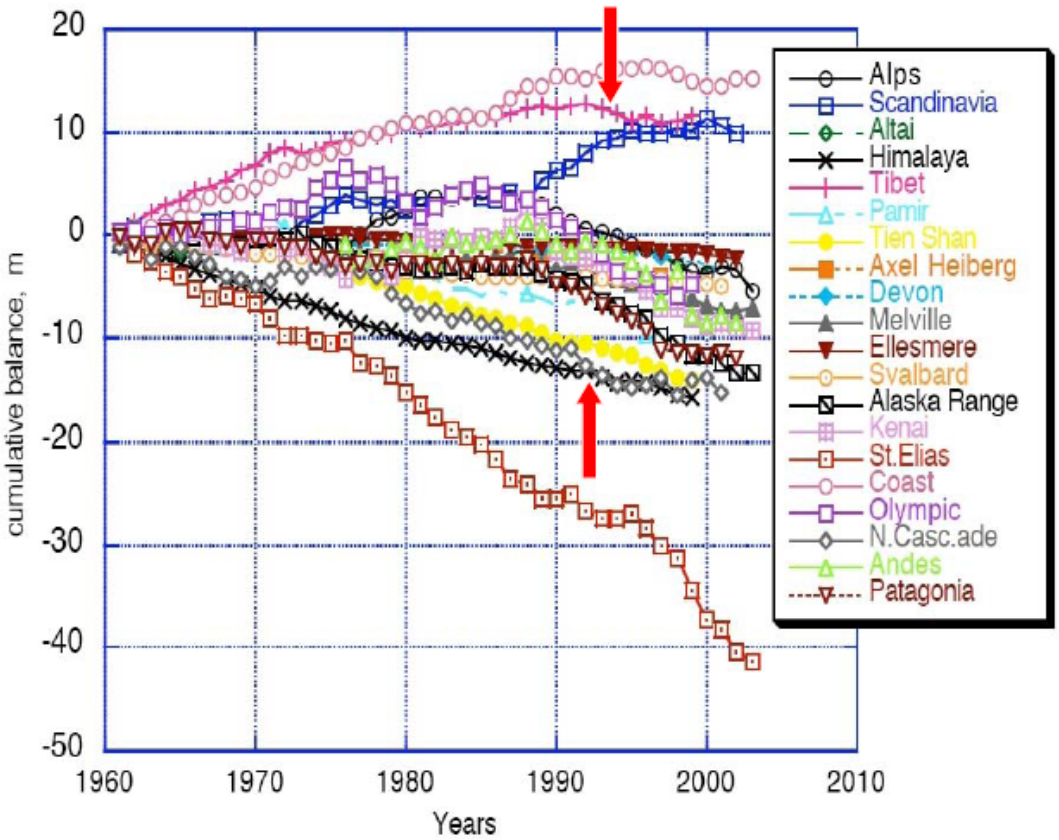


Figure 4-2: Cumulative Mass Balance for Selected Glaciers System

In general, the rate of retreat and/or down-wasting depends on several factors, independent of dynamics. These include elevation, debris cover, ice thickness, and topographic slope and aspect; and not all investigators consider these variables when they report retreat rates. Clearly, the greatest retreat and or down-wasting is associated with those glaciers located at the lowest altitudes on gentle slopes, with thin ice near the terminus, and the thickness of debris-cover that enhances rather than retards melt. Smaller glaciers at the lowest elevations with a southerly aspect, and those "hanging glaciers" cut off from a substantial accumulation area, will be the first to disappear.

4.2 Impact on Other Water Resources of Pakistan

A number of studies have been reported in the literature to assess the impact of climate change scenarios on hydrology of various basins and regions. In a number of studies, it is projected that increasing temperature and decline in rainfall may reduce net recharge and affect groundwater levels. However, little work has been done on hydrological impacts of possible climate change for Indus Basin (R. K. Mall, 2006).

Expected climate changes in Indus Basin include the following: 1) some climate models predict precipitation changes ranging from -20% to +20% for the upper Indus Basin and -20% to +30% in the main system; and 2) temperatures will increase too, with warming averaging 2.0 to 4.7 °C in the upper basin and 2.0 to 3.6 °C in the main system.

This page intentionally left balnk

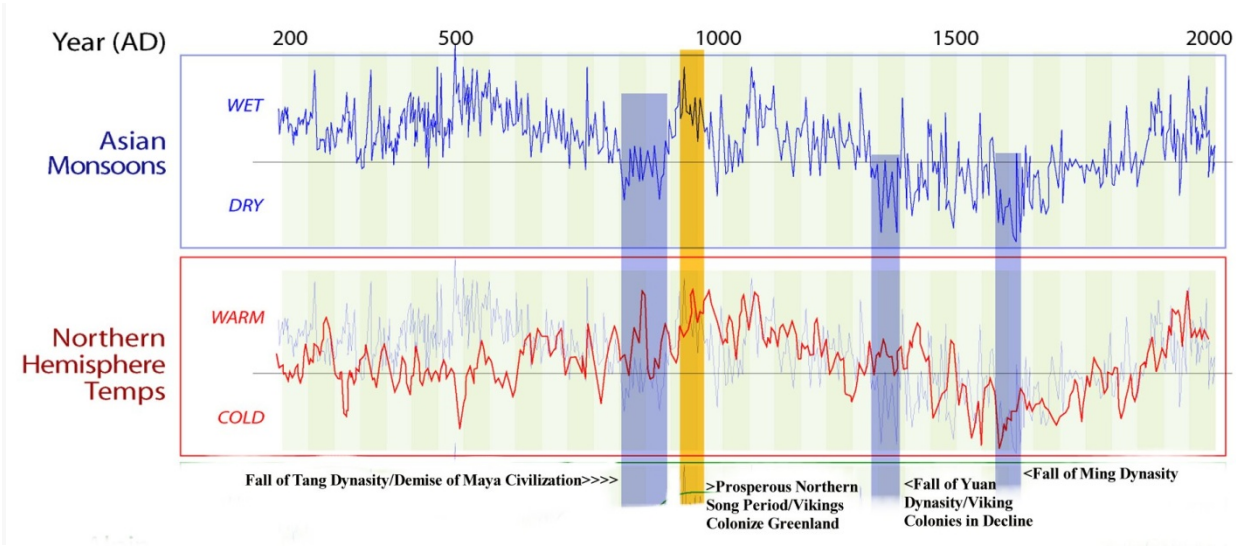


Figure 4-3: Correlations between Asian Monsoon Precipitation, Northern Hemisphere Temperature, and Some Events of Human History

Higher temperatures could increase evaporation leading to drier soils. However, this may be compensated for by higher precipitation and higher runoff from snowmelt as the Indus Basin will see increased runoff due to increased glacial melt. In essence, Pakistan will "mine" its glacial water over the next few years, as higher temperatures melt more of the glaciated north and less precipitation falls as snow during the winter months.

The Indus Basin climate is dominated by the South Asian Monsoon, which is poorly simulated by Global Circulation Models. In some extreme predictions, the South Asian Monsoon shuts down completely. Perhaps more realistically, increasing precipitation and temperatures could lead to a higher intensity monsoon. A result of the US National Science Foundation study on Asian monsoon and temperature is shown in **Figure 4-3**, and the anomaly in summer rainfall from 1871 to 2004 in India is shown in **Figure 4-4**.

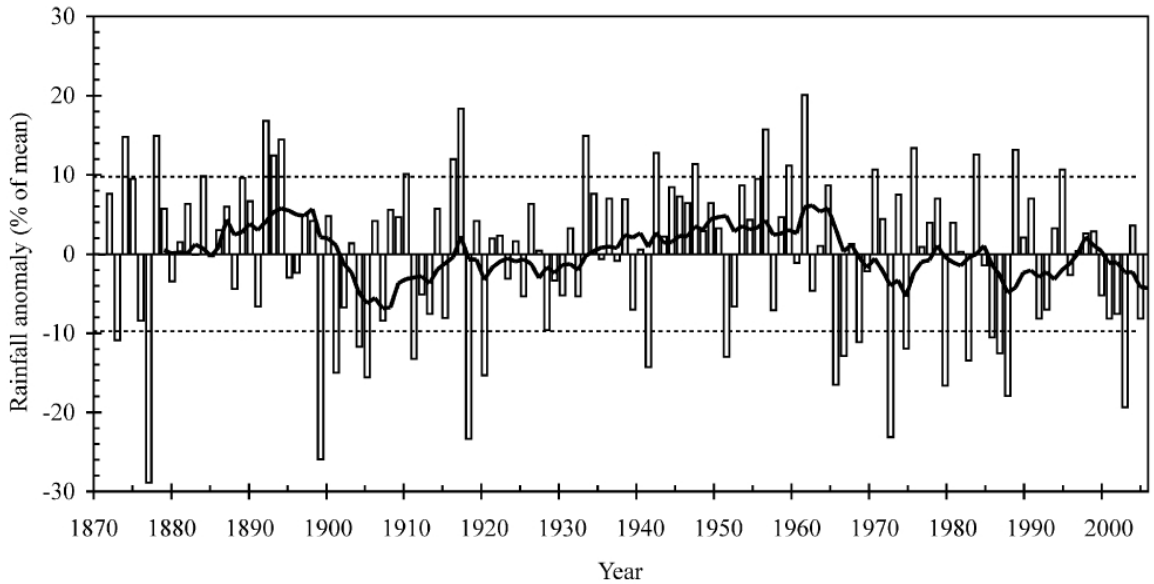


Figure 4-4: All India Summer Rainfall Anomalies (1871-2004). Dark Line Shows 10 Years Moving Average (after Mall R.K. et al)

Finally, glacial basins like the Indus will see an increase in snowmelt continuing until later in the year. Most of the increases in this runoff will occur between September and April. Some studies estimate that runoff will increase by about 5%, but predictions range from -19 per cent to +18 per cent.

Global warming and its impact on the hydrological cycle and nature of hydrological events have posed an additional threat to this mountainous region of the Indian subcontinent. Extreme precipitation events have geomorphologic significance in the Himalayas, where they may cause widespread landslides. The response of hydrological systems, erosion processes and sedimentation in this region could alter significantly due to climate change. It is estimated that the Himalayan Mountains cover a surface area of permanent snow and ice in the region which is about 97,020 km^2 with 12,930 km^2 volume. In these mountains, 10 to 20% of the total surface area is covered by glaciers, while an area ranging from 30 to 40% has seasonal snow cover (Bahadar J, 1999). These glaciers provide snow and the glacial melt waters keep the Himalayan rivers perennial. A conservative estimate gives 500 km^3/yr of snowmelt and ice melt contributions to Himalayan streams from the Lower Himalayas, while about 515 km^3/yr from the upper Himalayan Mountains. The most useful facet of glacial runoff is the fact that glaciers release more water in a drought year and less water in a flood year and thus ensure water supply even during the lean years. The snow line and glacier boundaries are sensitive to changes in climatic conditions. Almost 67% of the glaciers in the Himalayan mountain ranges have retreated in the past decade. Available records suggest that the Gangotri glacier is retreating about 28 m per year. A warming is likely to increase the melting more rapidly than the accumulation. Glacial melt is expected to increase under changed climate conditions, which would lead to increased summer flows in some river systems for a few decades, followed by a reduction in flow as the glaciers disappear.

The consequences of such environmental changes and impact on the poor of this region include:

- decreased water availability and water quality in many arid and semiarid regions
- an increased risk of floods and droughts in many regions
- reduction in water regulation in mountain habitats
- decreases in reliability of hydropower and biomass production
- increased incidence of waterborne diseases such as malaria, dengue, and cholera
- increased damages and deaths caused by extreme weather events
- decreased agricultural productivity
- adverse impacts on fisheries
- adverse effects on many ecological systems

As a result of these changes, climate change could hamper the achievement of many of the Millennium Development Goals (MDGs), including those on poverty eradication, child mortality, malaria, and other diseases, and environmental sustainability. Much of this damage would come in the form of severe economic shocks. In addition, the impacts of climate change will exacerbate existing social and environmental problems and lead to migration within and across national borders.

Archer (2003) has shown that river flow in the Indus does not depend uniquely on glacier melt but also depends on seasonal snowmelt and rainfall – thus giving three distinct regimes relating climate to river flow:

1. A nival regime at middle altitudes where flow is dependent on the melting of seasonal snow accumulated during the preceding winter and spring.
2. A glacial regime at very high altitudes where river flow is closely dependent on summer temperature.
3. A rainfall regime dependent on runoff from concurrent rainfall mainly during the monsoon season.

Of these three regimes, the greatest contribution to flow comes from the nival regime. The area of seasonal snow is an order of magnitude greater than the area of perennial snow and ice, although the area diminishes and cover is depleted through the melt season. In this zone, including the greater part of the upper Jhelum basin (Archer and Fowler, 2008), winter precipitation and summer runoff

are significantly positively correlated. Hence, trends in winter precipitation are likely to have the most significant impact on runoff. Archer and Fowler (2004) investigated historical trends in winter precipitation which mainly originates from westerly disturbances. They found upward trends in winter precipitation (October to March) at all stations across the region between 1961 and 1999 with three out of ten relationships being significant ($p > 0.05$). In contrast to the glacial regime, the relationship between runoff and temperature on snowmelt fed catchments is consistently negative both with respect to concurrent summer temperature and prior season temperature (Archer, 2003; Archer and Fowler, 2008). Singh and Bengtsson (2005) suggest that the negative link between temperature and runoff is explained by greater evaporative losses from the snow cover. under higher temperatures and thus reduced runoff. They estimate a reduction in runoff of 18% for a 2°C rise in summer temperature. The observed decline in summer temperature would, in contrast, tend to result in increased summer runoff. The negative link between preceding seasonal temperature and summer runoff combined with observed rising winter and spring temperature would tend to reduce summer runoff. There are two potential limitations to this analysis.

1. The trend analysis was limited to the available long term climate stations which are invariably located on valley floors and there is the possibility that they do not represent trends at higher elevations which receive much higher precipitation. However, the fact that the precipitation at these valley stations is strongly correlated with runoff originating at higher elevations indicates that precipitation measurements at valley level provide a satisfactory index of conditions at levels where snow is accumulating and melt occurring (Archer, 2003; Archer and Fowler, 2004).
2. Historic trends may not persist into the future (Milly et al., 2008). Updating of UIB precipitation trends to 2006, and including the drought years from 2000 to 2003, degrades the statistical significance of the trends. The IPCC (2007) projects precipitation increases in winter and spring for the "Tibetan Plateau" grid box, which includes but is larger than the UIB. The projected increases to 2039 vary between a 10% and 14% increase in winter between low and high emission scenarios and between 6% and 7% for spring. However, as these climate model projections are at a very coarse scale (300 km grid boxes) and will not provide adequate simulation of local processes over complex terrain, the projections are highly uncertain (Buytaert et al., 2010).

Heavy rainfalls (Rainfall Regime) of more than 200 millimeters (7.9 in) were recorded during the four day wet spell from 27 July to 30 July, 2010 (**Figure 4-5**) in the provinces of Khyber Pakhtunkhwa and Punjab based on data from the Pakistan Meteorological Department (**Table 4-1**).

Table 4-1: Rainfall Data for the Last Week of July 2010 of Different Cities of Pakistan

City	Rainfall (mm)	Rainfall (in)	Province
Risalpur	*415	16.3	Khyber Pakhtunkhwa
Islamabad	394	15.5	Islamabad Capital Territory
Murree	373	14.6	Punjab
Cherat	*372	14.6	Khyber Pakhtunkhwa
Garhi Dopatta	346	13.6	Azad Kashmir
Saidu Sharif	*338	13.3	Khyber Pakhtunkhwa
Peshawar	*333	13.1	Khyber Pakhtunkhwa
Kamra	308	12.1	Punjab
Rawalakot	297	11.7	Azad Kashmir
Muzaffarabad	292	11.5	Azad Kashmir
Lahore	288	11.3	Punjab

This page intentionally left balnk

City	Rainfall (mm)	Rainfall (in)	Province
Mianwali	*271	10.6	Punjab
Jhelum	269	10.6	Punjab
Lower Dir	263	10.3	Khyber Pakhtunkhwa
Kohat	*262	10.3	Khyber Pakhtunkhwa
Balakot	256	10.0	Khyber Pakhtunkhwa
Sialkot	255	10.0	Punjab
Pattan	242	9.5	Azad Kashmir
DIR	231	9.10	Khyber Pakhtunkhwa
Gujranwala	222	8.7	Punjab
Dera Ismail Khan	220	8.6	Khyber Pakhtunkhwa
Rawalpindi	219	8.6	Punjab

* Indicates new record.

Records show four months of rainfall falling in just a couple of days, and some areas in Northern Pakistan receiving more than three times their annual rainfall in 36 hours. Flowing quickly down the tributaries into the Indus River, the rain waters can lead to floods of catastrophic proportions. Given the scale of record downpours, some flooding is inevitable. Rivers are essentially channels to drain water; as one of the largest rivers of the world, the Indus should be able to carry excess waters into the Arabian Sea which it joins near Karachi, however during prior storm events the river was unable to carry excess waters without causing flooding. This is where human intervention – in terms of water resource planning and infrastructure development – plays an important role during floods.

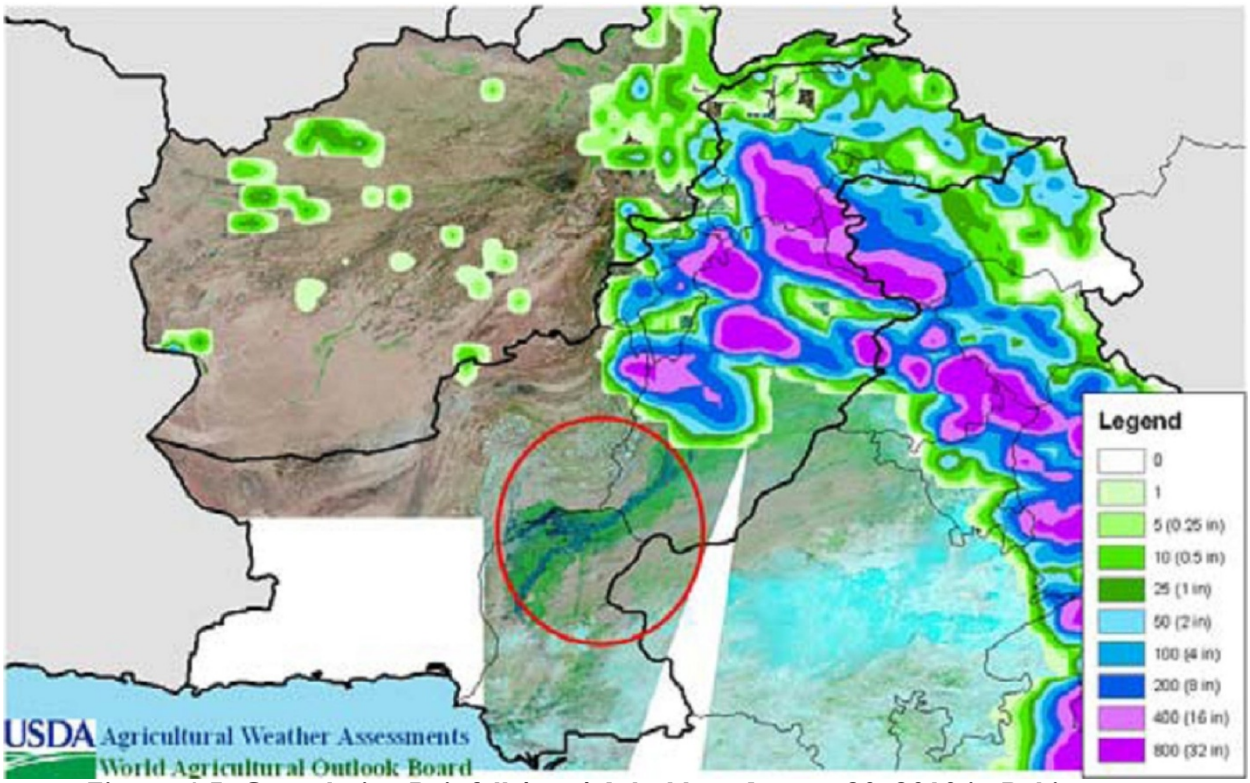


Figure 4-5: Cumulative Rainfall (mm) July 11 to August 20, 2010 in Pakistan

Besides the frozen jet stream that caused the unusual rains during the 27 July to 30 July, 2010 event, the water infrastructure on the Indus River and its tributaries are also to blame for the scale of

human impact of the floods in Pakistan. Floods are partly 'anthropogenic' in that they can be caused and/or the impacts more sever due to careless planning of water resources. Engineers and water planners have often given insufficient consideration to the sediment load that gets carried within the banks of the river channel, and through the interventions of their infrastructure they exacerbated this year's flood. They created a false sense of security amongst the rural peasants, whose lives and livelihoods were washed away in the floods.

There are two more contributing factors which made the river flows more furious and devastating during 2010 floods. They are:

1. Lack of storage capacity: Pakistan can store only 9% of its annual river inflows, which is significantly lower than the figures for India (33%), the Nile Basin in Egypt (347%) and the Colorado Basin in the US (497%). As a result, the floods took away 50 MAF water to the Arabian Sea, despite the fact that Pakistan is facing a 30% power shortage and 25-40% water shortage in the agriculture sector. The flood intensity would have reduced by half if the already identified technically feasible dams of Basha, Mangla raising, Munda, Akori and Kalabagh were constructed, with a combined storage of 23 MAF. Construction of additional storage will assume further importance in the face of possible rapid melting of glaciers in the Western Himalayas due to climate change.
2. Degraded watersheds: Pakistan has ignored integrated river basin management, especially watershed management. The watershed of the rivers Indus, Kabul, Swat and Jehlum, which fall within the boundaries of Pakistan, could have been used to store water locally through better land management practices (afforestation, increasing grass and shrub cover, terracing, ponding and community awareness). Nothing significant was done in these very important flood-proofing areas. The high intensity rainfall thus generated immense runoff down the steep slopes of Northern Pakistan (Khyber Pakhtunkhwa), adding destructive velocity to the Indus River system and quickly resulting in overflowing rivers.

The contribution of these floods to groundwater resources has not been covered by any agency in Pakistan.

5 TASK FORCE ON CLIMATE CHANGE (TFCC), GOVERNMENT OF PAKISTAN

A Task Force on Climate Change (TFCC) of the Planning Commission of Pakistan with Dr. Ashfaq Ahmad as Chairman, and MR. Shams ul Mulak, as Co Chairman, was established in 2008, and have submitted their report/findings in February 2010. Some of the main findings, concerns and recommendation of the TFCC are summarized in the following sub-sections.

5.1 Effect on Precipitation Pattern noted by TFCC

- The area averaged mean annual precipitation over Pakistan increased by 25% during the previous century.
- An increase in the intensity of precipitation has been observed over most areas of Pakistan during 1965-2000.
- Monsoon precipitation increased everywhere except in coastal regions (where there was a significant drop) and the Western Balochistan Plateau during 1951-2000.
- During the same period winter rains increased by 26-57% in Sub-Montane, Central & Southern Punjab, and North-Eastern Balochistan and decreased by 13-20% in Sindh and Western Balochistan.
- The Greater Himalayas region experienced the highest growth in Monsoon precipitation (86%) and a nominal decrease (2%) in winter (December-March) precipitation during 1951-2000.

5.2 Major Concerns raised by TFCC

The major climate change related threats to water security are identified as:

- Increased variability of river flows due to increase in the variability of monsoon and winter rains and loss of natural reservoirs in the form of glaciers.
- Likelihood of increased frequency and severity of extreme events such as floods and droughts.
- Increased demand of irrigation water because of higher evaporation rates at elevated temperatures in the wake of reducing per capita availability of water resources and increasing overall water demand.
- Increase in sediment flow due to increased incidences of high intensity rains resulting in more rapid loss of reservoir capacity.
- Changes in the seasonal pattern of river flows due to early start of snow and glacier melting at elevated temperatures and the shrinkage of glacier volumes (this will have serious implications for storage of irrigation water and its supply for Kharif and Rabi crops).
- Possible drastic shift in weather pattern, both on temporal and spatial scales.
- Increased incidences of high altitude snow avalanches and GLOFs generated by surging tributary glaciers blocking main un-glaciated valleys.
- The need for considerable expansion in reservoir capacity (a) to take care of the increasing frequency and intensity of floods and droughts, (b) to take advantage of the greater water flows over the next two to three decades due to glacier melting as well as to address the expected decreases of flows in the subsequent years after the glaciers have largely melted, (c) to provide regulated minimum environmental flows to the sea to prevent excessive intrusion of sea water into Indus deltaic region, (d) to take care of the loss in reservoir capacity due to silting, and (e) to meet future increases in water demand. (Even without specific consideration of the climate change related impacts, the Planning Commission envisages that without additional storage the water shortfall will increase by 12 per cent over the next decade alone (GoP-PC 2007).
- Increased degradation of surface water quality due to increase in extreme climate events like floods and droughts.

- Lack of current knowledge and monitoring effort on climate change impacts in the HKH region; also lack of understanding and modeling capability about the patterns of glacier melt and rainfall feeding the IRS and the corresponding impact on IRS flows.

5.3 Recommended Measures by TFCC in Enhancing Water Security

Some key adaptation measures that will help in enhancing water security in the wake of climate change are identified below:

- Reduce losses in the system of irrigation water supply and use to the maximum possible extent by reducing seepages from the canals and distribution networks and by adopting modern, more efficient irrigation techniques (e.g. use of sprinklers and trickle irrigation) to replace the conventional method of flood irrigation.
- Build sufficiently large reservoir capacity on Indus and its tributaries so as to ensure no flow of Indus water down Kotri, even during high flood years, in excess of that necessary for environmental reasons including prevention of excessive influx of sea water into the Indus deltaic region.
- Once a sufficiently large reservoir capacity is in place, use some of it as carry over dams instead of the current practice of seasonal storage only so as to be able to use excess water saved during a high flood year in the subsequent lean years.
- Ensure that, while making water allocations (within gross national availability) to various sectors in the medium- to long-term future, due consideration is given to changes in sector demands caused by climate change.
- Address seawater intrusion into Indus deltaic region by allocating enough water to ensure minimum environmental river flows down Kotri.
- Legislate and enforce industrial and domestic waste management practices to protect the environment, in particular water resources, from further degradation.
- Protect and enhance resilience of water-bodies, lakes, flood plains, etc.
- Protect groundwater through management and technical measures like regulatory framework, artificial recharge.
- Introduce local rain harvesting measures;
- Sensitize existing schemes like flood and drainage plans to climate change impacts.
- Introduce stringent demand management and efficiency improvement measures in all water use sectors, particularly in the supply, distribution and use of irrigation water.
- Improve efficiency of around one million ground water pumping units which are currently operating at typical efficiency of 20-25%.
- Ensure measurement and monitoring of water delivery at various points of supply system for effective planning and management. This will also provide base for volumetric water pricing in future which is essential for conservation and high value use of scarce water resources.
- Formulate national water law for improved governance and accountability.
- Manage wastewater through proper treatment and reuse it in agriculture, artificial wetlands and groundwater recharge. In particular, improve water efficiency by managing and reusing marginal quality irrigation effluent.
- Enhance national monitoring capacities for monitoring: (i) gross river flows, (ii) temporal changes in the volumes of major glaciers and snow cover, and (iii) meteorological parameters, by increasing the number of monitoring stations in accordance with international norms, particularly in the northern areas of the country, and by upgrading their data gathering, and data transmission and processing capabilities. Full use should be made of state-of-the-art analytical tools such as remote sensing (RS) and geographical information system (GIS) techniques to obtain information which cannot be gathered through conventional techniques.
- Also enhance national capacity for making quantitative assessments of climate induced changes and for analyzing and implementing appropriate technical and management solutions. Again, full use should be made of state-of-the-art analytical tools such as regional climate models and watershed models.

- Develop a National Water Resources Information System for fast data communication and analytical planning to meet challenges of droughts and floods.
- Enhance capacity to address the impacts of floods, flash floods, droughts etc. by strengthening National Disaster Management Authority and related provincial and district level organizations.
- Improve inter-agency as well as international coordination for information collection and sharing.
- Develop a national water policy which duly addresses the water related vulnerabilities induced by climate change.

This page intentionally left balnk

6 SUMMARY OF PAST AND EXPECTED FUTURE CLIMATE CHANGES IN PAKISTAN

Review of literature reveal that future changes in climate of the magnitude projected by most global climate models would cause some impacts on Pakistan water resources, and subsequently affect food supply, health, industry, transportation and ecosystem sustainability. Problems are most likely to arise first in the southern parts of country where the resources are already under stress, and that stress would be exacerbated by changes in supply or demand associated with climate change. During the last century, Pakistan saw an increase in average annual temperature of 0.6 °C, consistent with the global trend, with the temperature increase in northern Pakistan being higher than that in southern Pakistan (0.8°C versus 0.5°C). Studies performed by others in the past using GCM's project that the average temperature over Pakistan will increase in the range 1.3-1.5°C by 2020s, 2.5-2.8°C by 2050s, and 3.9-4.4°C by 2080s, corresponding to an increase in average global surface temperature by 2.8-3.4°C by the turn of the 21st century. Precipitation is projected to increase slightly in summer and decrease in winter with no significant change in annual precipitation. Furthermore, it is projected that climate change will increase the variability of monsoon rains and enhance the frequency and severity of extreme events such as floods and droughts (SIDA, 2010).

This page intentionally left balnk

7 REFERENCES

See references in the Supplemental Main Report on Climate Change.

This page intentionally left balnk