

**CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE
IN ARID REGION OF PAKISTAN
(1961-2000)**

**BY
SAIFULLAH KHAN**



**THE THESIS SUBMITTED TO THE UNIVERSITY OF
PESHAWAR IN PARTIAL FULFILMENT OF
Ph.D DEGREE IN GEOGRAPHY**

**INSTITUTE OF GEOGRAPHY, URBAN AND REGIONAL PLANNING,
UNIVERSITY OF PESHAWAR, KHYBER-PAKHTUNKHWA
PAKISTAN**

SESSION 2001-2002

**INSTITUTE OF GEOGRAPHY, URBAN AND REGIONAL
PLANNING, UNIVERSITY OF PESHAWAR,
KHYBER-PAKHTUNKHWA, PAKISTAN**



**IT IS RECOMMENDED THAT THIS THESIS SUBMITTED BY Mr. SAIFULLAH
KHAN TITLED, “CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE IN
ARID REGION OF PAKISTAN (1961-2000)” BE ACCEPTED FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY IN GEOGRAPHY.**

1. Prof. Dr. Mahood-UI-Hasan

Prof. Dr. Farhat Gulzar

2. Prof. Dr. Muhammad Aslam Khan

INTERNAL SUPERVISOR

EXTERNAL SUPERVISOR

List of Contents

Title	Page No.
List of Contents	I
List of Graphs	V
List of Tables	XIII
List of Maps	XVI
List of Figures	XIX
List of Acronyms	XX
Dedication	XXVI
Acknowledgement:	XXVII
Abstract:	XXIX

Chapter-1	1
------------------	----------

Introduction	
---------------------	--

1.1. Objectives of the study:	1
1.2. Conceptual framework:	2
1.3. Research problem:	3
1.4. Significance of the study:	3
1.5. Research questions:	4
1.6. Research hypothesis:	4
1.7. Research methodology:	4
1.8. Perception to climate change	19
1.9. Research organization:	20
1.10. Limitation of Research	21

Title	Page No.
Chapter-2	24
Literature Review	
2.1. Climate change:	24
2.2. Causes of climate change:	33
2.3. Impacts of climate change:	34
2.4. Climate change adaptation:	44
Chapter-3	51
Environment and Agriculture	
3.1. Physical setting:	51
3.2. Soils:	53
3.3. Climate:	58
3.4. Natural vegetation:	58
3.5. Human environment:	61
3.6. The agro-ecological zones and landuse pattern:	65
Chapter-4	83
Temperature Distribution and Fluctuation	
4.1. Annual temperature distribution:	85
4.2. Extreme maximum and minimum temperature:	89
4.3. Temperature regions:	92
4.4. Temperature fluctuation:	96
4.5. Seasonal fluctuation:	106
4.6. Temperature variation:	122

Title	Page No.
Chapter-5	128
Precipitation Distribution and Fluctuation	
5.1. Horizontal distribution:	128
5.2. Mean monthly precipitation:	129
5.3. Seasonal distribution:	133
5.4. Precipitation fluctuation:	146
5.5. Seasonal fluctuation:	158
5.6. Precipitation variation:	167
Chapter-6	177
Impact of Climate Change on Agriculture and Indus Drainage Basin	
6.1. Impact on crops:	176
6.2. Impacts on agriculture environment:	212
Chapter-7	230
Adaptation to climate change	
7.1. Adaptation Measures :	231
7.2. Perception of communities on climate change:	244
7.3. Adaptation implementation:	248
Chapter-8	250
Conclusions, Recommendations and Further Research	
8.1. Conclusions:	250
8.2. Recommendations:	257
8.3. Further research:	258

8.4. References:	260
Appendix-A: Questionnaire	287
Appendix-B: International Publication, Abstract,	298
Appendix-C: International Publication, Abstract	299
Appendix-D: International Publication, Abstract	300
Appendix-E: International Publication, Abstract	301
Appendix-F: International Publication, Abstract	302
Appendix-G: List of Graphs (chapter-4 and 5)	303
Appendix-H: Glossry	317

List of Graphs

Number	Title	Page
Graph-4.1	Arid region of Pakistan, mean monthly temperature and precipitation	84
Graph-4.2	Arid region, deviation of mean monthly temperature and precipitation from the mean	85
Graph-4.3	Arid region of Pakistan, annual trend of mean monthly temperature	99
Graph-4.4	Arid region of Pakistan, deviation of mean monthly temperature	99
Graph-4.5	Arid region of Pakistan, five years average temperature	104
Graph-4.6	Arid region of Pakistan, ten years average temperature	104
Graph-4.7	Arid region of Pakistan, fifteen years average temperature	105
Graph-4.8	Arid region of Pakistan, twenty years average temperature	105
Graph-4.9	Arid region of Pakistan, trend of mean monthly winter/summer temperature	108
Graph-4.10	Arid region of Pakistan, deviation of summer/winter temperature from the mean	108

List of Graphs

Number	Title	Page
Graph-4.11	Arid region of Pakistan, trend of seasonal mean monthly temperatures	112
Graph-4.12	Arid region of Pakistan, deviation of seasonal mean monthly temperatures	112
Graph-4.13	Arid region of Pakistan, trend of five years temperature.	115
Graph-4.14	Arid region of Pakistan, trend of ten years average temperature.	116
Graph-4.15	Arid region of Pakistan, trend of fifteen years seasonal temperature.	116
Graph-4.16	Arid region of Pakistan, total rise/fall of seasons after fifteen years.	119
Graph-4.17	Arid region of Pakistan, mean monthly temperature at observatories (1961-2000)	122
Graph-4.18	Arid region of Pakistan, deviation of mean monthly temperature from the mean (1961-2000)	123
Graph-4.19	Chhor, annual trend of mean monthly temperature	303
Graph-4.20	Hyderabad, annual trend of mean monthly temperature	303
Graph-4.21	Jacobabad, annual trend of mean monthly temperature	304

List of Graphs

Number	Title	Page
Graph-4.22	Karachi, annual trend of mean monthly temperature	304
Graph-4.23	Panjgur, annual trend of mean monthly temperature	305
Graph-4.24	Dalbandin, annual trend of mean monthly temperature	305
Graph-4.25	Drosh, annual trend of mean monthly temperature	306
Graph-4.26	Gilgit, annual trend of mean monthly temperature	306
Graph-4.27	Skardu, annual trend of mean monthly temperature	307
Graph-4.28	D I Khan, annual trend of mean monthly temperature	307
Graph-4.29	Bahawalpur, annual trend of mean monthly temperature	308
Graph-5.1	Arid region, Palmer Drought Severity Index, Latitudes 25 ⁰ -30 ⁰ North and Longitudes 62 ⁰ -72 ⁰ East (1871-2000)	148
Graph-5.2	Arid region, deviation of five years average of Palmer Drought Severity Index (1871-2000)	150
Graph-5.3	Arid region, deviation of ten years average of Palmer Drought Severity Index (1871-2000)	151

List of Graphs

Number	Title	Pages
Graph-5.4	Arid region, deviation of fifteen years average of Palmer Drought Severity Index (1871-2000)	151
Graph-5.5	Arid region, deviation of twenty years average of Palmer Drought Severity Index (1871-2000)	152
Graph-5.6	Arid region, deviation of thirty years average of Palmer Drought Severity Index (1871-2000)	152
Graph-5.7	Arid region, annual trend of precipitation 1961-2000.	153
Graph-5.8	Arid region, deviation of mean monthly precipitation 1961-2000.	154
Graph-5.9	Arid region, annual trend of five years precipitation 1961-2000.	308
Graph-5.10	Arid region, annual trend of ten years precipitation 1961-2000.	309
Graph-5.11	Arid region, annual trend of fifteen years precipitation 1961-2000.	309
Graph-5.12	Arid region, annual trend of twenty years precipitation 1961-2000.	310
Graph-5.13	Arid region, mean monthly summer/winter precipitation	158
Graph-5.14	Arid region, summer/winter deviation from the mean.	159

List of Graphs

Number	Title	Pages
Graph-5.15	Arid region, mean annual precipitation of sub-seasons 1961-2000	161
Graph-5.16	Arid region, seasonal deviation of precipitation 1961-2000	161
Graph-5.17	Arid region, five years average seasonal precipitation 1961-2000	162
Graph-5.18	Arid region, five years deviation of seasonal precipitation 1961-2000	162
Graph-5.19	Arid region, ten year average seasonal precipitation 1961-2000	163
Graph-5.20	Arid region, ten years deviation of seasonal precipitation 1961-2000	163
Graph-5.21	Arid region, fifteen years average of seasonal precipitation 1961-2000	168
Graph-5.22	Arid region, fifteen years deviation of seasonal precipitation 1961-2000	168
Graph-5.23	Arid region, twenty years average seasonal precipitation 1961-2000	169
Graph-5.24	Arid region, twenty years deviation of seasonal precipitation 1961-2000	169
Graph-5.25	Arid region, total oscillation of seasonal precipitation 1961-2000	170

List of Graphs

Number	Title	Pages
Graph-5.26	Quetta, annual trend of precipitation 1961-2000	310
Graph-5.27	D I Khan, annual trend of precipitation 1961-2000	311
Graph-5.28	Dalbandin, annual trend of precipitation 1961- 2000	311
Graph-5.29	Skardu, annual trend of precipitation 1961-2000	312
Graph-5.30	Gilgit, annual trend of precipitation 1961-2000	312
Graph-5.31	Drosh, annual trend of precipitation 1961-2000	313
Graph-5.32	Karachi, annual trend of precipitation 1961-2000	313
Graph-5.33	Pasni, annual trend of Precipitation 1961-2000	314
Graph-5.34	Chhor, annual trend of precipitation 1961-2000	314
Graph-5.35	Bahawalpur, annual trend of precipitation 1961- 2000	315
Graph-5.36	Hyderabad, annual trend of precipitation 1961- 2000	315
Graph-5.37	Jacobabad, annual trend of precipitation 1961- 2000	316
Graph-5.38	Panjgur, annual trend of precipitation 1961-2000	316
Graph-6.1	Cropping pattern of major crops	178
Graph-6.2	Pakistan, precipitation, temperature and Cotton production 1961-2000	181
Graph-6.3	Pakistan, precipitation, temperature and Rice production 1961-2000	182

List of Graphs

Number	Title	Pages
Graph-6.4	Pakistan, precipitation, temperature and sugarcane production 1961-2000	183
Graph-6.5	Pakistan, precipitation, temperature and tobacco production 1961-2000	184
Graph-6.6	Pakistan, precipitation, temperature and maize production 1961-2000	188
Graph-6.7	Pakistan, precipitation, temperature and <i>jowar</i> production 1961-2000	191
Graph-6.8	Pakistan, precipitation, temperature and <i>bajra</i> production 1961-2000	191
Graph-6.9	Pakistan, precipitation, temperature and wheat production 1961-2000	193
Graph-6.10	Pakistan, precipitation, temperature and barley production 1961-2000	194
Graph-6.11	Pakistan, precipitation, temperature and sesamum production 1961-2000	195
Graph-6.12	Pakistan, precipitation, temperature and pulses production 1961-2000	196
Graph-6.13	Pakistan, yield per hectare of major agriculture crops 1961-2000	204
Graph-6.14	Pakistan, per capita availability of water resources, 1951-2000	213

List of Graphs

Number	Title	Pages
Graph-6.15	Indus river, deviation from the mean flow at Terbella 1940-2000	214
Graph-6.16	Kabul river, deviation from the mean flow at Attock 1940-2000	216
Graph-6.17	Jhelum river, deviation from the mean flow at Mangla 1937-2000	217
Graph-6.18	Chenab river, deviation from the mean flow at Maralla 1937-2000	218
Graph-6.19	Ravi river, deviation of the mean flow at Balloki 1937-2000	219
Graph-6.20	Sutlej river, deviation from the mean flow at Sulemanki 1937-2000	220

List of Tables

Number	Title	Page
Table-1.1	Arid Region, Population Density Class Range	9
Table-4.1	Arid region, mean monthly temperature (⁰ C) 1961-2000	93
Table-4.2	Arid region, mean monthly temperature of summer and winter season (1961-2000)	95
Table-4.3	Arid region, extreme maximum temperature (⁰ C) 1931-90	95
Table-4.4	Arid region, extreme minimum temperature (⁰ C) 1931-90	97
Table-4.5	Arid region, mean monthly temperature (⁰ C) and deviation from the mean 1961-2000	100
Table-4.6	Arid region, five years average temperature (⁰ C) and deviation from the mean (1961-2000)	102
Table-4.7	Arid region, ten, fifteen and twenty years average temperature (⁰ C) and deviation from the mean (1961-2000)	103
Table-4.8	Arid region, mean monthly seasonal temperature (⁰ C) 1961-2000	124
Table-4.9	Arid region, mean monthly temperature variation (⁰ C) 1961-2000	127
Table-5.1	Arid region, mean monthly precipitation (Inches) 1961-2000	130

List of Tables

Number	Title	Page
Table-5.2	Arid region, mean annual precipitation (Inches) 1961-2000	131
Table-5.3	Arid region, mean monthly and deviation of seasonal precipitation (Inches) 1961-2000	143
Table-5.4	Palmer Severity Indices (PDSI) Ranges	147
Table-5.5	Arid region, annual deviation of Palmer Drought Severity Indices (1871-2000)	149
Table-5.6	Arid region, five years average precipitation (Inches) 1961-2000	156
Table-5.7	Arid region, ten, fifteen, and twenty years average precipitation (Inches) 1961-2000	157
Table-5.8	Arid region, seasonal fluctuation of precipitation (Inches)	174
Table-6.1	Arid region of Punjab, district wise rice area, production, and average yield (1990-2000)	208
Table-6.2	Arid region of Punjab, district wise wheat area, production and average yield (1990-2000)	209
Table-6.3	Arid region of Punjab, district wise sugarcane area, production, and yield (1990-2000)	210
Table-6.4	Arid region of Punjab, district wise cotton area, production, and yield (1990-2000)	211

List of Tables

Number	Title	Page
Table-6.5	Pakistan, <i>kharif</i> and <i>rabi</i> major crops production 1961-2000	212
Table-6.6	Arid Region, Flow of main rivers (MAF) 1940-2000	222
Table-6.7	Arid Region, Rivers flow 1968-1972 (MAF)	224
Table-6.8	Pakistan, Expansion of the arid region 1961-2002	225
Table-6.9	Historical droughts in India and Pakistan 1801-2002	227
Table-6.10	Major Flood Events in Pakistan	229

List of Maps

Number	Title	Pages
Map-1.1	Pakistan, location of the study area	15
Map-3.1	Arid region, physical relief	55
Map-3.2	Arid region, soil map	57
Map-3.3	Arid region, natural vegetation	60
Map-3.4	Arid region, population density 1998	64
Map-3.5	Arid region, agro-ecological zones	69
Map-3.6	Sind province, landuse	70
Map-3.7	Lower Punjab, landuse	74
Map-3.8	Chitral district, landuse	75
Map-3.9	Gilgit-Baltistan province, landuse	76
Map-3.10	Baluchistan province, landuse	78
Map-3.11	Dera Ismail Khan, landuse	82
Map-4.1	Arid region, mean monthly temperature	88
Map-4.2	Arid region, mean monthly winter temperature	90
Map-4.3	Arid region, mean monthly summer temperature	91
Map-4.4	Arid region, temperature regions (1961-2000)	94
Map-4.5	Arid region, mean monthly cold season temperature	111
Map-4.6	Arid region, mean monthly pre-monsoon season temperature	114
Map-4.7	Arid region, mean monthly monsoon Season temperature	118

List of Maps

Number	Title	Pages
Map-4.8	Arid region, mean monthly post-monsoon Season temperature.	121
Map-5.1	Arid region of Pakistan, mean monthly total precipitation	132
Map-5.2	Arid region of Pakistan, mean monthly winter precipitation	136
Map-5.3	Arid region of Pakistan, mean monthly summer precipitation	137
Map-5.4	Arid region of Pakistan, mean monthly cold season precipitation	139
Map-5.5	Arid region of Pakistan, mean monthly pre-monsoon precipitation	140
Map-5.6	Arid region of Pakistan, mean monthly monsoon precipitation	144
Map-5.7	Arid region of Pakistan, mean monthly post monsoon precipitation	145
Map-6.1	Arid region, cropping pattern 2010-11	179
Map-6.2	Arid region, cotton growing areas	180
Map-6.3	Arid region, rice growing areas	185
Map-6.4	Arid region, sugarcane growing areas	186
Map-6.5	Arid region, maize growing areas	189
Map-6.6	Arid region, wheat growing areas	190

List of Maps

Number	Title	Pages
Map-6.7	Pakistan, arid region cropping pattern and shift in Isohyets 1961-2000	198
Map-6.8	Arid region, shift in agro-ecological zones, Isotherms and Isohyets	199
Map-6.9	Arid region, shift in the Isotherms 1961 and 2000	200
Map-6.10	Arid region, temporal region 1961	201
Map-6.11	Arid region of Pakistan, temporal region 2000	202
Map-6.12	Pakistan, expansion of the arid region 1960-2000	226

List of Figures

Number	Title	Pages
Figure-2.1	Factors Effecting Agricultural Sustainability	2
Figure-2.1	Structure of literature review	24
Figure-7.1	Wet (Before 200) and Dry View (2000) of lake Hina, Quetta, Baluchistan	237
Figure-7.2	Ghazi Barotha dam and bypass canal	239
Figure 7.3	Exposed banks, base widening and waterlogging of Jhelum and Sutlej river	239
Figure- 7.4	Dry distributary of Indus river at Eastern Sind, 2000	244

Acronyms

Abbreviation	Stand For
AD	Anno Domini
ADB	Asian Development Bank
AEA	Adaptation option for European Agriculture
AFED	Arab Forum for Environment and Development
Amsl	above Mean Sea Level
Aver	Average
⁰ C	Degree Celsius
CARE	Cooperative for American Relief Everywhere
CDPC	Climatological Data Processing Centre
CFCs	Chlorofluorocarbons
CGIAR	Consultative Group on International Agricultural Research
CIER	Center for Integrative Environmental Research
Cm	Centimeters
CMI	Crop Moisture Index
CO ₂	Carbon Dioxide
DEFRA	Department for Environment, Food and Rural Affairs
Deviat	Deviation
DFID	Department for International Development
EdGCM	Educational Global Climate Model
EEPSEA	Economy and Environment Program for Southeast Asia
EU	European Union
FAO	Food and Agriculture Organization

FATA	Federal Administrative Tribal Area
GDP	Gross Domestic Product
GHG	Green House Gases
GIS	Geographical Information System
GoBANGLADESH	Government of Bangladesh
GoChina	Government of China
GoJAPAN	Government of Japan
GoNORWAY	Government of Norway
GoP	Government of Pakistan
GoUK	Government of United Kingdom
GoUSA	Government of United States of America
GPCWA	Gross per Capita Water Availability
GR	Growth Rate
IPCC	Intergovernmental Panel on Climate Change
ISET	Interdisciplinary Scientific Environmental Technology
IYM	International Year of the Mountains
ka BP	Kilo Annum before Present
KMs	Kilometers
KMZ	Keyhole Markup Zip
KPK	Khyber Pakhtoonkhwa
M	Meters
MAF	Million Acres Feet
Mds	Maunds per Acre
mm	Millimeters
mm/yr	Millimeter per year

N	Number of Years
NGOs	Non Government Organizations
NIC	National Institute of China
NIGEC	National Institute for Global Environment Change
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
PARC	Pakistan Agriculture Research Council
PDSI	Palmer Drought Severity Index
pH	Power of Hydrogen
PHEDs	Provincial Health Engineering Departments
PMDC	Pakistan Meteorological Data Center
PP	Projected Population in the year xyz
R&D	Research and Development
TNP	Total National Population
TP	Total Population in 1998
TV	Television
TWR	Total Water Required
UK	United Kingdom
UNCED	United Nations Conference on Environment and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCC	United Nations Framework Convention on Climate Change

USA	United States of America
USAID	United States Agency for International Development
USSR	Union of Soviet Socialist Republics
WAPDA	Water and Power Development Authority
WCDR	World Conference for Disaster Reduction
WHO	World Health Organization

إِنَّمَا مَثَلُ الْحَيَاةِ الدُّنْيَا كَمَاءٍ أَنْزَلْنَاهُ مِنَ السَّمَاءِ فَاخْتَلَطَ بِهِ نَبَاتُ
الْأَرْضِ مِمَّا يَأْكُلُ النَّاسُ وَالْأَنْعَامُ حَتَّى إِذَا أَخَذَتِ الْأَرْضُ زُخْرُفَهَا
وَأَزْيَنْتَ وَظَنُّ أَهْلُهَا أَنَّهُمْ قَدِرُوا عَلَيْهِمْ أَتَيْنَاهَا أَمْرُنَا
لَيْلًا أَوْ نَهَارًا فَجَعَلْنَاهَا حَصِيدًا كَأَن لَّمْ تَغْنِبْ بِالْأَمْسِ كَذَلِكَ
نُفَصِّلُ الْآيَاتِ لِقَوْمٍ يَتَفَكَّرُونَ ﴿٢٤﴾

The example of [this] worldly life is but like rain which We have sent down from the sky that the plants of the earth absorb - [those] from which men and livestock eat - until, when the earth has taken on its adornment and is beautified and its people suppose that they have capability over it, there comes to it Our command by night or by day, and We make it as a harvest, as if it had not flourished yesterday. Thus do We explain in detail the signs for a people who give thought?

Al-Quran, 10:24

وَهُوَ الَّذِي أَنْزَلَ مِنَ السَّمَاءِ مَاءً فَأَخْرَجْنَا بِهِ نَبَاتَ كُلِّ شَيْءٍ
فَأَخْرَجْنَا مِنْهُ خَضِرًا نُخْرِجُ مِنْهُ حَبًّا مُتَرَاكِبًا وَمِنَ النَّخْلِ
مِنْ طَلْعِهَا قِنْوَانٌ دَانِيَةٌ وَجَنَّاتٍ مِنْ أَعْنَابٍ وَالزَّيْتُونَ وَالرُّمَّانَ
مُشْتَبِهًا وَغَيْرَ مُتَشَبِهٍ انْظُرُوا إِلَى ثَمَرِهِ إِذَا أَثْمَرَ وَيَنْعِهِ إِنَّ فِي
ذَٰلِكُمْ لَآيَاتٍ لِّقَوْمٍ يُؤْمِنُونَ ﴿٩٩﴾

And it is He who sends down rain from the sky, and We produce thereby the growth of all things. We produce from it greenery from which We produce grains arranged in layers. And from the palm trees - of its emerging fruit are clusters hanging low. And [We produce] gardens of grapevines and olives and pomegranates, similar yet varied. Look at [each of] its fruit when it yields and [at] it's ripening. Indeed in that are signs for a people who believe.

Al-Quran: 6:99

Dedicated to:

My loving father, Haji Muhammad (late) and to my Spouse Ayesha:

Respectable Haji Muhammad (Late) was the first school teacher of Swat State, who has educated major population of the area in hujra and mosques (1931) in the English era and produced a number of scholars and doctors.

Acknowledgment

All glories and praises be to Almighty Allah, who bestowed me with the prospective and abilities to complete this research work and to his Holy Prophet, Muhammad (PBUH), whose life teaches us spiritual depth and utmost standards in every aspect of life.

I offer my deep sense of gratitude to my supervisor, Dr. Mahmood-ul-Hasan, professor, Institute of Geography, University of Peshawar, and Dr. Muhammad Aslam Khan, HEC professor and co-supervisor, Institute of Geography University of Peshawar for their valuable guidance, constructive criticism and critical review and efforts to get this research work completed.

My heartfelt thanks are also due to Mr. Nadeem Faisal, assistant meteorologist, Climate Data Processing Center (CDPC), Pakistan Meteorological Department Karachi, for providing weather data. In addition, I would like to thanks to Prof. Dr. Amir Nawaz Khan, Director, Disaster Management Center, and Prof. Dr. Amir Khan, professor, Institute of Geography, University of Peshawar and members of the supervisory committee for providing all necessary research facilities during the course of work. I am also thankful to Prof. Dr. Fazl-Ur-Rehman, Director, Institute of Geography, Urban and Regional planning for the provision of facilities, cooperation, and critical questions. My deep sense of gratitude to Prof. Dr. Muhammad Arif, Department of Geology, and member of the supervisory committee for his help and encouragement. Mr. Muhammad Anwar Khan, economist, and to Mr. Liaqat Ali, MINFALL project, Ministry of Food and Agriculture, Islamabad for the provision of agriculture data and their support and guidance is deeply appreciated. I am also indebted to Mr. Sher

Muhammad, assistant professor, Institute of Geography, Islamic University Bahawalpur for the filling of questionnaires in the lower Punjab and its provision with in time. Similarly, Mr. Taleem Badsha, assistant professor, Department of Geography University of Baluchistan, helped in filling questionnaires from the sample areas of Baluchistan and his help and cooperation is dully acknowledged. I also wish to thank Dr. Yavor Chapanov, environmental scientist, BAS, Bulgaria, for the provision of PDSI website and his help in the analysis of data. The assistance of Mr. Shaukat Zaman, and Irfan Ali, deputy director (Water), Pakistan Agriculture Research Center, Islamabad is appreciated for the sharing of surface flow data of the Indus drainage system 1937 to 2008. NOAA, weather data of Pakistan, was obtained online from NOAA website, which facilitated the correction of the missing weather data provided by Pakistan Meteorological Department Karachi. Dr. Abdul Ghaffar, director, Agricultural Census Organization, Lahore, for the provision of historical agriculture census data of Pakistan. His contribution is duly acknowledged. I am also thankful to the librarians of Agriculture University, Forests Institute, and Institute of Geography, Urban and Regional Planning University of Peshawar for the provision of forests statistics and literature cited.

Last but not least, I am also thankful to my office colleagues Mr. Umar Farooq Butt, manager coordination, Mr. Fayyaz Alam, GIS technician, Universal Service Fund, Islamabad, for their help and encouragement. The cooperation and encouragement of all staff Institute of Geography, Urban and Regional Planning university of Peshawar is highly conceded.

Khan Saif Ullah

Abstract

This study is aimed at the climate change and its impact on the agriculture sector in the arid region of Pakistan between 1961 and 2000 (40 years) taking into account the secondary data of temperature and precipitation of 21 weather stations of the Pakistan Meteorological Department. The agriculture data were collected from the Pakistan Agriculture Research Council, whereas the primary data sources are questionnaire survey, and personal interviews. Five international publications were published from the current research and placed in the last of dissertation.

Physiography and location of the study area with respect to sea are the key factors that control the climate. There are a number of factors that have their influence on the cropping pattern in the area apart from climate. They include the type of soils, availability of irrigation water, government policies, socio-economic condition, advance technologies, market value and human demand etc. The soil of irrigated plain in lower Punjab and Sind is more suitable for the agriculture as compared to other parts, where the water is insufficient for cultivation.

The results obtained through trend analysis of annual temperature indicate warming of 1.6°C from 1961 to 2000. The mean monthly temperature shows rise and fall after an interval of five, ten, fifteen and twenty years. There is a negative trend during summer because of an increase in the monsoon precipitation, while it remains positive in winters. Five temperature zones have been identified including hot, warm, mild, cool, and cold. There is a slight increase in temperature in cold, pre-monsoon, monsoon season, and

decrease in the post-monsoon season that adversely affect the agriculture sector in the arid region.

The precipitation trend shows decrease throughout the series and depletion in the flow of the Indus and its tributaries causing change in landuse pattern, growing season, yield per acre, and make the agriculture sector more vulnerable. Palmer Drought Severity Index shows the dry condition prevailed over the arid region of Pakistan (1871 to 2000). The meteorological data from 1961 to 2000 reveal a slight change after every five years, medium in ten and fifteen years and long term oscillation after 20 years. The decline in the winter precipitation is higher as compared to the summer season. This decrease is maximum in cold and pre-monsoon season, whereas it is minimum in monsoon and post monsoon season. The change in precipitation decrease yield in *rabi* season in the rainfed as well as in the irrigated plain of lower Punjab and Sind, while the production of the *kharif* crops remain stable due to increase in the monsoon lows, cultivated area, and human demand. The isohyets reveal heavy rains in the southern Sind in monsoon season, while in winter, it shifts towards northwest Baluchistan. Generally, the isohyets of the southern arid region reveal a shift in the boundary towards northwest. Resultantly, Quetta and the adjoining areas of Afghanistan fell into arid climate during 1961 to 2000 and aridity prevailed over most of Baluchistan, Sind and lower Punjab.

The flow of the Indus and its tributaries seem to have direct relationship with the precipitation fluctuation. The impact is not visible on the flow of the Kabul river, but it is more prominent on the Indus, Chenab, Sutlej, Ravi and rivers in Baluchistan.

The production of cotton, tobacco, *Jowar*, Bajra, millet, barely, and gram has decreased from 1961 to 2000 and are vulnerable to the ongoing climate change. Furthermore, the production of rice, sugarcane, maize, wheat, and sesamum has shown an increase and remained stable. This stability is the result of increase in the cultivated land, better irrigation facilities, and market value etc.

The southern arid region has extended towards northwest, while it is towards north in the northern arid region (China). The agro-ecological zones and cropping pattern have shifted towards northwest. Due to increase in temperature, most of the mountainous areas that grew single crop throughout the year are now able for cultivation of two crops.

The impact on water sector could be minimized by the construction of new water reservoirs, river embankments, improvement in the water supply and irrigation system, planning for the use of water resources and utilization of the flood water, and policy. The agriculture sector requires improvement in the irrigation infrastructure, new technologies, crop choices, extension of irrigation system to rainfed areas, control of landuse change, and human pressure. The perceptual study reveals a change in the growing season from 20 to 30 days, whereas decrease in the production from 10 to 15kilograms per acre. The evidence provide basis for the acceptance of the research hypothesis that is *"Changes in the temperature and precipitation in Pakistan have affected agriculture in arid region of Pakistan severely and adaptation strategies are needed to cope with the situation"*.

Chapter-1

Introduction

This chapter discusses the objectives of the study, conceptual framework, research problem, scope of the study, research questions, hypothesis and methodology, data presentation, and research organization.

Climate is not a static phenomenon; it is variable in all its aspects in space and time. According to Berret (1963), *“There are two scales of climatic variations: for short-range variation, that is relatively minor in respect of temperature and precipitation, for which the preferred term is climatic fluctuation. In case, where the variation is much greater and of long duration, the preferred term is climatic change. Departure from normal or mean values within the normal range of weather at any location is simply referred to as climatic variability.”* These variations are of little importance in themselves, but they do serve to emphasize the fact that it is the nature of climate and weather to vary from time to time and that the variations may be more or less extreme.

1.1. Objectives of the study:

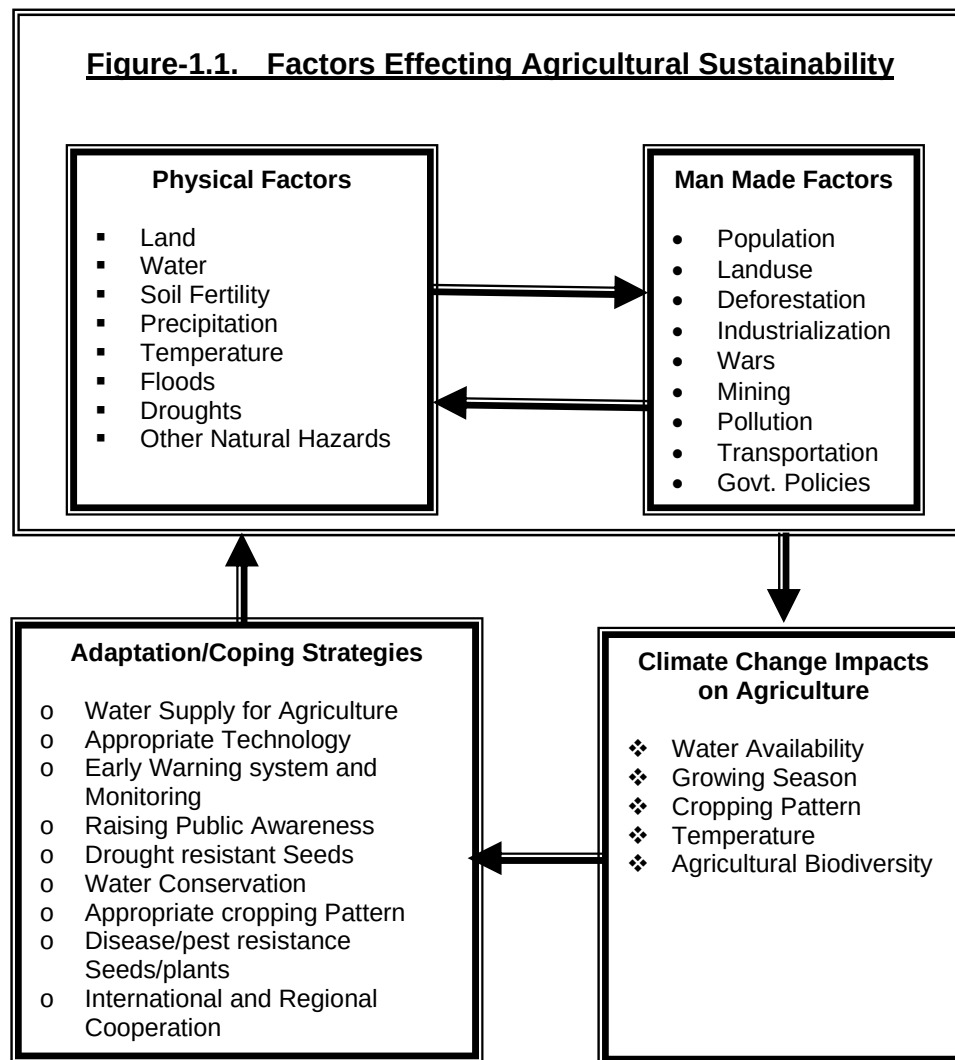
The present study has been proposed to achieve the following objectives.

- o To study the temperature and precipitation distribution pattern and trends in the arid region of Pakistan.
- o To identify hot/dry and wet/cold periods from 1961 to 2000 and to analyze their impacts on the agricultural conditions in the arid region of Pakistan.

- o To explore possible strategies that could be adopted for adjustments in agriculture to cope with the changes of temperature and precipitation in the arid region of Pakistan.

1.2. Conceptual framework:

Climate change and agricultural sustainability in the arid region of Pakistan is demarcated as follow.



1.3. Research problem:

Climate change and its impacts on the agriculture sector have attracted interest of the researchers on local as well as international level. Anthropogenic activities, socio-economic growth, as well as environmental changes are closely related with the phenomenon of climate. Moreover, climate and environmental condition like aridity, drought, flood, landsliding, and drainage system etc have impacts on the agriculture, food security, and well being of human in the arid region of Pakistan.

During 1990 to 2000, *"the temperature and precipitation of Pakistan has shown change that has affected the flow of water in Indus drainage basin and also caused a shift in the arid region of the country in the southern Punjab and Khyber-Pakhtoonkhwa. This fluctuation in the precipitation of the country has also caused damage to crops, livestock and resulted in shortage of the underground and running water in FATA, Khyber-Pakhtoonkhwa, Baluchistan, and Sind,"* (Khan, 2000 and Beig, 2001). Agriculture is the prime contributor to Pakistan's economy and this primary activity depends on the seasonal temperature, precipitation, and irrigation system in the Indus plain. Due to its physical and socio-economic importance, this study has been designed to analyze the climate change and its impact on agriculture and associated conditions in the arid region of Pakistan.

1.4. Significance of the study:

Despite vital role played by climate in the environmental as well as socio-economic condition of Pakistan, few studies have been conducted to evaluate climate change and its impact on agriculture. The proposed work is based on the study of temperature and precipitation fluctuation and its impact

on agricultural activities in the arid region of Pakistan. It will be a step forward in further research on climate change and beneficial in the adaptation of cropping pattern, agriculture, and climate change in Pakistan.

1.5. Research questions:

1. What type of fluctuation in the temperature and precipitation trends have been recorded in the arid region of Pakistan?
2. What are the impacts of temperature and precipitation fluctuation on the agriculture in arid region of Pakistan?
3. What kind of possibilities are there for adaptation of agriculture to the impacts of temperature and precipitation fluctuation in the arid region of Pakistan?

1.6. Research hypothesis:

Changes in the temperature and precipitation in Pakistan have affected agriculture in arid region of Pakistan severely and adaptation strategies are needed to cope with the situation.

1.7. Research methodology:

The following research methodology has been adopted to achieve the objectives of the study.

1.7.1. Data collection:

The work is based on monthly and annual averages of temperature and precipitation for 40 years (1961 to 2000). Data of 21 met-observatories of Pakistan have been collected from Climatological Data Processing Centre (CDPC), Pakistan Meteorological Department, Karachi. To analyze the impacts of temperature and precipitation fluctuation on the agriculture of arid

region in Pakistan, the data regarding crop yield and area have been collected from economical year books, agriculture census, and statistical supplement of the economic survey 2007 to 2008 from different organizations of the Ministry of Food and Agriculture, and Statistical Division, Islamabad. The historical agriculture annual production data regarding Pakistan have been extracted from the publication of Kurosaki (2007), who collected data on agriculture from 1901 to 2004 for India, Pakistan, and Bangladesh.

The satellite images have been collected from NOAA online. Discharge data of the Indus, Kabul, Jhelum, Chenab, Ravi, and Sutlej rivers have been collected from WAPDA, Lahore, covering time duration of 1937 to 2000. The public opinion regarding climate change and its impact on the agriculture sector and how to cope with the problem has been collected through questionnaire survey and personal interviews. To map the landuse of the arid region, topographic maps of 1:50K (2000 edition) for the arid region have been acquired from Survey of Pakistan. Areas that are restricted from defense point of view and not covered by 1:50K toposheets were digitized from 1:250 K topographic maps (1965 edition) collected from University of Texas Library, USA (Online, 1955). Besides, the native, international contributions of researchers have also been collected from different sources like books, journals, articles, and internet.

1.7.2. Variables:

The study is intended to document the fluctuation of temperature and precipitation as independent variables, and aridity, surface run-off, landuse, and agriculture as dependent variables.

1.7.3. Data analysis:

Temperature and precipitation are the main elements of weather and climate that play vital role in environmental condition of an area. The current work deals with the fluctuation of temperature and precipitation and their impact on the agricultural condition of the arid region in Pakistan.

In primary stage, the monthly and annual averages and deviation from the mean have been calculated for each met-observatory and tabulated for the purpose of analysis. The monthly and annual data of temperature and precipitation are further processed into seasonal means and deviation.

Furthermore, the seasonal and monthly means of the temperature and precipitation have been plotted on maps for the purpose to draw isotherms and isohyets. These maps are representing the spatial and temporal as well as general distribution and variation of temperature and precipitation. The same procedure has been used for construction of seasonal maps and charts. These weather maps were correlated to each other for the purpose to analyze fluctuation in the annual and seasonal isohyets for the study area.

Based on temperature, the area under study was classified into two main seasons that is winter and summer. Therefore, months of the year having positive deviation from the mean condition were considered as summer months, otherwise winter. Moreover, based on annual march of temperature and precipitation, these two seasons were further divided into four sub-seasons.

To evaluate the trends of dry/hot and wet/cold spells of temperature and precipitation, the data are further classified into different class ranges. These class ranges are arranged as comprising of 5 years, 10 years, 15

years, and 20 years using statistical techniques. The averages of each range are plotted on maps and graphs. A trend line for the whole series is plotted on the graph that shows a clear picture of the hot/dry and cold/wet spells of temperature and precipitation. Years of the series having values above the trend line are considered as wet (in case of precipitation) and hot (in case of temperature), while the converse will be considered dry/cold.

The deviation from the mean is calculated for each year and sum of that deviation from the mean condition shows increase or decrease in temperature and precipitation in the form of negative or positive trend during the past 40 years. The same procedure is used for data having different class ranges.

The annual sum of precipitation (inches) is plotted on maps and the isohyets are drawn for the purpose to mark the boundary of the arid region. The shift in decrease of precipitation is evaluated from the isohyets and the trend of shift in the arid region is calculated using geographical information system. The increase or decrease of the arid and semi-arid regions is calculated from the isohyets made for different class ranges. Based on precipitation, the arid region is further sub-classified into 0 to 5 and 5 to 10 inches sub-regions. The same method is applied for evaluation of frontal shift in summer as well as winter precipitation in Pakistan, as it will show the shift in seasonal precipitation levels towards Central Asia or Iran. The same procedure is applied for temperature ($^{\circ}\text{C}$) for the identification of hot, warm, cool, and cold regions of the arid region.

The fluctuation in temperature and precipitation is compared/cross matched with the agriculture and water availability etc in the arid region of the

country. A questionnaire survey is conducted to know the public opinion regarding climate change and its impact on agriculture sector and how to cope with this problem using random sampling method. The impacts and public opinion are presented at the end of the work with suitable recommendations, strategies, and policies to cope/adapt with the impacts of the ongoing temperature and precipitation fluctuation and its impact in the entire arid region in Pakistan.

1.7.4. Data presentation:

The location of the arid region in Pakistan has been clipped from 1:50K and 1:250K toposheets using GIS technology. The population of the arid region has been calculated from the District Census Reports, 1998. In some cases, where the population data were not available for the concerned district, the methodology has been generalized and average population of Pakistan has been considered. But on maps, only the demographic characteristics of the arid region of Pakistan have been highlighted. The projected population for the districts that fall in the arid region of Pakistan has been calculated using the following statistical formula.

$$PP = TP * (1 + GR/100)^N$$

The projected population, composition, and distribution have been plotted on maps and charts and matched with the precipitation and temperature of the arid region.

The method adopted for the population density of the arid region of Pakistan is as follow:

**Table-1.1: Arid Region
Population Density Class Ranges**

S_No	Population Density Classes	Density range
1	Thinly populated areas	<100
2	Moderately populated areas	101 to 200
3	Thickly populated areas	201 to 300
4	Very thickly populated areas	301 to 400
5	Most thickly populated areas	>401 and above

1.7.4.1. Temperature:

The mean monthly temperature above 22⁰C has been taken as a criterion for a summer month. These isotherms separate highlands from hot plains of the arid region. The temperature of arid region in Pakistan shows negative variation from November to March, while other months of the year have positive deviation from the mean condition. Temperature distribution of arid region in Pakistan shows high variation from south towards north. Based on temperature variation, the arid region has been divided into five macro-regions that are hot, warm, mild, cool, and cold. The criterion taken for hot climates is mean monthly temperature of the hottest month June, which is above 32⁰C, while for very hot (sub-region of the hot climates); it is above 35 degree Celsius. The temperature between 21⁰C to 32⁰C in June has been selected for warm climates and the temperature of warmest month, November, between 10⁰C to 21⁰C, in general, is for mild climates. Temperature of coldest month January between 0⁰C to 10⁰C has been considered for cool climates and temperature below freezing (less than 0⁰C) for cold climates. These temperature limits mostly determine the vegetation zones of the arid region with highlands and continental plain climate.

Most of the previous works have taken the mean daily values of temperature, as deciding factor, but for present study, the mean monthly values of temperature, have been taken for summer as well as winter months. The mean monthly values in general, are better indicators of seasons instead of mean daily temperature. Therefore, the year has been divided into two main seasons and the values have been calculated separately for each observatory. It can thus be generalized that winter in the plain lasts from November to March (five months) and in mountainous areas from October to April (seven months). Similarly, the summer season, in plains, has a span from April to October (seven months) and in mountainous areas from May to September (five months).

The statistical formulas used for the calculation of average and deviation from the mean are as follow.

$$\text{Average} = \frac{\text{Sum of Values}}{\text{Number of Years}}$$

$$\text{Deviation from the Mean (DM)} = \text{Value} - \text{Mean}$$

The annual averages for the arid region have been calculated from the monthly means of the surface temperature. To findout the fluctuation at different intervals, the series anomalies have been divided into different classes from 1961 to 2000. Primarily, the series have been analyzed taking into account class interval of five, 10, 15 and 20 years respectively. The annual mean of each series has been plotted on graphs, which represents the trend line for the different class ranges and from 1961 to 2000 as a whole. The trend line for the series anomalies clearly shows the cold, warm, and hot years of the arid region.

To analyze the positive and negative trends of the series, the mean monthly temperature from 1961 to 2000 has been calculated from the annual averages. The deviation from the mean condition has been calculated by subtracting the annual mean of temperature from the average condition of the arid region. Thus the result for each year has been calculated in the form of positive and negative deviation. The same procedure has been used for the series of different time interval that is five, 10, 15, and twenty years. The sum of deviation has been calculated that represents the degree of hot or cold condition over the arid region of Pakistan.

All of the results have been plotted on graphs, which show a clear condition of temperature fluctuation in the entire arid region. To analyze the variation of mean monthly temperature at different observatories, the annual mean temperature and deviation from the mean condition have been plotted on maps and the isotherms have constructed at different intervals that lead to the increase or decrease at different parts of the arid region in Pakistan.

To analyze the fluctuation in the two main and four sub-seasons of the arid region in Pakistan, the seasonal mean and deviation from the mean condition have been calculated using statistical techniques. To observe the maximum and minimum fluctuation of the different seasons the same procedure has been adopted as used for the analysis of the annual anomalies. The result of the seasonal data has been plotted on graphs and maps to findout the negative and positive anomalies for the arid region in different seasons of the year.

For the evaluation of mean monthly temperature variation, the arid region of Pakistan has been divided into six micro-regions i.e. Northern arid

region, Thar and Cholistan, Central irrigated plain, piedmont/Baluchistan plateau, and the coastal region.

1.7.4.2. Precipitation:

To study the distribution of precipitation, Pakistan has been divided into five regions. The precipitation ranges for each region are as follow:

Regions	Precipitation
Scanty rainfall or arid	<10inches (<254mm)
Light rainfall or semi-arid	10-20inches (254-508mm)
Moderate rainfall or sub-humid	20-40inches (508-1016mm)
Heavy rainfall or humid	40-80inches (1016-2032mm)
Very heavy rainfall or wet	>80inches (>2032mm)

The arid region for this study has been demarcated as per above criteria. Arid region extends northeast to southwest from latitude 37°N into $23\frac{1}{2}^{\circ}\text{N}$ and longitude 60°E to 75°East . The northern part of the arid region consists of high mountain ranges like Himalayas, Hindu Kush and Karakorum with highest peaks like, *K-2 (8475m)*, *Rakaposhi (7665m)* and *Trichmir* having an altitude of *7569meters* (Khan, 1993). The study area covers about 63 districts with a total area of 668,300 square kilometers (77.1% of Pakistan) having a total population of 78.7 million (Map-1.1).

The arid region extends from the coastal areas to the interior of the country in the south, while in the extreme north it covers Gilgit-Baltistan province and a part of the Chitral district in Khyber-Pakhtoonkhwa.

Some of the observatories in the surrounding of the arid region have been considered for the purpose to demarcate the isohyets on an accurate position. The statistical formula used for isohyets is;

Range of Isohyets= Highest Value-Lowest Value/Number of Isohyets

The annual march of precipitation in arid region shows, twice, both positive and negative deviation from the mean condition. Therefore, the two main seasons of the country i.e. summer and winter are further divided into four sub-seasons i.e. winter precipitation (December to mid-April), pre-monsoon (mid-April to June), monsoon precipitation (July to mid-September) and post monsoon precipitation (mid-September to November).

The data for few months/years are missing or some of the observatories may fall outside the arid region of the country. Therefore, these meteorological stations were excluded for the purpose to achieve reliable results. Only 12 observatories having complete precipitation data covering the entire arid region were considered for the analysis. The observatories of Drosh, DI Khan, Astore, and Quetta, located in the surrounding of the arid region (semi-arid) have been selected for the purpose to draw isohyets and to analyze the oscillation of aridity (desertification) towards or away from these observatories.

The annual mean of the region was calculated from the monthly mean of each observatory. The deviation from the mean was calculated by subtracting the average of each observatory from the mean condition of the arid region. The sum of deviation was estimated, that gives a clear picture of positive or negative oscillation and also the net values of extreme events, moderate and low precipitation in the region. The series anomalies were divided into different class intervals. From 2001 to 2002, the class range is less than five years and affects the results of the previous classes and therefore, it has been dropped from the analyses. Prominently, the series

were analyzed taking into account class intervals of 5, 10, 15, and 20 years respectively. The annual means of the data plotted on graphs and maps reveal pattern of precipitation at different time interval for the entire arid region of the country. The trend line for all observations represent a clear picture of high and low concentration of precipitation in the entire arid region.

Map-1.1: Pakistan
Location of the Study Area

The map displays the geographical context of the study area within Pakistan. The study area is shaded in red and includes districts such as Chitral, Gilgit, Skardu, and Ghanche. Other regions shown include FATA, Khyber Pakhtunkhwa, Punjab, Sindh, and Balochistan. The map also indicates the borders with Afghanistan, China, and India, and the Arabian Sea to the south. A legend, scale bar, and north arrow are provided for reference.

The values of the seasonal precipitation plotted on maps and graphs led to positive and negative anomalies and expansion of arid region to its surroundings at different seasons and time intervals. As the precipitation of the arid region is not uniform across the region, therefore the area has been divided into five zones namely, western, northern, coastal, eastern, and central zones.

1.7.4.3. Agriculture:

There are two principal crop seasons in the arid region of Pakistan, namely "*kharif*," and "*rabi*". *Kharif* is the summer season of the country in which the crops are planted from April to June and harvested from October to December. *Rabi* is the winter season in which the crops are planted from October to December and harvested in April and May. A questionnaire based survey has been conducted for the purpose to findout the exact time of sowing and harvesting of different crops in the arid region of the country. The main aim of this survey was to observe the public opinion regarding the impact of climate change on the cropping seasons and agriculture production of the arid region in Pakistan.

The agro-ecological zones of Pakistan are previously classified by the Agriculture Research Council Govt. of Pakistan in 1972 (GoP, 1972), taking into account the crop's water demand and cropping pattern. For the current work in most cases the cropping pattern and water demand procedure defined by the PARC with addition to temperature and precipitation from 1961 to 2000 has been considered. The agro-ecological zones have been extracted from the map made by PARC and updated on the basis of isotherms and isohyets pattern. Beside, for

some agro-ecological zones, the methodology presented by Mandal *et al* (1999) with some modification per requirements has been followed.

To define the different agro-ecological zones of the arid region of Pakistan, the Isotherms of mean monthly temperature ($^{\circ}\text{C}$) and isohyets of mean monthly precipitation (Inches) have been constructed on the district boundaries of the arid region. The class interval for isotherms has been considered 2°C , whereas for isohyets it is in inches (1inch=25.4mm). Both of the variables cross each other at different locations and represent a clear picture of the different agro-ecological zones of the arid region. In some cases, it is difficult to identify the agro-ecological zones with the same class interval; therefore the methodology has been extended to 4 class range for the purpose to clearly demarcate the boundaries of the agro-ecological zones of the arid region in Pakistan. The name of each agro-ecological zone has been selected on the basis of its location keeping in view its physiography, growing seasons, soil characteristics, temperature, precipitation, and vegetation cover.

1.7.4.4. Water resources:

The most serious potential threat arising from climate change in the arid region of Pakistan is water scarcity that is calculated taking into account the formula;

$$\text{GPCWA} = \text{TWR} / \text{TNP}$$

The annual mean and deviation from the mean condition for each major river has been calculated using statistical techniques and the data plotted on graphs for the purpose to evaluate the impact of climate change on the flow of

water in Indus and its tributaries. The data are further condensed into two growing seasons that is *kharif* (April to September) and *rabi* (October to March). The length of each growing season is the same as defined by the Agriculture Research Council Govt. of Pakistan, Islamabad.

The data of different rivers in Baluchistan are not available for the same time period and it is difficult to make any clear opinion about the impact of climate change on the surface flow in the province. Some of the historical discharge data of Khost, Hub, and Porali rivers in Baluchistan and Gilgit, Hunza rivers in Gilgit-Baltistan province have been downloaded from the NOAA library covering time period of 1968 to 1972. As the data do not cover a long time period but to some extent it will give us a trend for the future flow of these rivers.

To calculate the average expansion in the arid region of Pakistan, the arid region boundary has been converted into polygons using GIS and remote sensing for the year 1961. Then the boundaries of the arid region have been plotted on map for the year 2000. Both of the layers were intersected using ArcView software. The area of the remaining intersecting polygons was calculated and added to the entire area of the arid region, which easily shows the expansion of arid land towards north from 1961 to 2000.

Lastly, different climate change adaptation measures have been proposed for the stability of the inhabitants of the arid region and how to cope with the ongoing climate change in the area.

1.7.4.5. Landuse:

Most of the layers were digitized from the 1:50K and 1:250K topographic maps and updated from the Google earth. The layers considered as vector data are, fertile land, rainfed, residential area, forests, mountains, barren land, water bodies, deserts, marshy land, glaciers, and moraines. All of the features were extracted in one layer and then separated with the help of features coding in the vector data. All of the layers were digitized in MapInfo software and converted to shape files (ArcView) for the purpose to separate the constituent layers from each other and give them final structure. The layers were converted to KMZ files for the purpose to update the GIS data per recent information on the Google earth. As the arid region of Pakistan covered a vast area of the country, therefore the methodology has been generalized and mapped for the landuse of the arid region.

1.8. Perception to climate change:

The main objective of the people perception is to know the public opinion and awareness about the climate change and adaptation. The specific questions are: what is the public opinion regarding climate change, its impacts, and how to cope with the problem? Are people of the arid region aware about this issue and willing to participate in the actions required?

The major parameters in the questionnaire are the temperature and precipitation fluctuation, deforestation, overgrazing, drought, desertification, landuse change, wars, crop production, population growth, construction of water reservoirs, river flow, environment policies, and willingness to cope with the

climate change issue. As the security situation is not encouraging in the arid region, questionnaire survey was conducted in the arid region of the lower Punjab, parts of Balochistan, Sind, Gilgit-Baltistan, upper and lower Khyber-Pakhtoonkhwa province taking into account random sampling method. The sample area covers 25 districts having different kind of landforms (Map-1.1). The questionnaires were distributed among the students and teachers of the University of Bahawalpur, Peshawar, Karachi, and Quetta. The people who are surveyed and interviewed include professors, lecturers, M.Sc and M.Phil students, farmers, lawyers, and statisticians. Total of 150 questionnaires were distributed in which 130 questionnaires were returned with complete answers that were analyzed. Generally, five questionnaires were collected from each district. A master sheet has been prepared from the public opinion that classified into tables and charts for the purpose of analysis and conclusion (Appendix-A, Questionnaire).

1.9. Research organization:

This research work has been presented in eight chapters. The first chapter of the study is introduction dealing with the objectives of the study, conceptual framework, and research problem, scope of the study, questions, hypothesis, methodology, and data presentation. A short summary of the previous studies regarding climate change, causes, impacts and adaptation to agriculture sector in Pakistan and the world as a whole is presented in chapter-2. The third chapter explains the environmental conditions and the farming patterns in the arid region of Pakistan. It has been divided into four sections that are physical setting,

human environment, socio-economic set up, and agro-ecological zones. The fourth and fifth chapters discuss the temperature and precipitation distribution, fluctuations, variation, and findings. Chapter six deals with impacts of climate change on agriculture and Indus water system. Chapter seven discusses the short and long term adaptation to the recent temperature and precipitation fluctuation with reference to agriculture sector in the arid region of Pakistan. The last chapter is about the conclusions and recommendations.

1.10. Limitations of Research:

Climate change is a broad phenomenon and it is not possible to cover the problem statement within the objectives of the current study. Some of the limitations were identified during course of work and explain as follow.

- The study has covered the impact of climate change on agriculture sector in terms of temperature, precipitation, and running water in the arid region of Pakistan. But it is observed that climate change has also been effected the agriculture sector in the entire country. It is therefore needed to study the impact of climate change on the agriculture sector in the semi-arid, sub-humid, and humid regions with special reference to environmental disasters, marine influence, and costal ecosystem in Pakistan.
- The data of temperature and precipitation have been covered the time period of 1960-2000 (40 years), while the research completed in the 2014. So it is expected that there might be some positive or negative changes during the last 14 years. It is therefore need to update the results in view

of the average weather data from 2000 to 2014 using the same methodology.

- As the data for the aridity indices used by Koppen's (1901-18), Warren Thornwaite's (1931), Koppen and Rudolf Geigger (1953) regarding evapotranspiration, number of rainy days, and daily observations of precipitation are not accessible for the use in the current study and identification of the arid region, the total precipitation of less than 10 inches (254mm) has been considered as criterion for the demarcation of the arid region in Pakistan.
- The isohyets and isotherms were constructed on the basis of data provided by the Pakistan meteorological department. But the agriculture data is available on district, provincial, and national level. Therefore, the whole districts have been considered for analysis that touches the boundaries of the arid region.
- The data for few months/years are missing or some of the observatories may fall outside the arid region of the country. Therefore, these meteorological stations were excluded for the purpose to achieve reliable results.
- The observatories of Drosh, DI Khan, Astore, and Quetta, located in the surrounding of the arid region (semi-arid to humid) have been selected for the purpose to draw isohyets/isotherms and to analyze the oscillation of aridity (desertification) towards or away from these observatories.

- The winter precipitation of the arid region has decreased with passage of time and showed shift towards north. Synoptic study has been required to find out the shift in the warm front of the western disturbances.
- The natural vegetation, environmental disasters, soil degradation, marine influence, number of rainy days, evapotranspiration, sunshine, relative humidity, visibility and storms, wind speed and direction, and cloudiness were not considered for the current work. These are the key variables of the physical environment and needed to study its influence on the lives of the locals in the arid region of Pakistan.
- It is expected that the climate change in Pakistan is influenced the glaciers and permafrost in the Gilgit-Baltistan province. It is needed to analyze the impacts of temperature fluctuation on the glaciers and permafrost in the upper catchment area of the Indus drainage basin and its adaptation to climate change.
- The average temperature of the arid region shows seven months summer and five months winter in the arid region, but it is only applicable for the southern arid region, while in the north there is converse seasonal condition (Mountainous).
- The climate fluctuation is increased the drought and desertification in the arid region of Pakistan and the lives of the locals are on risk. It is required to evaluate the impacts of climate change on the process of desertification and drought in Thar, Cholistan, and Kharan deserts.

Chapter-2

Literature Review

This chapter includes four aspects of climate change including pattern of climate change in time and space, causes, impacts and adaptation strategies that have or needs to be adapted (Figure-2.1). Although, the research and studies incorporated different parts of the world but an effort has been made to include literature from Pakistan as much as possible.

1. Climate Change	3. Impacts	4. Adaptation
○ Historical (In Geological Timescale) ○ Comparatively Recent	i. Social ○ Migration/Displacement ○ Employment ○ Health ○ Others ii. Economical ○ Food ○ Energy ○ Water ○ Income Level iii. Environmental ○ Impact on Forest ○ Parmafrost and Glaciers ○ Drought and Desertification ○ Surface run-off ○ Hydrological Cycle ○ Sea Level Rise ○ Natural Disasters ○ Others	i. Physical ○ Plantation ○ Construction of Dams ○ Advance technologies ○ Others ii. Economical ○ Cost Estimation ○ Funding ○ R & D
2. Causes i. Natural Causes ○ Variation of Solar energy ○ Orbital Revolution ○ Others ii. Man Made ○ Addition GHG's ○ Removal of Sank's ○ Others		

Figure-2.1: Structure of literature review

2.1. Climate change:

The literature regarding climate change in Pakistan and the World as a whole has been divided into the historical and meteorological climate changes and discussed as follow.

2.1.1. Historical climate change:

The historical climate change has been divided into two phases concerning geological time scale and relating recent changes. VOSE and PETERSON (1997) have discussed, *"the global historical climatology network temperature database,"* taking into account monthly surface observations around the World. SIROCKO et al in 1999 have analyzed, *"the 5000 years record of climate change in varved sediments from the oxygen minimum zone of Pakistan,"* taking into account Holocene marine sections. KHAN (2001) has produced a paper titled, *"searching evidence for climate change based on analysis of hydro-meteorological time series in the upper Indus basin."* HAYAT, BARI, SHEIKH, and CHAUDHRY in 2001 have studied, *"the history's worst drought condition prevailed over Pakistan and its impacts as compared to other disasters like floods, tropical storms etc".* COLE, OVERPECK and MORRILL in 2002 have presented a synthesis regarding, *"the abrupt changes in the Asian summer monsoon since the last de-glaciations. They have compiled 36 previously published palaeo-climate records to determine the timing and spatial pattern of century-scale abrupt changes in Asian monsoon precipitation since the last deglaciation".* OVERPECK, ANDERSON and GUPTA in 2003 have evaluated, *"the changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean."* They have suggested that the link, *"between North Atlantic climate and the Asian monsoon is a persistent aspect of global climate."* YAFENG et al (2002) have presented, *"the general characteristics of temperature variation in China during the last two millennia."*

SEGAL et al in 2003 have studied, *"the climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene South Asian monsoon variability. They have discussed the regional chronology, historical drought, and cause of Holocene monsoon change in the great plain of the Indus basin particularly the Indus civilization."* DUTTA and AGNIHOTRI (2003) have analyzed, *"the centennial scale variation in monsoonal rainfall manifestations of solar variability in India and Bangladesh. The work has explained the variability of the Indian monsoon rainfall and its impact over agricultural output in the entire study area."* JIAWU et al (2003) have studied, *"the temperature variations on the Tibetan plateau over the last two millennia in China taking into account the palaeo-climate data recovered from ice cores, tree rings, and lake sediments during the last 2000 years"*. JUNG et al (2003) have highlighted, *"the monsoonal precipitation variation in the East Asia since A.D. 1840."* They have considered, *"the three tree-rings rainfall reconstructions from China and Korea."* They have opined, *"The East Asian summer monsoon precipitation suddenly changed from more into less around mid-1920."* BUSH (2004) has studied the, *"late quaternary climate over Asia."* According to him, *"Through the late Quaternary, the global climate system ranged from full glacial to temperate interglacial conditions."* MOSELEY and BAKER (2007) have discussed, *"the advancing treeline and retreating glaciers in Yunnan China. They have found out that the mean annual temperature in the last two decades of the 20th century has been increased at the rate of 0.06⁰C."* LEZINE and IVORY in 2009 have analyzed, *"the climate and*

environmental change at the end of the Holocene humid period taking into account a pollen record of the Makran coast in Pakistan."

2.1.2. Meteorological climate change:

KHAN and KAZI (1959) have evaluated, *"the variations of moisture types and their bearing on soil erosion in Pakistan. They have discussed the potential of evapotranspiration, precipitation distribution and its variation in Pakistan."*

KHAN (1960) has found out, *"the recent climate fluctuation over South Asia and the Indian ocean from 1870 to 1960."* He has stated, *"the rainfall has been persistently decreasing over the Middle East, Southwest Asia and increasing over the Soviet Republics of Central Asia. The trend seems to be most probably connected with a northerly shift of the tracks of western disturbances."*

KALNICKY (1987) has discussed, *"the seasons, singularities, and climate changes over the mid-latitudes of the Northern Hemisphere during 1899-1969."*

This analysis found seasons separated by abrupt circulation transitions. Other singularities including Indian summer and the January thaw have identified in the hemispheric circulation." SOLOMINA, SEREBRYANNY, and KOTLYKO (1991)

have evaluated, *"the climate change and glacier fluctuation during the last 1000 years in the southern mountains of the USSR."* According to them, *"many Tien Shan glaciers have evidence of advances that predate the conventional time span of the Little Ice Age; many advances and recessions have occurred synchronously, although the magnitude of such trends varied significantly between regions and within the same region; fluctuations in equilibrium line altitudes were more pronounced in the outer, or more maritime, areas and*

became progressively more prominent toward the interior where the climate is more continental". LIVERMORE et al (1999) have presented, "the climate change and world food security in England. They have opined that the climate change has expected to increase yields at high and mid-latitudes, and lead to decreased at lower latitudes." ZHANG et al (1999) have discussed, "the changes of climate in China taking into account weather data from 1950. They have concluded that the mean minimum temperature has increased significantly in China during the past forty years, especially in the winter. Meanwhile, mentioned-wide cold wave activity has weekend and the frequency of cold days in Northern China has been reduced significantly." BURBANK and BROZOVIC (2000) have evaluated, "the dynamic fluvial systems and gravel pro-gradation in the Himalayan foreland. They have presented that although the large-scale stratigraphy of many terrestrial foreland basins have punctuated by major episodes of gravel pro-gradation, the relationships of such facies to hinterland tectonism and climate change have often unclear". CLARK and SERREZE (2000) have studied, "the four different models of snow cover variability in Asia to modulate atmospheric circulation over the North Pacific Ocean during winter." SINGH and SONTAKEE (2000) have examined, "the climate fluctuations and environmental change of the Indo-Gangetic plains, India. They have stated that the spatial changes in rainfall activities have attributed to global warming and associated change in the Indian summer monsoon circulation and the general atmospheric circulation." CHEN and LIU (2000) have evaluated, "the climate warming in the Tibetan plateau during recent decades in China." According to

them, *"The analyses of the temperature series show that the main portion of the Tibetan plateau has experienced statistically significant warming since the mid-1950, especially in winter, but the recent warming in the central and eastern Tibetan plateau did not reach the level of the 1940 warm period until the late 1990"*. YEE et al (2000) have presented, *"the trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific from 1961 to 1998 using high-quality data from 91 stations in 15 countries. They have concluded that the trends in the average intensity of the wettest rainfall events each year have generally weak and not significant."*

BEG in 2001 has studied, *"the impact of global warming on the climate change in Pakistan."* He has made attempt that, *"The average temperature of the earth surface is 15⁰C that has increased during the last century by about 0.5⁰C"*. HASAN and KHAN (2001) have analyzed, *"the temperature and rainfall fluctuation at Udigram Swat valley, northwest Pakistan. They have concluded that the temperature of the valley increases at the rate of 1⁰C per year since 1998. The summer rain showed little decrease, whereas the winter rainfall declined at the rate of 5cm (127mm) per year during the past six years since 1995"*. HO and GONG (2001) have evaluated, *"the Siberian high and climate change over middle to high latitude Asia."* ZHU and QIAN (2001) have discussed, *"the climate change in China from 1880 to 1998 and its impact on the environmental condition."* KUMAR (2001) has presented, *"the monthly mean sea level variations at Cochin, southwest coast of India."* AGBOOLA et al 2002 have evaluated, *"the global warming and solar variation in Turkey."* FRANKS in 2002

has worked on, *"the identification of a change in climate using regional flood data."* GLANTZ (2002) studied, *"the water, climate, and development issues in the Amudarya (Oxus River) basin in Central Asia."* ARSHAD, SHAHID AND ROHI in 2002 have discussed, *"the characterization and classification of agro-climates of Pakistan taking into account crop evapotranspiration and 50% rainfall probability."* BLIUNAS and SOON (2003) have evaluated, *"the re-constructed climate and environmental changes of the past 1000 years."* FINAN, WEST, and LEON in 2003 have studied, *"the comparative assessment of climate vulnerability with reference to agriculture and ranching on both sides of the US-Mexico border."* KEEFE (2003) has discussed, *"the different aspects of climate change and its policy for the developed and underdeveloped countries on international level."* KAROON et al in 2003 have studied, *"the variations in tropical convection as an amplifier of global climate change at the millennial scale."* LIGATES (2003) has discussed, *"the climatic and environmental changes of the past 1000 years."* PANT (2003) has deliberated, *"the long term climate variability and changes over monsoon Asia. The study has based on the historical climate records, forests, glacio-climate, ice core investigation, long-term climate change, and modeling studies."* RANDALL and SCHWARTZ (2003) have discussed, *"the abrupt climate change scenario and its implications for United States national security."* WANG et al (2003) have studied, *"the detection and projection of climate changes in Jianghuai Valley in China."*

DUFFY and MAUREN in 2005 have studied, *"the uncertainty in projections of stream flow changes due to climate change in California."* JONES

in 2005 has evaluated, *"the climate change in the western United States grape growing regions."* MIR, KHAN and FAROOQI in 2005 have adopted study on, *"the climate change perspective in Pakistan. They have analyzed the past climate changes and computed the projected changes in different agro-climatic regions of Pakistan for next half century"*.

WHO in 2005 has presented a study on, *"The health and climate change in Europe"*? CLARK, YIRIDOE, and ASTATKI in 2006 have discussed, *"the testing for trend in the variability of monthly and seasonal temperature using the range and the standard deviation as measures of variability in Canada."* SPEKTORMAN et al in 2006 have evaluated, *"the changes in daily temperature and precipitation extremes in Central and South Asia."* AI et al (2007) have discussed, *"the precipitation variations of Longxi, northeast margin of Tibetan plateau since AD 960 and its relationship with solar activity."* CHAUDHARI in 2007 has presented, *"the South Asian summer monsoon precipitation variability."* IPCC in 2007 has prepared, *"the climate change synthesis report and presented the key projected regional impacts regarding Asia."* KAUFFMAN in 2007 has analyzed, *"the climate change of the world. He has claimed that the human-caused warming of the earth to dangerous and unprecedented levels by human-related emissions of carbon dioxide"*. SHAOWU and JIANBIN (2007) have highlighted, *"the variations of geographical latitude of summer rain belts over Eastern China during the last millennium."* YADAV (2007) has studied, *"the basin specificity of climate change in western Himalaya, India."*

JILANI, KHAN, and KHAN in 2008 have evaluated, *"the sea surface temperature variability along Pakistan coast and its relation to el Niño-southern oscillation during 1885 to 2006."* LEDUC in 2008 has discussed, *"the climate change in the Himalayas with special focus on the women's and suggested some factors to decline the impacts of climate change on the women's health."* GADEMA and RAJARYAL in (2008) have studied, *"the climate change and disaster impact reduction in Nepal."* SEYMOUR in 2008 has highlighted, *"the forests, climate change, and human rights. He has discussed that the forestry sector illustrated how human rights have put at risk not only by the direct impacts of climate change, but also by policy responses designed to advance adaptation and mitigation objectives"*. MARKHAM in 2008 has studied, *"the U.S. population, energy, and climate change."* USAID/ASIA in 2008 has presented, *"the global climate change in the Asia-Pacific region."* YIYONG et al in 2008 has studied, *"the snow cover variation in the past 45 years (1959 to 2003) in the Tianshan mountains, China."*

AKHTAR in 2009 has studied, *"the climate change and flow of environmental displacement in Bangladesh."* JABBOUR and MCMULLEN (2009) have worked on the *"climate change."* They have suggested, *"The improvement in the process-level understanding, climate models, and observations of climate-relevant parameters and climate monitoring systems in specific areas."* URDAL and RALEIGH in 2008-09 have evaluated, *"the climate change, demography, environmental degradation, and armed conflict. They have assessed the risk of conflict for a global sample, and then for richer and poorer states separately"*.

SADIQ (2010) has studied, *"the climatic variability and linear trend models for the five major cities of Pakistan. He has estimated that the average temperature of Earth's near surface air and oceans has risen by $0.74 \pm 0.18^{\circ}\text{C}$ during last 100 years."*

2.2. Causes of climate change:

KATO (1998) has discussed, *"the climate changes in Asia due to global warming by analyzing upper-level wind and water vapor's flow in entire Asia."*

GoUSA (2000) has studied, *"the annotated summary of climate change related resources in the United States for the purpose to provide the reader with a tool for identifying the range of available resources pertaining to climate change."*

LAMMERS et al in 2000 have analyzed, *"the global water resources vulnerability from climate change and population growth. They have summarized that a large proportion of the world's population is currently experiencing water stress and rising water demands."*

CROWLEY in 2000 has presented, *"the causes of climate change over the past 1000 years in Northern Hemisphere."*

CARTER (2007) has discussed, *"the human-caused global warming. In his executive summary he has stated that the global warming caused by human activities has become one of the major political issues of our time."*

ESPLEN, DEMETRIADES, and BRODY in 2008 have highlighted, *"the gender and climate change."*

They have concluded, *"It is by now widely accepted that failure to include women in decision-making processes around climate change mitigation and adaptation at local, national, regional and international levels not only exacerbates gender inequalities, but also undermines the effectiveness of climate change responses".* OXFAM's in

2008 has evaluated, *"the climate change implications for Oxfam's program, policies, and advocacy with reference to impact and adaptation of climate change to human lives."* NIC (2009) has opined that *"over the past century (1908 to 2007), the average temperature in China has risen by 1.1degree Celsius. Although no significant trend was observed in nationally averaged precipitation amounts over the past 50 years, a drying trend was observed in the Yellow River basin and north China plain. Over the past 30 years, the sea level and sea surface temperature have increased 90millimeters (mm) and 0.9°C, respectively. Agricultural growing seasons have lengthened and the risk of extreme heat episodes increased. Storms intensified and warming temperatures have likely to enhance drying in already-dry areas, so both droughts and floods have increased that need adaptation."* ROZELLE, HUANG, and WANG (2010) have stated that, *"overall, rainfed crops are projected to be much more severely affected by climate change than irrigated crops. Higher incidences of drought and rising temperatures have increased water demand per unit of cropland area and negatively affect crop yields."*

2.3. Impacts of climate change:

NEILL and HUFF (1982) have evaluated, *"the effects of natural climatic fluctuation on the temporal and spatial variation in crop yields in United States."* They have investigated, *"the variation in corn and soybean yields resulting from natural fluctuation in weather conditions between years in a five states area in the mid-west"*. DREGNE in 1986 has studied, *"the desertification of arid lands in USA."* He has stated, *"the overgrazing and woodcutting have responsible for*

most of the desertification of rangelands, cultivation practices inducing accelerated water and wind erosion, improper water management leading to salinization has the cause of the deterioration of irrigated lands". AVISSAR and PIELKE (1990) have presented, *"the influence of landscape structure on local and regional climate. The paper has discussed the physical linkage between the surface and the atmosphere, and demonstrates how even slight changes in surface conditions can have a pronounced effect on weather and climate"*. KAISAR (1991) has studied, *"the climate change and agriculture in USA. He has discussed recent scientific evidences on global warming, review the potential impacts of climate change on agriculture, and presented some views on what needs to be done to improve our understanding of the possible outcomes of climate change."* SMADJA (1992) has presented his opinion on, *"the climate and human impacts and their relationship to a mountain slope above Salme in the Himalayan middle mountains in Nepal."* CHAUDARY (1994) has highlighted, *"the Impact of climate change on agriculture and forests in Pakistan."* He has the opined that, *"there is a pole ward shifting of climate and agriculture zones."* ISSAR et al 1995 have studied, *"the Impacts of climate variations on water management and related socio-economic systems in different parts of the world under the UNESCO programme."* HOUEROU in 1996 has reviewed, *"the climate change, drought and desertification in France."* TUCKER in 1997 has studied, *"the drainage basin responses to climate change. He has studied the sensitivity of drainage basins to climate change using a physically based model."* FRESCO and GOMES in 1998 have presented, *"the impacts of climate change on*

agriculture in different parts of Europe. This work has stressed the close links that exist between climate resources and agricultural production potential, including biodiversity." AYAZ, IQBAL and SIDDIQUI (1999) have evaluated, *"the forest ecosystem climate change impact assessment and adaptation strategies for Pakistan. They have determined the impact of climate change on natural forest ecosystems in Pakistan assuming a 0.3°C rise in temperature and a precipitation with 1990 as the base year."* CHANGNON et al in 1999 have presented, *"the review of the temporal fluctuations in weather and climate extremes that caused economic and human health impacts in the United States."* GEIJN and ROTTER in 1999 have discussed, *"the climate change effects on plant growth, crop yield, and livestock in different parts of the United States."* HEWITT et al in 1999 have analyzed, *"the integrated impact assessments, climate variability and economic adaptation in Great Plains agriculture in central United States."* RHODES, MEARNS, MILLER, and TRENBERTH in 2000 have analyzed, *"the effects of changing climate on weather and human activities on global level."*

JUN (2001) has discussed, *"the weakening of the Asian monsoon circulation after the end of 1970's. He has indicated the trend of the transition over the mid-latitude Asia has opposite to that of global average for some variables at the middle troposphere."* FARQUHARSON and TATE (2001) have evaluated, *"the sensitivity of the impacts of climate change on White Nile flows. The paper has concluded a brief discussion of some other areas of uncertainty in*

the hydrological modeling of White Nile flows and possible alternative external forcing mechanisms for flows in the next few decades."

WARNER and FREEMAN (2001) have presented a study on, *"the climate variability contributed to rising trends in total direct damage from extreme events in affected areas of the World."* REITER in 2001 has studied, *"the climate change and mosquito-borne disease in Sweden especially malaria, yellow fever, and dengue"*. MOORE, SHARMA and VOROSMARTY (2002) have presented, *"the sensitivity of the Himalayan hydrology to landuse and climate change. They have opined that landuse and climate changes have of major concerns in the Himalayan region because of their potential impacts on a predominantly based economy and a regional hydrology dominated by the monsoon."* TROBE (2002) has evaluated, *"the climate change and poverty."* He has discussed, *"the fact that climate change has serious consequences for development is revealed through the growing numbers of humanitarian catastrophes, the imminent disappearance of coastal zones and even small island states, and the steadily growing numbers of 'environmental refugees' that the world is experiencing as a result of higher temperatures and rising sea levels"*. ALI (2003) has analyzed, *"the climate change influence on avian diversity of wetlands at Ramsar site from Pakistan. He has presented that several ecological factors, such as habitat loss related to siltation, pollution, expanding agricultural activities and drastic hydrological fluctuations, have induced considerable changes in the dynamics and distribution pattern of sustained biota."* BENISTON in 2003 has reviewed, *"the possible impacts of climatic change in mountain regions. This paper has addressed a*

number of issues related to current and future climatic change and its impacts on mountain environments and economies, focusing on the 'Mountain Regions' Chapter 13, of Agenda 21, a basis document presented at the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, and the International Year of the Mountains (IYM) 2002". STREM, MILLER and BASHFORD in 2003 have studied, "the potential impacts of climate change on California hydrology." ARNELL in 2004 has discussed, "the climate change and global water resources." He has stated that, "In 1995, nearly 1400 million people lived in water-stressed watersheds mostly in Southwest Asia, the Middle East and around the Mediterranean".

CHOWDHURY (2004) has studied, "the water resources in South Asia with reference to an assessment of climate change-associated vulnerabilities and coping mechanisms." ZELL in 2004 has presented, "the global climate change and the emergence/re-emergence of infectious diseases." He has stated about, "variation in the incidence of vector-borne diseases is associated with extreme weather events and annual changes in weather conditions." ONSGAARD and VASEPALLI in 2004 have discussed, "the socio-economic consequences of global warming and abrupt climate change in the Pacific Northwest." MENDELSON in 2005 has studied, "the climate change impacts on Southeast Asian agriculture. The study has extrapolated results from India and selected experiments to the rest of Southeast Asia in order to measure the impact of climate change on agriculture that vary from a small benefit to a loss of 37% of agricultural GDP by 2100". AHMAD and RAFI in 2005 have evaluated, "the

wheat crop model based on water balance for agro-meteorological crop monitoring in Pakistan. In this study, effort has been made to develop a simple crop model based on water balance for crop monitoring." BASHIR and BUTT 2005 have highlighted, "the satellite snow monitoring in northern Pakistan." DEFRA in 2005 has submitted a report to Government of UK on, "the impacts of climate change on agriculture for rural landscape. The report has presented that agricultural businesses needed to adapt to the effects of changing climatic conditions to ensure economic viability, while at the same time continuing to improve sustainable practices to reduce agriculture's impact on the environment". FOLEY et al in 2005 have presented, "the review on the impact of regional climate change on human health." GoUK in 2005 has studied, "the impacts of climate change on soil functions. The report has presented sixteen steps about adaptation to the impact of climate change on soil function in the United Kingdom." QAMAR and BRISCOE in 2005 have discussed, "the Pakistan's water economy running dry. They have opined that the natural flow regime was dramatically altered: rivers which had previously meandered over wide plains were now confined within narrow channels; sediments which had previously nourished the delta were trapped; and vast quantities of water were disgorged onto deserts, substantial parts of which were of oceanic origin and highly saline". RABBANI and KHAN in 2005 have studied, "the sea level monitoring and study of sea level variations along Pakistan coast. They have opined that the Sind coastal zone is more vulnerable to sea level rise than Baluchistan coast, as uplifting of coast by about 1-2 mm/year due to subduction of Indian Ocean plate."

HANDWERK in 2006 has suggested, *"The study of some glaciers in the upper Indus basin that seems to be growing due to the increased winter snow fall in the glaciated regions in Pakistan."* AHMAD in 2006 has produced, *"the research report in which he has evaluated the climate change impacts and vulnerability in Bangladesh."* MEHDI in 2006 has prepared a workshop report on, *"the outcomes and possible next steps to be taken towards adaptation in the hydropower sector and climate change in Canada."* SAVONIS and BURKETT in 2006 have presented, *"the impacts of climate variability and change on transportation systems and infrastructure of the Gulf coast in USA."* ESTIARTE et al in 2007 have presented, *"the climate-change effects on Mediterranean shrub lands."* GoUK in 2007 has reviewed, *"the civil society coalition on climate change. This report has provided an independent assessment of the implications of climate change for humanity and the policy options that might be adopted."* MCANENEY, NARISMA, and PITMAN in 2007 have discussed, *"the impact of climate change on the risk of forest and grassland fires in Australia."* SUNSTEIN in 2007 has published, *"An essay on the divergent American reactions to terrorism and climate change."*

BLANCO in 2008 has studied, *"the impacts of climate change on water resources on global level. The work has presented a general procedure to incorporate the climate change impacts on hydrological and water resources models."* EEPSEA in 2008 has presented, *"the report on the climate change impacts, adaptation, and policy in Southeast Asia."* IRANI et al in 2008 have evaluated, *"the economic impacts of climate change on North Carolina."* PESU

and BERGHALL in 2008 have discussed, *"the climate change and the cultural environment; recognized impacts and challenges in Finland."* SMAKHTIN, KALUARACHI, and KIM in 2008 have submitted, *"A report on climate change impacts on hydrology and water resources of the upper Blue Nile River Basin."* YE in 2008 has studied, *"The response of glaciers and lakes variations to climate change in Mapam Yumco basin on Tibetan plateau during 1974 to 2003."* YUE et al in 2008 have evaluated, *"the impacts of climate change on Chinese agriculture."* According to him, *"the meteorological observations show that since the 1950s Ningxia has experienced a warming trend in annual mean temperature, high rainfall variability, with a major drought during 2004 to 2007, and some evidence for an increase in drought frequency/severity. These events have imposed impacts, though differing in magnitude, on all aspects of farmers livelihoods, including accessibility to drinking and irrigation water, grain production, cropping composition, sowing area, and income"*.

ADB in 2009 has analyzed, *"the understanding and responding to climate change in developing Asia in terms of planning both adaptation measures to respond to the predicted impacts of climate change and mitigation measures to avoid rapid increases in global emissions."* ADB in 2009 has studied, *"the climate change and migration in Asia and Pacific. This study has concluded that it is possible to not only cope with these changes but also to harness population mobility to reduce poverty and enhanced economic and social development in the region."* CARES (2009) has presented, *"the humanitarian implications of climate change mapping emerging trends and risk hotspots in Vietnam. They*

have opined that by combining current and historical data sets with climate change models, it is possible to make reasonably certain projections about the nature of floods, droughts, and cyclones during the next 20 to 30 years." GoUSA (2009) has analyzed, *"the effects of climate change on Florida's ocean and coastal resources. The report has concluded that the temperature increases since the mid-20th century is very likely caused by increased concentrations of greenhouse gases from human activities. These gases, which included carbon dioxide, are produced naturally and are also generated by human activities such as burning fossil fuels and widespread deforestation."* HASHMI, GHUMAN, and HASAN (2009) have evaluated, *"the impact of environmental changes and global warming on temperature in Pakistan. The temperature changes in Pakistan have been extracted from simulations made using EdGCM model developed at Columbia University."* SAAB and TOLBA in 2009 have studied, *"the impact of climate change on Arab countries. They have opined that the Arab countries are in many ways among the most vulnerable in the World to the potential impacts of climate change, the most significant of which are increased average temperatures, less and more erratic precipitation, and sea level rise".* SCHNEIDER et al in 2009 have prepared a report on, *"the ecological impacts of climate change in USA. They have stated that the rising temperatures, new precipitation patterns, and other changes have affected many aspects of human society and the natural environment."* UNFCCC in Copenhagen Accord (2009) has agreed on, *"the different steps including environmental disasters, causes of climate change and adaptation etc, to combat climate change."* HEWITT in 2009

has discussed, *"the glaciers and climate change in the Karakoram Himalaya with special context of developments affecting water resources and environmental hazards. He has opined that there has been no net reduction in the ice cover in the last three decades. Many glaciers have retreated or thinned slowly but, since 1995, he has found more than 35 glaciers advancing, mid-glacier thickening in a dozen others, and a sudden increase in glacier surges"*. KAO in 2009 has evaluated, *"the impacts of climate change on dry-lands. He has divided the dry lands into three types that are semi-arid, arid, and hyper-arid."* Go CHINA in 2009 has studied, *"the impact of climate change upto 2030 with special reference to high-risk impacts, Water resources, coastal regions, social and political uncertainties, and policy implementation in China."* GoUSA in 2009 has presented, *"the impact of animal agriculture on global warming and climate change. They have stated that the animal agriculture sector is responsible for 18%, or nearly one-fifth, of human-induced greenhouse gas (GHG) emissions, greater than the share contributed by the transportation sector."* NERLANDER (2009) has evaluated, *"the climate change and health in Sweden. She has opined that the climate change does not create new health hazards. Instead it may act as a multiplier of existing health problems or change the location of health concerns."* CHEN, MCCARL, and SCHIMMELPFENNIG in 2010 have discussed, *"the yield variability as influenced by climate change in USA. This study has presented the maximum likelihood panel data estimated of the impacts of climate on yield variability for the major U.S. agricultural crops."*

2.4. Climate change adaptation:

GOKLANY (1997) has studied, *"the adaptation to climate change. His work deals with the often ignored issue of adaptation to human-induced climate change. The work has provided criteria for evaluating policy and identifies options, which are compatible with both climate change mitigation and adaptation."* GoNORWEY in 1998 has discussed, *"the climate change adaptation and poverty reduction. In this report, the linkages between poverty and adaptation to climate change have been identified, and how these linkages can be addressed in development aid."* MCLOED and KERR in 2001 have analyzed, *"the potential adaptation strategies of climate change in Scotland."* The two important implications of the work are, *"There is a natural (and healthy) tension between the needs of strategic planning to cope with climate change and the local decisions needed to implement appropriate adaptation strategies to climate impacts. Many of the difficulties with respect to managing climate change reflect the crosscutting nature of its impacts. This can lead to a lack of clarity about or coordination between existing lines of responsibility."*

MUHAMMAD (2002) has presented, *"a workshop report on the assessment of climate change-associated vulnerabilities and coping mechanisms to water resources in South Asia."* FAO in 2002 has reported, *"On the long term plans for drought mitigation and management in the Near East region of Iran. Realizing the serious ramifications of drought impact on communities and governments of the Near East Countries and discussed the different aspects how to cope with the problem."* WHO in 2002 has presented, *"a report on floods,*

climate change and adaptation strategies for human health in different parts of the World." OECD (2002) has highlighted, *"a report on the climate change and sustainable development strategies for Brazil."* GoP, Ministry of Environment in 2003 has presented a comprehensive report on, *"the Pakistan's initial national communication on climate change and discussed the climate change, impacts, and adaptation strategies."* HULME et al (2003) have studied, *"the adaptation to climate change in the developing World."* According to them, *"The world's climate is changing and will continue to change into the coming century at rates projected to be unprecedented in recent human history".* RANA, SHUKLA and NASIR (2003) have highlighted, *"the policy analysis for the energy use and climate change in India."* According to them, *"In the coming years South Asia has faced great challenges in energy and environment. Beside, with rapid increase in population and economic development, the demand for electricity generation and vehicular usage is expected to go up."* VIET et al (2003) have analyzed, *"the climate change and strategies to be adapted in agriculture for sustainable development in Vietnam."* According to them, *"The Vietnam climate change and variability are part of global climate change; if it occurs will definitely effects agriculture."* GoP (2004) has prepared, *"a report under the funding of IUCN with special contribution of Ministry of Environment, Islamabad about the climate change vulnerabilities in agriculture in Pakistan."* The report discusses the issues, risks, and challenges, raised by the ongoing climate change in Pakistan."

IUCN in 2005 has studied, *"the community perceptions on climate change in Bagrote valley, Pakistan. Discussions held with residents of Bagrote have*

indicted climate induced changes in the natural and social environment."

NARAYANAN and PATNAIK in 2005 have analyzed, *"the vulnerability and climate change in the eastern coastal districts of India. The first aspect of the work has reflected through agricultural and industrial development, while the second through infrastructure and others."* PANDEY in 2005 has presented, *"a report on societal adaptation to abrupt climate change and monsoon variability of the sustainable livelihoods of rural communities in India."* DFID in 2006 presented, *"report on energy efficiency and climate change considerations, for on-road transport in Asia."*

SHAW in 2006 has studied, *"the community-based climate change adaptation in Vietnam with special reference to inter-linkages of environment, disaster, and human security."* AEA in 2007 has presented, *"a report for the adaptation to climate change in the agricultural sector in EU countries."* This study on 'adaptation to climate change in the agricultural sector' aims to provide, *"European Commission with an improved understanding of the potential implications of climate change and adaptation options for European agriculture, covering the EU 27 Member States."* ADGER and BARNETT in 2007 have evaluated, *"the climate change, human security and violent conflict. This paper has integrated three disparate but well founded bodies of research on the vulnerability of local places and social groups to climate change, on livelihoods and violent conflict, and the role of the state in development and peacemaking, to offer new insights into the relationships between climate change, human security, and violent conflict"*. BAAS and RAMAMASY (2007) have discussed, *"the climate*

variability and change: adaptation to drought in Bangladesh. The impacts of increasing climatic variability and change are global concerns but in Bangladesh, where large numbers of people are chronically exposed and vulnerable to a range of natural hazards, they are particularly critical. Agriculture is the largest sector of the economy, but agricultural production is already under pressure from increasing demands for food. Increasing climate variability and climate change have expected to aggravate vulnerabilities further by causing more frequent and intense droughts and increasing temperatures." DOBERMANN and WASSMANN in 2007 have highlighted, *"the climate change adaptation through rice production in regions with high poverty levels in the World. Climate change has severely set back agricultural development in tropical countries, where an increasing share of the poorest and most vulnerable population resides."* MIRZA in 2007 has discussed, *"the climate change, adaptation and adaptive governance in water sector in South Asia."* BIZIKOVA, NEALE, and BURTON in 2008 have presented, *"the Canadian communities' guidebook for adaptation to climate change and explained the different aspect about the adaptation, mitigation and sustainable development."* Go JAPAN in 2007 has presented, *"the recommendations for adaptation to climate change in developing countries in the light of Agenda 21 and Kyoto protocol."* Go BANGLADESH has studied, *"the Bangladesh climate change strategy and action plan 2008. The report has explained that Bangladesh is one of the most climate vulnerable countries in the World and has become even more so as a result of climate change".* ISET in 2007 has analyzed, *"the climate adaptation in Asia, knowledge gaps and research issues in South Asia."*

The report has concluded that, *"In South Asia the processes of globalization and increasing mobility have created unprecedented inter-linkages among livelihoods, economic, social, and environmental and communication systems."* KOHLIN et al in 2008 have presented, *"the impact of climate change and adaptation on food production in low-income countries, evidence from the Nile Basin, Ethiopia. The work has presented an empirical analysis of the impact of climate change on food production in a typical low-income developing country (Ethiopia)".* MONDAL, SHAW, SVRK, and HUY in 2007 have evaluated, *"the adaptation strategies to drought in Ninh Thuan province, Vietnam."* IPCC in 2007 and 2009 has opined that *"a wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. Adaptive capacity is intimately connected to social and economic development but is unevenly distributed across and within societies."*

A wide variety of policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and sectoral context. In several sectors, climate response options can be implemented to realize synergies and avoid conflicts with other dimensions of sustainable development. Decisions about macro-economic and other non-climate policies can significantly affect emissions, adaptive capacity, and vulnerability."

REVI in 2008 has discussed, *"the climate change risk, an adaptation and mitigation agenda for Indian cities, where the urban population is likely to grow by*

around 500 million over the next 50 years." STEVENSON et al 2008, has evaluated, *"the consequences of climate change on the eco-geomorphology of coastal wetlands of the World. They have used a bio-complexity framework to provide a perspective of the consequences of climate change for coastal wetland eco-geomorphology. They have concentrated on three dimensions of climate change affects on eco-geomorphology, sea level rise, and changes in storm frequency and intensity, changes in freshwater, sediment, and nutrient inputs."*

TROBE and VANTON in 2008 have linked, *"the climate change adaptation and disaster risk reduction in different parts of the World. The recommendations within this report have focused on improving communication and collaboration between the climate change adaptation and disaster risk management communities. Some are relevant to both communities, while others are more specifically directed at one or the other."* TAY, STEVENSON and LOH (2008) have studied, *"the climate change negotiations Asia and their contribution with the international communities."* UNO in 2008 has presented, *"a report in the General Assembly regarding climate change and the most vulnerable countries of the World. The report has explained that in many developing countries, there are difficulties in integrating adaptation concerns into national policy due to low staff capacity for planning, monitoring and evaluation; poor data on adaptation options and lack of mechanisms for information sharing and management across sectors; and limited awareness of adaptation among stakeholders and the population".* GOHEER in 2009 has presented, *"the current capabilities in the analysis of climate risks and adaptation strategies in critical areas of Pakistan."*

PANAGARIYA in 2009 has discussed, *"climate change and policy option in India."* He has expressed, *"Estimates of how much climate change has impacted India in the last century and predictions of how much it will impact the country in the current century have subject to vast amounts of errors. This uncertainly calls for sufficient preparation for adaptation to possible extreme weather change effects. This makes sustaining high rates of growth and poverty alleviation even more urgent."* SAAB in 2009 has analyzed, *"the Arab public opinion and climate change. The survey has proved that the general opinion in Arab countries recognized climate change as a reality, and largely accepts that it is mainly caused by human activities."* PAL in 2010 has evaluated, *"how to assess climate change and adaptation from poor peoples in Bangladesh. He has examined the households' opinions based on what they noticed or can reveal due to climate change issues."* Sterrett (2011) has reviewed, *"climate change adaptation practices in South Asia. He has opined that adaptation efforts in South Asia have so far been fragmented, lacking a strong link between national climate change strategies, plans, and existing disaster risk reduction, agricultural, and other relevant policies."*

Chapter-3

Environment and Agriculture

This chapter covers the environment of arid region in relation to agriculture. The carrying capacity of any area in the biosphere to produce enough food and other crops for the human population and domesticated animals depend a lot on environmental conditions and human technical capabilities to adapt to the environment. This chapter discusses the environmental conditions in arid region of Pakistan and how the farming patterns have been adjusted to these conditions. It has been divided into four sections. The first section on physical setting explores the landform, soil, climate, and natural vegetation and their role in agriculture of the region. The second section on human environment discusses the distribution of population, human settlements and the socio-economic set up and their relationship to agriculture in the region. Based on above, in the third section, agro-ecological zone have been identified, highlighting the agricultural characteristics of each region. The concluding section highlights the finding of the chapter.

3.1. Physical setting:

The physical features of the earth play vital role in controlling of temperature, precipitation, natural disasters, and evapotranspiration etc. The temperature decreases from low to high altitude, while it is converse for precipitation. The moisture contents of the soil decreases from high to low altitudes that influences the crop productivity at low lands. Beside, the height of

the trees, crops and the length of cropping seasons are also some how depended on the topography of the area. In most cases the crops in arid and semi-arid areas are confined to isolated patches where the soil is fertile and the water is available. There are two arid regions identified in Pakistan that is the southern and northern arid region, separated by a wide zone of semi-arid, sub-humid, and humid region of central and upper Punjab and Khyber-Pakhtoonkhwa provinces. Therefore, it is necessary to discuss the physiography of each one of the arid regions in Pakistan.

The southern arid region covers entire Sind and Baluchistan provinces lower Punjab and Dera Ismail Khan district of the southern Khyber-Pakhtoonkhwa province. The landforms of the southern arid region have three main units - the northwestern highland, Baluchistan plateau and the Indus plain (Map-3.1). The northwestern highland of Baluchistan consists of two parallel regions of Toba-Kakar extending from northeast to southwest in Baluchistan and another parallel range of Sulaiman-Dera Bugti mountains along the Indus plain. The second major physiographic unit is the Baluchistan plateau that lies between the Toba-Kakar ranges and the Sulaiman-Kirthar mountains is also a dry rugged area with harsh environment. Mainly pastoral agriculture is practiced on the Baluchistan plateau. Crops are grown only in those areas where, water is available.

The third major landform unit is the Indus plain, which lies south of the Himalayas and the Salt range stretching southward to the Arabian Sea. The Sind province and lower Punjab of the Indus plain fall in the arid region. This is the

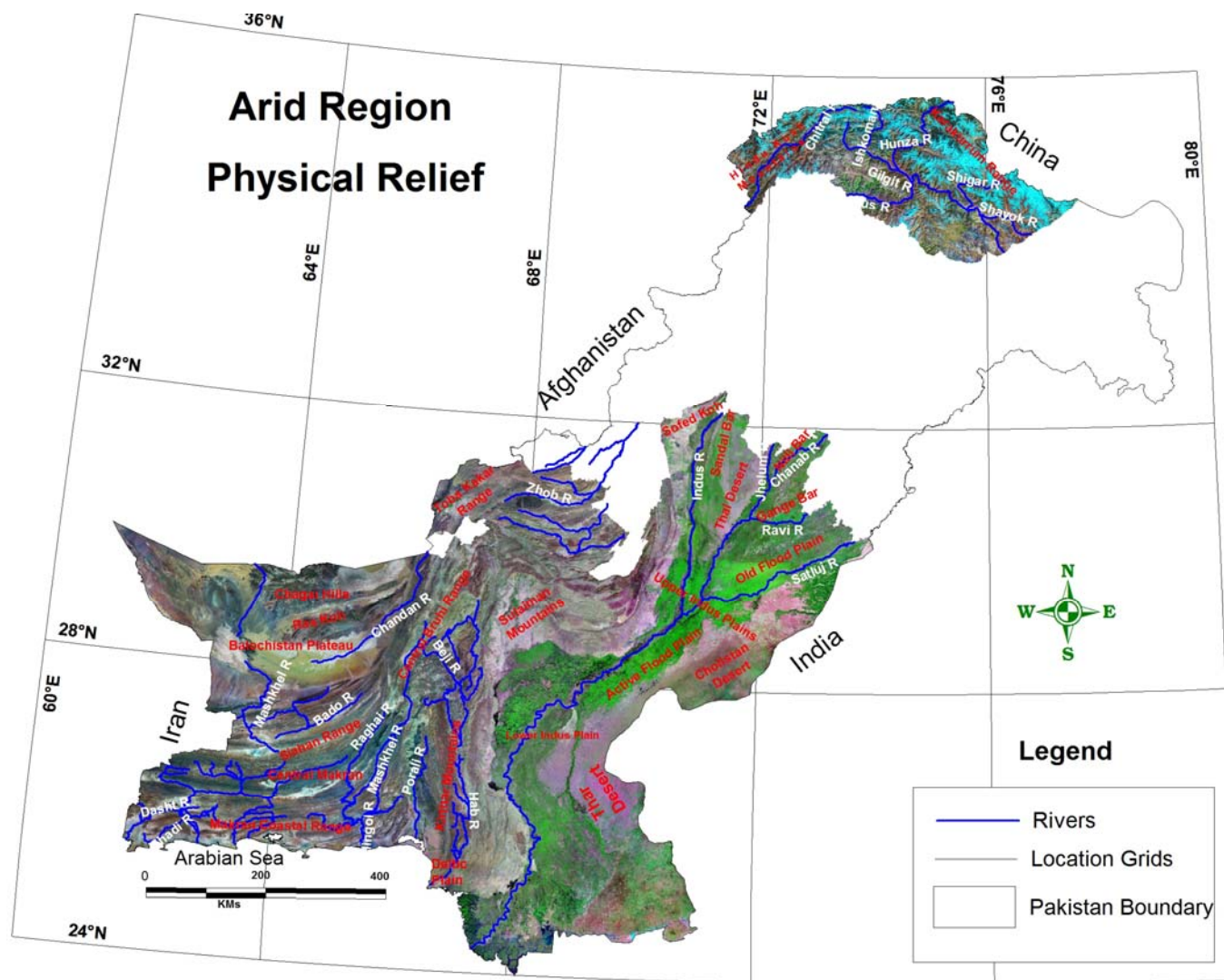
main agricultural area where the canal irrigation has developed during the 19th century. Deltaic plain that has developed at the mouth of the Indus river, is also an important agricultural area. The rolling sand plain covers an extensive area to the southeast of the canal irrigated arid region covering Cholistan and Thar deserts in Sind and lower Punjab. To the west of Kalat Plateau is the rolling sand plain of Kharan and Chagai, while in the southwestern Baluchistan there are dry and arid mountain ranges of the Makran coastal region. They are not very conducive to agriculture because of their dryness and rough topography, but agriculture is practiced to some extent in the Dasht river valley around Turbat in Kech district.

The northern arid region covers the extreme north of Pakistan, consisting of the Trans-Himalayas or the Karakoram and Hindukush mountains. The slopes are very steep and natural hazards particularly the land slide are frequent and the agriculture land is confined to the narrow belts along the rivers and streams in the valley. Therefore, in this rugged mountainous belt, agriculture is practiced mainly in the valleys primarily in the form of terraced cultivation (Map-3.1).

3.2. Soils:

Agriculture and climate of the arid region has also been greatly influenced by the soil composition and structure. *"The soil has three distinct constituents, which are solid particle, air and water."* These three major components have also great effects on the climate and crops productivity of a region. For example, salts, minerals, and organic matters help in the reflection, deflection, and

absorption of solar radiation, consequently, the temperature of the earth surface and atmosphere fluctuates (Khan, 1991).

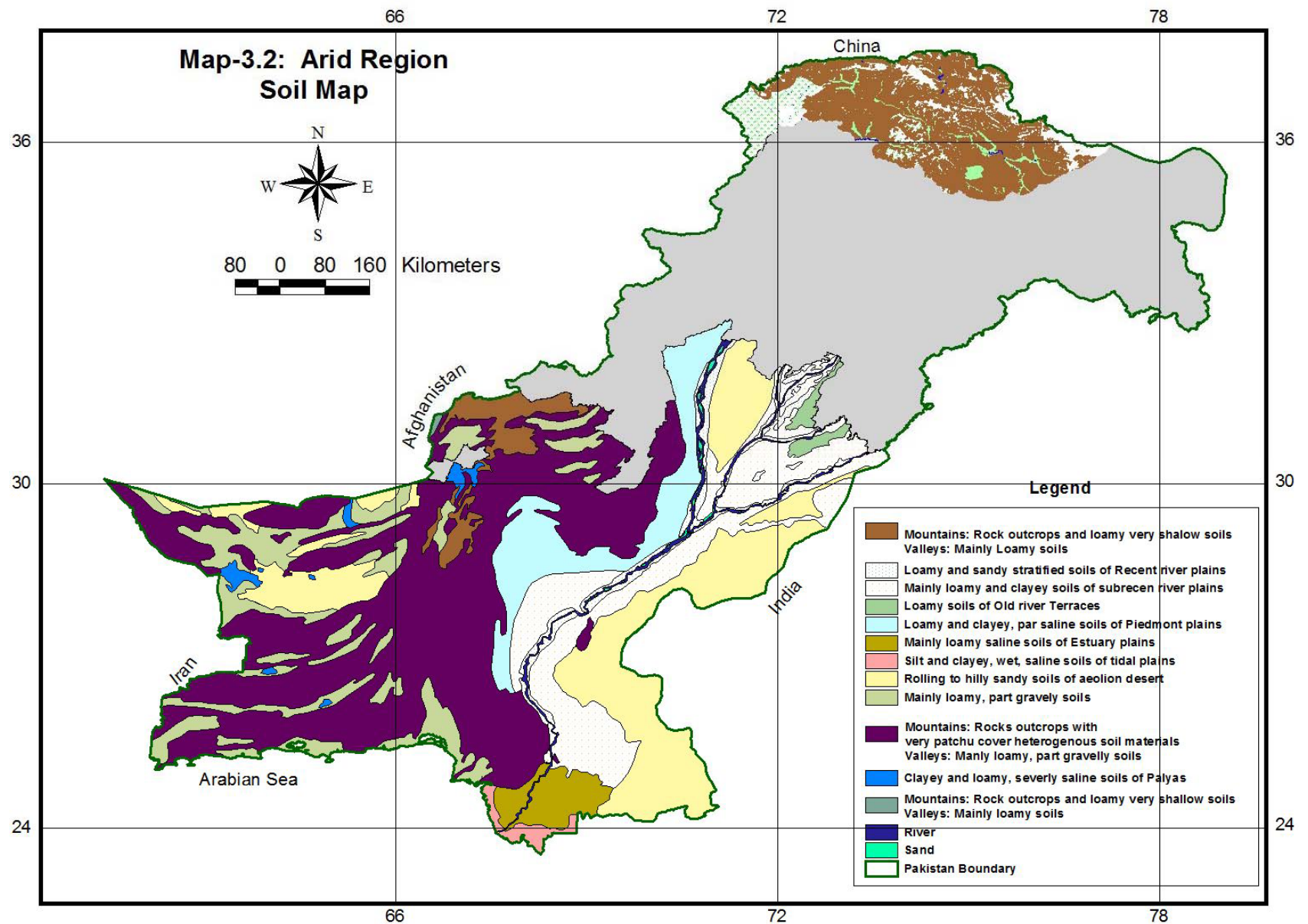


Map-3.1: Modified from landsat satellite image of Pakistan, 2005, by, <ftp://ftp.glcg.umd.edu>.

Arid region has peculiar types of soil due to its topography, climate, vegetation cover, parental materials, and time period of formation. Factors that play a vital role in the formation of soils in the arid region are climate, vegetation, living organism, parental materials, topography, and time period.

Based on structure and composition, the soil of the arid region can be classified into, “*soil of the flood plain, loamy soils of bar uplands, loamy and clayey, partly saline soils of the piedmont plains, rolling to hilly sandy soils of Aeolian desert, highlands, Baluchistan plateau*”. The soil of the flood plain is sub-classified into loamy and some sandy stratified soil of recent river plains, mainly loamy and clayey soils of sub-recent river plains, mainly loamy saline soils of estuary plains, salty and clayey wet saline soils of tidal plains.

They loamy and clayey soils are rich in soil contents and suitable for agriculture activities. These are located at the bar uplands in lower Punjab and also on both sides of the Indus river in Sind (Arid region) and both of the areas produce a major part of the agriculture economy on national level. Most of the arid region of Baluchistan, eastern Sind, and lower eastern Punjab is characterized by the rolling to hilly sandy soils, which is poor for crop cultivation, while the remaining areas are converted to cultivated lands after establishment of better irrigation system that originated from Indus and its tributaries (Map-3.2).



Map-3.2: Soil map of the arid region, modified from Soil Survey of Pakistan, Lahore, 1998.

3.3. Climate:

Temperature and precipitation are the main drivers of crop growth; therefore agriculture has always been highly dependent on climate patterns and variations. Since the industrial revolution, humans have been modifying the earth's climate by emitting CFC's into the atmosphere, resulting in higher global temperatures, affecting hydrological cycle and accelerating the frequency of climate fluctuation. Overall, climate change can have a variety of impacts on agriculture particularly bio-physical, ecological, and economical etc.

The agriculture of a region is generally highly influenced by the weather and climate elements that determine the growing seasons of plants, influences the plant life, crop production, and also help in the classification of plants species. In arid region, the types of agriculture like rainfed or irrigated and the cropping pattern and distribution are highly influenced by climate conditions. In most of Baluchistan, eastern Sind, and lower Punjab the crops in the rainfed areas are mostly dispersed and its production is declining with passage of time, which is a sign of negative effects of climate change on agriculture sector in the arid region of the country. This aspect has been dealt with in detail in chapter-4 and chapter- 5 of the present study.

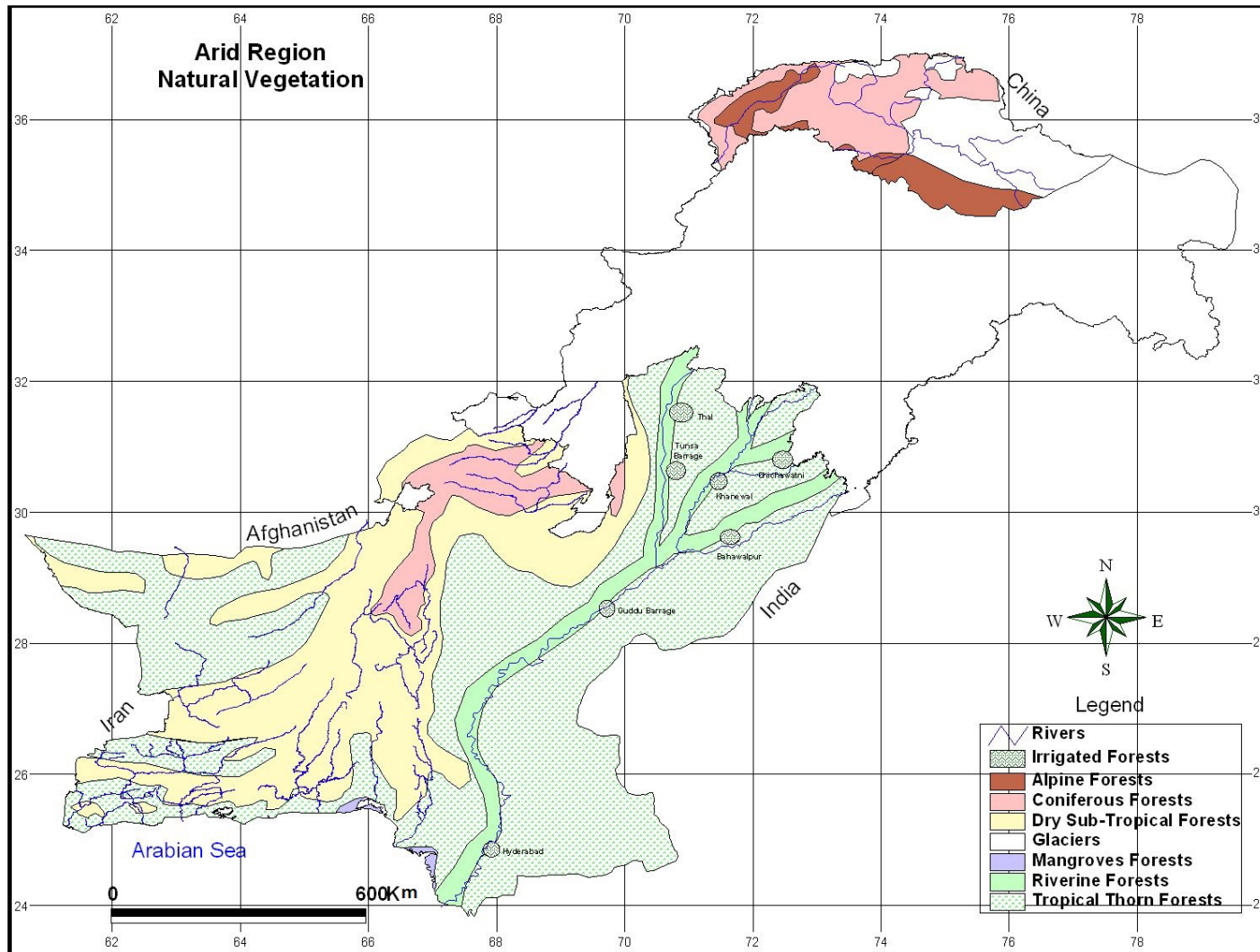
3.4: Natural vegetation:

It is one of earth's most vital natural resources that provide food, fiber, and fuel for the sustainability of human life, while vegetation preserves biodiversity, soil, and plays outstanding role in the hydrological cycle. Man has cleared the land surface by cutting the natural vegetation cover for the cultivation of crops in

the arid region in Pakistan. Vegetation cover also controls the soil erosion, storage, and filtration of water, and wildlife habitat, playing a key role in the transfer of material between the atmosphere, soil, and water bodies that is basic to the crops cultivation, production, and growth.

Dense forests can influence the local climate to some extent. Temperature is lower in a region of dense forests, light is reduced greatly, and the soil is several degrees colder. Humidity is greater and dew and fog is formed readily over the adjoining fields. Evapotranspiration from the soil, and wind velocities under a forests covered area is greatly reduced, and also increases the capacity of water storage of the soil. The barren land and mountains have inverse climate condition.

In arid region, there is a variety of natural vegetation due to climates, topographical and soil condition. *"Natural vegetation covers about 4.8% of the total area of Pakistan, while about 20-25% of forests are needed for the balanced economy of a country"* (Khan, 1991). The province based, distribution shows that Khyber-Pakhtoonkhwa has the leading percentage (15.6%), followed by Sind (2.1%), the Gilgit-Baltistan (13.5%), and Azad Jammu & Kashmir (13.6%). The



Map-3.3. Natural vegetation of the arid region in Pakistan, modified from Geography of Pakistan, by Khan, 1991.

arid region has two distinct types of forests i.e. natural vegetation and the plantation forests (Map-3.3).

The natural vegetation consists of different type of forests including alpine forests, coniferous forests or sub-tropical pine forests, sub-tropical dry forests, tropical thorn forests, and coastal mangrove forests. Plantation forests are divided into riverain and irrigated forests that are located at the roads side, canals, and rivers.

3.5. Human environment:

Agriculture is practiced in diverse economic, social, and environmental conditions. Hence, great diversity has developed in agriculture practices and products. In some areas of the arid region, farming is carried out to meet the local demand; in other it is primarily cultivated for commercial purposes. *"The different types of farming in the arid region of Pakistan are intensive subsistence farming, dairy farming, plantation farming, truck farming, and extensive herding"* (Khan, 1989). Among the factors that have influenced the type of farming include distribution of population and human settlements, as well as socio-economic conditions.

3.5.1. Population:

Due to population stress, the arid region of Pakistan is now facing the crisis in land use and agriculture production that could undermine the health, security, and sustainability of the inhabitants in the region. While climate change has received enormous attention, human population growth, and the corresponding rising country demand for meat and dairy products, as well as the growing need for bio-energy from corn, sugarcane, and other sources should be equal cause for concern. The population growth in the arid region is

putting tremendous pressure on the country agriculture resources. With abrupt increase in population in the last 30 years in the arid region (1981-2010), it is needed to be double, perhaps triple, the agricultural production of the area in the next 30 to 40 years. But due to population explosion and climate change in the arid region of Pakistan, the production and agriculture landuse are declining with passage of time and need adaptation to cope with the problem.

The total population of the arid region in 1998 was 60.3 millions comprises 31.5 millions male and 28.7 millions female. It is estimated that the projected population of the arid zone will be 78.7 million including 41.2 millions male and 37.5 millions female by the year 2012. The population density of the arid region was 137 persons per sq km area in 1998 that raised up to 179 persons per sq kilometer by the year 2012.

3.5.2. Population distribution:

The distribution of rural population brings out the man-land relationship effectively in an agriculture area like Pakistan. The pressure of population on land in arid region has been increasing with passage of time. The population density of the arid region has been categorized into the following major classes (Chapter-1, Table-1.1).

3.5.2.1. Thinly populated region:

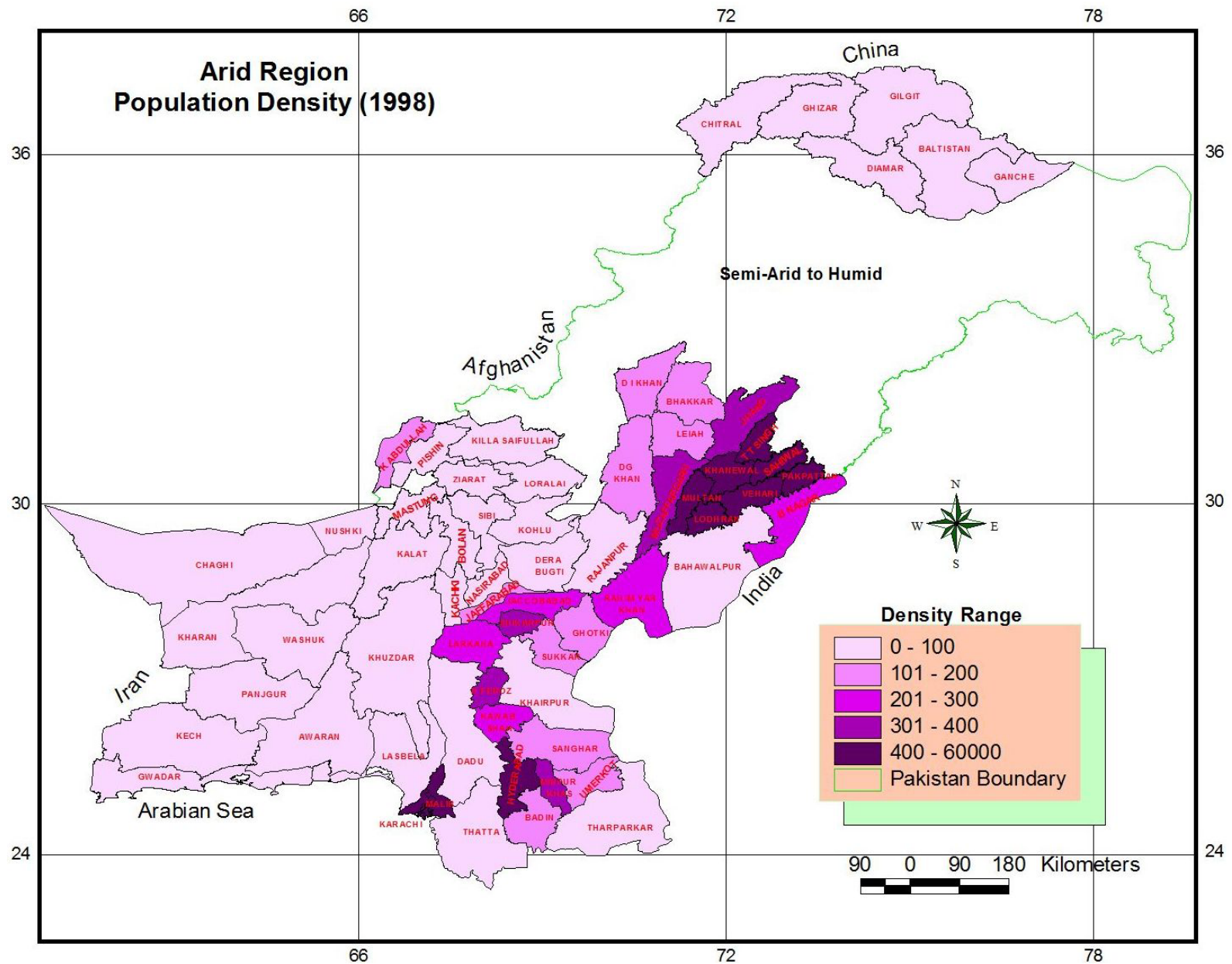
The thinly populated areas of the arid region mostly cover the entire area of Baluchistan and Gilgit-Baltistan Provinces. These areas comprise of hills, mountains, and barren sandy lands. Most of the land consists of rainfed areas having scarce agriculture activities (Map-3.4).

3.5.2.2. Moderate populated region:

Moderate population varies from 101 to 200 persons per square kilometer. The moderate population is mostly located in the northwestern part of Baluchistan (Pishin district), parts of Sind and lower Punjab provinces. Most of the agriculture is based on rainfall or canal system with low productivity (Map-3.4).

3.5.2.3. Thickly populated region:

The range for this class has been considered between 201-300 persons per square kilometer area. The arid areas having thick population mostly cover the fertile land of Sind and Punjab. These are the areas, where intensive agriculture is carried out with a high productivity (Map-3.4).



Map-3.4: Arid region projected population 2011-12

3.5.2.4. Very thickly populated region:

The very thickly populated region varies from 301-400 and comprises parts of Punjab and northwestern Sind. Most of these areas are characterized by fertile soils and located close to the major cities. These are the most important agriculture lands forming source of food for the entire region (Map-3.4).

3.5.2.5. Most thickly populated region:

There are thirteen most thickly populated districts in the arid region where the population density is above 400 persons per square kilometer. These are located around the major cities and fall in the old flood plains of the Punjab and active flood plain of Sind excluding Karachi (Map-3.4).

3.6. The agro-ecological zones and landuse pattern:

The agriculture sector continues to play a basic role in the arid region economy. *"It is the second largest sector, accounting for over 22 percent of GDP, and remains by far the largest employer, absorbing 45 percent of the country's total labor force. Nearly 62 percent of the country's population resides in rural areas, and is directly or indirectly linked with agriculture for their livelihood,"* (GoP, 2008-09).

About nine different agro-ecological zones have been identified in the arid region of Pakistan by PARC (1972) and the map produced has been updated on the basis of the recent data. The general description, physiography, landuse, and environmental condition of each agro-ecological zone has been given below,

3.6. i. Indus delta:

The region comprises of the Indus delta and the surrounding areas of Thatta, Badin districts and part of Hyderabad that formed through successive advancement of land into the sea. The tall grasses and salt bushes had hampered the spread of agriculture in large areas. The changing nature of the Indus distributaries, the floods, and marshes make the reclamation of the land a major challenge (Map-3.5). The region is characterized by arid tropical marine climate with moderate hot summers and very mild winters. However, due to prevalence of sea breeze during summer the day temperatures are not very high.

There are two types of soils in the region comprising of clayey and salty soils. The clayey soils cover about one half of the area (Map-3.6). Generally, the saline and clayey soils of the region are barren. Parts of clayey soils are under irrigated cultivation to grow mainly rice and some sugarcane and pulses. Berseem fodder has high potential in the rotation of the crops. Locally, banana and orchards are also located on clayey soils.

3.6. ii. Central and northern Sind:

The region consists of Hyderabad, Badin, Tharparker, Sanghar, Dadu, Khairpur, Larkana, Nawabshah, Jacobabad, Sukkur, and Shikarpur in Sind, Nasirabad in Baluchistan, and Rahimyar Khan of Punjab (Map-35).

The climate is arid sub-tropical continental with hot summer and mild winter. The zone could be sub-divided into northern and southern regions. The northern region is extremely hot in summer with mean daily maximum temperature of above 40°C. The precipitation of the region varies from 16-20mm.

The minimum temperature in winter remains below 10⁰C with mean monthly lowest of 2.4⁰C.

The region is characterized by three main soils types with loam as a common feature. Along the river one meets the silt and sandy loam soils associated with the active flood plain. Outside the range of active flood plain in the upper part of the region calcareous, loamy, and clayey soils cover vast stretches. In the rest of the region soil texture is almost the same but there are saline patches (Map-3.6).

Most of this area comprises of arable irrigated land, with small patches of unused land under rough grazing. There are distinct cropping patterns emerged with the varying availability of irrigation water.

Canal irrigated agriculture is the predominant landuse of the region. Cotton and wheat, colza (mustard), sugarcane and Berseem fodder are the main crops in the area on the left bank of the Indus. Rice, wheat, gram and Berseem fodder are the main crops in the area on the right bank. Bicolor sorghum is the main crop in southern part of Dadu district because of water shortage.

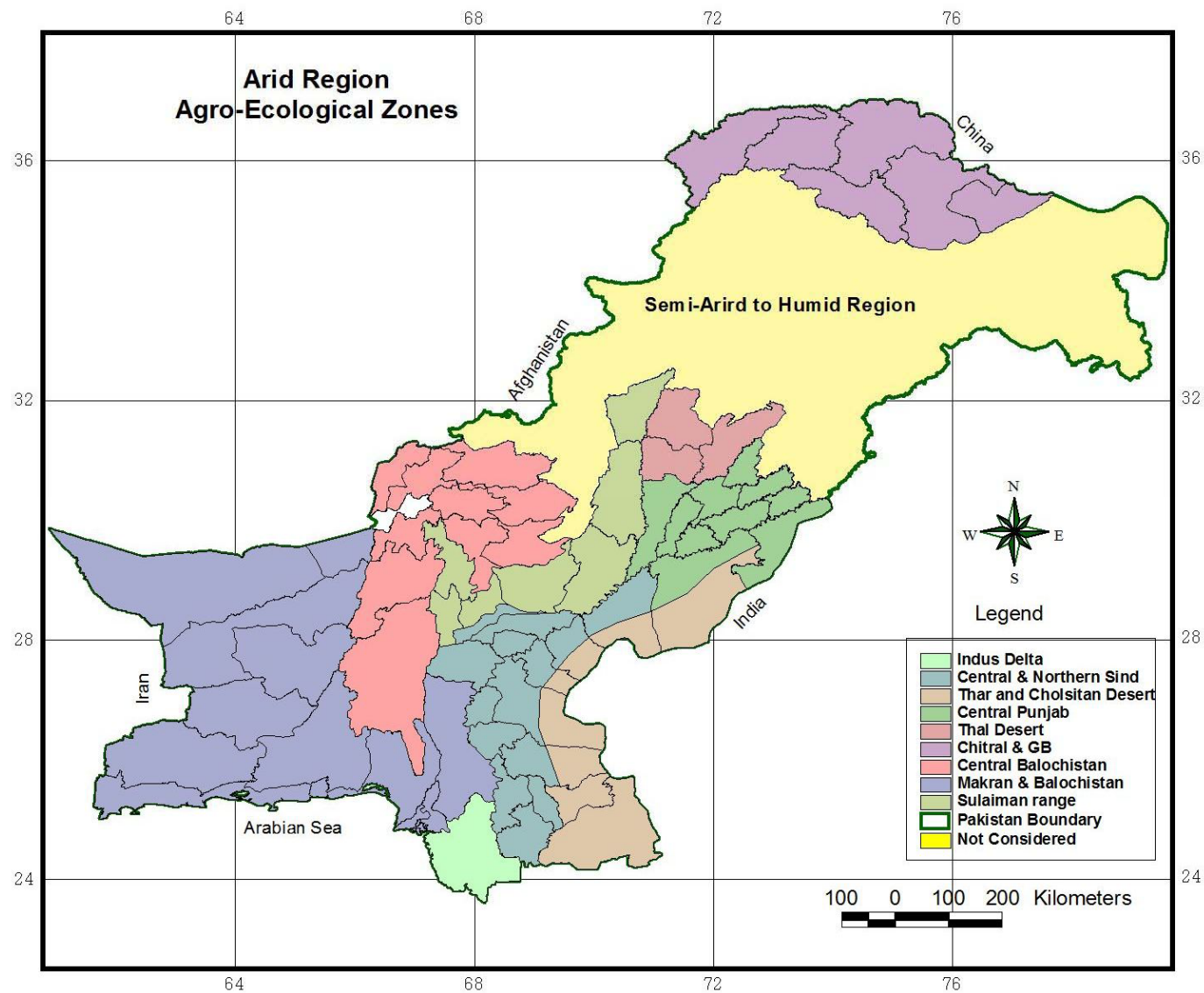
3.6. iii. Thar and Cholistan desert:

Parts of Tharparker, Khairpur, Nawabshah, Sanghar in Sind and Rahimyar Khan, Bahawalpur in Punjab cover this region, which is a part of Great Indian Desert. The area is higher than the adjoining Indus plain, characterized by elongated sand ridges formed by wind process. The desert is covered by thorny bushes.

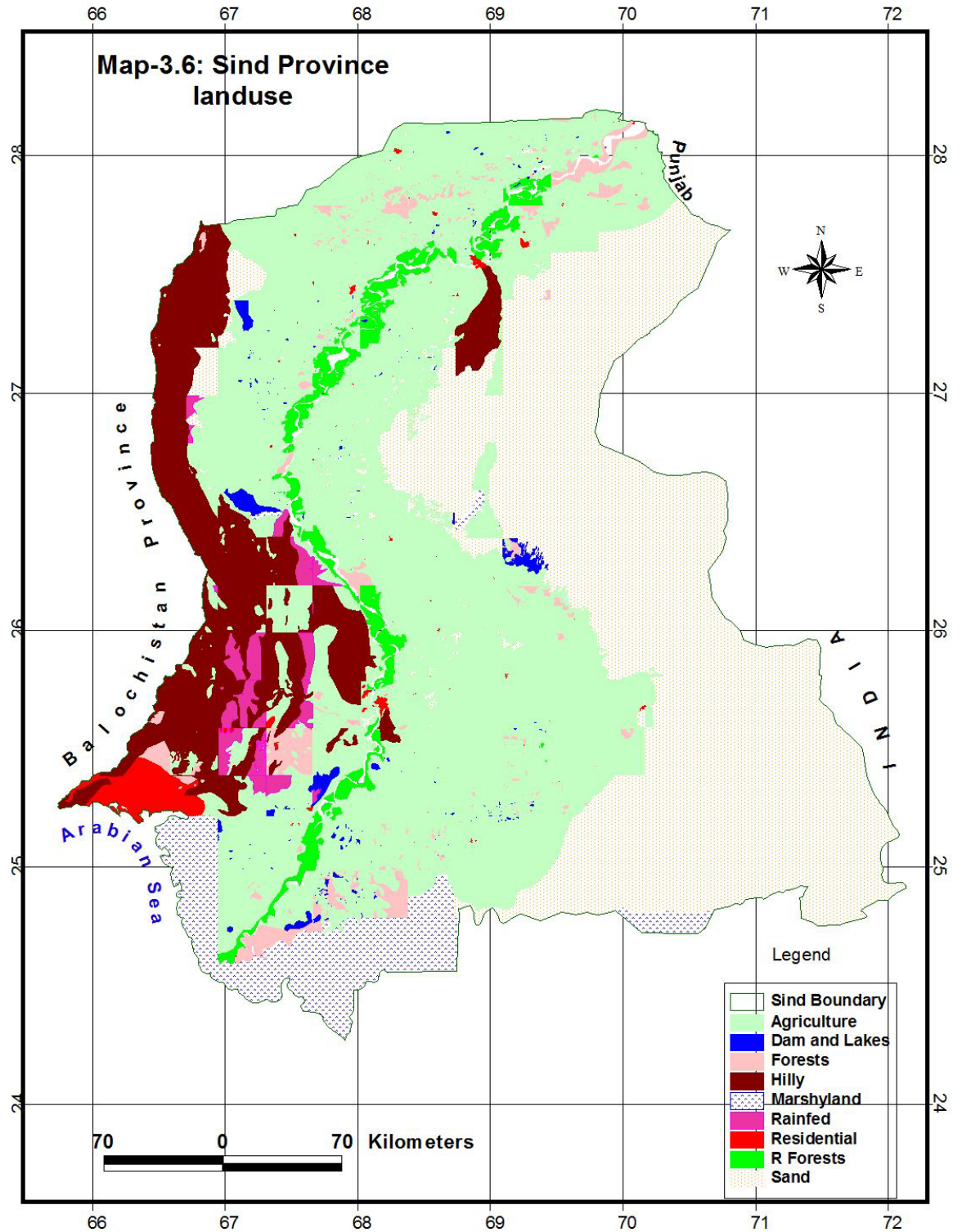
The inter-dune areas are devoid of shifting sand. During the rainy season, the runoff from the adjoining dunes collects in the central part providing enough moisture to support some scanty agriculture in the south eastern Sind. Most part of the desert is rainfed. The depth of the underground water at several hundred meters and difficult to support the fauna, agriculture and human needs. The climate of the desert is tropical with hot long summers and short warm winters. The climate is desert type with very hot days in summer and cold nights in winter with frost and fogs. Dust storms are common during summer season (Map-3.5).

The area is characterized by the sandy soils and moving sand dunes. The valleys between the dunes have sandy loam but these cover a very small proportion of the area. However, in the southern part, sandy loam soil covers considerably large patches of land. The western part of this region has long strips of clayey soils formed in the deposits of Hakra River.

The region comprises of the pastures for the grazing of sheep, goats, camel, and cattle. In the southern part jawar and millet s are important crops, which are grown in years of favorable precipitation. In the southeastern part of the region, where rainfall is about 300mm (Tharparkar), wheat is also an important crop on loamy soils and castor on sandy loam soils (Map-3.6).



Map-3.5: Agro-ecological zones of Pakistan, modified from PARC, 1972



3.6. iv. Central Punjab:

The region consists of Bahawalnagar, Rahimyar Khan, Multan, Vehari, Muzaffargarh, Sahiwal, and Jhang districts of the south central Punjab, famous for the agriculture activities. The area is arid (steppe) with sub-tropical continental climates. The mean monthly temperature of the area remains above 35⁰C, whereas the winter minimum temperature is above 10⁰C. The area is characterized by hot summers and warm winters with dust storms in the month of June and July (Map-3.5).

The soils are sandy loam to clayey loams (Khan, 1993). Along the rivers, narrow strips of recent alluvium are deposited during the rainy season when the flow remains high. In the southern and central parts of central Punjab dominating soils are calcareous salty loams having weak structure, whereas clayey soils occurring in minor patches.

The area is covered by canal system for irrigation. Both *Rabi* and *Kharif* crops are cultivated in the region with high productivity. The main crops of the region are cotton, sugarcane, maize, and wheat. The area is also famous for the fruit orchards of citrus and mangoes throughout the arid region (Map-3.7).

3.6. v. Chitral and Gilgit-Baltistan province:

The region comprises of Gilgit-Baltistan province and part of Chitral district in Khyber-Paktunkhwa. Enclosed by high mountains, the valleys located in Chitral, Gilgit-Baltistan are characterized by extreme aridity. However, a large number of glaciers fed streams bring abundant water, which is used for irrigation of terraced agriculture. The terraces formed of fluvio-glacial materials are highly

fertile. The higher slopes of these valleys and the mountains in the neighborhood of snow line are covered with a narrow belt of pine forests (Map-3.5).

The climate of the region varies from arid climate to undifferentiated highlands. The tops of high mountains are covered with snow generally for the greater part of the year. The summers are mild and the winters are cold.

"The soils are generally deep, clayey and are formed in colluvial material accumulated on lower parts of mountain slopes and in alluvial deposits in narrow valleys," (Khan, 1993). Most of the area is used for grazing and a part is under the scrubs forest. Deep soils of valleys and lower parts of the mountains are used for growing maize and wheat under rainfed cultivation. Locally, in favorable condition rice is also grown with irrigation. Fruit orchards are confined to flanks of streams where irrigation water is available (Map-3.8 and 3.9).

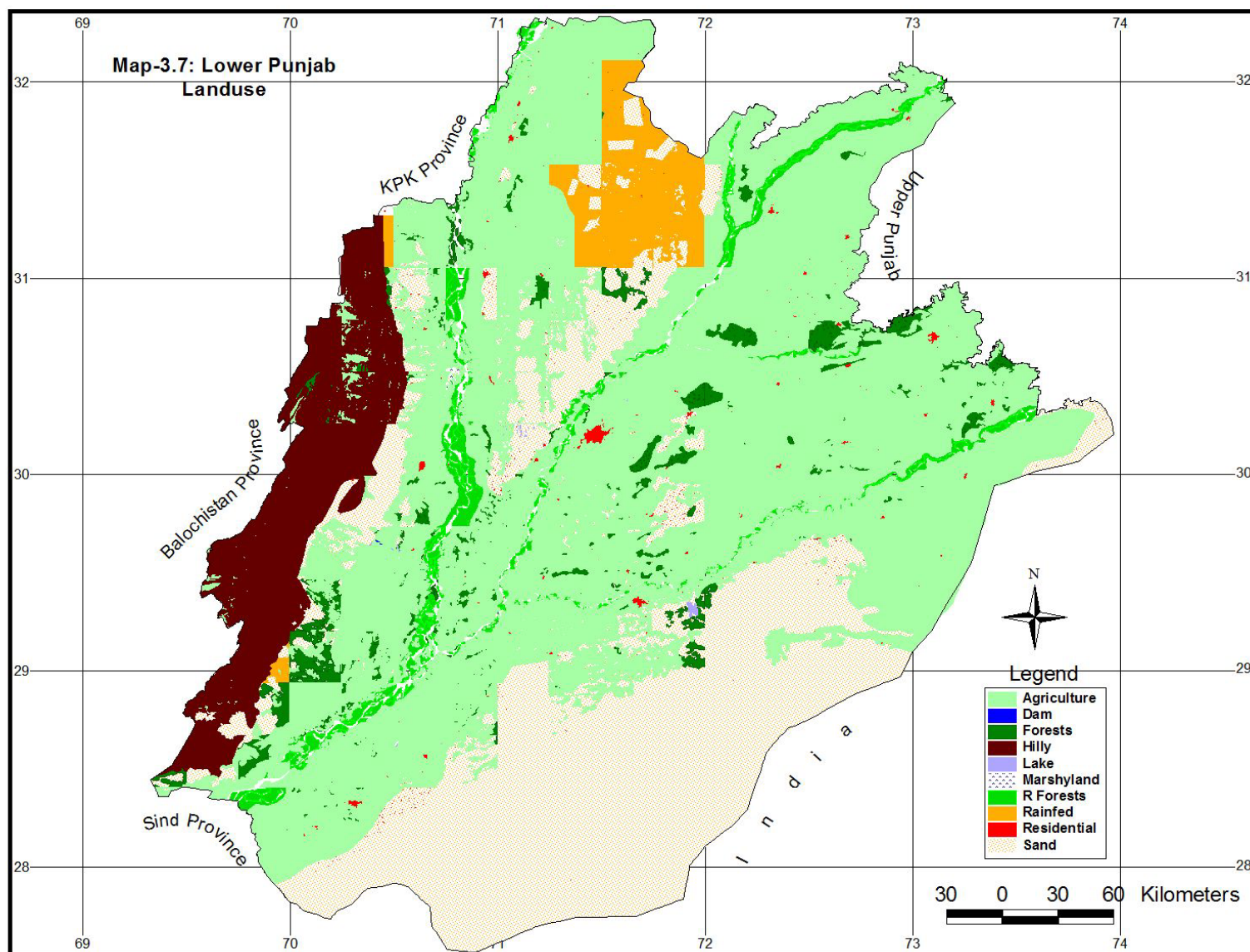
3.6. vi. Central Baluchistan:

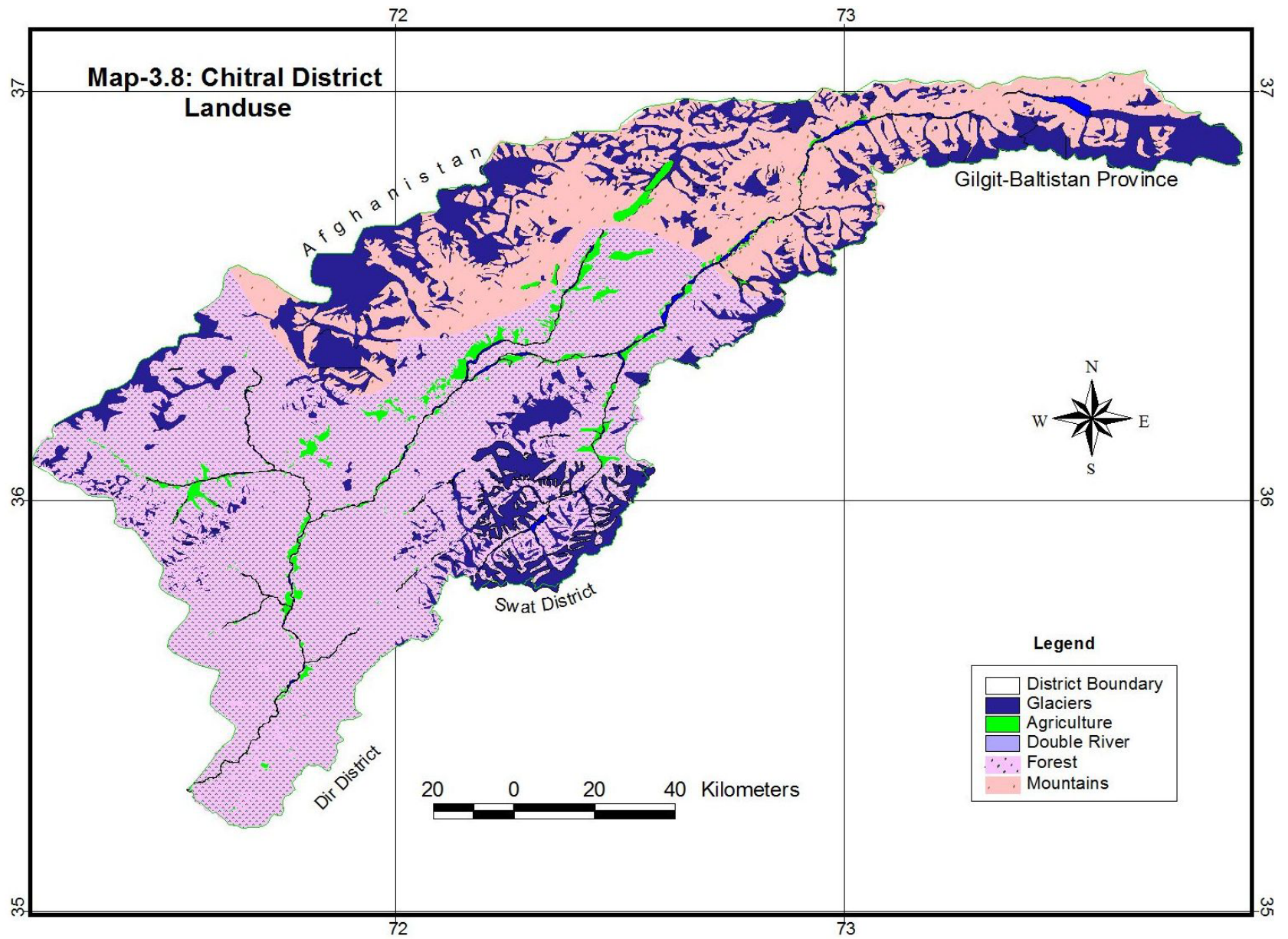
The region consists of Northern and central Baluchistan. The region comprises of barren hills with steep slopes intervened by valleys filled with Pleistocene deposits and the gravels, alluvium and loessic materials Kachi plain.

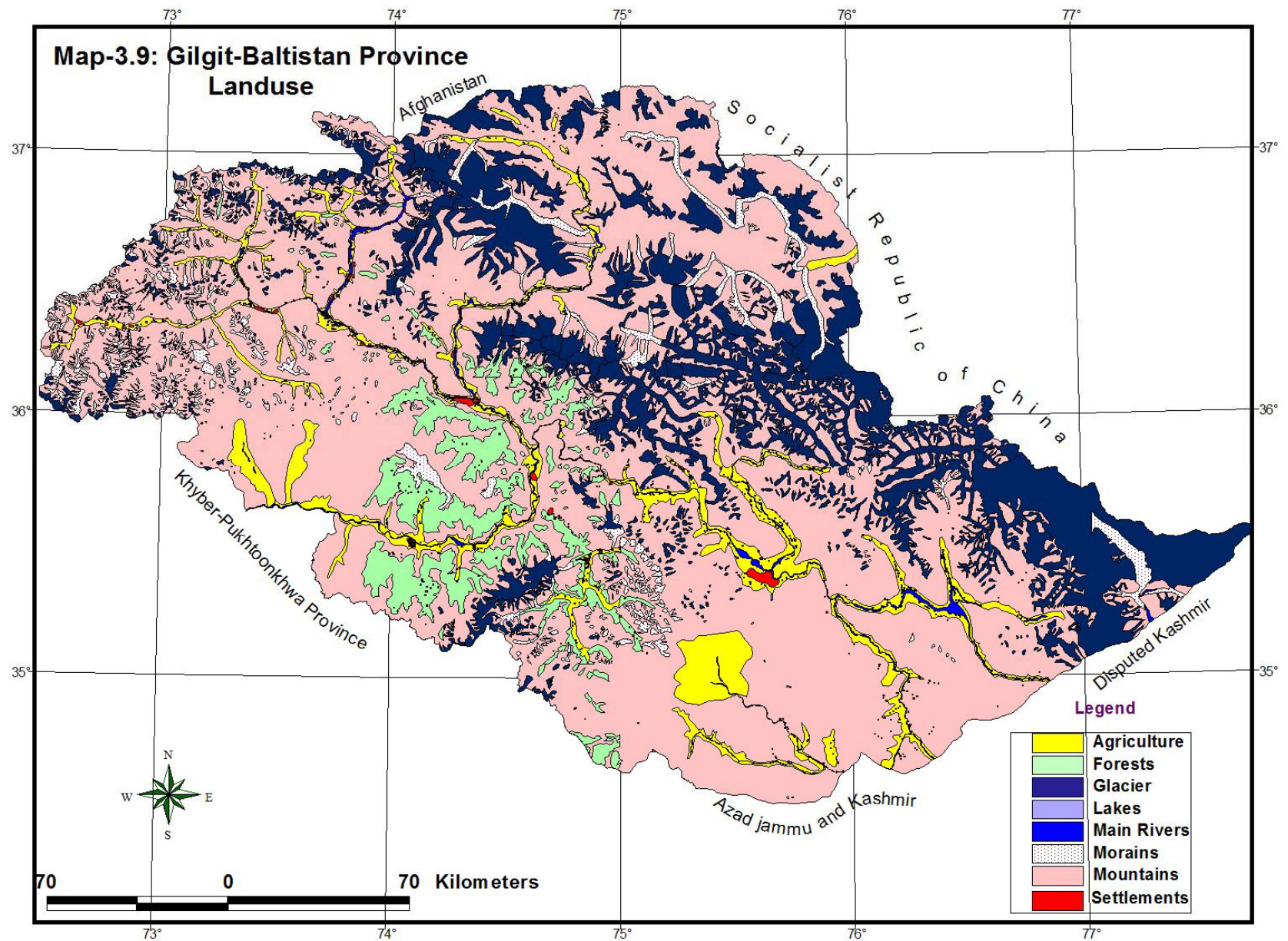
Due to steep slopes soil erosion is severe and extensive. Most of the land is almost devoid of vegetation except some xerophytes bushes and poor grasses, which are being worn down by human and animal exploitation. There are numerous hill torrents that carry flash floods and occasionally cause considerable damage to land and population. The area is mountainous having an arid climate with mild short summers and cold long winters (Map-3.5).

The area is mountainous with deep valleys. The main soils of the valleys are strongly calcareous but deep and loamy, with weak sub angular blocky structure and low organic matter content of 0.3 to 0.5%. Only at high altitudes, the virgin soils have 1-1.5% organic matter content. The higher parts of valleys have gravelly soils; the lowest parts are occupied by plains containing strongly saline soils and in between are loamy. The mountains have either very shallow soils or bare rocks with soil materials only in crevices (Map-3.10).

Predominant landuse of the area is grazing. Parts of the loamy soils of the valleys are, however, used for growing wheat under a system of spate irrigation by diverting torrent floods into fields having high embankments. A very small proportion of the area is under irrigated fruit orchards, mainly apples, peaches, plums, apricots, and grapes. Also grown under the irrigation are crops of wheat, maize, and alfalfa.





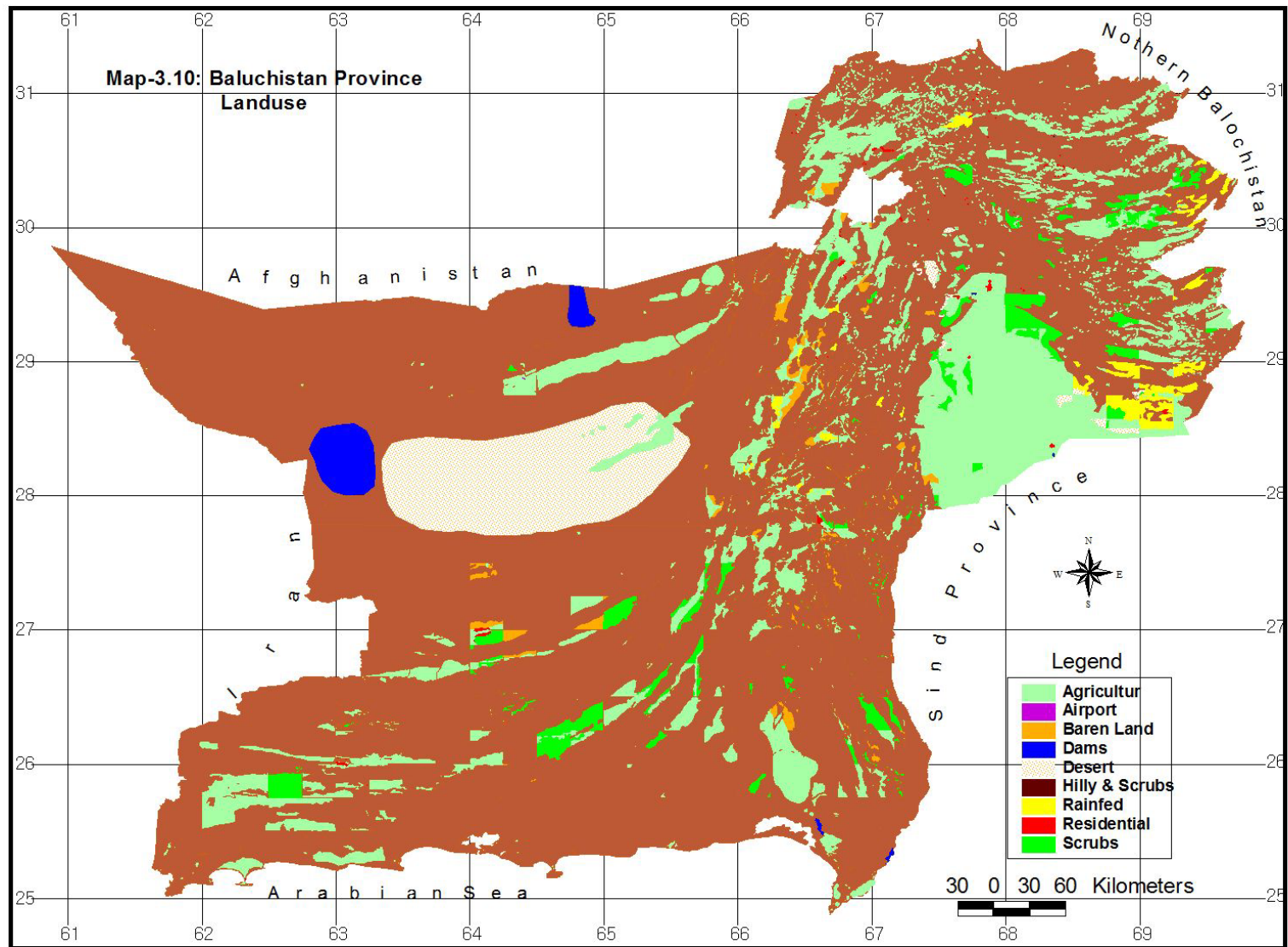


3.6. vii. Makran coast, southwestern Baluchistan, and Sind:

This agro-ecological zone covers Karachi and Dadu district in Sind, Gwadar, Kharan, Chagai, and Lasbela districts in Baluchistan. The climate of the region comprises of long hot summers and mild short winters with dust storms in June and July. The winter precipitation is higher as compared to the summer monsoon. The area is characterized by the mountains with inter-mountain basins, plateaux, and desert. It is the watershed between the Indus drainage system and the rivers that drains directly into the Arabian Sea including Porali, Nal, Hingol, and Dasht rivers of Baluchistan. In the north and the west, it has inland drainage system (Map-3.5) with isolated patches of agriculture scattered in the area.

The valleys generally have their floors covered with recent and sub-recent deposits of alluvium derived from the adjoining hill ranges. Most of the non-perennial streams from these valleys in the area converge on Hamun-e-Mashkhel, and conspicuous salt pan in western Kharan desert.

The soils of the plain area in this region are deep, strongly calcareous silt loams with weak structure. The slopes of the mountains and hills comprise either bare rocks or have very shallow soils. The lower parts of hills and higher parts of the plain have gravelly soils with a strong zone of lime accumulation at 30-40centimeters depth. Vegetation is xerophytes and is characterized by thorny scrubs and poor grasses in the lower regions. On higher altitudes there are forests of Junipers and wild olive, which merge with barren lands with scanty bushes and grasses in low lying areas (Map-3.10).



The most important landuse of the area is grazing. Cultivation on deep valley soils depends mainly on spate irrigation practiced by diverting torrent water into fields, which have high embankments for pending of water. The soil is soaked with 30-50centimeters of water to grow the crop. In the north wheat is the main crops but some melons are also grown. In the south Bicolor sorghum and millets are the important crops along the coast; castor bean is grown quite extensible. Fruits, vegetable, and wheat are grown wherever water is available from springs or Karez.

3.6. viii. Piedmont zone of the Sulaiman range:

The region contains Dera Ismail Khan in Khyber-Pakhtoonkhwa, Dera Ghazi Khan, and Rajanpur of the Punjab, Dera Bugti, Nasirabad, Jhal Magsi, and Bolan districts in Baluchistan. The piedmont plains of the Suleiman range are sloping towards the Indus river. A large number of alluvial fans have been built by the streams, which slope from the hills on to the piedmont slope. Barkhan, Dera Bugti, Nasirabad, and Jhal Magsi districts are lies to at the foot of the Sulaiman range to the west.

The piedmont deposits in this area show a generalized grading in texture, with gravel and boulders near the hills and silty material farther away. However, this grading of material is not in evidence everywhere, because it has been obscured by subsequent fine or coarse materials, producing geo-hydrological inequalities laterally and vertically in the deposits. Severe soils erosion, heterogeneity of soils, shifting of stream channels, lack of vegetation and meager and highly variable rainfall have made it into one of the most desolate areas of

the arid region. The weather is generally hot and arid with hot long summers and short cool winters.

The soils are loamy on gentle slope near mountains but clayey in level areas. All these soils are strongly calcareous and low in organic matter content. Strong salinity occurs only in narrow strip, which is the junction of piedmont plain and the river flood plain.

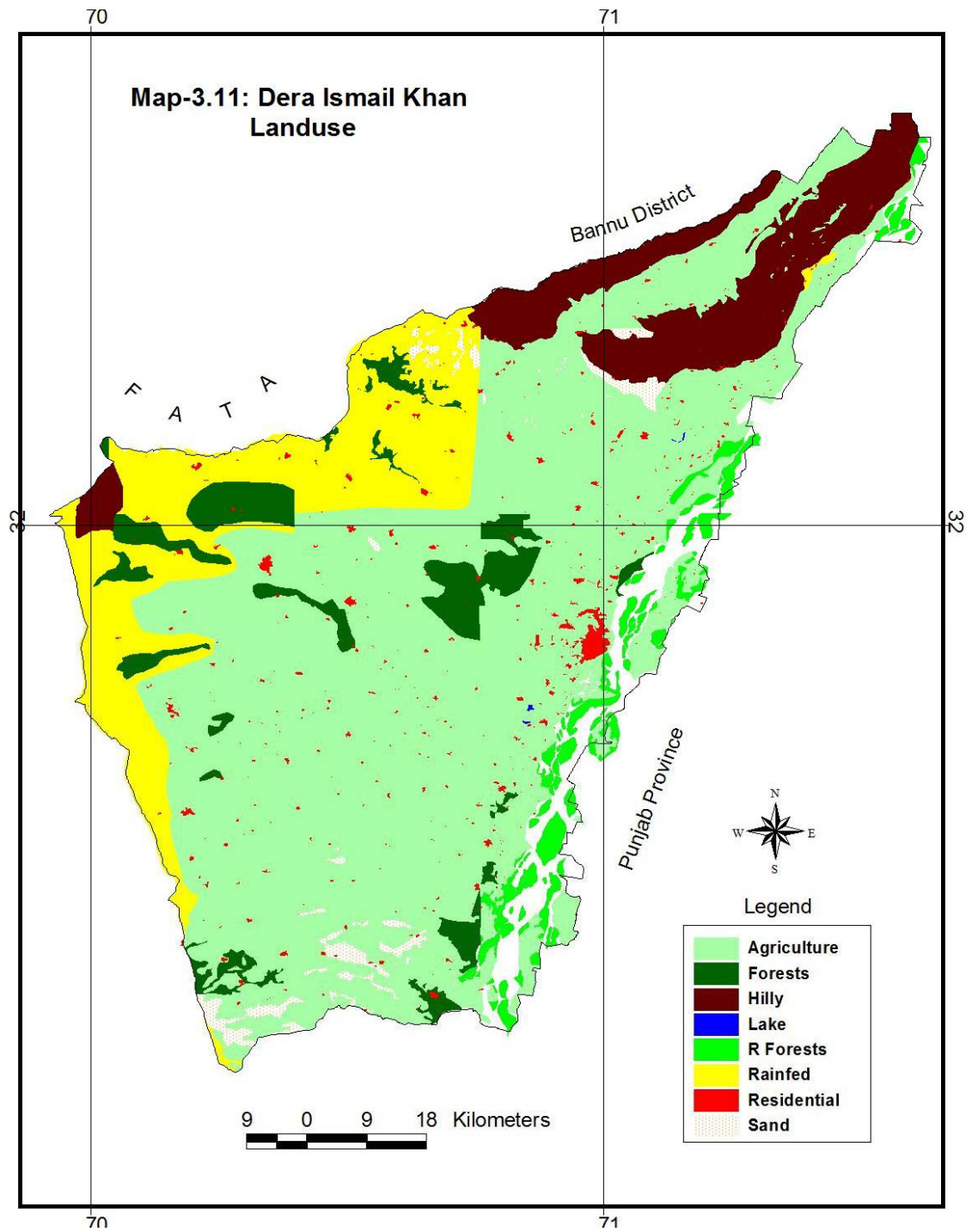
Torrent watered cultivation is the main landuse, under which wheat, Bicolor sorghum, millets and some gram are grown. Some parts of the clayey soils in the central part of the region are under canal irrigation and bicolor sorghum and colza are the main crops. Rice is grown in a narrow strip forming the junction of the piedmont and river plains. Extensive grazing is carried out in some parts, especially in torrent beds where coarse tall grasses grow (Map-3.11).

3.6. ix. Thal desert:

The region consists of Leyya, Bakkhar, and Khushab districts in western Punjab. This is a typical desert area with desert landforms including sand ridges, dunes, and sand sheets. However, it places silty and clayey deposits occur in narrow strips. *The sand ridges are 5-15 meters high* (PARC, 1972). Between the sand ridges, there are depressions that turn into ponds after the rain. In the central parts of the desert, there are large elongated channels showing the palaeo channels the Indus. The desert is quite profusely dotted with vegetation comprising short trees and canals for irrigation. The climate is arid with hot long summers and warm short winters.

"This is an area of the stable sand ridges, which have sand and loamy fine sand soils," (GoP, 2004). The hollows between the sand ridges have sandy loams and loams, which accounts for about 10% area. However, in the south-western part of the area, the proportion of loamy soils increases. All the soils are moderately calcareous and have low organic matter content. In addition, there are some narrow strips of silty and clayey soils, which are moderately to strongly calcareous and locally saline. Predominant landuse of the area is grazing of livestock especially goats, sheep, camels and cattle (Map-3.7 and 3.8).

A part of the area is used for dry farming of mainly gram and wheat, while cotton, sugarcane sorghum, millets, and wheat are also grown by canal irrigation.



Chapter-4

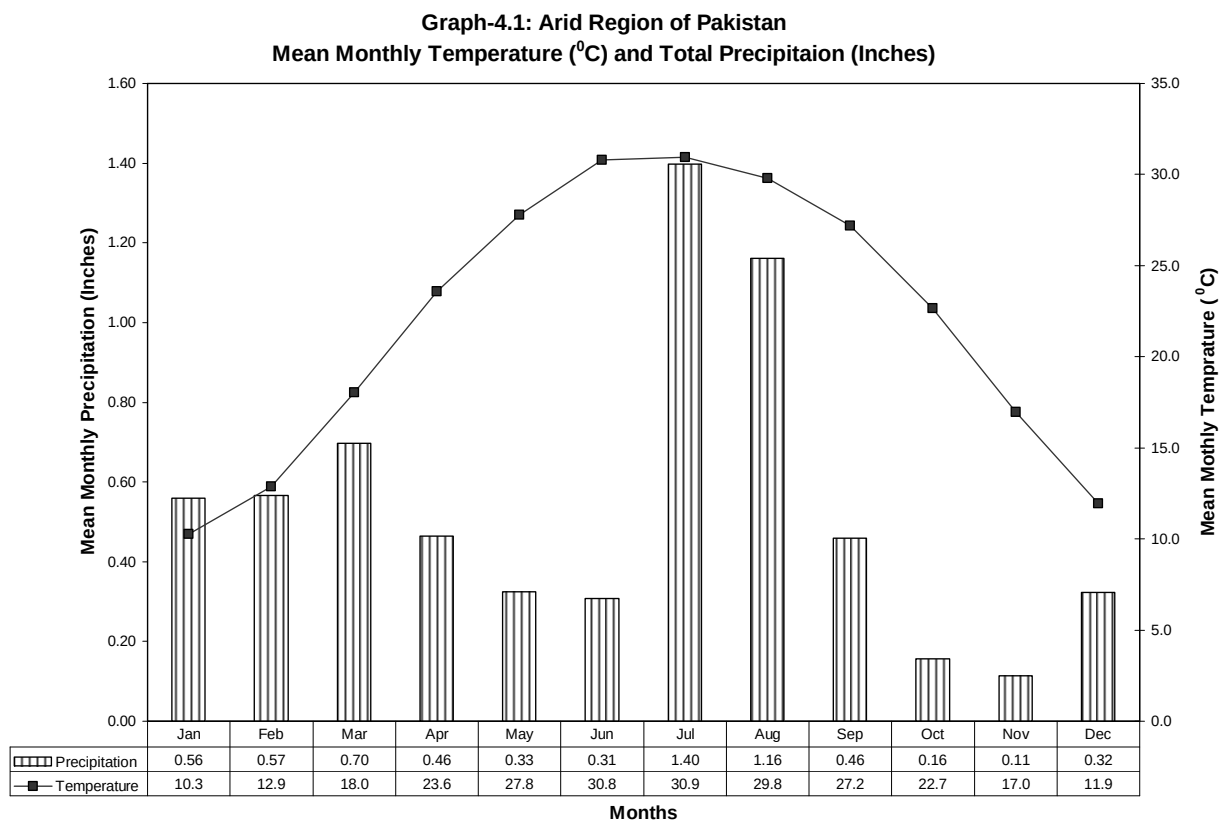
Temperature Distribution and Fluctuation

The importance of temperature for agriculture can be gauged from the fact that many bio-climate indices are based on temperature. It is one of the most important elements of climate that affect crop ecology. The chapter discusses the annual average, mean monthly and seasonal temperatures. This is followed by a discussion on overall temperature fluctuations in the study area on annual and seasonal basis. It highlights trends of temperature fluctuation using deviation from the mean condition. The variation of temperature forms the topic of the next section with special reference to different isothermal zones in the study area as well as sub-regions within it. The findings of the chapter have been summarized in the concluding section.

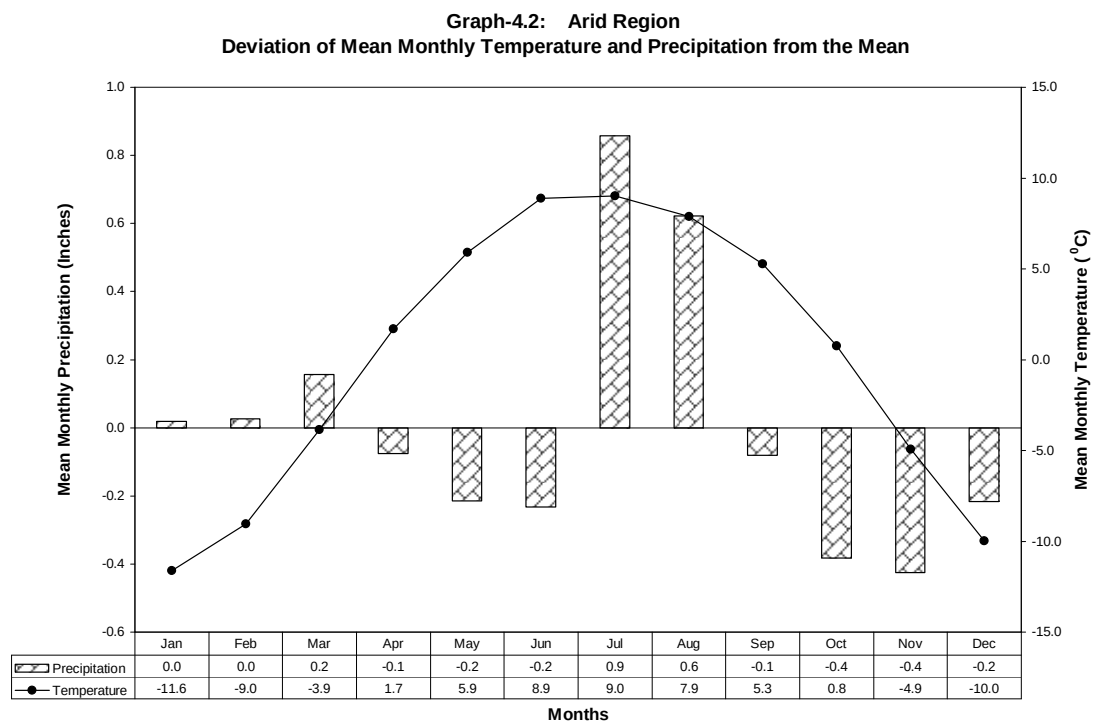
"The increase in temperature generally extends the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation, harvesting, possibility of completing two or more cropping cycles during the same season, and expansion of crop-producing areas towards northward. The increased temperatures in arid area may accelerate the rate at which plants release CO₂ in the process of photosynthesis , resulting in less than optimal conditions for net growth" (Daniel., Cynthia, 1995). When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If minimum temperature rises more than do daytime maximum as is expected from greenhouse warming projections then the heat stress during the day may be less severe than otherwise, but increased

nighttime respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation, and reduced yield (Daniel., Cynthia, 1995).

The annual cycle of temperature in the arid region is important for the identification of the timeline of the cropping season. It shows the maximum and minimum temperature of different months throughout the year, which make us able for the limitation of the duration of cropping seasons, requirements of irrigation, harvesting, and sowing timings of different crops. Generally, the summer months in coastal areas may not be the same as inland, while the summer months of plains are different from that of the highlands. For the present study, mean monthly temperature above 22⁰C has been taken as a criterion for a



summer month. These isotherms separate highlands from hot plains of the arid region (Map-4.3). The temperature of arid region in Pakistan shows negative variation from November to March, while other months of the year have positive deviation from the mean condition (Graph-4.1 and 4.2). Due to this annual march of temperature, there are five winter and seven summer months in the plain area and the converse is condition in the highland.



4.1. Annual temperature distribution:

The mean monthly temperature of the arid region not only helps to demarcate the different temperature regions but it also plays a vital role in the cropping seasons, pests conditions, duration of degree days for the crop sowing and harvesting, degree of evapotranspiration and the water requirements.

Kienzler (2012) has studied, *"the characteristics of climate change in the remote mountain areas of Khyber-Pakhtoonkhwa in northwestern Pakistan and the possible impacts of temperature and precipitation changes on agriculture, which is the mainstay of food security in these rural areas."* Prasad et al in 2008 have analyzed, *"the impacts of drought and heat stress on physiological, developmental, growth, and yield processes of crops."* Rehman et al (2010) have studied, *"the effect of temperature on development in spring wheat in Faisalabad, Punjab. They have used variation and correlation coefficient for the analysis of the effect of temperature on spring wheat."* Hansen (2005) has studied, *"the integrating seasonal climate prediction and agricultural models for insights into agricultural practice. He has used an integrating crop simulation models with dynamic seasonal climate forecast models."* The current study is based on the annual, seasonal, and extreme records of temperature distribution in the arid region of Pakistan. The main purpose is to know about the temperature fluctuation and its impact on agriculture sector and to suggest a suitable adaptation. The methods used for the current study are calculation of mean temperature, deviation from the mean, and trends of change/shift in the isotherms on the maps.

Generally, the highest mean monthly temperature of the arid region in Pakistan is 27.7⁰C, recorded at Hyderabad (40m, amsl) and the lowest is 11.7⁰C at Skardu (2205m, amsl) with mean monthly annual temperature of 22.4⁰Celsius (Map-4.1 and table-4.1). The isotherm of 25 to 30⁰C demarcates the lower Punjab, southern Baluchistan, Makran coast, and the Kachhi-Sibi areas. Plain

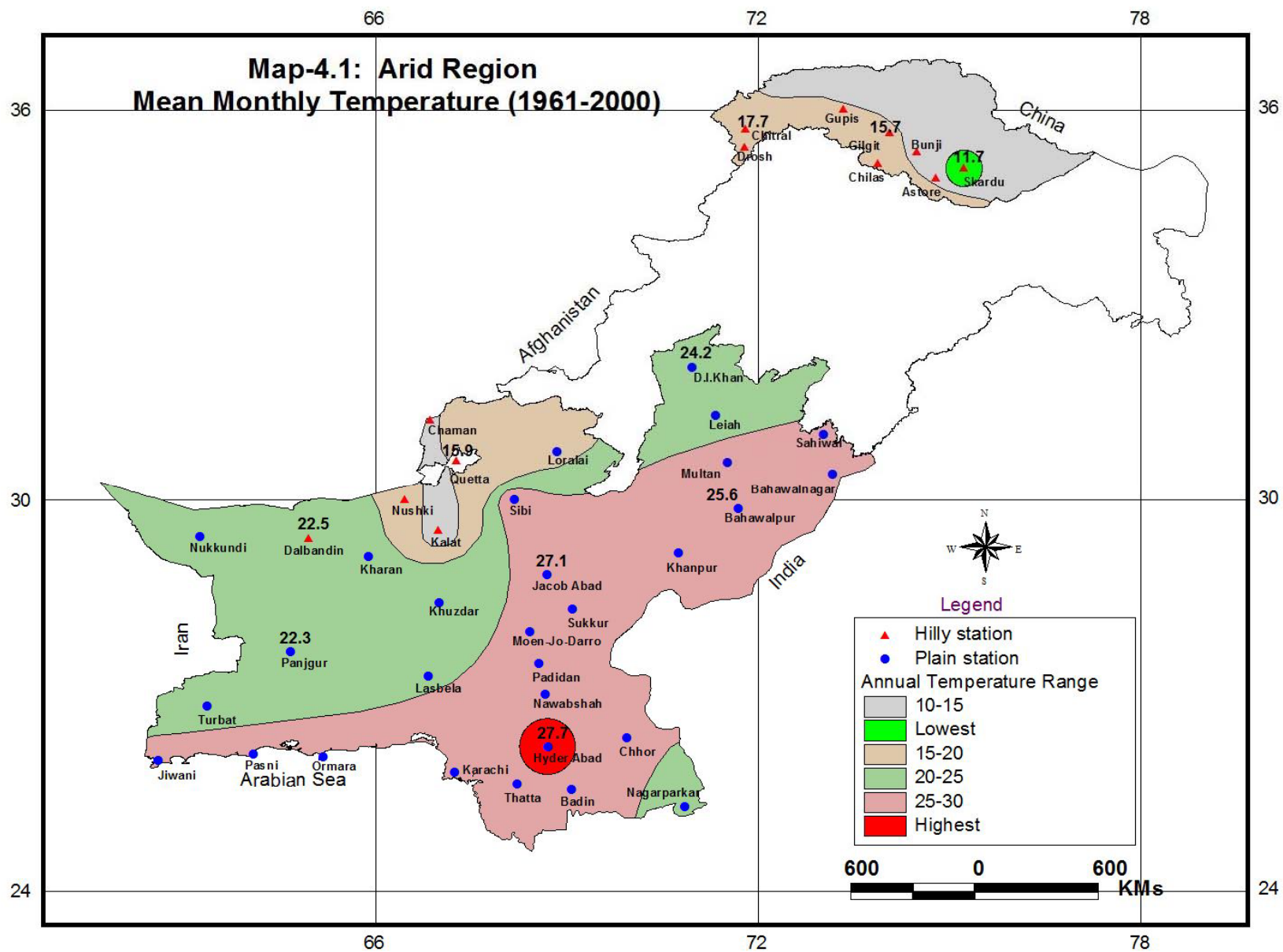
areas located at an altitude of above 100m (amsl) have been considered as the hottest region. The upper Indus plain, lower Khyber-Pakhtoonkhwa and part of the lower Baluchistan and Nagar Parkar in Sind, have mean monthly temperature between 20°C to 25°C. Most of the mountainous areas have mean monthly temperature below 20°C and constitute the coldest region.

The mean monthly temperature of the arid region decreases from south towards north, due to latitudinal and altitudinal variation and the accessibility of prevailing winds and rains. The coastal belt has lower temperature than inland areas as the sea breeze blows from ocean towards continent at day and inverse at night time.

4.1.1. Winter season:

The average temperature of winter season for the arid region is 17.2°C. The isotherm of 15°C approximately, marks the mountainous region of the arid region (Map-4.2 and Table-4.2). The minimum average winter temperature of the arid region in Pakistan is 5.1°C at Skardu, and the highest is 24.2°C at Hyderabad. Most of the plains have winter mean temperature of above 14°C, while in highland, it is vice versa.

In general, the winter temperature of the arid region in Pakistan shows decrease from northeast to southwest due to variations in altitude and latitude, prevailing winds and precipitation. The Baluchistan has low temperature in winter due to Siberian cold waves, while it is high at the Makran coast.



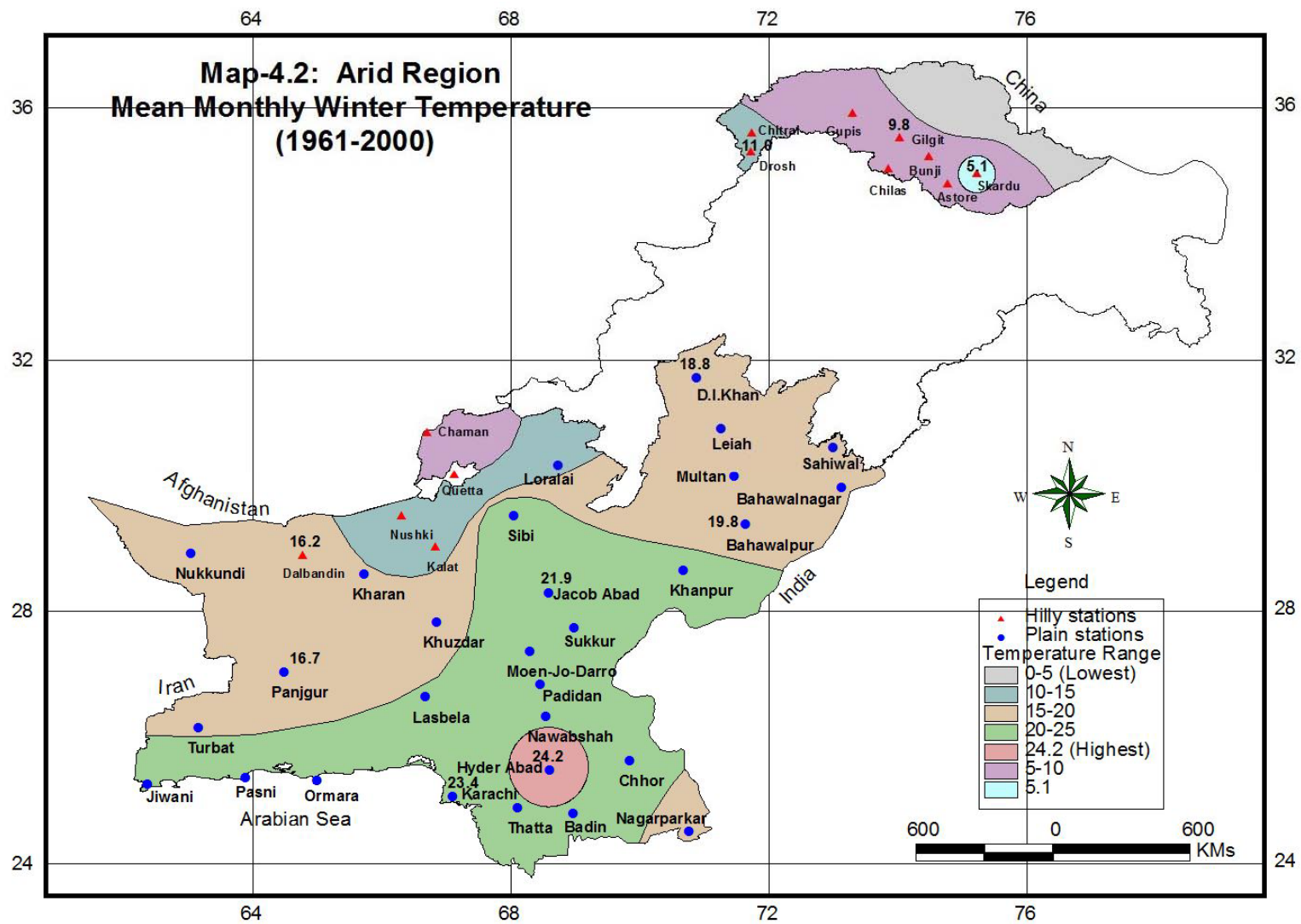
4.1.2. Summer season:

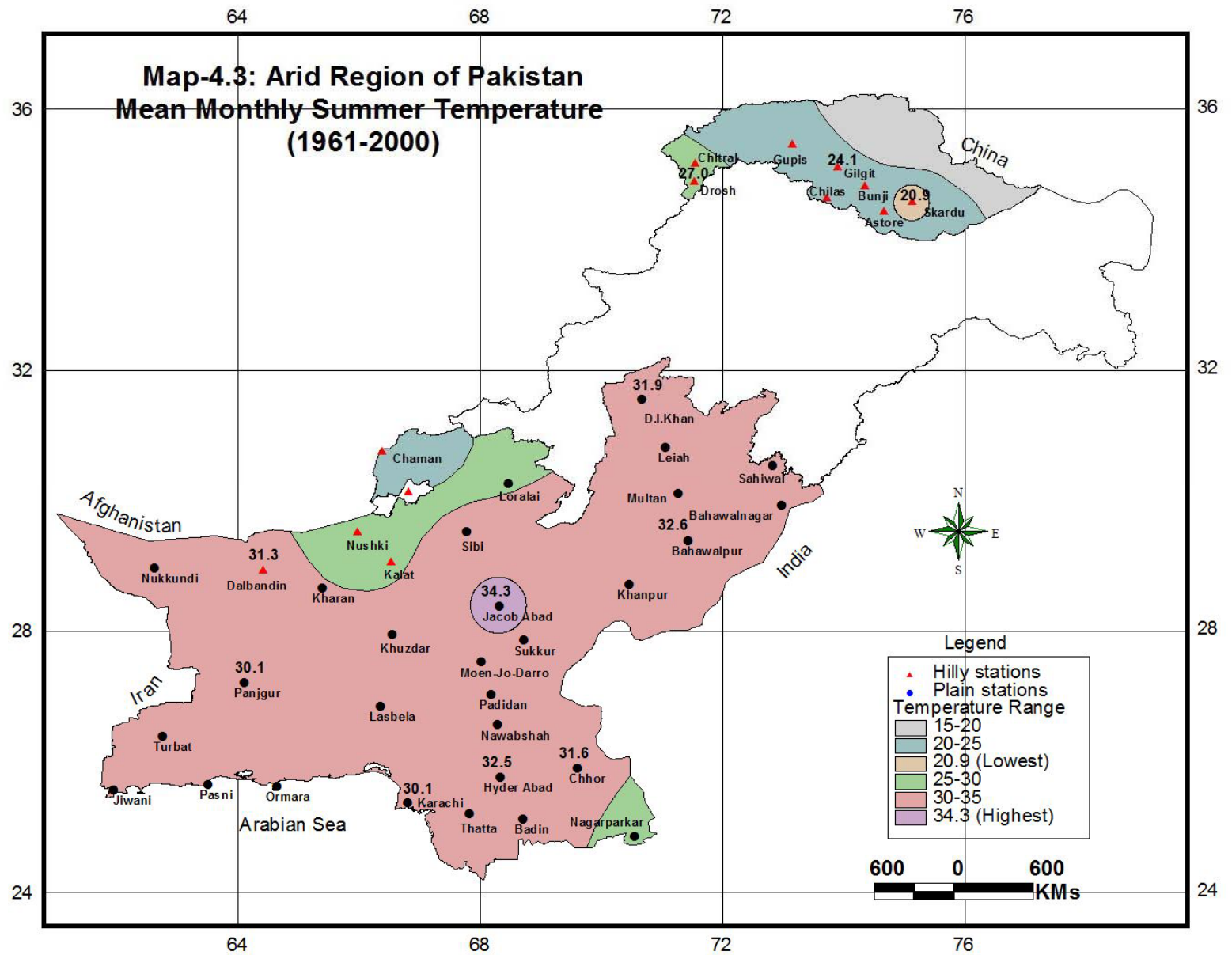
The highest mean monthly summer temperature of the arid region is 34.3°C at Jacobabad and the lowest is 21°C at Skardu (Map-4.3 and Table-4.2). The isotherm of 24°C marks the coldest region of the arid region in Pakistan. The summer temperature is between 24°C to 32°C in plain areas and converse in the highland. The average mean temperature of summer season for the arid region is 29.7°C.

4.2. Extreme maximum and minimum temperature:

Extremes of heat and cold have broad and far-reaching impacts on the agriculture sector. It affects the crop yield and production, growing season, and increase evapotranspiration from plants leaves and cause chilling condition etc. It is therefore, needed to study the distribution of extreme maximum and minimum temperature in the arid region of Pakistan.

Krishnamurthy (2011) has studied, *"the climate extreme, agriculture and natural resources in India. He has discussed the current scenario of climate change in India and its impact on the agriculture sector using regression, covariance, and quartile distribution."* Catoire et al, (2011) have presented, *"the extreme weather's impact on agriculture through decades in the United States of America. They have discussed the impact of extreme precipitation like flood, tornados, hurricanes, and droughts on agriculture sector in different part of Virginia, United States of America. But they have not presented the impact of extreme temperature on agriculture sector in their research."* Chivian et al (2001) have discussed, *"the climate change and extreme weather events -implications*





for food production, plant diseases, and pests. They have opined that warming temperatures and a greater incidence and intensity of extreme weather events may lead to significant reductions in crop yields.” In the light of stated facts, it is necessary to study the extreme ever recorded temperature of the arid region that will help to analyze the impacts of ever recorded temperature on agriculture sector and its adaptation in the arid region in Pakistan.

The general distribution of extreme temperature in the arid region of Pakistan shows that the highest extreme maximum temperature of 52°C is at Sibi, recorded on 5th June 1995 (for more than five times) and being the hottest region, while the lowest is 33°C at Murree, recorded on 12th June 1953. In plain, the highest maximum temperature varies from 48°C to 52°C, while in mountainous areas; it is between 33°C to 47°C due to elevation factor (Table-4.3). Throughout the arid region, the highest temperature is recorded in June but some time, it has also been recorded in May and July.

The highest ever-recorded minimum temperature is 4°C at Ormara, recorded on 3rd January 1949 (Table-4.4). The lowest minimum temperature is – 21°C, recorded at Astore and Skardu on 9th February 1974 and 11th January 1986. In the plain areas, it ranges from 1°C to -4°C, while in highland, it is between –3°C to -21°Celsius.

4.3. Temperature regions:

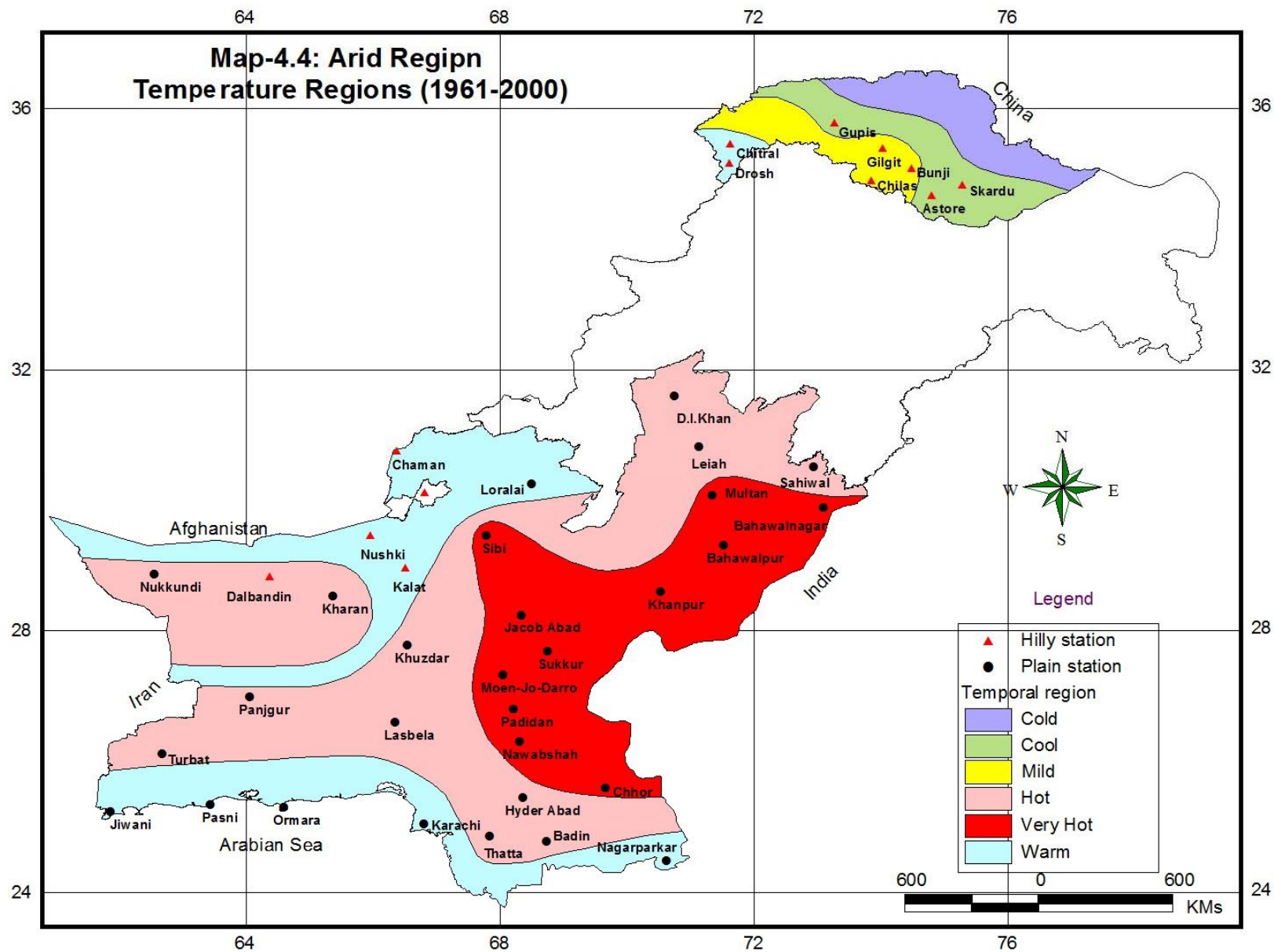
Based on temperature, the arid region of Pakistan has been divided into two main temperature zones that is plain and highlands, which is further divided into five sub-temperature regions namely hot, warm, mild, cool, and cold (Map-

4.4). The very hot region covers the vast area of Thar and Cholistan deserts, followed by the hot climates covering most of the western Sind, lower Punjab, Kharan desert, and Kachhi plain in Baluchistan. The warm region comprises the coastal belt, the western mountainous area of Baluchistan, and Chitral in Khyber-Paktunkhwa. The remaining three regions of warm, cool, and cold temperature run from south towards north and cover the northern arid region of Pakistan including Gilgit-Baltistan and part of Chitral district.

**Table-4.1: Arid region
Mean Monthly Temperature (°C) 1961-2000**

Observatories	Annual	Deviation	Observatories	Annual	Deviation
Chhor	26.2	4.4	Bahawalpur	25.6	3.8
Dalbandin	22.5	0.7	DI Khan	24.2	2.4
Hyderabad	27.7	5.9	Drosh	17.7	-4.1
Jacobabad	27.1	5.3	Gilgit	15.7	-6.1
Karachi	26.2	4.4	Skardu	11.7	-10.1
Panjgur	22.3	0.5	Average	21.8	
Quetta	15.9	-5.9	Deviation		1.6

Source: MPDC, Karachi



**Table-4.2: Arid Region
Mean Monthly Temperature of Summer and Winter Season (1961-2000)**

Observatory	Winter	Summer	Observatory	Winter	Summer
Chhor	22.4	31.6	Bahawalpur	19.8	32.6
Dalbandin	16.2	31.3	DI Khan	18.8	31.9
Hyderabad	24.2	32.5	Drosh	11.0	27.0
Jacobabad	21.9	34.3	Gilgit	9.8	24.1
Karachi	23.4	30.1	Skardu	5.1	20.9
Panjgur	16.7	30.1	Average	17.2	29.7

Source: PMDC, Karachi

**Table-4.3: Arid Region
Extreme Maximum Temperature (°C) 1931-90**

Station.N.	Maxi.T.	Date	Station.N.	Maxi.T.	Date
Astore	37	24/7/77	Sibi	52	12/6/1979
Chilas	48.1	1/8/1983	Hyderabad	50	9/6/1941
Gilgit	45	13/7/88	Jacobabad	51.1	19/6/72
Gupis	41.1	13/7/73	Karachi	48	9/5/1938
Skardu	41	2/8/1990	Moen-Jo-Daro	49.5	1/9/1987
Barkhan	44.2	20/6/86	Drosh	47.3	24/6/90
Dalbandin	51.4	1/7/1990	Chhor	51	24/5/32
Jiwani	48	8/6/1979	Badin	49.4	22/5/62
Kalat	38	19/6/77	Nawabshah	51	1/6/1954
Khuzdar	43	2/7/1990	Padidan	51	27/6/82
Lasbela	51	31/5/44	Sukkur	50	11/6/1979
Nokkundi	49.6	26/6/88	Chitral	44.4	10/6/1971
Ormara	47	24/5/32	D.I.Khan	50	5/6/1978
Panjgur	45	26/6/88	Bahawalnagar	50.1	20/6/86
Pasni	47	25/5/89	Bahawalpur	49	29/5/56
Sahiwal	48	19/6/52	Multan	49	21/6/80

Source: PMDC, Karachi

4.4. Temperature fluctuation:

"Over the past century (1908 to 2007), the average temperature in China has risen by 1.1 degree Celsius. Although, no significant trend was observed in averaged precipitation of the past 50 years, a drying trend was noted in the Yellow River Basin and North Chinese Plain. Over the past 30 years, the sea level and sea surface temperature have increased 90 millimeters (mm) and 0.9°C, respectively" (Zhu., Qian, 2001). The northern arid region of Pakistan is adjacent to China and may be taken as the continuation of the Chinese arid region in the west, the increasing trend in temperature and its impact on agriculture in China are the signs of climate change in the inner Asia and its influence may also be in the arid region of Pakistan that need adaptation and mitigation.

The most important climate factors that influence growth, development, and yield of crops are solar radiation, temperature, and precipitation. Temperature is the most important dominating factor influencing the suitability of a crop to a particular area. The temperature is important for growth and development, maximum dry matters accumulation in soil, and high night temperature for the growth of shoots in different crops. Keeping in view the importance of temperature, it is necessary to analyze the temperature fluctuation of the arid region in Pakistan. For fluctuation, a trend line has been drawn on the annual temperature series (1961-2000) that shows a clear picture of change of the mean monthly temperature. The annual mean monthly temperature of the arid region is 22.4°C. The lowest temperature of the series is 21.7°C recorded in 1971, whereas the highest temperature of 23.2°C recorded in 1988.

**Table-4.4. Arid Region
Extreme Minimum Temperature (°C) 1931-90**

Station.N.	Mini.T.	Date	Station.N.	Mini.T.	Date
Astore	-21	9/2/1974	Hyderabad	1	14/1/35
Bunji	-6	6/1/1978	Jacobabad	-2	5/1/1949
Chilas	-4.4	15/1/67	Karachi	0	21/1/34
Gilgit	-11.1	20/12/84	Moen-Jo-Daro	-4	24/12/84
Gupis	-12	29/1/77	Badin	-2	15/1/35
Skardu	-21	11/1/1986	Chhor	-2.8	12/1/1967
Barkhan	10	30/12/77	Nawabshah	-3	8/2/1974
Dalbandin	-12.2	11/12/1964	Padidan	-4	4/1/1949
Jiwani	2	26/1/57	Sukkur	-1.5	15/12/86
Kalat	-18	9/1/1945	Chitral	-16.1	27/12/65
Khuzdar	-8	24/1/75	D.I.Khan	-3	6/1/1934
Lasbela	-5	17/1/35	Drosh	-9	23/1/61
Nokkundi	-10	9/2/1974	Bahawalnagar	-2.8	12/1/1967
Ormara	4	3/1/1949	Bahawalpur	-3	15/1/35
Panjgur	-7.8	28/12/72	Faisalabad	-4	15/1/78
Pasni	2	14/12/86	Multan	-3.9	11/1/1967
Sibi	-3.3	10/1/1967	Sahiwal	-2	3/1/1938

Source: PMDC, Karachi 1931-90

All of the annual means of the series have been subtracted from the average mean monthly temperature of 22.4⁰C. The sum of the positive and negative deviation is 1.6⁰C, the total increase of mean monthly temperature in the arid region of Pakistan from 1961-2000 (Table-4.5).

The annual trend of mean monthly temperature indicates ups and downs for the period of 1961-2000 (Graph-4.3). In some cases they raise upto 22.9⁰C as in 1963, followed by slack to 22.2⁰C in 1966. Furthermore, the trend shows an increase upto 22.8⁰C in 1971 and a decrease for the following three to five years extending upto seven to ten years. In 1961, the average temperature of the arid region was 22.3⁰C, while it was 22.1⁰C in 1974 with an increasing trend of 23.1⁰C in 1977. Subsequent to 1977, no significant trend can be observed for five years

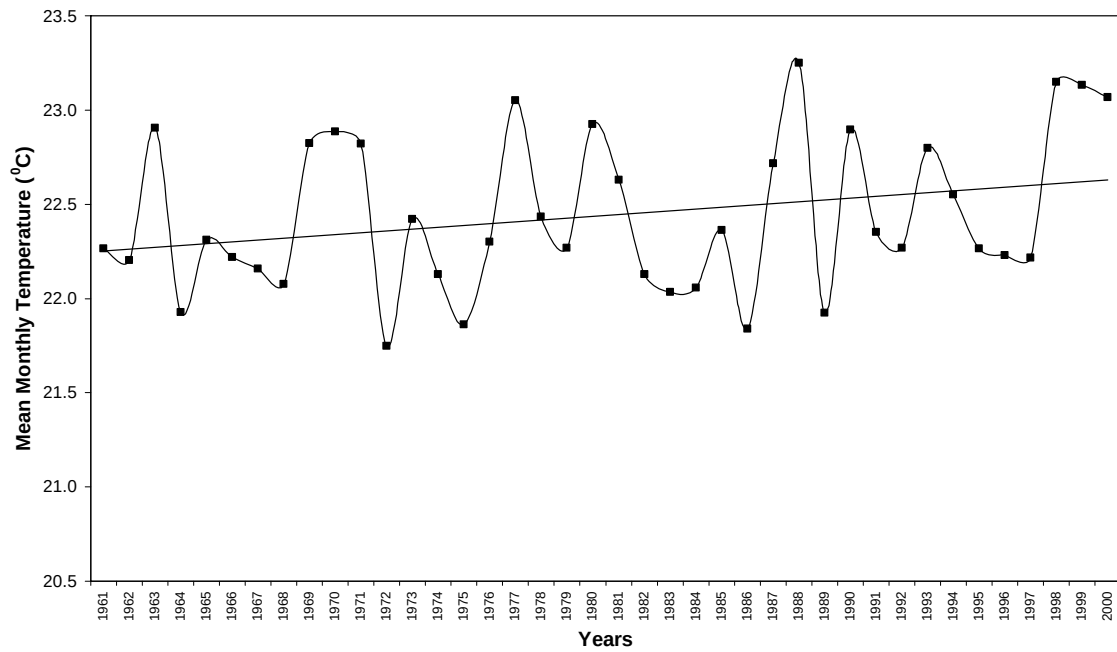
interval, but it declines to 22⁰C in 1983 and rose up to 23.2⁰C in 1988. It slackens again to 22.2⁰C in 1997 but afterward it shows continuous increase till 2000 (Graph-4.3 and Table-4.5).

The deviation from the mean condition indicates negative trend from 1961 to 1968, positive trend in 1971, and turn again into negative till 1976. From 1977 to 1993, the deviation from mean condition shows ups and downs for a time period of 17 years having positive trend in most of the years. From 1994 to 1997, the trend remains negative and then change into positive deviation till 2000 and it is expected that this positive trend in temperature shall continue. The lowest deviation of -0.7⁰C was recorded in 1972 and considered as the coldest year of the series, whereas the positive deviation of 0.8⁰C was recorded in 1988 and declared as the hottest year of the arid region in Pakistan (Graph-4.4).

4.4.1. Temperature trends at different class intervals:

Panagariya (2009) has observed, "*The three different figures for the increase in the mean temperature in India during the 20th century. The World Bank reports no change, the Government of India (2004) found 0.4 percent increase and the IPCC Fourth Assessment shows 0.68 percent increase. The Government of India further notes that on a seasonal scale, warming in the annual mean temperatures is mainly contributed by the post-monsoon and winter seasons*". There is also need to study the trends of temperature in terms of annual, seasonal and periodic to reach at the value of temperature fluctuation, to analyze its impacts on agriculture and adaptation strategies in the arid region of

Graph-4.3: Arid Region of Pakistan
Annual Trend of Mean Monthly Temperature ($^{\circ}\text{C}$)
1961-2000



Graph-4.4: Arid Region of Pakistan
Deviation of Mean Monthly Temperature ($^{\circ}\text{C}$)
(1961-2000)

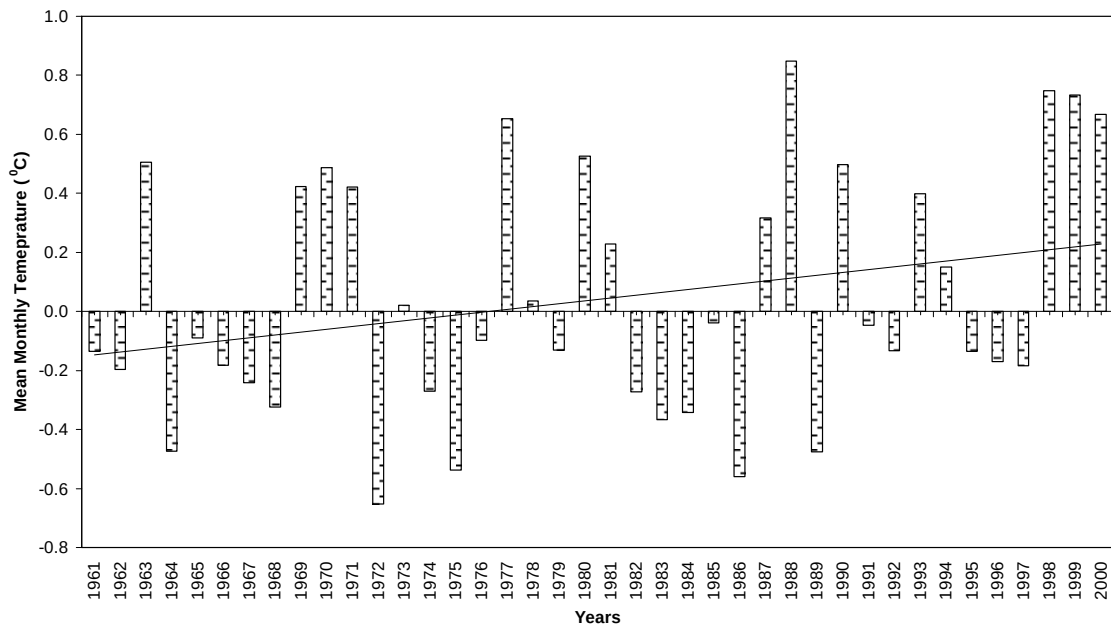


Table-4.5: Arid Region
Mean Monthly Temperature °C and Deviation from the Mean 1961-2000

Years	Chhor	Dalbandin	Hyderabad	Jacobabad	Karachi	Panjgur	Bahawalpur	D I Khan	Drosh	Gilgit	Skardu	Aver.	Deviat
1961	25.5	22.2	27.2	26.8	25.6	21.5	25.6	24.5	17.8	16.4	11.9	22.3	-0.1
1965	26.1	22.3	27.7	27.1	26.0	22.2	25.7	24.2	16.9	15.5	11.6	22.3	-0.1
1970	26.4	22.8	27.9	27.6	26.1	22.6	26.5	24.9	18.9	15.8	12.2	22.9	0.5
1975	26.0	21.5	27.5	26.7	25.9	21.5	25.1	23.8	17.1	15.1	10.2	21.9	-0.5
1980	26.7	23.3	28.2	27.4	26.4	23.3	26.1	24.6	18.1	16.0	12.2	22.9	0.5
1985	25.9	22.8	27.9	26.9	26.1	22.1	25.4	23.9	16.3	16.2	12.6	22.4	0.0
1990	26.1	23.5	27.3	27.2	25.9	22.8	25.7	24.8	18.9	16.2	13.4	22.9	0.5
1995	25.7	23.1	26.6	27.2	26.6	22.6	25.0	24.2	17.8	15.5	10.7	22.3	-0.1
2000	27.1	22.9	27.8	27.5	27.1	23.5	26.2	25.3	19.1	15.7	11.6	23.1	0.7
Aver.	26.2	22.5	27.7	27.1	26.2	22.3	25.6	24.2	17.7	15.7	11.7	22.4	1.6

Source: PMDC, Karachi 1931-90

Pakistan. The annual and seasonal fluctuation of temperature from 1940 to 2000 in Pakistan is as follow.

The series have been divided into different class ranges that are five, ten, fifteen, and twenty years (Table-4.6 and 4.7). The five years class range shows an increase of 0.3°C (Graph-4.5). The mean values of the series indicate a minimum of 22.2°C from 1971 to 1975 and considered as a coldest time period. The maximum temperature of 22.8°C recorded from 1996 to 2000 is the hottest class range of the series.

The sum of the deviation from the mean for ten years of the series reveals a total increase of 0.2°C (Graph-4.6). The graph shows the same temperature in the first and third half of the series (0.2°C), but during 1991 to 2000, it raises upto 0.22°C . The ten years average of the mean monthly temperature reveals two minima (1961 to 1970 and 1981 to 1990), and two maxima (1971 to 1980 and 1990 to 2000).

The sum of deviation from the mean for fifteen years average leads to a total increase of 0.2°C (Graph-4.7). The mean monthly temperature remains low during 1961 to 1975 (22.32°C), while from 1976 to 1990, it raised upto 22.45°C having net increases of 0.13°C . From 1991 to 2000 (ten years average) the temperature of the region reached to its climax with mean temperature of 22.6°C and supposed to be hottest period of the arid region in Pakistan.

Graph-4.8 reveals the twenty years average fluctuation of the arid region. The sum of deviation of the series shows an increase of 0.1°C . The first half of

Table-4.6: Arid Region

Five Years Average Temperature (⁰C) and Deviation from the Mean (1961-2000)

Years	1961-65	1966-70	1971-75	1975-80	1981-85	1986-90	1991-95	1996-2000	Mean
Chhor	26.0	26.2	26.1	26.4	26.1	26.3	26.0	26.8	26.2
Dalbandin	22.1	22.3	21.7	22.4	22.7	23.2	22.8	23.2	22.5
Hyderabad	27.5	27.7	27.7	27.9	27.7	27.9	27.2	27.6	27.7
Jacobabad	27.2	27.2	27.0	27.1	26.8	26.9	27.2	27.1	27.1
Karachi	25.9	25.9	25.9	26.2	26.0	26.3	26.5	26.7	26.2
Panjgur	22.0	22.5	21.6	22.5	22.1	22.2	22.5	22.7	22.3
Bahawalpur	25.8	25.9	25.6	25.7	25.2	25.5	25.4	25.4	25.6
D I Khan	24.4	24.3	24.1	24.3	23.7	24.4	24.2	24.3	24.2
Drosh	17.5	17.6	17.7	18.1	16.7	17.7	17.5	18.6	17.7
Gilgit	15.8	15.6	15.5	16.1	15.7	15.5	15.8	15.9	15.7
Skardu	11.4	11.5	11.3	11.9	11.8	11.9	11.7	12.0	11.7
Average	22.3	22.4	22.2	22.6	22.2	22.5	22.4	22.8	22.4
Deviation	-0.1	0.0	-0.2	0.2	-0.2	0.1	0.0	0.4	0.3

Source: PMDC Karachi 1961-2000

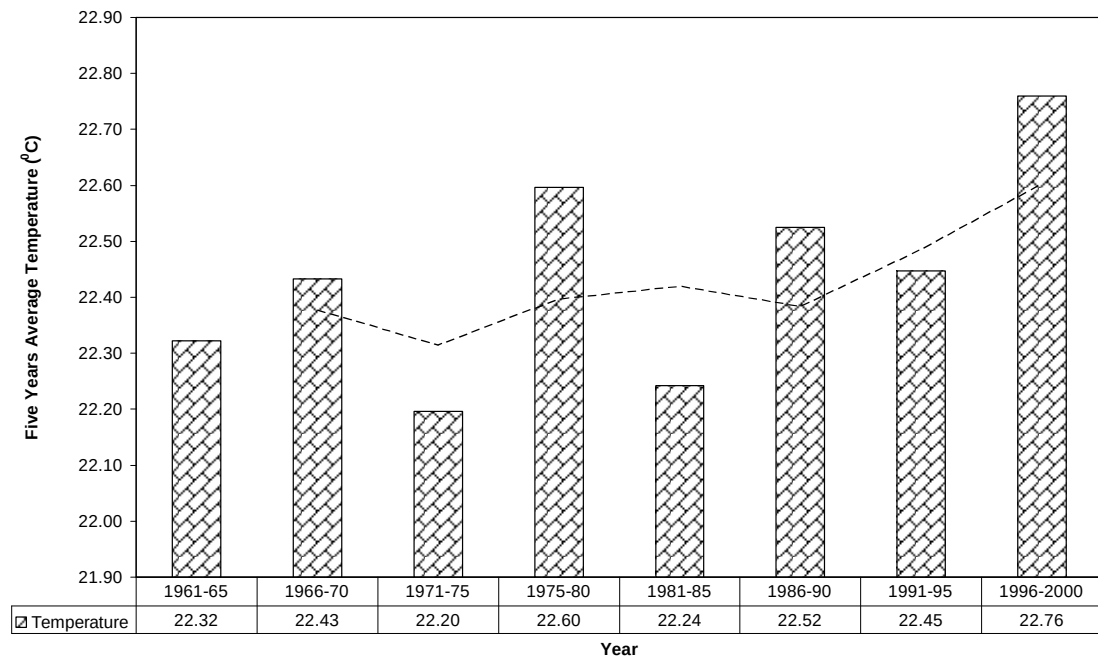
Table-4.7: Arid Region

Ten, Fifteen and Twenty Years Average Temperature (°C) and Deviation from the Mean (1961-2000)

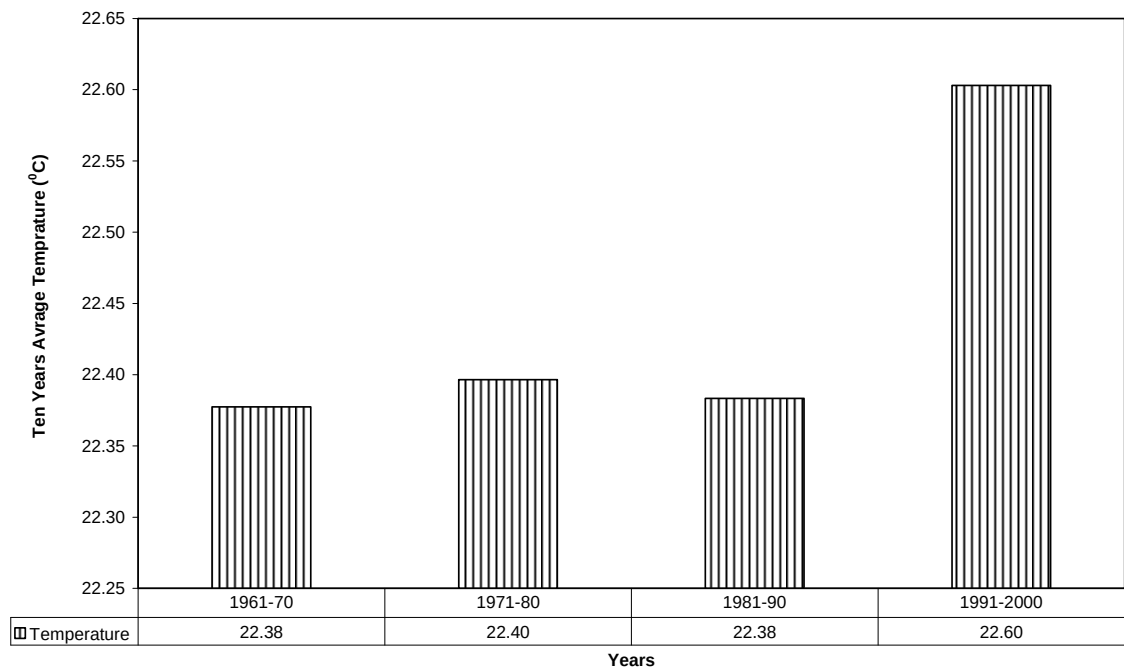
S_No	Years	Ten Years					Fifteen Yeas				Twenty Years		
		1961-70	1971-80	1981-90	1991-2000	Mean	1961-75	1976-90	1991-2005	Mean	1961-80	1981-2000	Mean
1	Chhor	26.1	26.2	26.2	26.4	26.2	26.1	26.3	26.4	26.2	26.2	26.3	26.2
2	Dalbandin	22.2	22.0	22.9	23.0	22.5	22.0	22.7	23.0	22.6	22.1	23.0	22.5
3	Hyderabad	27.6	27.8	27.8	27.4	27.7	27.7	27.8	27.4	27.6	27.7	27.6	27.7
4	Jacobabad	27.2	27.0	26.9	27.1	27.1	27.1	27.0	27.1	27.1	27.1	27.0	27.1
5	Panjgur	25.9	26.1	26.2	26.6	26.2	25.9	26.2	26.6	26.2	26.0	26.4	26.2
6	Quetta	22.2	22.0	22.2	22.6	22.3	22.0	22.3	22.6	22.3	22.1	22.4	22.3
7	Bahawalpur	25.8	25.7	25.4	25.4	25.6	25.8	25.5	25.4	25.5	25.7	25.4	25.6
8	D I Khan	24.4	24.2	24.1	24.3	24.2	24.3	24.1	24.3	24.2	24.3	24.2	24.2
9	Drosh	17.5	17.9	17.2	18.1	17.7	17.6	17.5	18.1	17.7	17.7	17.6	17.7
10	Gilgit	15.7	15.8	15.6	15.8	15.7	15.6	15.8	15.8	15.7	15.7	15.7	15.7
11	Skardu	11.4	11.6	11.9	11.9	11.7	11.4	11.9	11.9	11.7	11.5	11.9	11.7
Average		22.4	22.4	22.4	22.6	22.4	22.3	22.5	22.6	22.4	22.4	22.4	22.4
Deviation		0.0	0.0	0.0	0.2	0.2	-0.1	0.1	0.2	0.2	0.0	0.1	0.1

Source: PMDC, Karachi 1961-2000

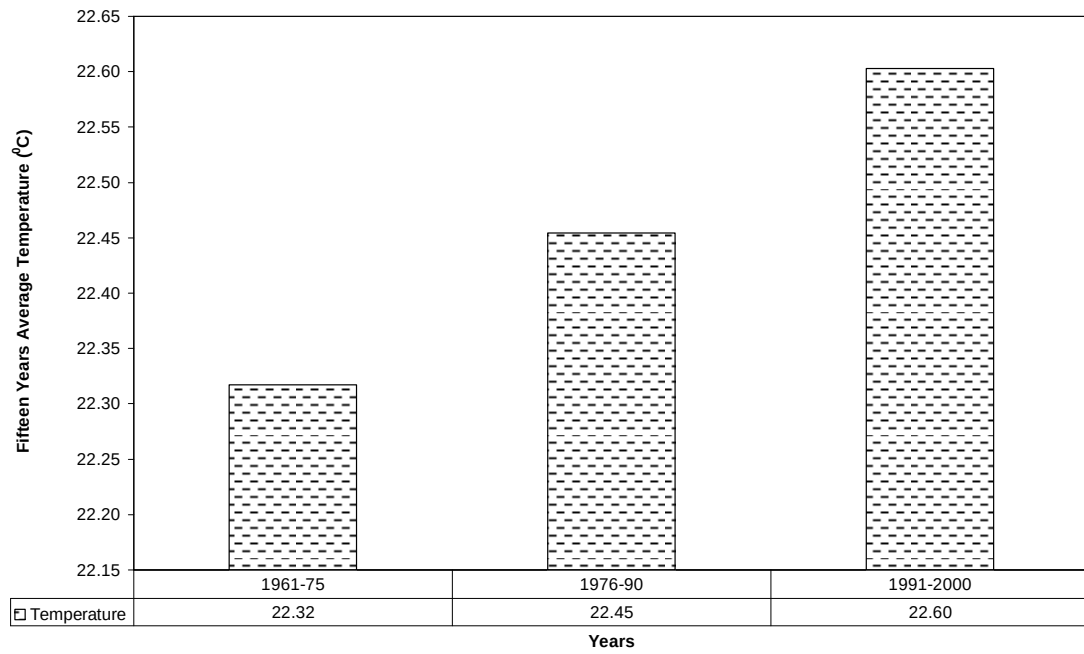
**Graph-4.5: Arid Region of Paksitan
Fiver Years Average Temperature 1961-2000**



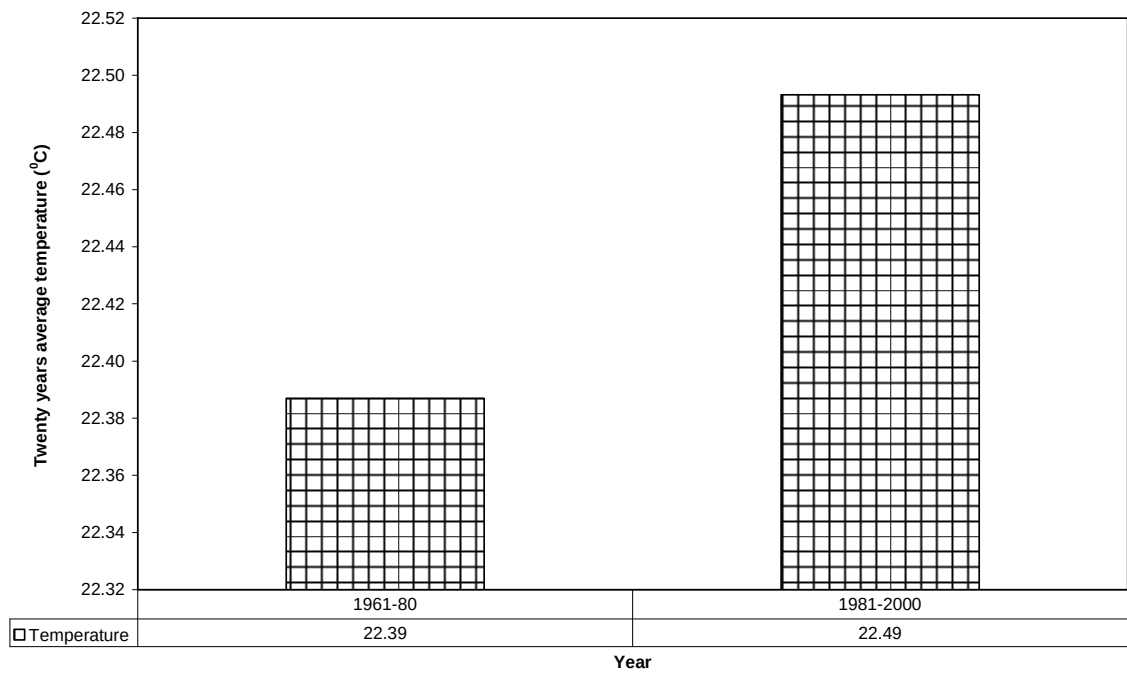
**Graph-4.6: Arid Region of Pakistan
Ten Years Average Temperature 1961-2000**



**Graph-4.7: Arid Region of pakistan
Fifteen Years Average Temperature 1961-2000**



**Graph-4.8: Arid Region of Pakistan
Twenty Years Average Temperature 1961-2000**



the series (1961 to 1980) shows a warm condition, while in the second half (1991 to 2000) there is an abrupt increase and appears to be the hottest period of the arid region in Pakistan.

4.5. Seasonal fluctuation:

According to Beg 2001, *"there has been a noticeable change in the climate of the region in which Pakistan is located, but instead of a general warming of about 0.1 to 0.3°C and lowering of rainfall, a reverse trend has been observed. The meteorological data available from 11 observatories in Pakistan indicate a general cooling by 0.1 to 0.3°C at the stations of rural towns and a warming of 0.7°C at the stations of the cities during the last four decades. Precipitation has in general increased at a number of locations by 10 to 30 percent during the same period."*

According to Mir, Khan, and Farooqi (2005), *"in Pakistan the annual mean surface temperature has a consistent rising trend since the beginning of 20th century. Rise in mean temperature of 0.6 to 1.0°C in arid coastal areas, arid mountains, and hyper arid plains. There is 0.5 to 0.7% increased in solar radiation over southern half of country."* GoP, Ministry of Environment (2009) has studied, *"Pakistan temperature is predicted to rise by 3 degrees centigrade by 2040 and up to 5 to 6 degrees by the end of the century."* Most of the previous studies based on the annual anomalies of temperature in Pakistan. For the present study, the seasonal fluctuation of temperature along with annual anomalies has been discussed as follow:

4.5.1. Summer season:

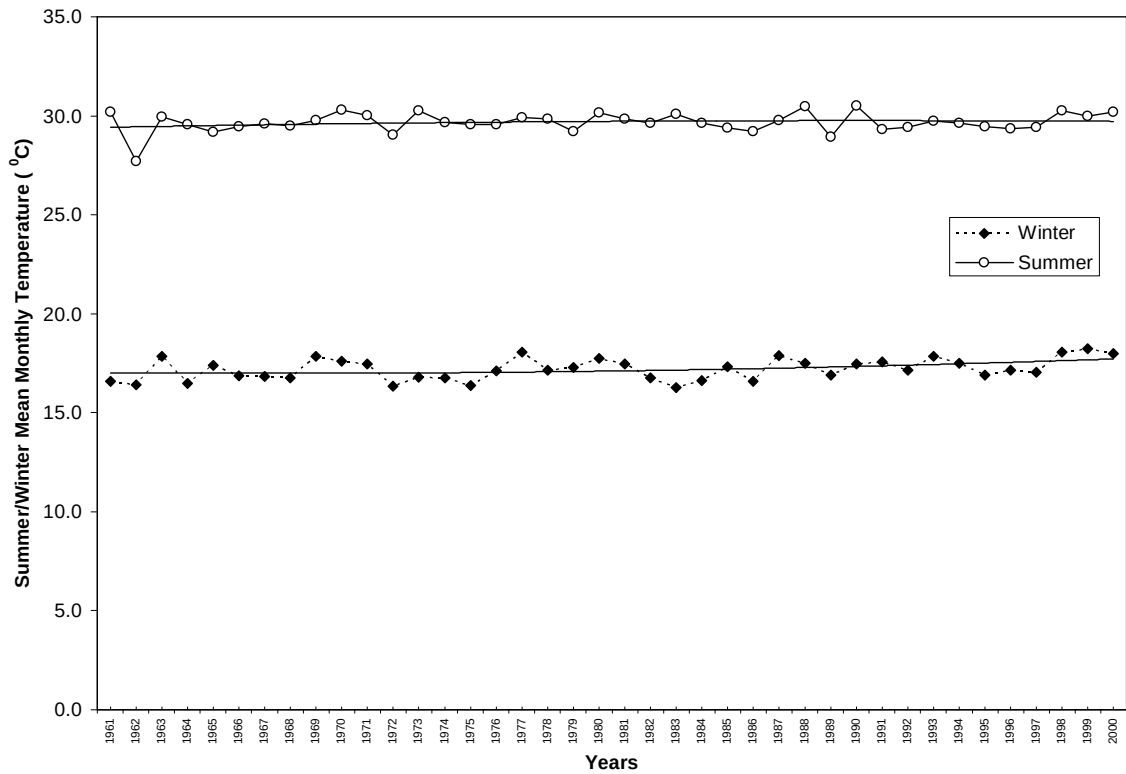
The summer season of the arid region lasts for seven months that is April to October in plain and May to September (five month) in hilly areas (Graph-4.1). The average temperature of summer season is 29.7°C having total decrease of -1.2°C . The high temperature of the summer season is 34.3°C recorded at Jacobabad of Sind province whereas, the lowest of 20.9°C at Skardu of Gilgit-Baltistan province (Table-4.8). The lowest mean monthly temperature of the season is 27.7°C recorded in 1962, while the highest of 30.5°C in 1988 and 1990.

The annual trend of temperature in summer season shows ups and downs throughout the series having an increase from 1998 to 2000 (Graph-4.9). The deviation from the mean temperature reveals a negative deviation from 1961 to 1970. From 1971 to 1984, there is an increase and decrease in the temperature with a positive deviation till 2000 (Graph-4.10).

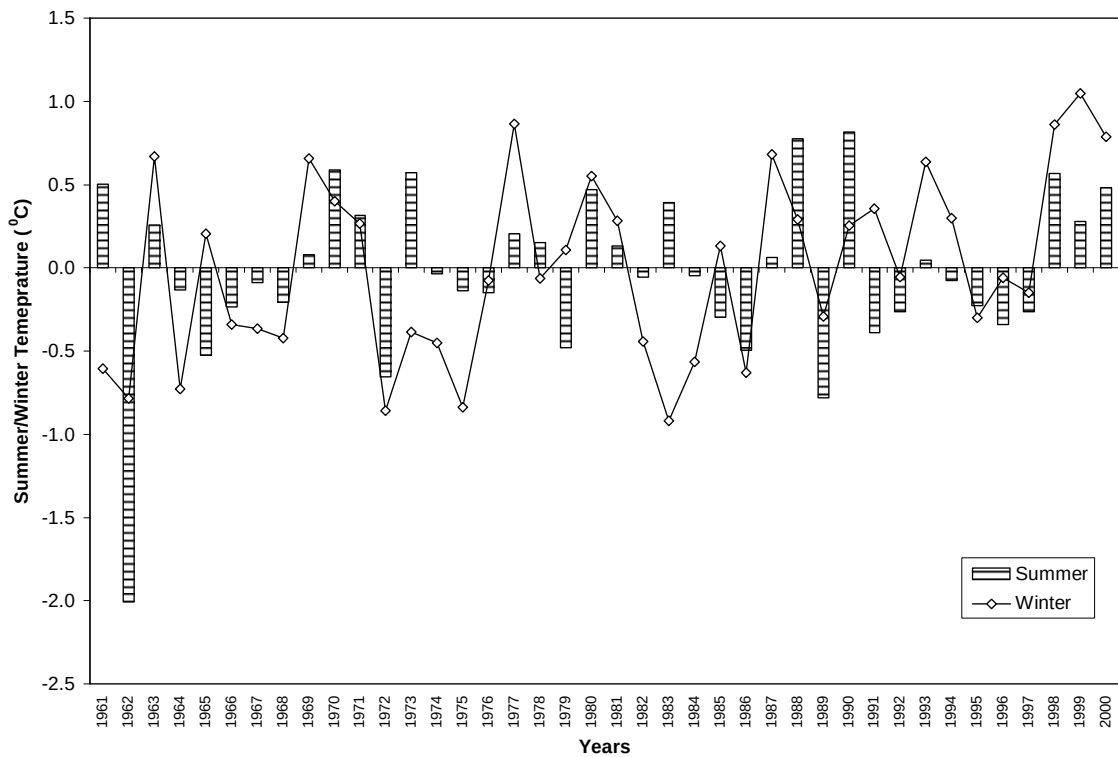
4.5.2. Winter season:

The winter season of the arid region varies from November to March (five months) in plains and seven months (October to April) in mountainous areas (Graph-4.1). The average mean monthly temperature of the season is 17.2°C with no rise and fall (0.0°C) and remain constant throughout the series. The highest temperature of 24.2°C recorded at Hyderabad with a lowest of 5.1°C in Skardu. The minimum temperature of 16.3°C has been recorded in 1972 and 1983, whiles the maximum of 18.2°C in 1999, and is the coldest and hottest years of the region (Table-4.9).

Graph-4.9: Arid Region of Pakistan
Trend of Mean Monthly Summer/Winter Temperature (1961-2000)



Graph-4.10: Arid Region
Deviation of Summer and Winter Temperature from the Mean (1961-2000)



Generally, the annual temperature of the winter season shows a minor increase throughout the series. The trend line reveals a decline from 1961 to 1981 (20 years) and then slight increase till 2000 (Graph-4.9). The deviation from the mean condition indicates negative deviation from 1961 to 1978 with a converse trend from 1977 to 1981 and slacks again till 1984. From 1985 to 2000, the series leads to the positive deviation for 15 years. Overall, the deviation from the mean shows positive and negative anomalies after each fifteen years (Graph-4.10).

4.5.3. Temperature fluctuation of the sub-seasons:

Weare *et al* in 2008 have studied, "*the seasonal temperature responses to landuse change in the western United States. He has opined that more than 79,000 km² has been converted to irrigated agriculture and urban areas. These changes have the potential to alter surface temperature by modifying the energy budget at the land–atmosphere interface.*" In light of the above statement, the two main seasons of Pakistan are further sub-divided to identify the season of major temperature fluctuation and its impacts on agriculture in the arid region. As the temperature does not give a clear picture of the sub-seasons, precipitation has been taken as a variable to define them. Based, on precipitation the two main seasons of the arid region in Pakistan are divided into the following four sub-seasons.

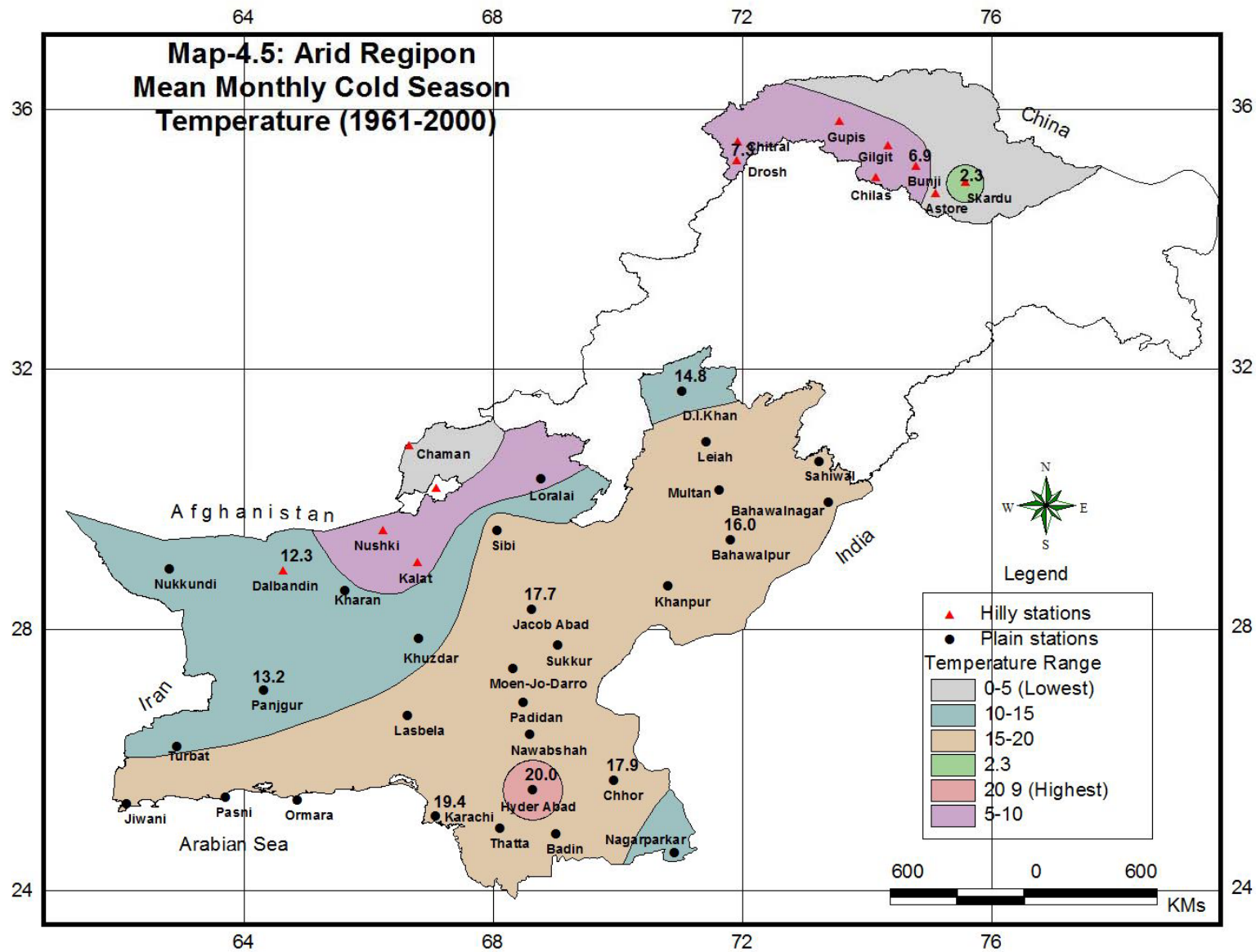
4.5.3.1. Cold season:

The cold season of the arid region varies from mid-November to March (Graph-4.2). The average temperature of winter season is 13.4⁰C with a positive

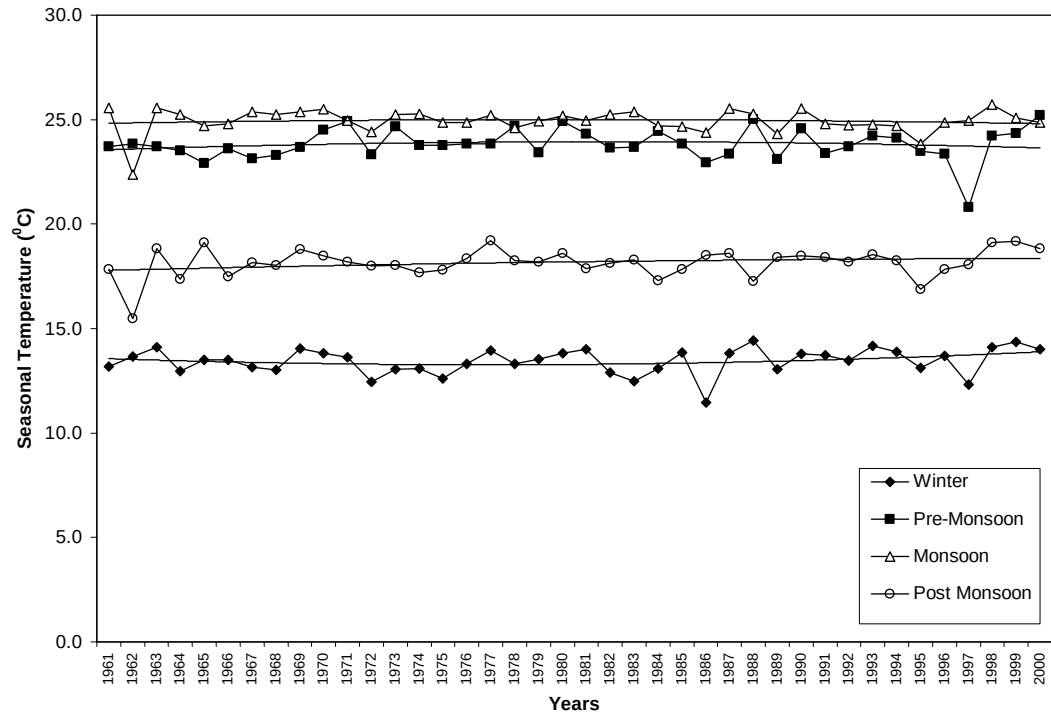
deviation of 1.5°C throughout the series. The lowest temperature of 2.3°C has been recorded at Skardu and the highest temperature of 20°C at Hyderabad. The minimum temperature of 11.5°C has been recorded in 1986 and the maximum of 14.4°C in 1988 and 1999 respectively (Table-4.6 and Map-4.6).

The annual trend of mean monthly winter temperature reveals a decrease from 1961 to 1980 and then follows an increasing trend till 2000 (Graph-4.11). The deviation from the mean condition indicates a positive trend from 1961 to 1964 and inverse condition from 1965 to 1978. During 1979 to 2000, the temperature shows a positive trend with ups and downs in some years. The deviation from the mean condition of the winter season reveals a change in temperature after each 20 years (Graph-4.12).

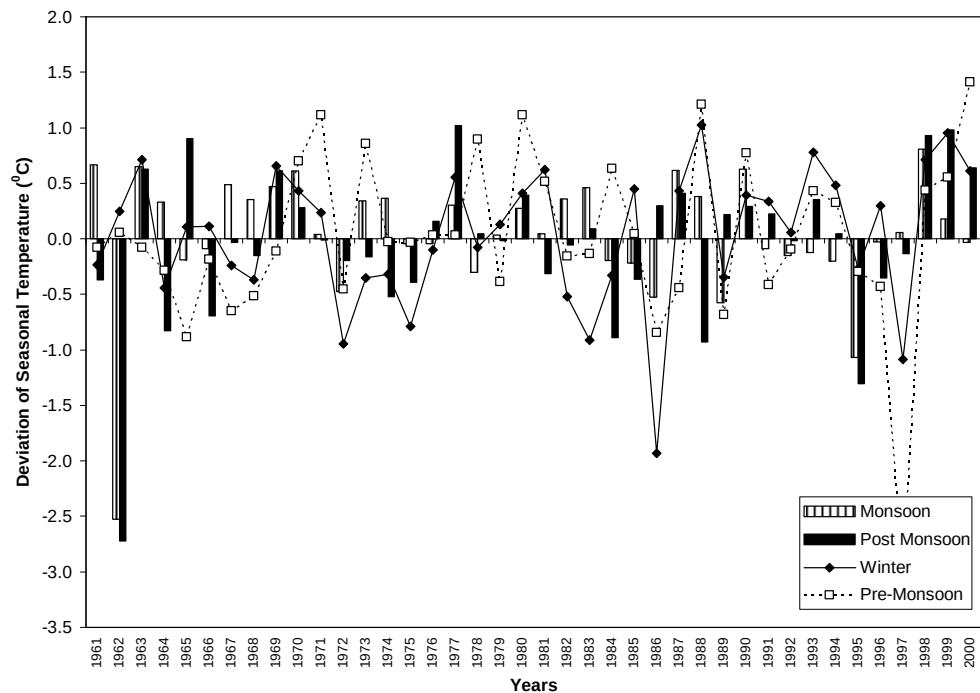
The five years average temperature of the cold season reveals a decreasing trend from 1961 to 1970 and considered as a coldest period of the series. From 1971 to 2000, the mean temperature of the season leads to an increasing trend for 30 years (Graph-4.13). The ten years average temperature of the season shows the same pattern as of five years average condition (Graph-4.14). The fifteen years average temperature shows an increase after each fifteen years having lowest temperature of 11.3°C from 1961 to 1975 and highest of 12.2°C for the period of 1991 to 2000 (Graph-4.15).



Graph-4.11: Arid region of Pakistan
Trend of Seasonal Mean Monthly Temperature (1961-2000)



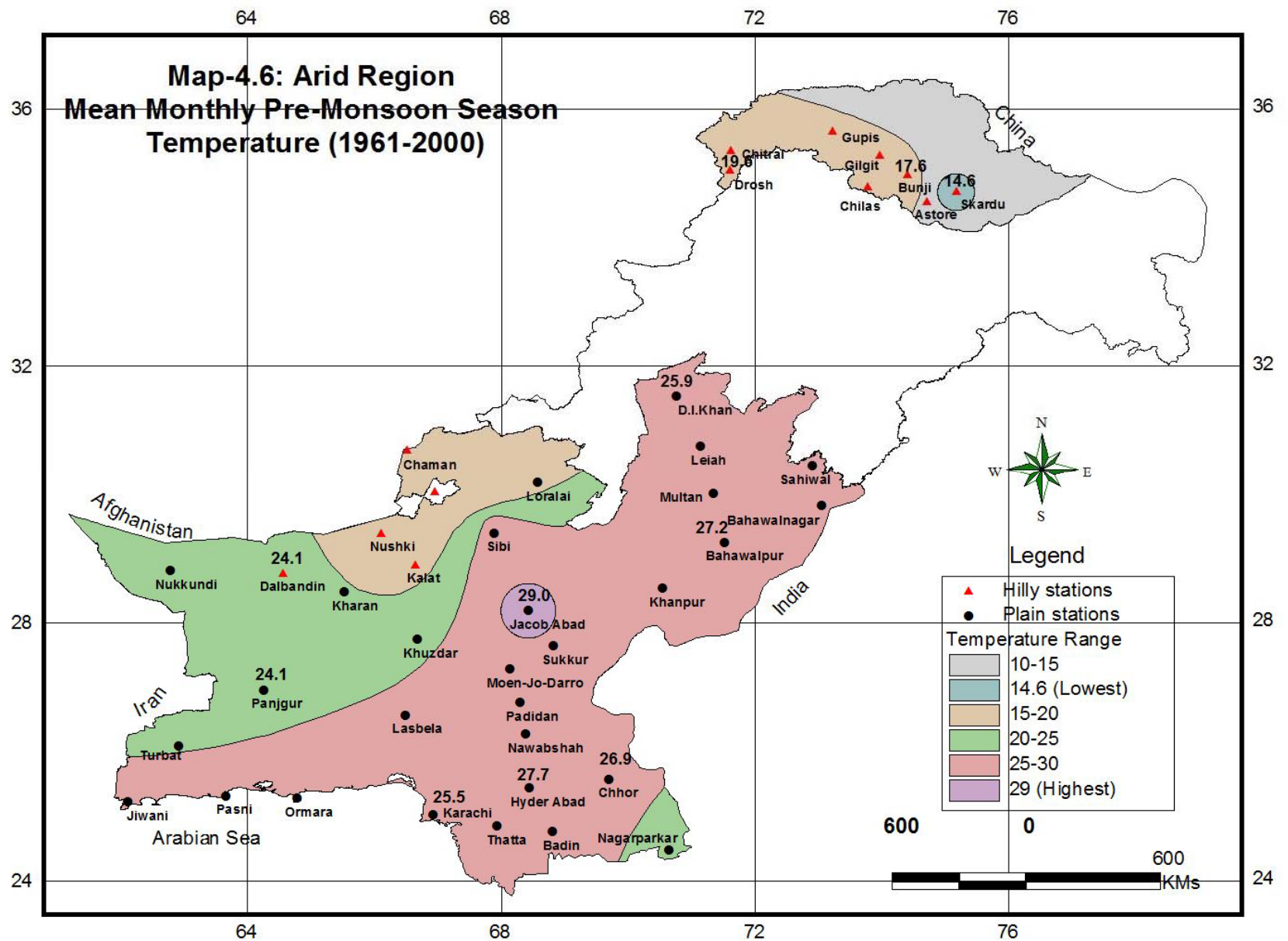
Graph-4.12: Arid Region of Pakistan
Deviation of Seasonal Mean Monthly Temperature (1961-2000)



4.5.3.2. Pre-monsoon season:

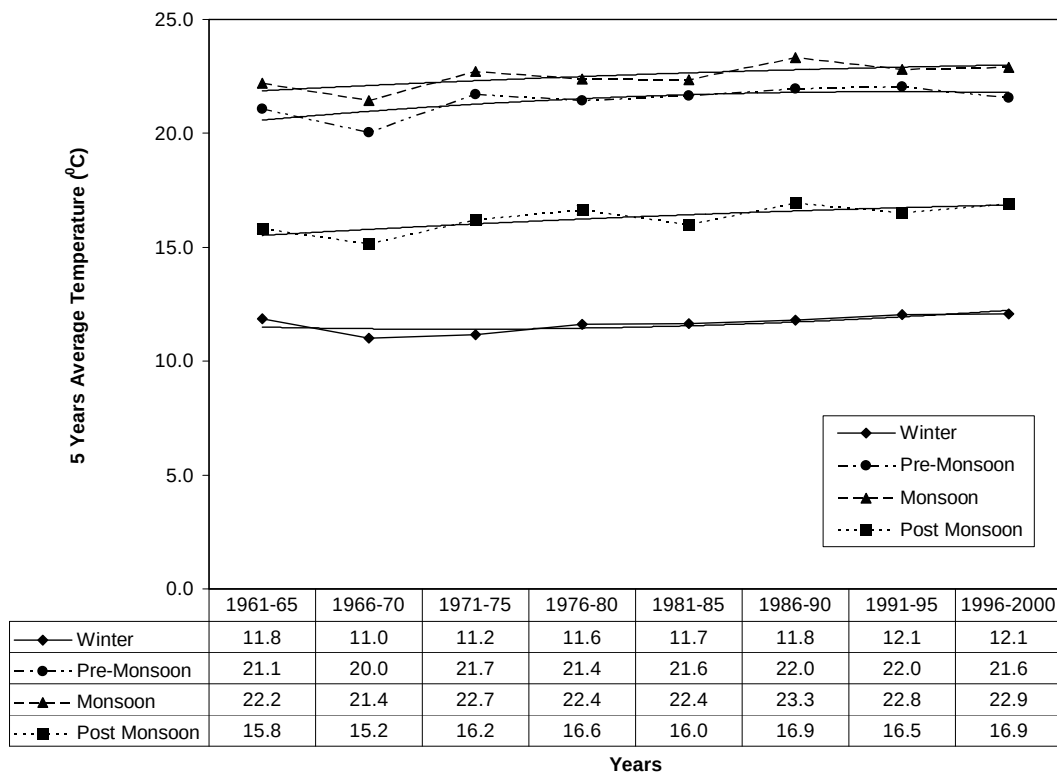
The average temperature of the pre-monsoon season (April-June) is 23.8°C having total increase of 1°C . The minimum temperature of 14.6°C has been recorded at Skardu and the maximum of 29°C at Jacobabad. The lowest temperature of 20.8°C has been recorded in 1997, whereas the highest of 25.2°C in 2000 (Table-4.7 and Map-4.7).

The annual trend of temperature in pre-monsoon season shows a decrease from 1961 to 1970, while an increase from 1971 to 1976 and then it goes on decline till 1980. There is an increasing trend in temperature during 1981 to 2000 (Graph-4.11). The deviation from the mean condition of temperature indicates a negative trend from 1961 to 1970 having ups and downs from 1971 to 1990 and then rise up till 2000. Generally, the temperature of the pre-monsoon season shows positive and negative deviation after each fifteen years (Graph-4.12).

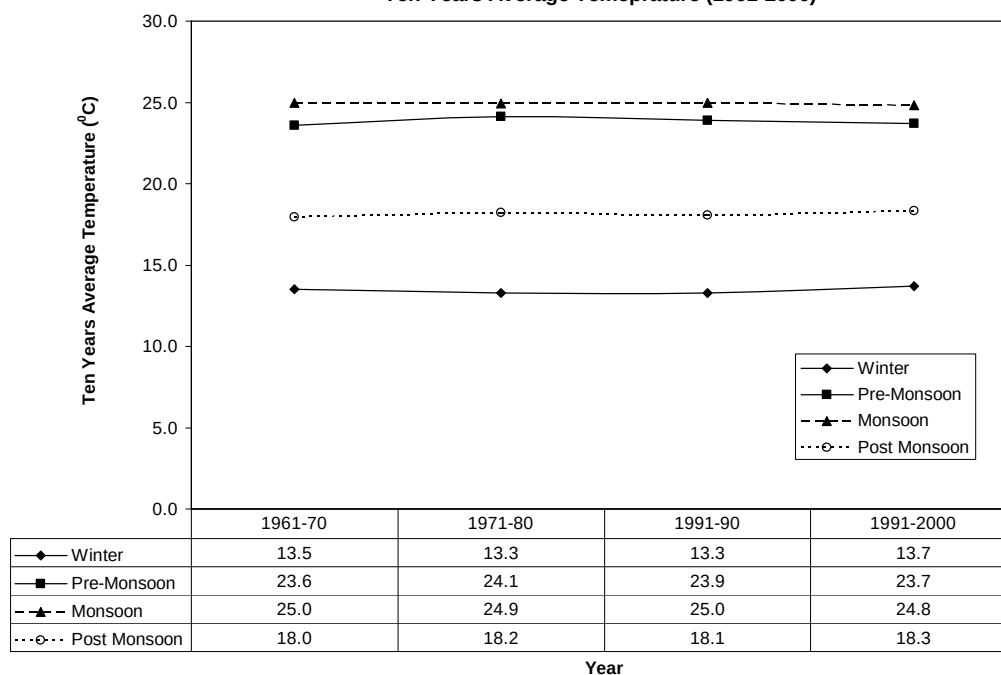


The five year's average temperature of the season shows that the minimum temperature of 20⁰C is from 1966 to 1970 and converse in the remaining years of the series with maximum of 22⁰C in 1986 to 1995 (Graph-4.13). Generally, the temperature shows a change after each ten years throughout the series. The ten years average of the pre-monsoon season reveals an increasing trend from 1961 to 2000 with minimum of 20.6⁰C in 1961 to 1970 and maximum of 21.8⁰C in 1981 to 1990 and 1991 to 2000 (Graph-4.14). The fifteen years average temperature of the season has been plotted on graph-4.15 that reveals an increasing trend after each fifteen years.

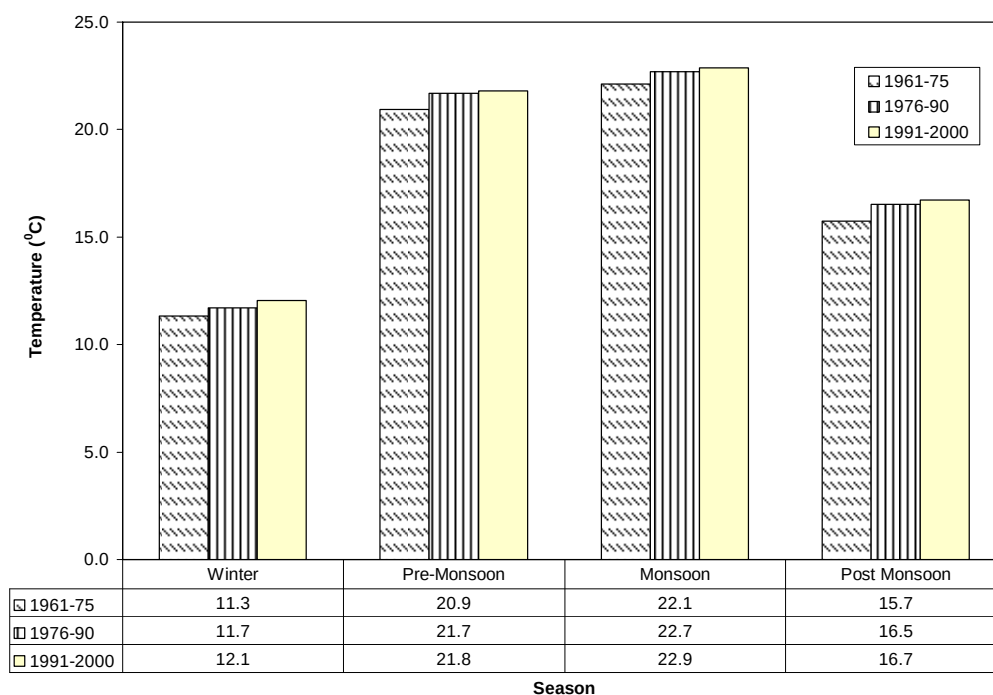
Graph-4.13: Arid Region of Pakistan
Trend of 5 years Average Temperature (1961-2000)



Graph-4.14: Arid Region of Pakistan
Ten Years Average Temperature (1961-2000)



Graph-4.15: Arid Region of Pakistan
Trend of 15 Years Average Seasonal Temperature (1961-2000)

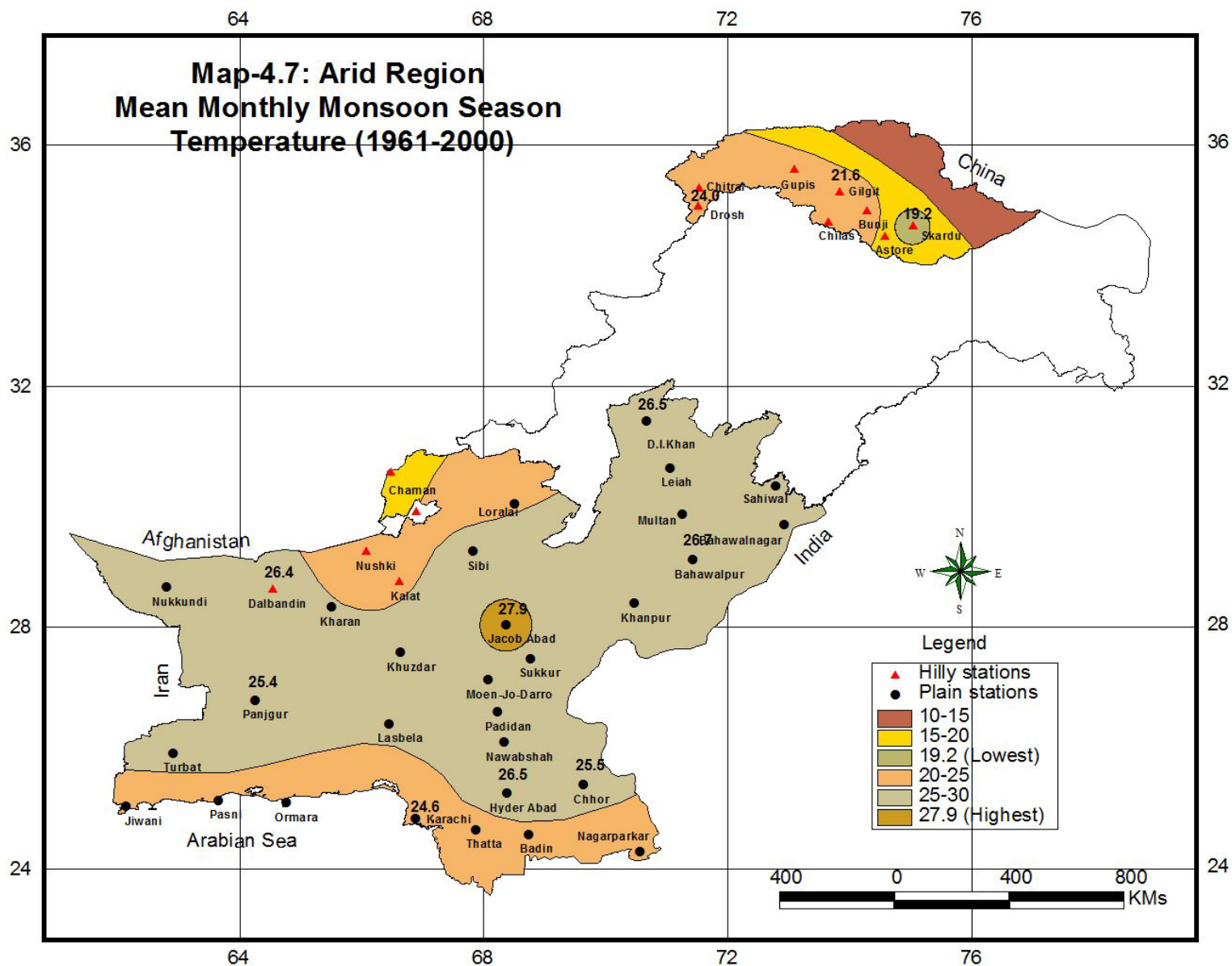


4.5.3.3. Monsoon season:

The monsoon season of the arid region ranges from July to mid-September (Graph-4.2). The average temperature of the season is 24.9°C with an increase of 1.6°C from 1961 to 2000. The maximum temperature of 27.9°C has been recorded at Jacobabad and a minimum of 19.2°C at Skardu. The lowest of 22.4°C has been recorded in 1962 and the highest of 25.7°C in 1998 (Table-4.8 and Map-4.8).

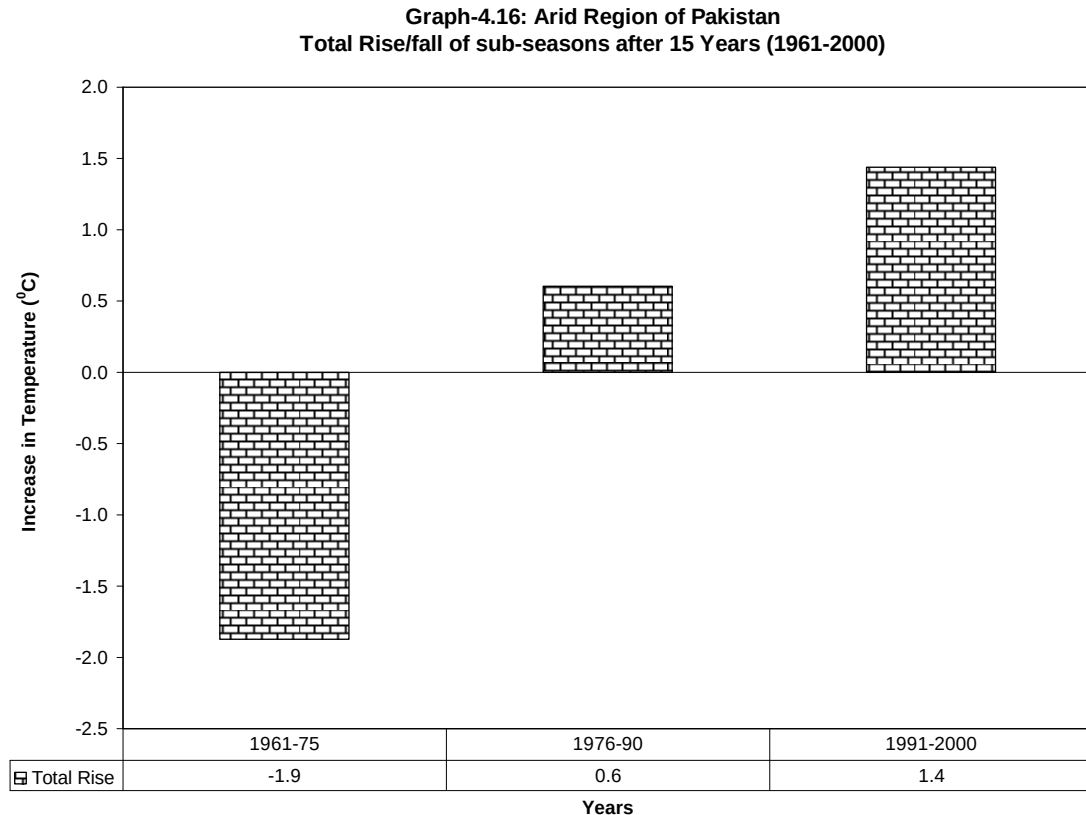
The mean monthly annual temperature shows a decrease from 1961 to 1970 followed by an increase during 1971 to 2000. Generally, the graph-4.11 shows an increasing trend throughout the series. The deviation from the mean condition of temperature in monsoon season indicates a negative trend from 1961 to 1972 and onward 1973 to 2000; it shows positive deviation with rise and fall in some years (Graph-4.12).

The trend of five years averages indicate a decrease from 1961 to 1970 and an increase from 1971 to 1985 followed by a slight fall upto 2000 (Graph-4.13). The ten years average temperature of the season reveals an increase from 1961 to 1990 with a subsequent decrease upto 2000 (Graph-4.14). The fifteen years average temperature remains low from the mean during 1961 to 1975 and onward from 1976 to 2000, it moves up (Graph-4.16).



4.5.3.4.1. Post-monsoon season:

The post-monsoon season of the arid region lasts from mid-September to November (Graph-4.2). The mean monthly temperature of the season is 18.2°C with a decrease of -1.9°C throughout the series. The highest temperature of 22.2°C has been noted at Karachi with a lowest of 9.2°C at Skardu (Map-4.9). The maximum temperature of 19.2°C recorded in 1977 and the minimum of



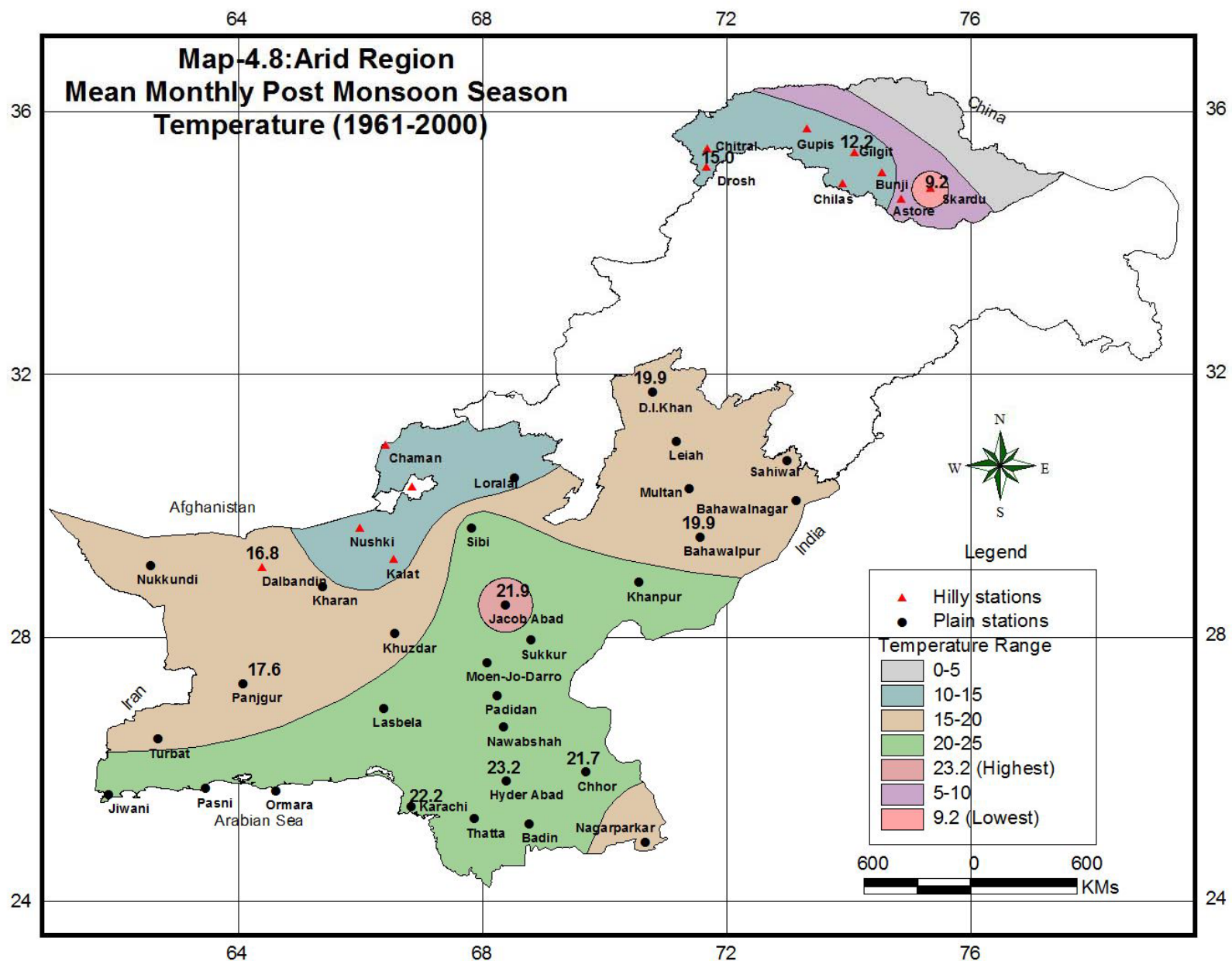
15.5°C in 1962 (Table-4.8).

Generally, the annual trend of temperature in post-monsoon season reveals decrease in the first half of the series and then rises up in the second half till 2000 (Graph-4.11). The deviation from the mean of the season shows negative trend from 1961 to 1970 with ups and downs up to 1980. After negative

trend from 1981 to 1985 the temperature changes into positive deviation till 2000 (Graph-4.12).

The five years average temperature of the post-monsoon season reveals rise and fall after each ten years (Graph-4.13). The ten years average temperature of the season shows a decrease from 1961 to 1980 and an increase from 1981 to 2000 (Graph-4.14). The fifteen years average temperature of the post-monsoon season reveals an increasing trend after each fifteen years (Graph-4.15).

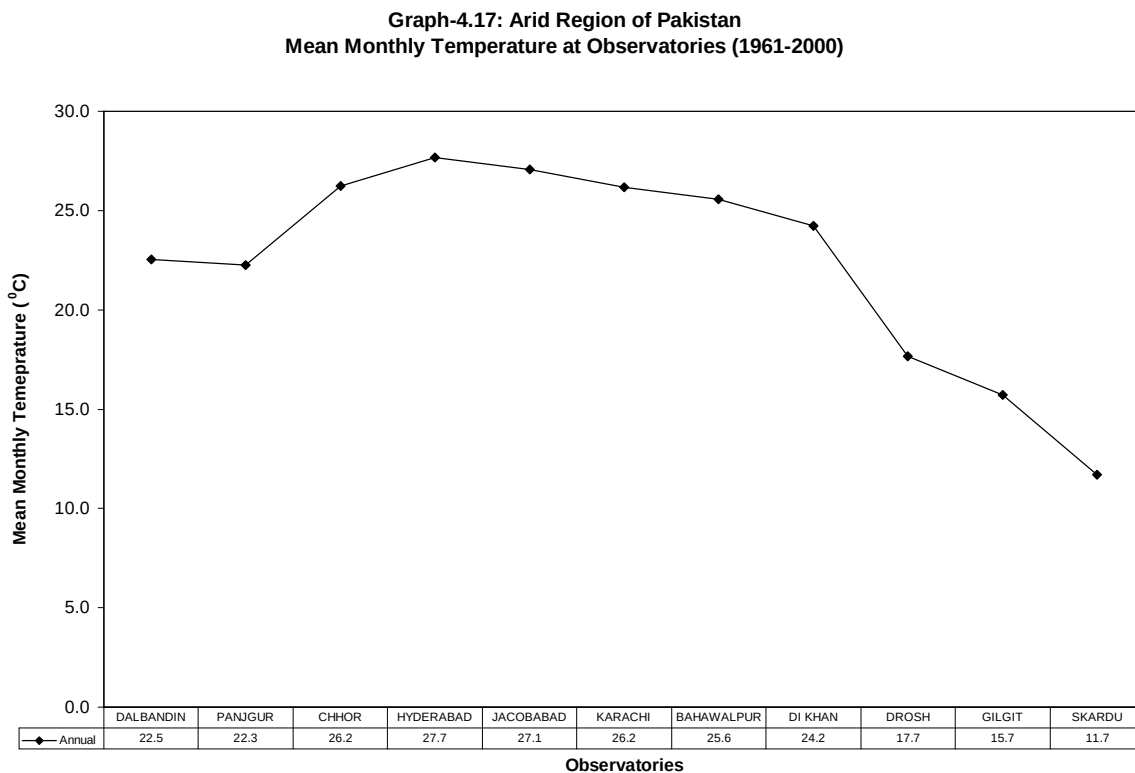
The deviation from the mean condition of fifteen years for sub-seasons is placed on graph-4.16. The figure shows that the temperature of the arid region is below the mean condition (-1.9°C) from 1961 to 1975. From 1976 to 1990, it raises upto 0.5°C and continuously increases to 1.4°C from 1991 to 2000.



4.6. Temperature variation:

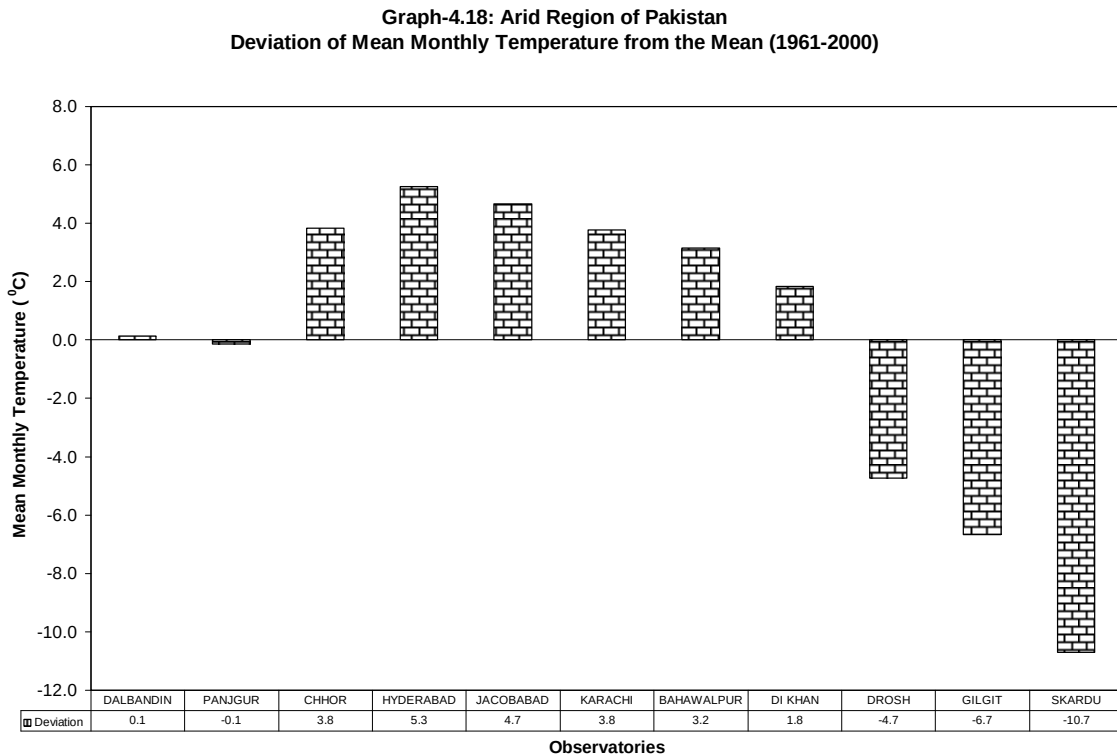
For the evaluation of mean monthly temperature variation the arid region of Pakistan has been divided into six micro-regions that are Gilgit-Baltistan, lower Khyber-Pakhtoonkhwa, lower Punjab, Sind, Baluchistan, and the coastal region.

The annual temperature (Graph-4.17) reveals that the highest temperature of 27.7⁰C has been recorded at Hyderabad and the lowest of 11.7⁰C at Skardu. Generally, the mean monthly temperature trend at each observatory shows a high temperature at Sind and Baluchistan with a slight decrease in lower Khyber-Pakhtoonkhwa and Gilgit-Baltistan (Graph-4.18 and Table-4.1). The general temperature condition of each region is stated as follow:



4.6.1. Gilgit-Baltistan:

The region covers Gilgit-Baltistan province and Chitral district in Upper Khyber-Pakhtoonkhwa. The average temperature of the region has remained 15°C from 1961 to 2000. The sum of deviation from the mean temperature shows an increase of 1.2°C in 40 years. The ever recorded highest temperature of the region is 16.2°C in 1990 and the lowest is 14°C in 1986 (Table-4.9). The graph-4.25, 4.26, and 4.27 shows an increasing trend throughout the series.



**Table-4.8 Arid Region
Mean Monthly Seasonal Temperature (⁰C) 1961-2000**

Year	Sub-Seasons								Main Seasons			
	Winter		Pre-Monsoon		Monsoon		Post Monsoon		Summer		Winter	
	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.
1961	13.2	-0.2	23.7	-0.1	25.6	0.7	17.8	-0.4	30.2	0.5	16.6	-0.6
1965	13.5	0.1	22.9	-0.9	24.7	-0.2	19.1	0.9	29.2	-0.5	17.4	0.2
1970	13.8	0.4	24.5	0.7	25.5	0.6	18.5	0.3	30.3	0.6	17.6	0.4
1975	12.6	-0.8	23.8	0.0	24.9	0.0	17.8	-0.4	29.6	-0.1	16.4	-0.8
1980	13.8	0.4	24.9	1.1	25.2	0.3	18.6	0.4	30.2	0.5	17.8	0.6
1985	13.8	0.4	23.8	0.0	24.7	-0.2	17.8	-0.4	29.4	-0.3	17.3	0.1
1990	13.8	0.4	24.6	0.8	25.5	0.6	18.5	0.3	30.5	0.8	17.5	0.3
1995	13.1	-0.3	23.5	-0.3	23.8	-1.1	16.9	-1.3	29.5	-0.2	16.9	-0.3
2000	14.0	0.6	25.2	1.4	24.9	0.0	18.8	0.6	30.2	0.5	18.0	0.8
Aver.	13.4	1.5	23.8	1.0	24.9	1.6	18.2	-1.9	29.7	-1.2	17.2	0.0

Source: PMDC, Karachi 1961-2000

4.6.2. Lower Khyber-Pakhtoonkhwa:

This region covers Dera Ismail Khan district and Frontier Region Dera Ismail Khan. The average temperature of the region is 24.2°C and the sum of deviation from the mean shows an increase of 1.5°C (Table-4.9). Generally, the mean monthly temperature of the region shows an increasing trend from 1961 to 2000 (Graph-4.28).

4.6.3. Lower Punjab:

The lower Punjab covers the northeastern part of the arid region in Pakistan. The mean monthly temperature of the region reveals an average condition of 25.6°C with a negative deviation of -1.6°C from 1961 to 2000. Due to well developed canal system and agriculture activities, the temperature of the region shows a negative trend from the average condition (Table-4.9 and Graph-4.29).

5.6.4. Sind:

The Sind province covers a vast area of the arid region excluding the coastal belt. Three observatories fall in Sind province including Chhor, Hyderabad, and Jacobabad. The average temperature of the region is 28°C with a decrease of -0.4°C from 1961 to 2000. The highest temperature of 27.9°C recorded in 1988 and the lowest of 26.3°C in 1989 (Table-4.9). At Chhor, the temperature shows an increase, whereas at Hyderabad it shows a decreasing trend with a slight increase at Jacobabad. Generally, the average condition of the region shows a decreasing trend from 1961 to 2000 (Graph-4.19, 4.20, and 4.21).

5.6.5. Baluchistan plateau:

The arid region covers a considerable area of northern, northwestern, and central plateau Baluchistan. There are two observatories in this region at Dalbandin and Panjgur. The average temperature of the region is 22⁰C with an increase of 0.1⁰C from 1961 to 2000. The highest temperature of 24.2⁰C has been recorded in 1998 and the lowest of 21.3⁰C in 1964 (Table-5.14). Generally, the average condition of the region shows an increasing trend (Graph-5.23 to 5.24).

4.6.6. Coastal areas:

This region extends along the coast of Baluchistan and Sind having marine climates. The region consists of Karachi, Pasni, Jiwani, and Gwadar meteorological observatories. The average mean monthly temperature of the region is 26.2⁰C from 1961 to 2000. The highest temperature of the costal belt is 27.3⁰C recorded in 1998, while the lowest of 25.6⁰C in 1961, 67, 68, and 1984. Generally, the mean monthly temperature of the region indicates a decrease of - 0.6⁰C from 1961 to 2000 (Table-4.9 and Graph-4.22).

Table-4.9: Arid Region
Mean Monthly Temperature variation 1961-2000

Year	Gilgit-Baltistan		Lower Punjab		Baluchistan		Sind		Lower KPK		Coastal Area	
	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.
1961	15.3	0.3	25.6	0.0	21.9	-0.5	26.5	-0.5	24.5	0.3	25.6	-0.6
1965	14.7	-0.3	25.7	0.1	22.2	-0.2	27.0	0.0	24.2	0.0	26.0	-0.2
1970	15.6	0.6	26.5	0.9	22.7	0.3	27.3	0.3	24.9	0.7	26.1	-0.1
1975	14.1	-0.9	25.1	-0.5	21.5	-0.9	26.8	-0.2	23.8	-0.4	25.9	-0.3
1980	15.4	0.4	26.1	0.5	23.3	0.9	27.4	0.4	24.6	0.4	26.4	0.2
1985	15.0	0.0	25.4	-0.2	22.4	0.0	26.9	-0.1	23.9	-0.3	26.1	-0.1
1990	16.2	1.2	25.7	0.1	23.2	0.8	26.9	-0.1	24.8	0.6	25.9	-0.3
1995	14.6	-0.4	25.0	-0.6	22.9	0.5	26.5	-0.5	24.2	0.0	26.6	0.4
2000	15.5	0.5	26.2	0.6	23.2	0.8	27.5	0.5	25.3	1.1	27.1	0.9
Aver.	15.0	1.2	25.6	-1.6	22.4	0.1	27.0	-0.4	24.2	1.5	26.2	-0.8

Source: PMDC, Karachi 1961-2000

Chapter-5

Precipitation Distribution and Fluctuation

Precipitation is the next most important element of the climate that affects agriculture of the arid region. Both crop production and rearing of farm animals are totally dependent on precipitation. The yield of wheat, sugarcane, maize and numerous other crops varies with the precipitation. It also, to a large extent, determines the carrying capacity of grazing land to support livestock in the arid region. This chapter discusses the precipitation distribution, its fluctuations in different class intervals using deviation from the mean condition. In the next section, variation of precipitation has been dealt with special reference to agriculture in the study area. The findings of the chapter have been summarized in the concluding section.

5.1. Horizontal distribution:

The study of horizontal distribution of precipitation is important as it provides a base for the crop production, cropping seasons, and choice of the crops. It is the main agent, which sets in motion, the nutrients of the soil and effect or makes them available to plants. It affects the morphology and physiology of the plants as well.

Alam *et al* in 2011 have studied, "*the spatial analysis of precipitation distribution and its impact on agricultural drought at Bangladesh. They have measured the agriculture drought severity index using the Markov Chain Model and discussed the impact of meteorological drought with special reference to*

kharif and Rabi cropping seasons. According to IPCC (2009), "by the 2050s, the freshwater availability in the large river basins of Asia will decrease; while the coastal areas, especially heavily populated mega deltas will be at the greatest risk due to increase flooding from the sea and rivers".

In Pakistan, the average precipitation of the arid region is 1.48inches (37.6mm) with a maximum of 0.74inch (18.8mm) at Chhor and minimum of 0.27inch (6.9mm) at Dalbandin. The heavy annual precipitation of 4.19inches (106.4mm) has been recorded in 1984, while the lowest of 0.42inch (6.1mm) in 1971 (Table-5.2). The general pattern of isohyets in the arid region is as follow:

5.2. Mean monthly precipitation:

The mean monthly precipitation of the arid region is plays a vital role in the length of the growing season and cropping pattern. It shows the intensity of precipitation in different months of the year at different areas and seasons. As can be seen from map-5.1 and table-5.1, the highest total precipitation of the arid region is 9.94inches (251.5mm) at Quetta and the lowest of 3.3inch (83.8mm) at Dalbandin. The annual total precipitation of arid region is 6.53inches (165.9mm), decreasing from north at Quetta towards northeast and southwest, while in Gilgit-Baltistan province, it also decreases from west to east. This variation in precipitation is mainly caused by the size and relief of the arid region and also by the summer and winter precipitation concentrations.

Due to uneven distribution of precipitation from monsoon lows, the eastern part of the arid region has heavy precipitation as compared to the western margin with heavy precipitation in summer, decreasing towards west because of the

prevailing winds (monsoon) over the Indo-Pakistan sub-continent. The western margin of the arid region receives heavy precipitation in winter particularly from western depressions decreasing towards east. The Gilgit-Baltistan province experiences very low precipitation in summer due to the deflection of monsoon lows by the Himalayan ranges. Most of the valleys extending from northeast toward southwest receive precipitation from local thunderstorms (pre-monsoon season).

Table-5.1: Arid Region
Mean Monthly Precipitation (Inches) 1961-2000

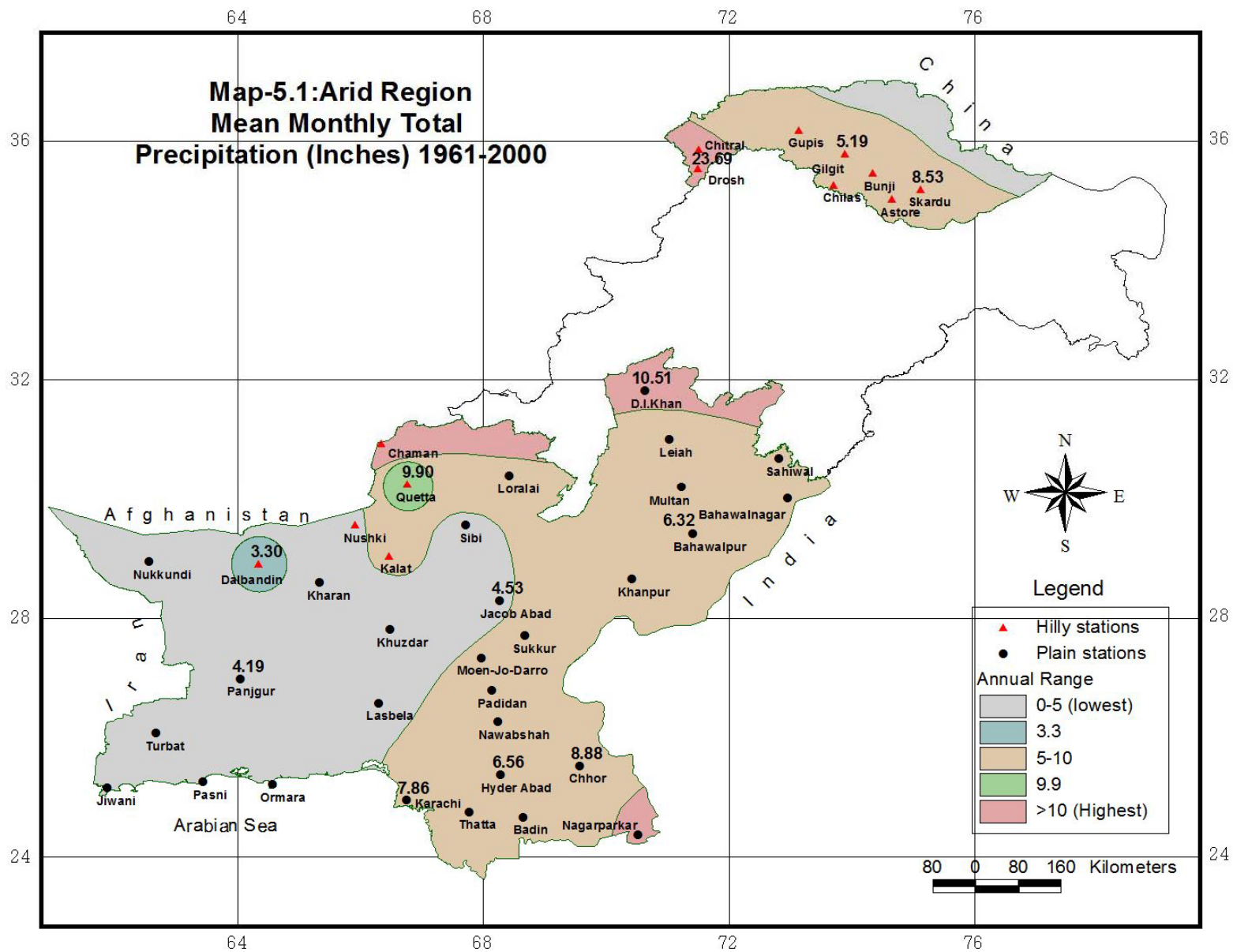
Station	Total	Mean	Deviation	Station	Total	Mean	Deviation
Chhor	8.88	1.37	0.36	Panjgur	4.19	0.65	-0.36
Dalbandin	3.30	0.51	-0.50	Quetta	9.94	1.53	0.52
Hyderabad	6.57	1.01	0.00	Bahawalpur	6.32	0.97	-0.04
Jacobabad	4.53	0.70	-0.31	Gilgit	5.19	0.80	-0.21
Karachi	7.87	1.21	0.20	Skardu	8.54	1.31	0.30
				Average	6.53	1.01	-0.05

Source: PMDC, Karachi, 1961-2000

**Table-5.2: Arid Region
Mean Annual Precipitation (Inches) 1961-2000**

Year	Chhor	Dalbandin	Hyderabad	Jacobabad	Karachi	Panjgur	Quetta
1961	2.12	0.27	1.10	0.60	2.04	0.54	7.92
1965	0.47	0.29	0.41	0.08	0.42	0.33	10.49
1970	1.07	0.36	0.89	0.41	1.56	0.57	7.02
1975	0.87	0.08	0.48	0.75	0.54	0.28	9.15
1980	0.20	0.37	0.39	0.05	0.64	0.28	9.64
1985	0.64	0.08	0.38	0.60	0.51	0.26	10.12
1990	1.57	0.52	0.56	0.38	0.45	0.30	12.33
1995	0.63	0.50	0.31	0.31	0.85	0.37	13.15
2000	0.30	0.01	0.18	0.06	0.16	0.07	6.49
Aver.	0.74	0.27	0.55	0.38	0.66	0.35	10.17
Year	Bahawalpur	Drosh	DI Khan	Gilgit	Skardu	Average	Deviation
1961	0.57	1.87	0.78	0.26	0.24	1.57	0.09
1965	0.15	2.98	0.55	0.39	0.27	1.33	-0.15
1970	0.34	1.53	0.74	0.42	0.42	1.31	-0.17
1975	1.16	2.24	1.04	0.49	1.08	1.49	0.01
1980	0.46	1.78	0.79	0.44	0.48	1.29	-0.19
1985	0.33	1.18	0.46	0.33	0.49	1.38	-0.11
1990	0.35	1.36	1.13	0.29	0.96	1.77	0.29
1995	0.67	2.13	1.35	0.36	0.58	1.77	0.29
2000	0.26	1.40	0.84	0.32	0.61	0.85	-0.63
Aver.	0.53	1.97	0.88	0.43	0.71	1.48	-0.05

Source: PMDC, Karachi, 1961-2000



5.3. Seasonal distribution:

The total and seasonal precipitation determines choice of crops in different parts of the arid region. The region is more suitable for the drought resistant crops like bicolor sorghum, pearl millet, barley, pulses etc. On the other hand, in irrigated areas especially in lower Punjab and Sind, crops such as rice, cotton, wheat, etc. are grown. Cold season precipitation is more beneficial to crops as compared to warm season, when evapotranspiration is at its climax. Similarly, light and prolonged precipitation (winter season) is more favorable to plants than the torrential and heavy ones like monsoon. The seasonal distribution of precipitation in the arid region of Pakistan is as follow:

5.3.1. Winter season:

The winter precipitation covers an extensive area of Baluchistan and Sind provinces. Due to its long duration, it is more suitable for the crop cultivation. The winter season is not the same in plains as compared to mountainous area. The plain area of the region experiences short winters as compared to the long winters of the highlands. The mean annual precipitation of the series (1961 to 2000) is 0.45inch (11.4mm), with the heaviest of 1.53inches (38.9mm) recorded at Quetta and the lowest of 0.09inch (2.3mm) at Chhor (Map-5.2 and Table-5.3). The moist year of the series is 1982, when the arid region received an average precipitation of 1.12inches (28.4mm), while the driest year was 1969, when the mean annual precipitation received was 0.17inch (4.3mm). Generally, the western part of the arid region receives heavy precipitation in winter season from

western-depressions, decreasing towards east that is Thar and Cholistan deserts.

5.3.2. Summer season:

The summer is characterized by the heavy torrential monsoon rainfall, more suitable for the agriculture but sometime due to floods and sequel winds it causes damages to crops. As evident from map-5.3, in summer season the isohyets pattern moves towards east as compared to winter season, when it is in the west. This variation in the isohyets is due to the shift in low pressure center from Arabian Sea to the Indo-Pakistan sub-continent that attracts monsoon winds from the southwest across the equator. The mean annual precipitation of the summer season is 0.61inch (15.5mm) having heaviest of 1.36inches (34.5mm) has been recorded in 1994 and lowest of 0.15inch (3.8mm) in 1974 (Table-5.3). It is evident from the map-5.3 that the highest annual precipitation of 1.2inches (30.5mm) has been recorded at Chhor, while the lowest of 0.09inch (2.3mm) covered the entire Kharan desert and barren Chagai hills in Baluchistan. The isohyets reveal that the Thar and Cholistan desert, southern Khyber-Pakhtoonkhwa and southern Punjab receives 1-2inches (25.4 to 50.8mm) precipitation in summer. The southern Punjab, northwestern Sind, northern Baluchistan, and southern Gilgit-Baltistan get summer precipitation between 0.5 (12.7mm) to 1inch (25.4mm). The rest of the arid region receives precipitation below 0.5inch (12.7mm) throughout the summer season.

5.3.3. Sub-seasons:

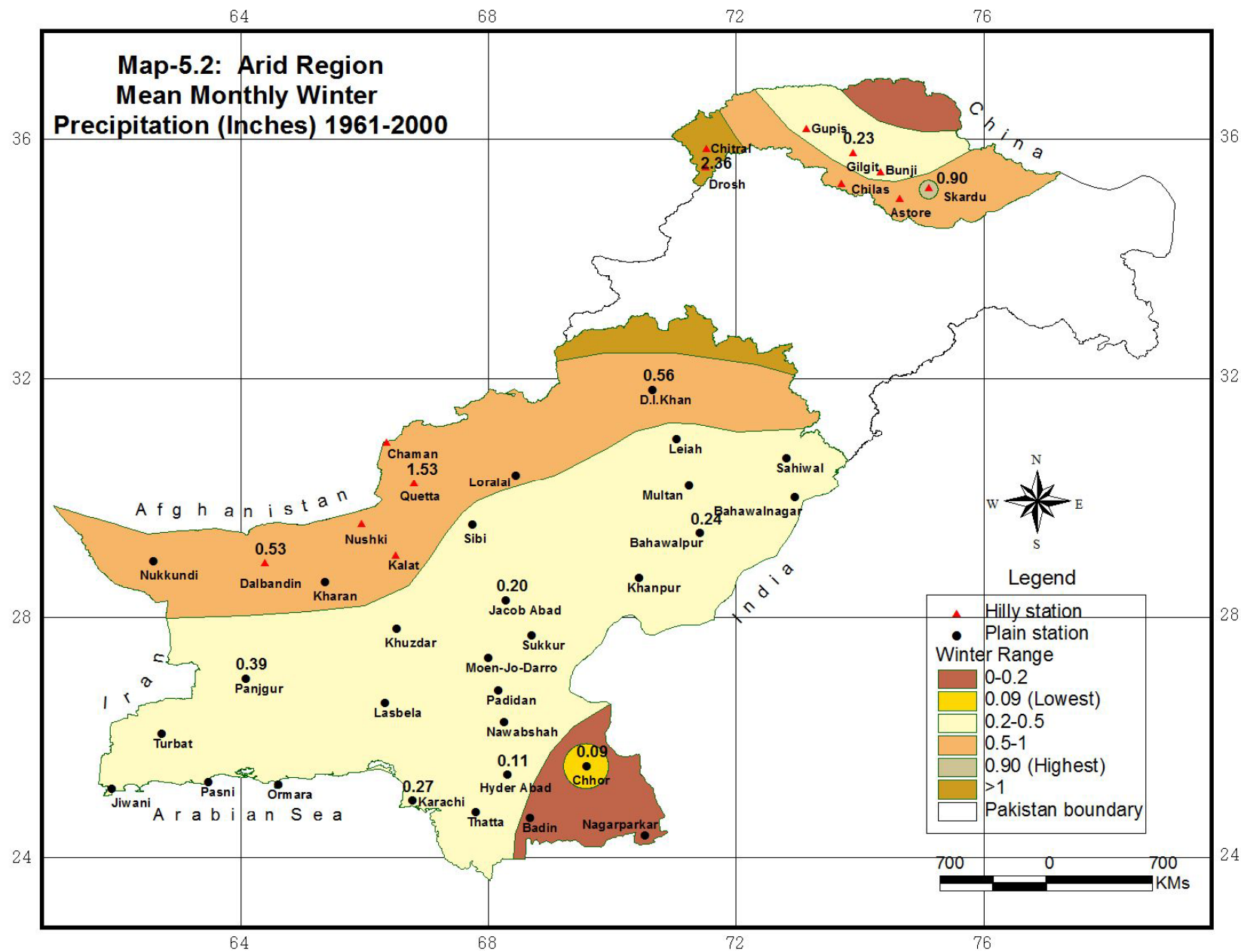
Based on the annual march of precipitation and deviation from the mean condition (Graph-4.1 and 4.2), the summer and winter seasons of the arid region in Pakistan have been divided into the following four sub-seasons (Chapter-1).

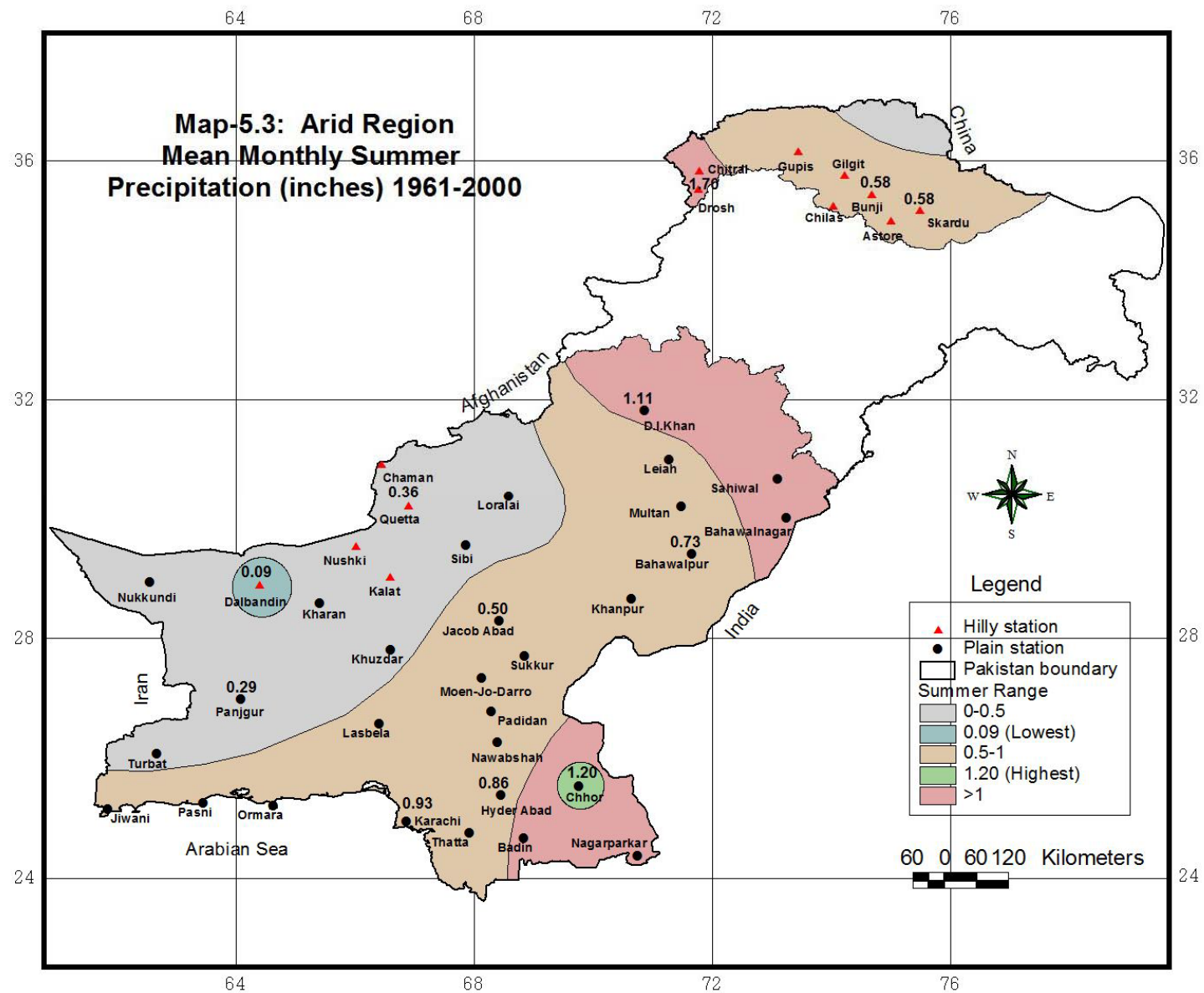
5.3.3.1. Cold Season:

The season varies from December to mid-April with a slow and gradual increase in precipitation from western depressions. It is the season of the prevalence of anticyclones subsidence over Pakistan, when the weather is coldest (Map-5.4). The winter precipitation over arid region is associated with disturbances, entering the area in the extreme northwest after passing through Iraq, Iran, and Afghanistan.

The total precipitation of the arid region during cold season is 0.48inch (12.2mm) with the heaviest of 1.6inches (40.6mm) recorded at Quetta and the lowest of 0.08inch (2mm) at Chhor. The western margin of the arid region and coastal areas excluding Karachi, receives intensive precipitation from western depressions.

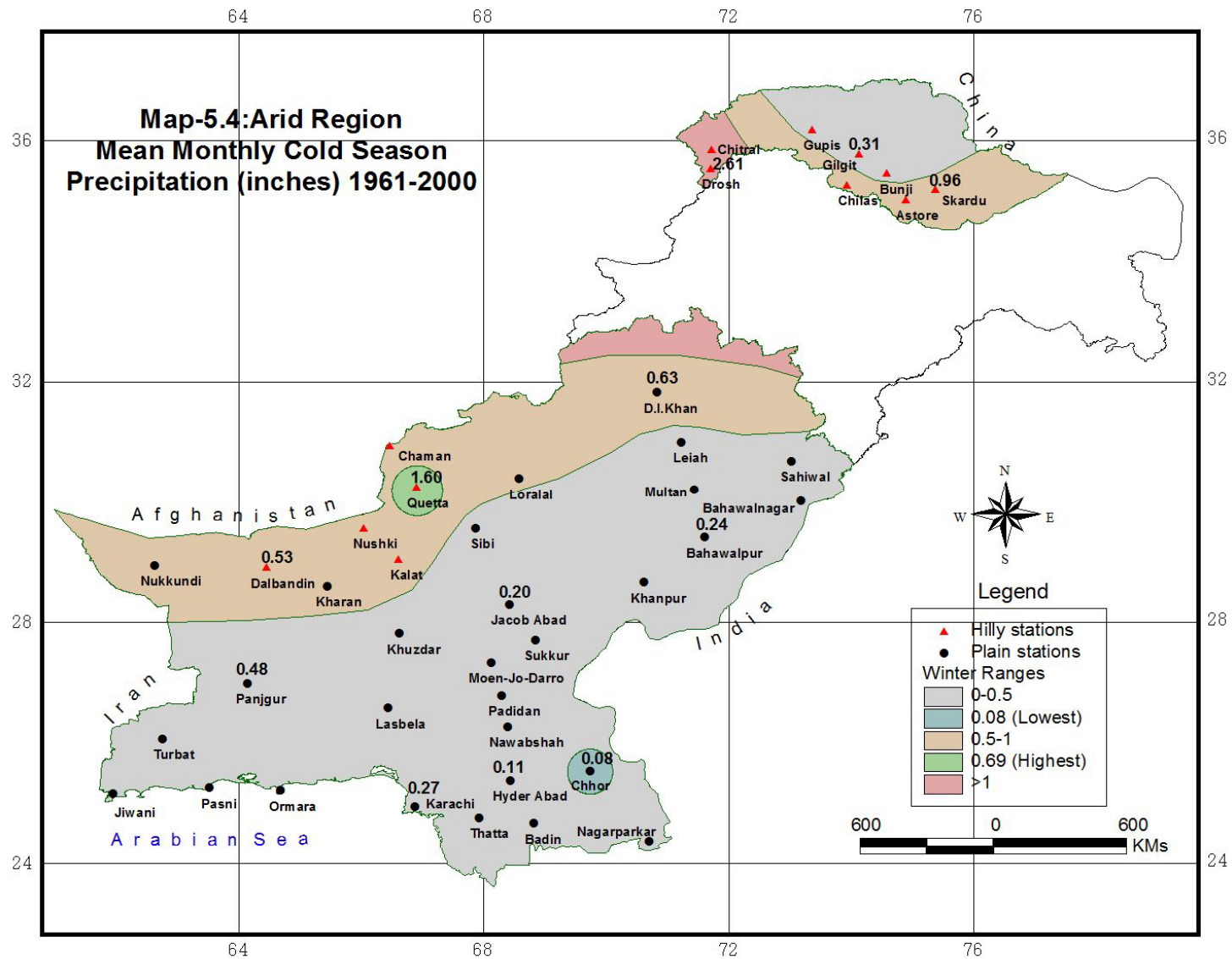
Generally, southern Baluchistan, coastal areas, Sind, Gilgit-Baltistan and lower Punjab have precipitation less than 0.5inch (12.7mm), whereas the southern Khyber-Pakhtoonkhwa, central Punjab, and northwestern Baluchistan have precipitation between 0.5 (12.7mm) to one inch (25.4mm). The heaviest mean precipitation of the series is 1.11inches (28.2mm) in 1982 and the lowest of 0.13inch (3.3mm) in 1971, wet, and dry years of the series respectively (Map-5.4 and Table-5.3).

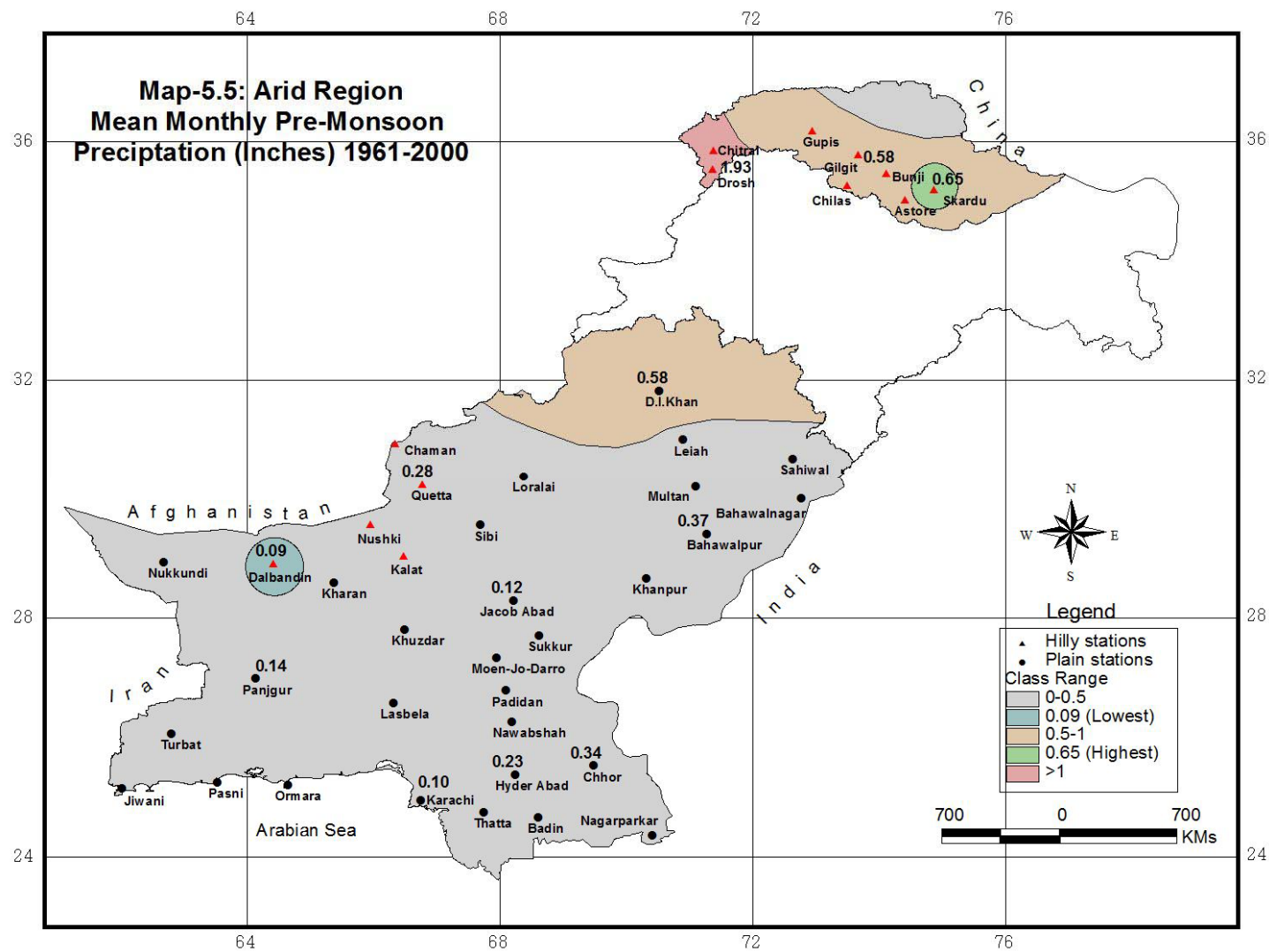




5.3.3.2. Pre-monsoon season:

The season varies from April to June with low pressure, high temperature, and maximum sunshine duration. During this season, a low pressure is developed over arid region in Pakistan, which moves from south towards north and causes local thunderstorms. These thunderstorms bring precipitation in the form of heavy showers and hail that cause damages to fruit trees and crops especially in northern arid region of the country. The season is characterized by low relative humidity, water vapors, and hot dry season. It is the harvesting period of the *Rabi* crop in Sind, lower Punjab and parts of Baluchistan. The average precipitation is 0.29inch (7.4mm) having maximum of 0.67inch (17mm) has been recorded in 1996 and the lowest of 0.09inch (2.3mm) in 2000. The highest precipitation of the season is 0.65inch (16.5mm) at Skardu and lowest is 0.09inch (2.3mm) at Dalbandin. The isohyets show that Sind, lower Baluchistan, coastal region, southern Punjab, and Gilgit-Baltistan have precipitation below 0.5inch (12.7mm). The central Punjab, lower Khyber-Pakhtoonkhwa, and northwestern Baluchistan are experiences pre-monsoon precipitation from 0.5inch (12.7mm) to one inch (25.4mm). The precipitation of the season decreases from Quetta towards south in plain and from Skardu towards northwest in the Gilgit-Baltistan province (Map-5.5 and Table 5.3).





5.3.3.3. Monsoon season:

In arid region, the monsoon precipitation starts in the first week of July and continues upto mid-September. In coastal areas, these lows enter in the last week of June and provide light precipitation from the Arabian Sea branch. These winds are the only source that protects the arid region from dryness (Map-5.6 and Table-5.3). This is the sowing period of *kharif* crops in the northern arid region (Gilgit-Baltistan) and growing season in the lower Punjab and Sind. The heavy precipitation of the season causes floods, damaging crops in the lower Punjab and Sind.

The average monsoon precipitation of the arid region is 0.93inch (23.6mm) with heaviest of 2.15inches (54.6mm) at Chhor and the lowest of 0.06inch (1.5mm) at Dalbandin. The heavy precipitation of 2.49inches (63.3mm) has been recorded in 1978 (moist), whereas the lowest is 0.07inch (1.8mm) in 1991 (driest). The precipitation shows decrease from east toward southwest in the southern arid region and reverse pattern in the northern arid region (Gilgit-Baltistan).

5.3.3.4. Post monsoon season:

The arid region of Pakistan has dry and wet seasons twice in a year. It is the driest season that varies from mid-September to November having annual precipitation of 0.17inch (4.3mm). The season is characterized by light precipitation with moderate temperature, sowing season of the *rabi* and harvesting season of the *kharif* crops. The highest annual precipitation of

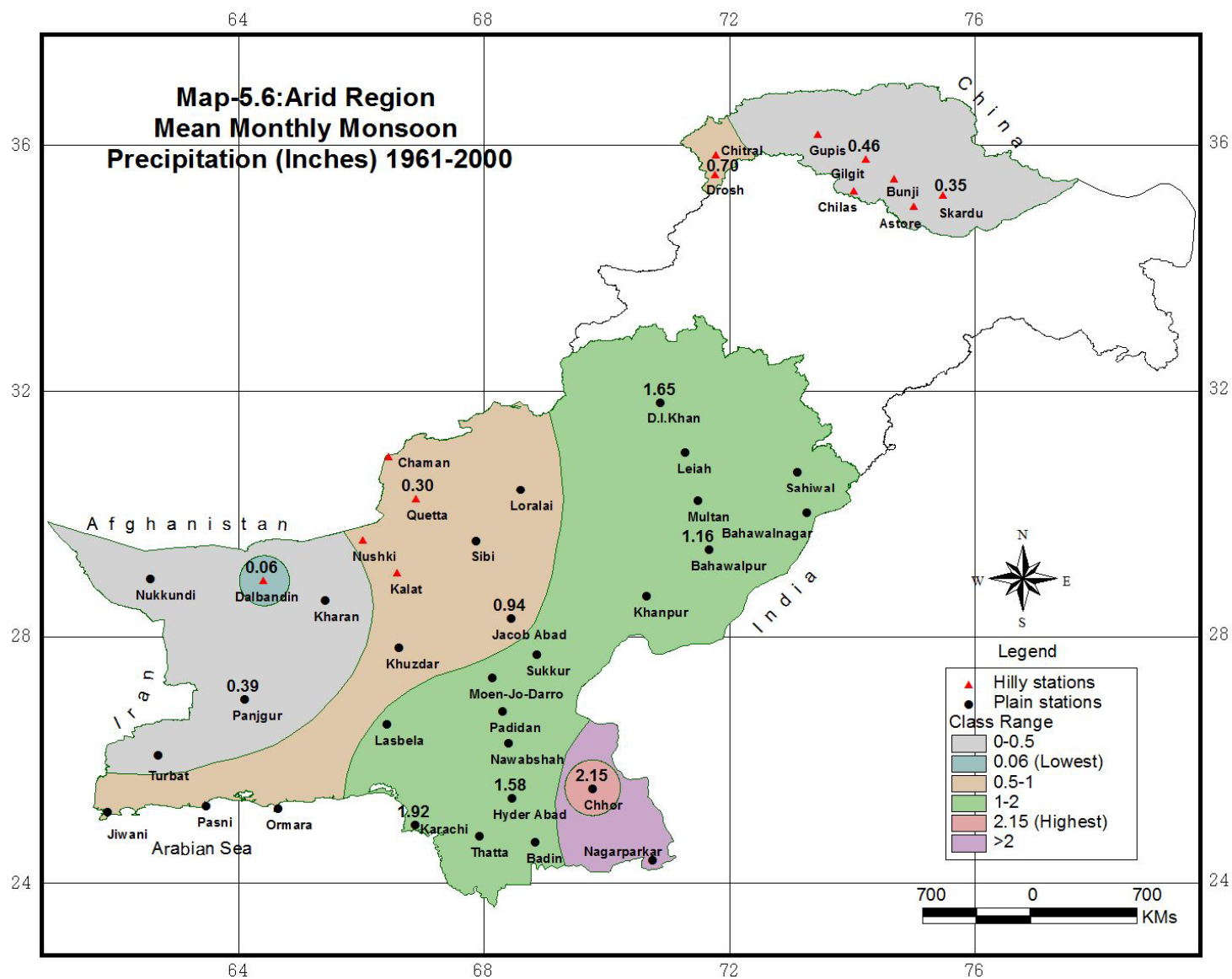
0.55inch (14mm) was received in 1997, while the lowest of 0.01inch (0.25mm) in 1971 and 1985 respectively. The precipitation decreases from northeast to southwest in the southern arid region (Map-5.7 and Table-5.3), while in northern arid region precipitation decreases from southwest to northeast. Chhor has received a maximum of 0.34inch (8.6mm) and Dalbandin of 0.07inch (1.8mm) respectively.

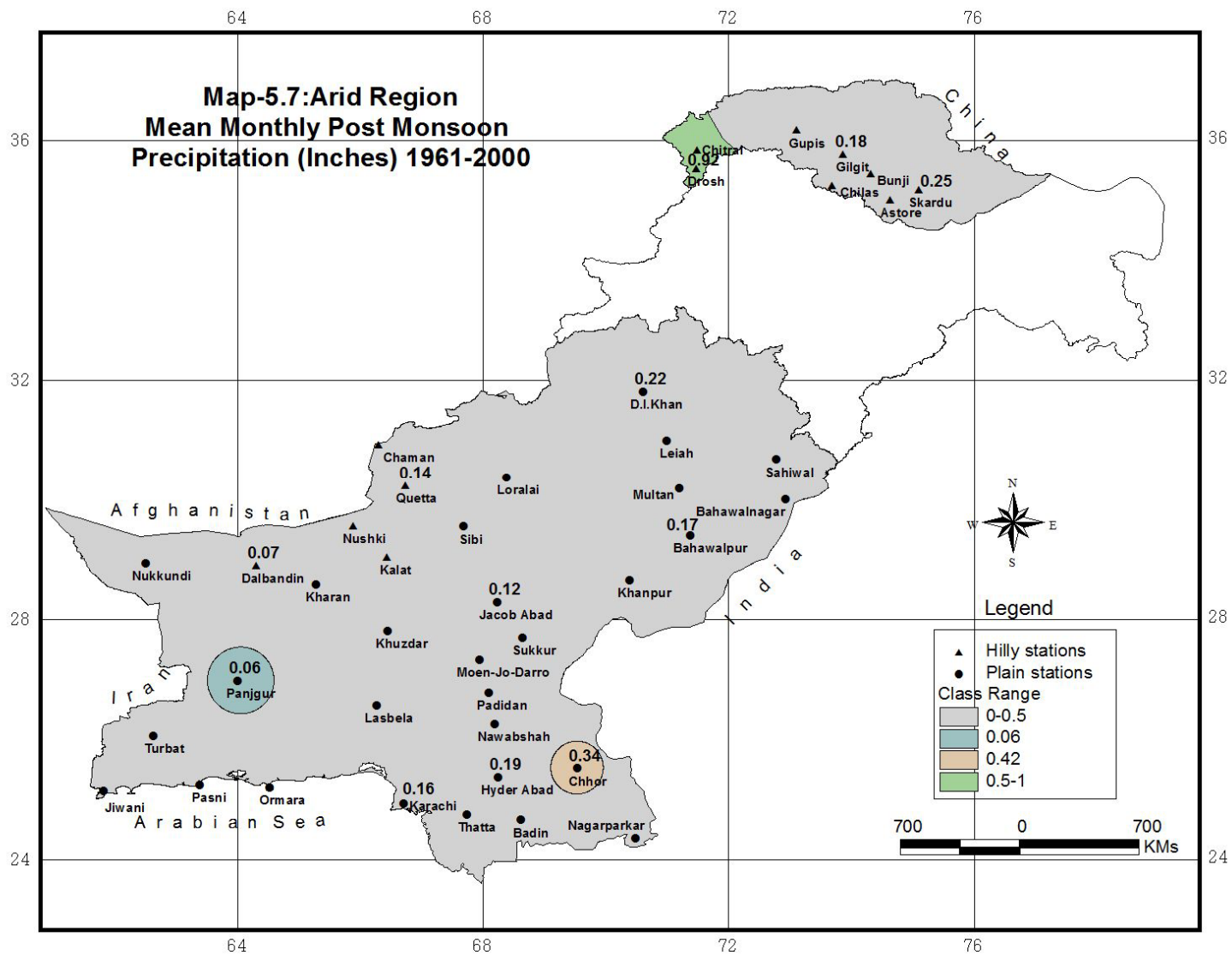
Table-5.3: Arid Region

Mean Monthly and Deviation of Seasonal Precipitation (Inches) 1961-2000

Year	Main Season				Sub-Seasons							
	Winter		Summer		Cold		Pre-Monsoon		Monsoon		Post Monsoon	
	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.	Mean	Dev.
1961	0.29	-0.16	1.24	0.63	0.37	-0.11	0.60	0.31	1.86	0.93	0.29	0.12
1965	0.28	-0.17	0.42	-0.19	0.35	-0.13	0.20	-0.09	0.64	-0.29	0.05	-0.12
1970	0.50	0.05	0.77	0.16	0.56	0.08	0.15	-0.14	1.34	0.41	0.23	0.06
1975	0.48	0.03	0.76	0.15	0.51	0.03	0.21	-0.08	1.33	0.40	0.20	0.03
1980	0.49	0.04	0.34	-0.27	0.48	0.00	0.31	0.02	0.31	-0.62	0.23	0.06
1985	0.28	-0.17	0.57	-0.04	0.37	-0.11	0.36	0.07	0.80	-0.13	0.01	-0.16
1990	0.74	0.29	0.56	-0.05	0.77	0.29	0.13	-0.16	1.01	0.08	0.14	-0.03
1995	0.51	0.06	0.60	-0.01	0.56	0.08	0.18	-0.11	1.03	0.10	0.13	-0.04
2000	0.27	-0.18	0.24	-0.37	0.28	-0.20	0.09	-0.20	0.43	-0.50	0.02	-0.15
Mean /Sum	0.45	-0.08	0.61	0.14	0.48	-0.05	0.29	-0.04	0.93	0.05	0.17	-0.11

Source: PMDC, Karachi, 1961-2000





5.4. Precipitation fluctuation:

Climate change has created both risks and opportunities throughout the arid region of Pakistan. The consequences of climate fluctuation are potentially more significant for the people living in the arid region than for those living in sub-humid, humid, and wet region. Most of the people depend on the primary economic activities, which is vulnerable to precipitation fluctuation. Agriculture and vegetation depend on precipitation and a change in it could directly impact productivity in the arid region. Climate change can cause abrupt disruptions, such as floods, droughts and can take a major toll on the arid region economy. It is therefore, necessary to study the precipitation fluctuation of the arid region in Pakistan and to evaluate the dry and wet spells during the past 40 years (1961 to 2000).

5.4.1. Palmer drought severity index:

"The Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI) are indices of the relative dryness or wetness effecting water sensitive economies. The CMI gives the short-term or current status of purely agricultural drought or moisture surplus and can change rapidly from week to week," (Palmer, 1965). Input to the calculations includes the weekly total precipitation and average temperature, division constants (water capacity of the soil, etc.) and previous history of the indices.

Table-5.4. Palmer Climate Severity Indices

-4.0 or less (Extreme Drought)	+2.0 or +2.9 (Unusual Moist Spell)
-3.0 or -3.9 (Severe Drought)	+3.0 or +3.9 (Very Moist Spell)
-2.0 or -2.9 (Moderate Drought)	+4.0 or above (Extremely Moist)
-1.9 to +1.9 (Near Normal)	

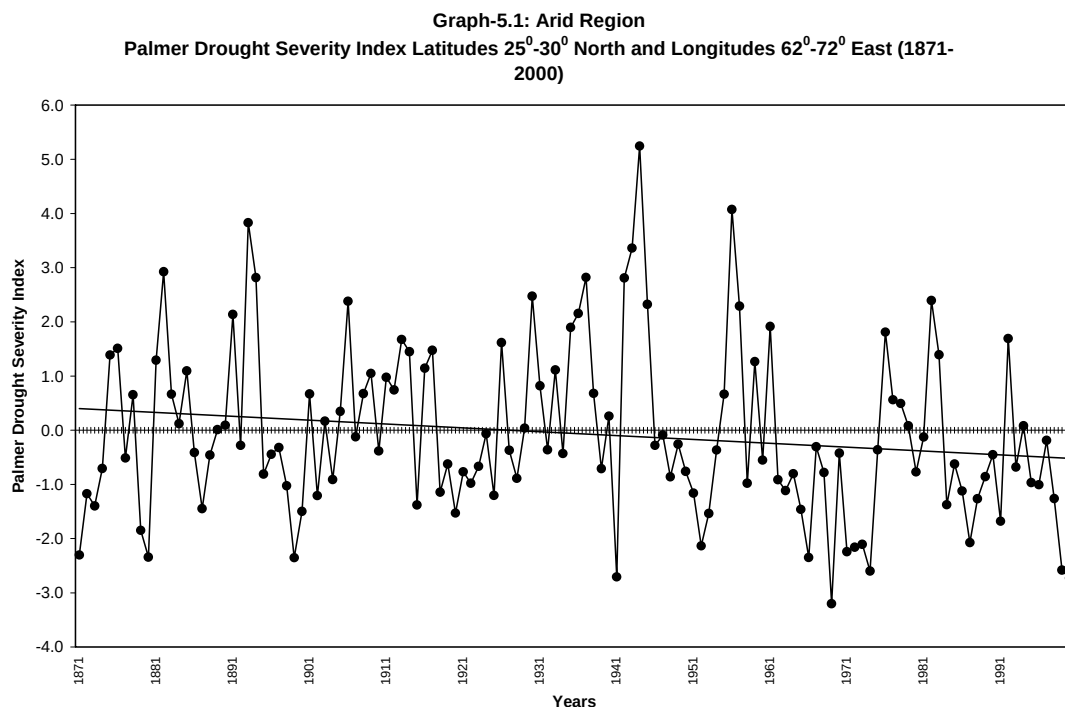
Source: Palmer Severity Indices (PDSI) Ranges, 1965

The arid region of Pakistan has highly variable precipitation and history of recurrent and severe droughts and desertification that affect agriculture production. A Palmer Drought Severity Index (PDSI) at 25° to 30° north latitudes and 62°-5' to 72°-5' east longitudes, where Pakistan is located, reveals a decreasing trend from 1871 to 2000 (Graph-5.1). This PDSI is above the mean condition from 1871 to 1931 and below the average line till 2000 having extreme droughts and wet spells in some years of the series. The area has passed through extreme droughts during 1871 (-2.7inch or -68.6mm), 1881 (-2.3inch or -58.4mm), 1899 (-2.8inch or -71.1mm), 1941 (-2.7inch or -68.6mm), 1969 (-3.2inch or -81.3mm), and 2000 (-2.7inch or -68.6mm). The wet spells of the series having major floods with minor oscillation in some years have been observed in 1882 (2.9inches or 73.7mm), 1893 (3.8inches or 96.5mm), 1906 (2.4inches or 61mm), 1944 (5.2inches or 132.1mm), 1956 (4.1inches or 104.1mm), 1982 (2.4inches or 61mm), and 1992 (1.7inches or 43.2mm).

The data reveal that there is an average fall of -0.1inch (-25.4mm)/year and total of -7.7inch (-195.6mm) during 1871 to 2000 and fall the arid region of

Pakistan in the range of sever drought (Table-5.4). The high concentration of 5.2inches (132.1mm) is observed in 1944, whereas the sever drought, prevailed in most of the area, in 1969, when the deviation from the mean dropped to - 3.2inch or -81.3mm (Table-5.5).

The five years sum from 1871 to 2000 has been plotted on graph-5.2. The trend of precipitation after each five years shows a high concentration of the series recorded during 1941 to 1945, when the deviation from the mean exceeded to 11inches (279.4mm). The trend of five years total precipitation indicates that after fifteen years there is an increase or decrease in the moisture index of the region, but from 1876 to 1900, the pattern of precipitation shows change after each five years.



The deviation of ten years since 1871 to 2000 has been shown on graph- 5.3 and table-5.7. The oscillation line reveals that after each 40 years (1881 to

1920) the precipitation remained above the average having ups and downs from 1921 to 1960, and negative trend onward from 1961 to 2000.

The deviation from the mean shows that after each 15 years there is slight oscillation in the precipitation of the region. After each 30 years the deviation is above the mean condition but since 1960 to 2000, it remains below the mean line (Graph-5.4).

It reveals that the precipitation decreases with time affecting the productivity of agriculture in the arid region. It has also influence the flow of surface water in the Indus and its tributaries that affect the irrigation system of the lower Punjab and Sind.

Table-5.5: Arid Region

Annual Deviation of Palmer Drought Severity Index (1871-2000)

Year	Deviation	Year	Deviation	Year	Deviation
1871	-2.3	1920	-1.5	1970	-0.4
1875	1.4	1925	-1.2	1975	-0.4
1880	-2.3	1930	2.5	1980	-0.8
1885	1.1	1935	1.9	1981	-0.1
1890	0.1	1940	0.3	1985	-0.6
1895	-0.8	1945	2.3	1990	-0.5
1900	-1.5	1950	-0.8	1995	-1.0
1905	0.3	1955	0.7	2000	-2.7
1910	-0.4	1960	-0.6	Average	-0.1
1915	-1.4	1965	-1.5	Sum	-7.7

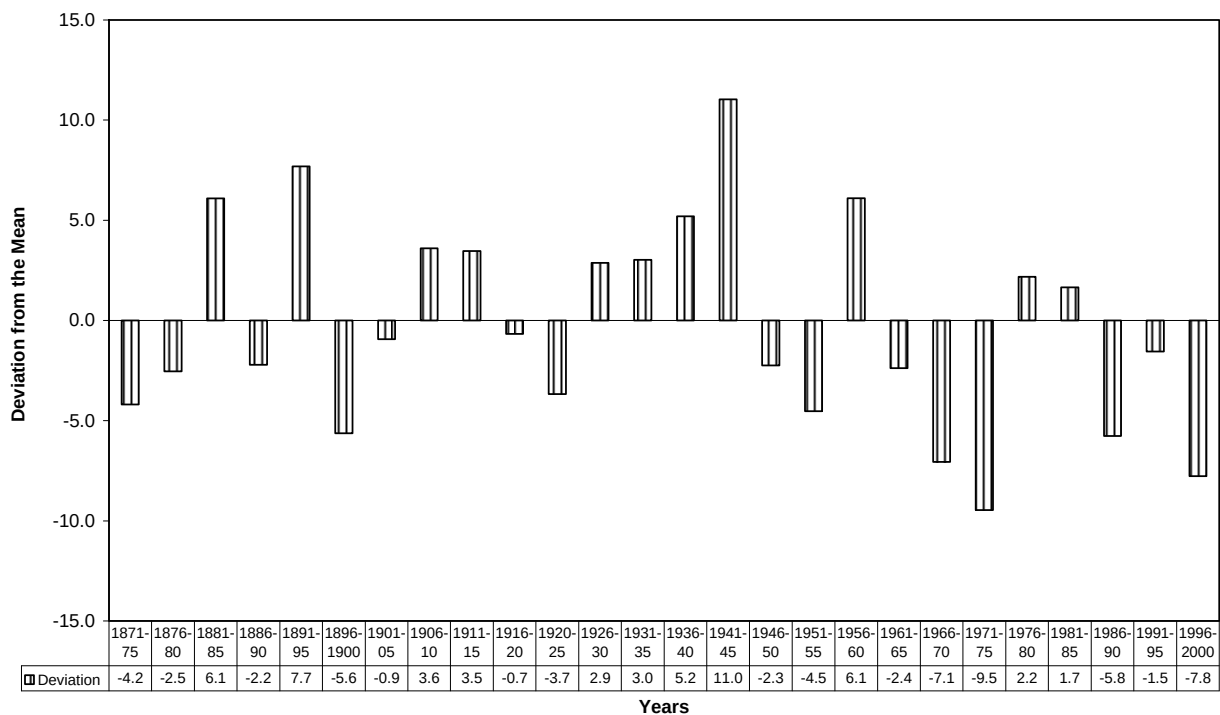
Source: <http://www.egd.ucar.edu/cas/catalog/climind/pdsi.htm>

The precipitation concentration of 20 years deviation shows a clear condition of wet and dry periods (Graph-5.5). From 1871 to 1890, the

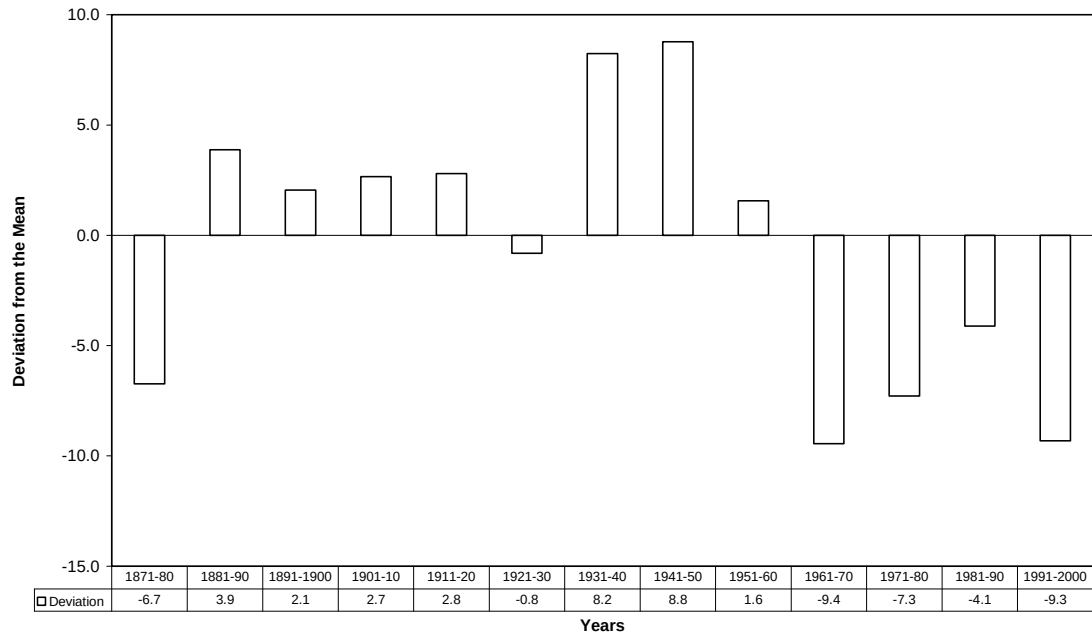
precipitation of the area was below the mean value and rose up during 1991 to 1950 and turn into negative trend in the last 60 years (1951 to 2000).

Graph-5.6 of 30 years precipitation reveals a clear picture of the future trend in the arid region. In the first quarter (1871 to 1900), the precipitation was below the average condition that change to positive deviation from 1901 to 1960 (60 years) followed by slacking in the third quarter of 1961 to 2000.

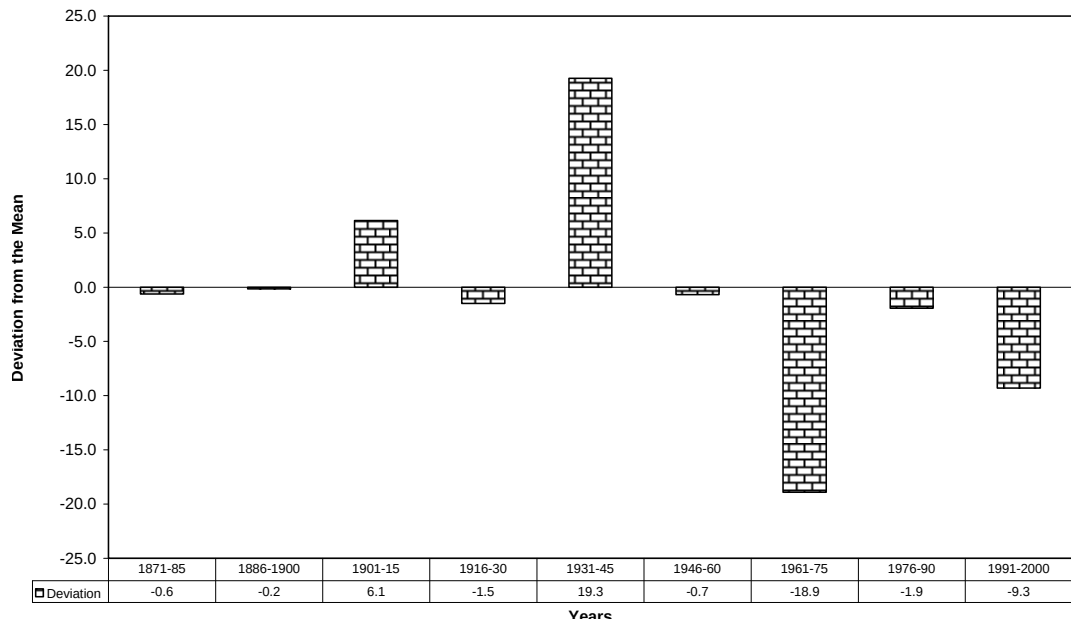
Graph-5.2: Arid Region
Five Years average of Palmer Drought Severity Index (1871-2000)



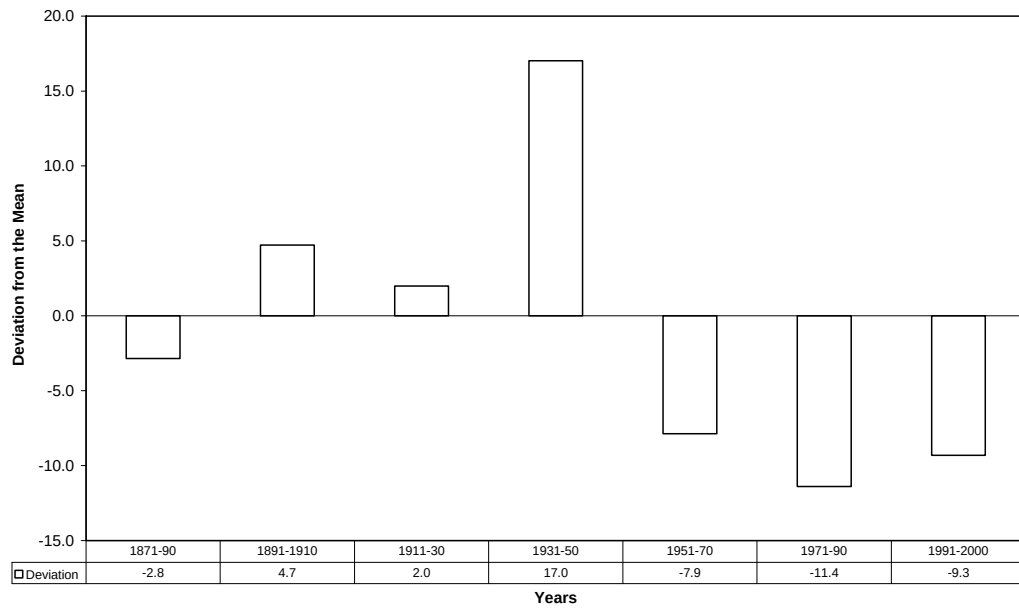
Graph-5.3: Arid Region
Ten Years average of Palmer Drought Severity Index (1871-2000)



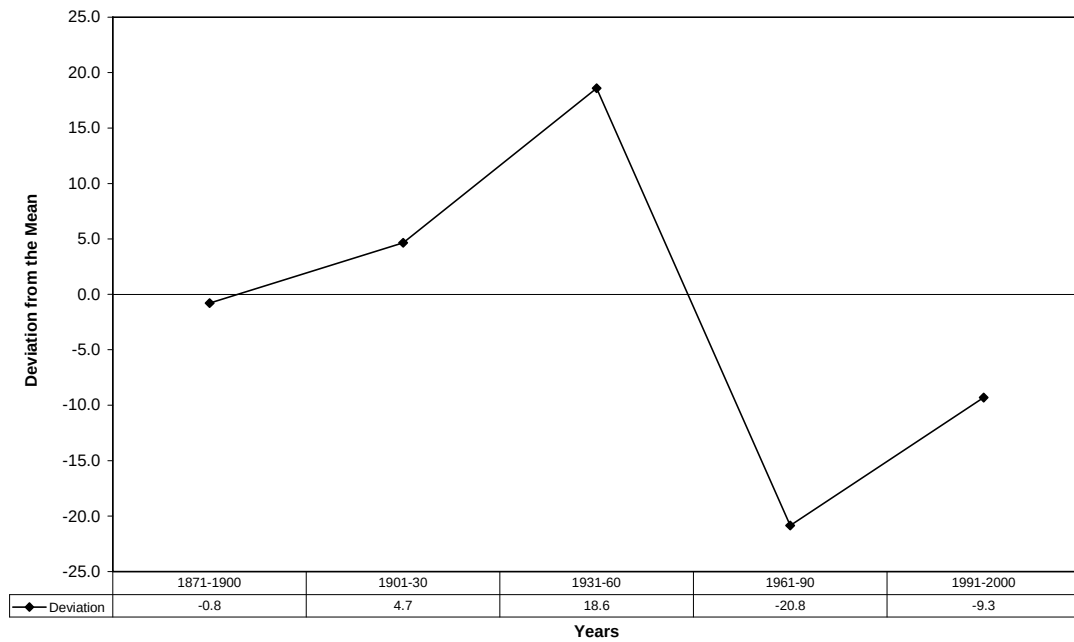
Graph-5.4: Arid Region
Fifteen Years average of Palmer Drought Severity Index (1871-2000)



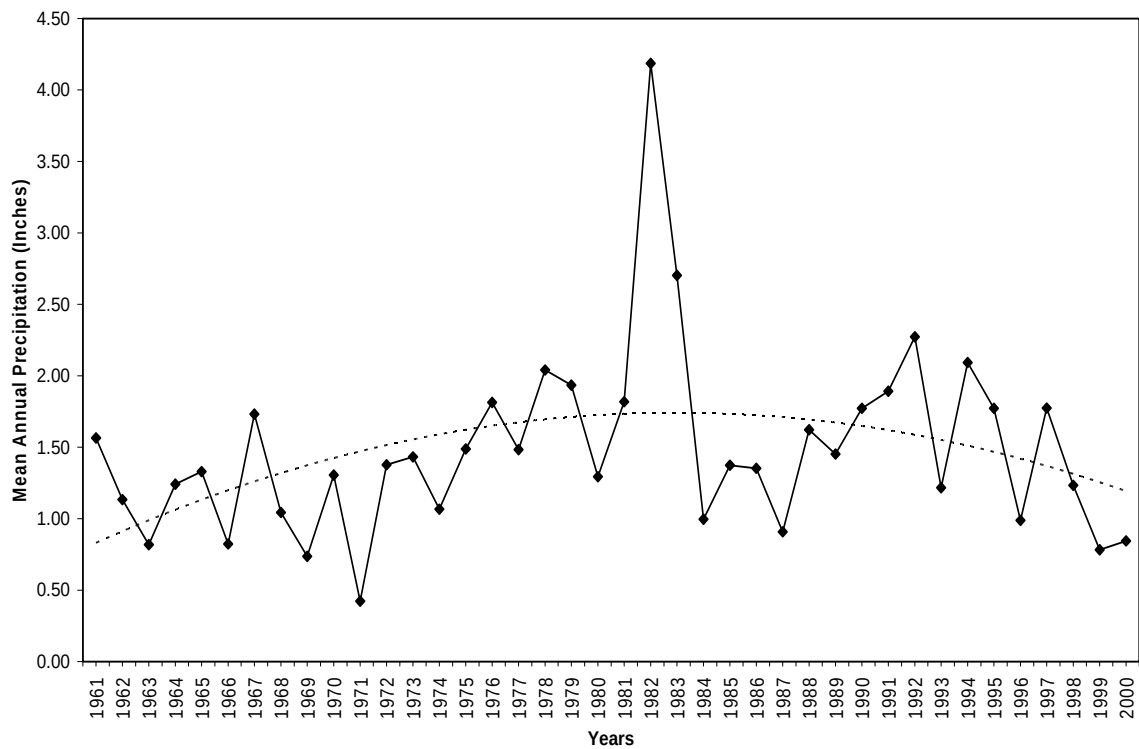
Graph-5.5: Arid Region
Twenty Years average of Palmer Drought Severity Index (1871-2000)



Graph-5.6: Arid Region
Thirty Years Average of Palmer Drought Severity Index (1871-2000)



Graph-5.7: Arid Reigion
Annual Trend of Precipitation (1961-2000)



5.4.2. Meteorological data fluctuation:

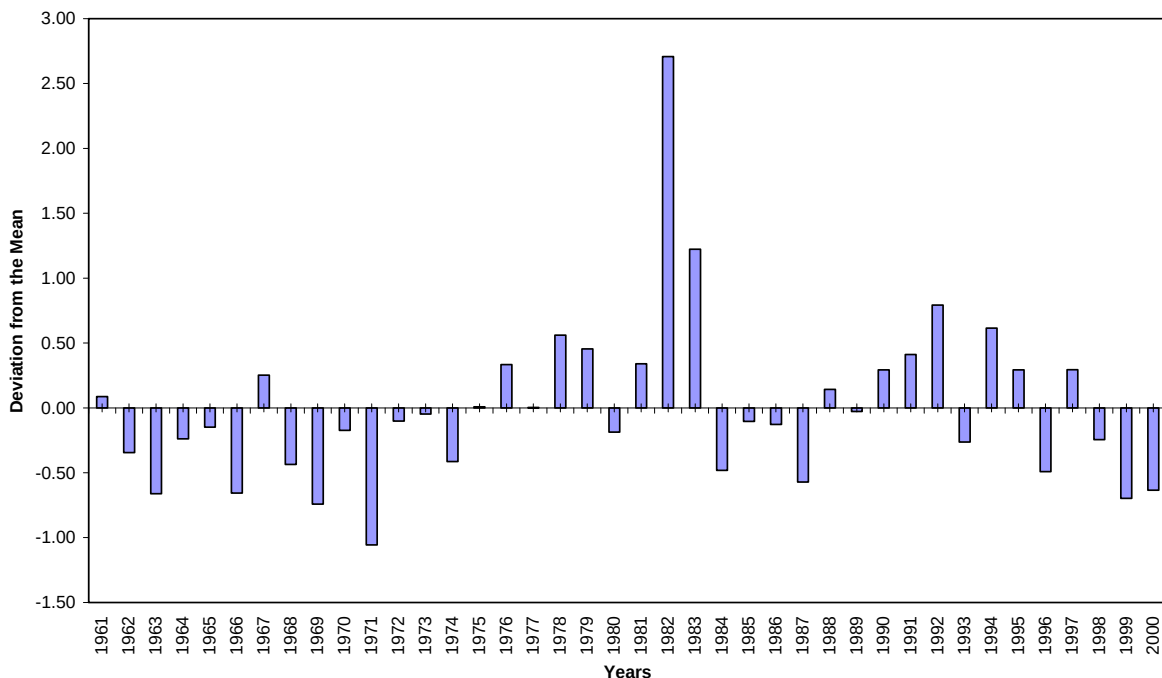
The study of trends of the annual precipitation is the basic factor to know about the rise and fall of precipitation in different time intervals since 1961 to 2000. The comparison of fluctuation provides a base to analyze the effects of precipitation on agriculture productivity. It further elaborates the decline in precipitation and its impact on agriculture.

An irregular pattern of precipitation has been noted from 1961 to 1970 followed by gradual increase from 1971 to 1990 and a decreasing trend during 1991 to 2000. The data reveal a total decrease of -0.05inch (-1.27mm) from 1961 to 2000. The high concentration of 2.71inches (68.8mm) has been recorded in 1982 and the lowest of -1.06inches (-26.9mm) in 1971 (Graph-5.7 and Table-5.2).

From graph-5.8 and table-5.2, it is evident that the precipitation has remained below the average from 1961 to 1974 and shows a positive trend during 1975 to 1983. In 1984 to 1989, it is below the average and turns to positive upto 1995 and negative trend till 2000. Generally, the precipitation of the arid region shows a minor change in the trend after each five years and a high concentration after ten years (Graph-5.8 and Table-5.2).

For micro-level analysis of precipitation oscillation, the data have been condensed into 5, 10, 15 and 20 years class intervals. The average of five years

Graph-5.8: Arid Reigion
Annual Trend of Precipitation (1961-2000)



series reveals lowest of 1.12inches (28.5mm) in 1996 to 2000 and supposed to be the driest years of the series. The sum of variation from the mean condition of the five years series is 1.45inches (36.8mm) having wet period of 2.22inches (56.4mm) in 1981 to 1985. Generally, the trend of the series indicates that there is a slight decrease from 1961 to 1975 that increased from 1976 to 1985. The

pattern change once again from 1986 to 1990 and rises up in 1995 to 2000 (Table-5.6 and Graph-5.9).

The ten years average has been presented in table-5.7 and graph-5.10. The sum of the series reveals a decrease of -0.001inch (-0.02mm). The lowest precipitation of the series is 1.22inches (31mm) during 1961 to 1970 and wettest of 1.74inches (44.2mm) in 1981 to 1990. The precipitation reveals an increasing trend in the first three quarters and then declines in the last quarter of the series.

The fifteen years average of the series indicates a minimum of 1.22inches (31mm) from 1961 to 1975 and a highest of 1.71inches (43.2mm) in 1976 to 1990 (Table-5.7 and Graph-5.11). The sum of deviation after each fifteen years is -0.01inch (-0.25mm). The lowest of 20 years average is 1.33inches (33.8mm) recorded in 1961 to 1980 and a highest of 1.61inches (40.9mm) in 1991-2000. The fall in precipitation after each 20 years is 0.0004inch (0.01mm). The trend line shows a clear picture of increase during the last twenty years (Table-5.7 and Graph-5.12).

**Table-5.6: Arid Region
Five Years average Precipitation (Inches) 1961-2000**

Year	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-95	1996-2000	Average
Chhor	0.92	0.50	0.47	0.75	0.85	0.77	0.87	0.79	0.74
Dalbandin	0.25	0.22	0.19	0.36	0.29	0.27	0.35	0.26	0.27
Hyderabad	0.89	0.48	0.20	0.85	0.54	0.55	0.71	0.17	0.55
Jacobabad	0.24	0.31	0.26	0.48	0.38	0.50	0.51	0.34	0.38
Karachi	0.80	0.87	0.33	1.22	0.69	0.38	0.71	0.26	0.66
Panjgur	0.35	0.30	0.34	0.45	0.39	0.30	0.30	0.36	0.35
Quetta	7.55	7.29	7.61	11.22	17.57	9.57	13.47	7.10	9.91
Bahawalpur	0.38	0.28	0.74	0.83	0.48	0.56	0.45	0.50	0.53
Drosh	2.21	2.08	2.03	1.77	1.59	1.88	2.32	1.89	1.97
DI Khan	0.72	0.82	0.92	0.93	1.02	0.89	0.93	0.79	0.88
Gilgit	0.36	0.43	0.45	0.44	0.39	0.47	0.36	0.56	0.43
Skardu	0.44	0.62	0.99	0.53	0.58	0.86	0.78	0.90	0.71
Average	1.22	1.13	1.16	1.71	2.22	1.42	1.85	1.12	1.45

Source: PMDC, Karachi, 1961-2000

Table-5.7: Arid Region

Ten, Fifteen, and Twenty Years Average Precipitation (Inches) 1961-2000

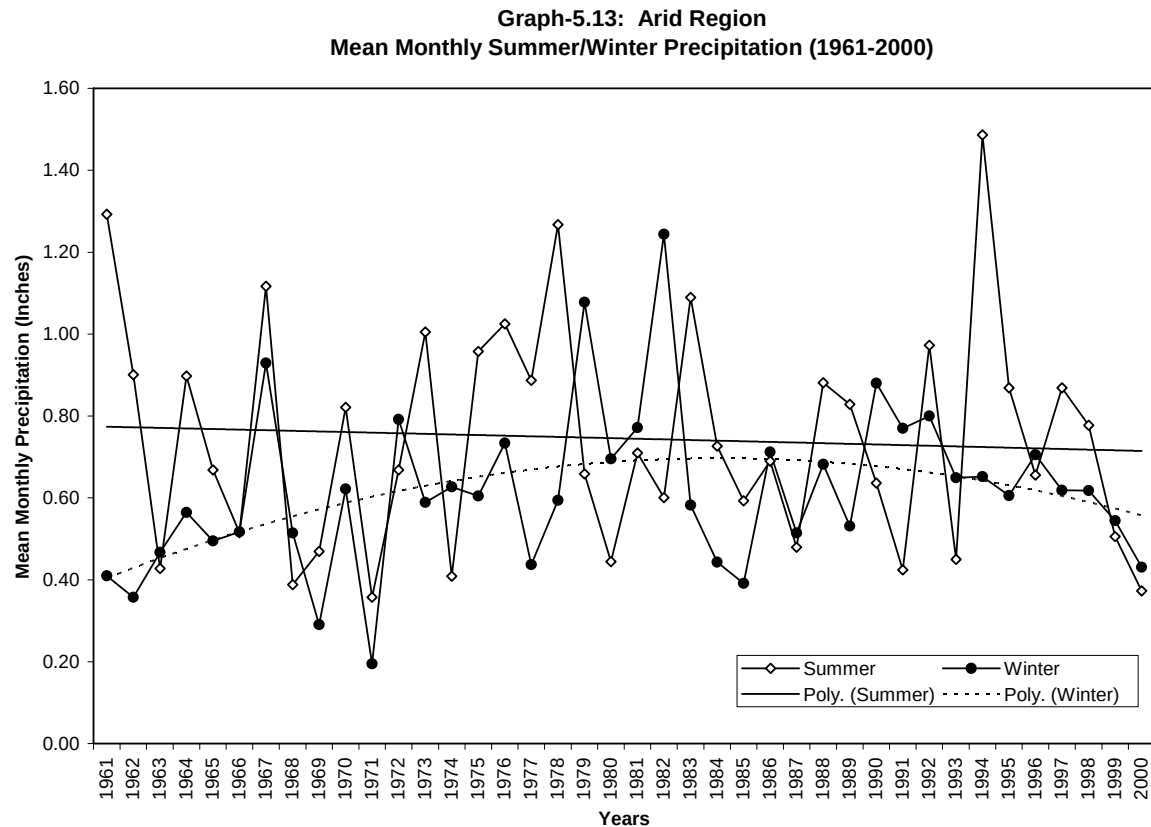
Stations	10 Years Average					15 Years Average			20 Years Average		
	1961-70	1971-80	1981-90	1991-2000	Average	1961-75	1976-90	Average	1961-80	1981-2000	Average
Chhor	0.71	0.61	0.81	0.83	0.74	0.63	0.79	0.71	0.66	0.82	0.74
Dalbandin	0.24	0.27	0.28	0.31	0.27	0.22	0.31	0.26	0.26	0.29	0.27
Hyderabad	0.69	0.52	0.54	0.44	0.55	0.52	0.64	0.58	0.60	0.49	0.55
Jacobabad	0.27	0.37	0.44	0.42	0.38	0.27	0.46	0.36	0.32	0.43	0.38
Karachi	0.83	0.77	0.53	0.48	0.66	0.66	0.76	0.71	0.80	0.51	0.66
Panjgur	0.32	0.40	0.35	0.33	0.35	0.33	0.38	0.36	0.36	0.34	0.35
Quetta	7.42	9.42	13.57	10.28	10.17	7.48	12.78	10.13	8.42	11.93	10.17
Bahawalpur	0.33	0.78	0.52	0.47	0.53	0.47	0.62	0.54	0.56	0.50	0.53
Drosh	2.15	1.90	1.74	2.11	1.97	2.11	1.75	1.93	2.03	1.92	1.97
DI Khan	0.77	0.92	0.96	0.86	0.88	0.82	0.95	0.88	0.84	0.91	0.88
Gilgit	0.39	0.45	0.43	0.46	0.43	0.41	0.44	0.42	0.42	0.45	0.43
Skardu	0.53	0.76	0.72	0.84	0.71	0.68	0.66	0.67	0.64	0.78	0.71
Average	1.22	1.43	1.74	1.49	1.47	1.22	1.71	1.47	1.33	1.61	1.47
Deviation	-0.25	-0.04	0.27	0.02	-0.001	-0.25	0.24	-0.01	-0.14	0.14	-0.0004

Source: PMDC, Karachi, 1961-2000

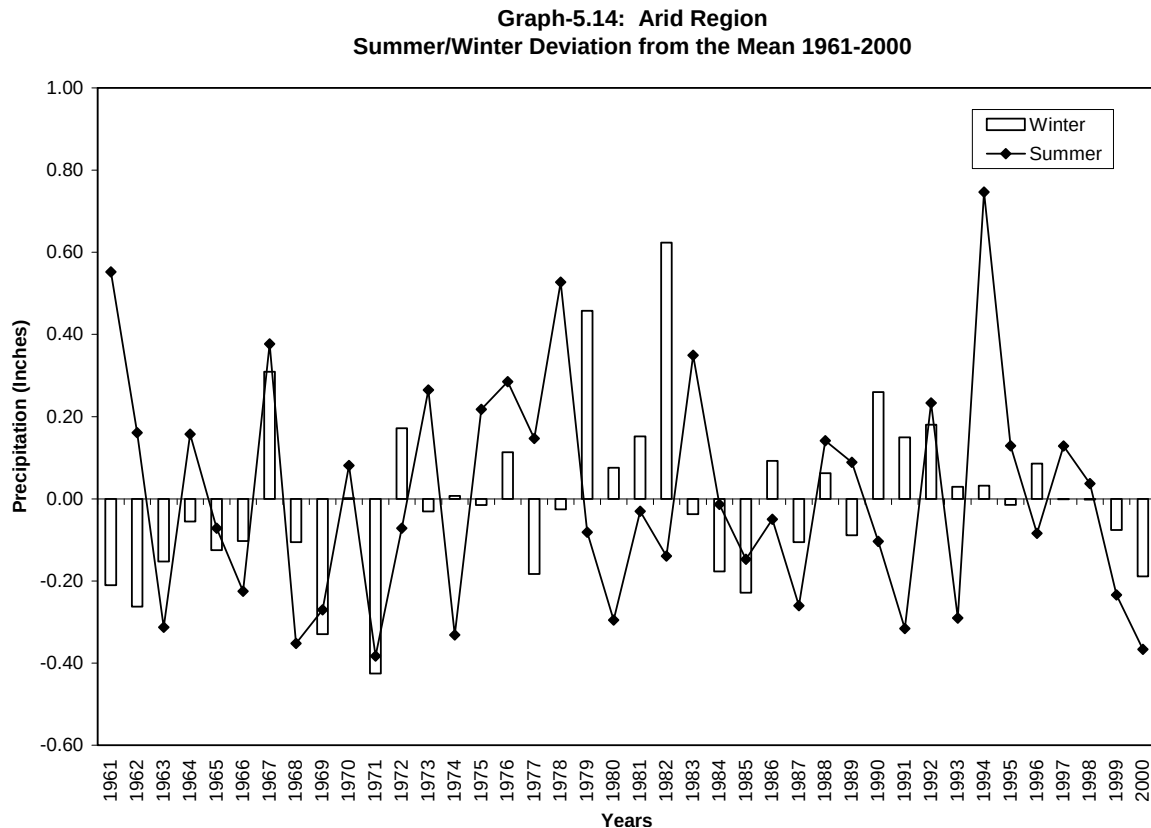
5.5. Seasonal fluctuation:

The seasonal pattern of precipitation is more important to know in which season of the year precipitation is going to decline and how it affected the agriculture of the arid region in Pakistan.

The summer season covers the growing period of *kharif* crops and shows an increase of 0.14inch or 3.6mm (Table-5.3). The season reveals a decreasing trend from 1961 to 2000 but the individual years show very conspicuous deviation from the trend line as it is evident from graph-5.13 and 5.14.



The winter season covers the growing period of *rabi* crops. The decrease of precipitation calculated is -0.08inch (-2.03mm) for the time period of 40 years. The maximum precipitation of 0.67inch (17.02mm) has been received in 1982 and minimum of -0.33inch or -8.4mm in 1971 (Table-5.3). The annual trend



reveals an increase from 1961 to 1982 and continuously slackens till 2000 (Graph-5.13 and Graph-5.14). Generally, the pattern of winter precipitation shows fluctuation after every five and ten years.

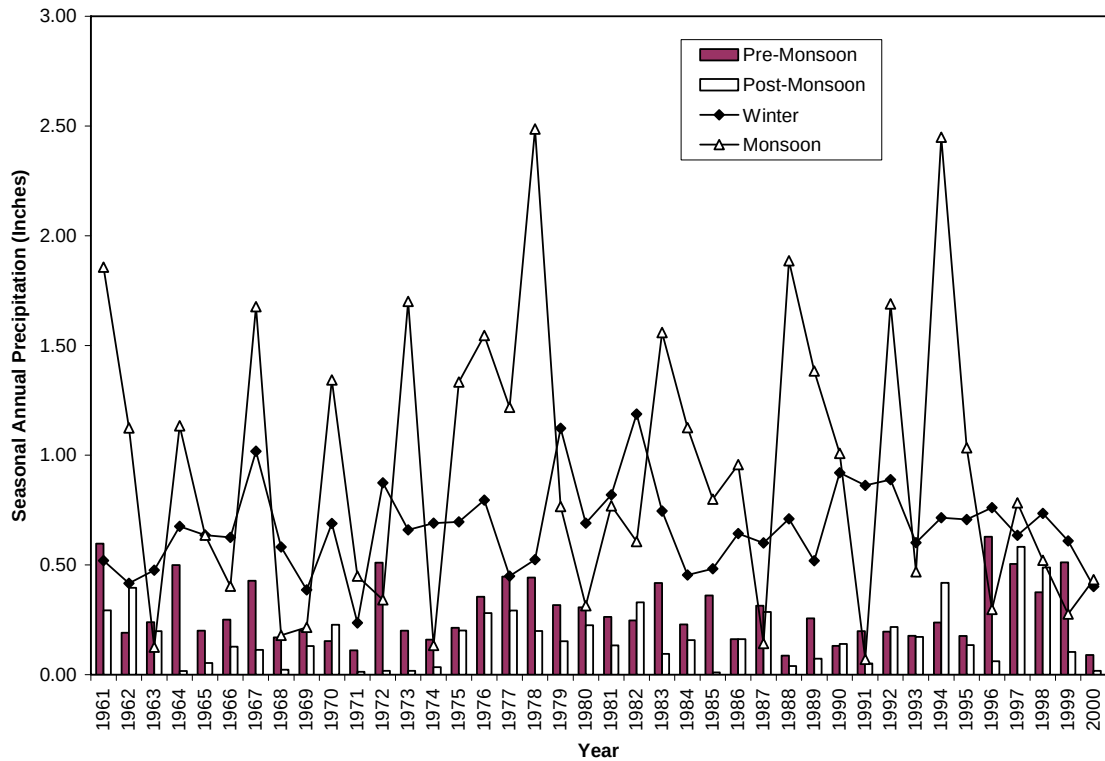
5.5.1. Sub-season fluctuation:

There are four rainy seasons in the arid region of Pakistan namely cold, pre-monsoon, monsoon, and post monsoon. The cold season varies from mid-November to March having total fall of -0.05inch (-1.3mm) from 1961 to 2000

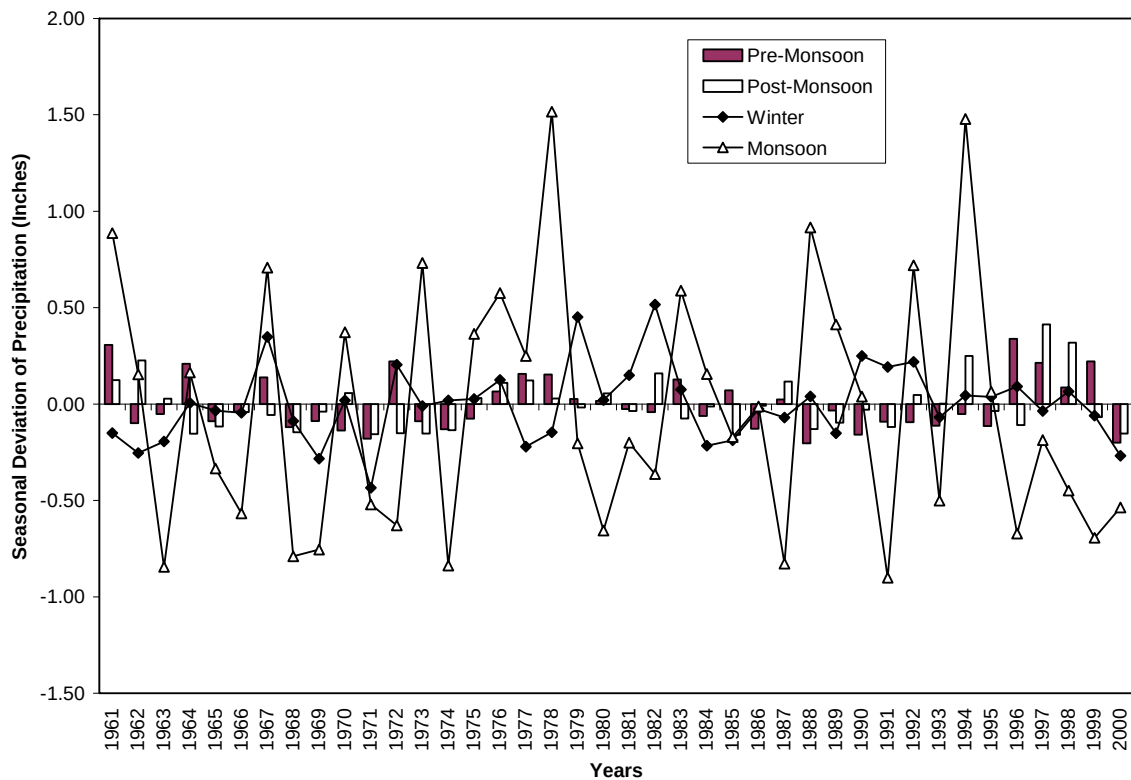
(Table-5.3 and Graph-5.15). The highest value of 0.63inch (16mm) has recorded in 1982 and lowest of -0.35inch (-8.9mm) in 1971 and supposed to be moist and driest years of the series. The precipitation shows a decreasing trend from 1980 to 2000 with short term oscillation after every five years. The deviation from the mean reveals a negative trend in most of the years during 1961 to 2000. It indicates that the winter quota of precipitation has decreased with passage of time (Graph-5.16).

The five years average of the cold season plotted on graph-5.17 shows a continuous increase from 1961 to 1985 and fall till 2000. The deviation reveals that the trend is below the average condition from 1961 to 1975 and then rises up during 1976 to 1985 and turns into negative from 1986 to 2000 (Graph-5.18). The ten years average of the season indicates sum of precipitation of 0.92inch (23.4mm) from 1981 to 1990 and the lowest of 0.21inch (5.3mm) from 1991 to 2000. The trend shows a rise and fall after each ten years (Graph-5.19 and Graph-5.20). The value of fifteen years average precipitation plotted on graph-5.21 reveals that the winter precipitation remains low during 1961 to 1975 and high in 1976 to 1990. The precipitation of the season shows a change after every fifteen years (Graph-5.22). The twenty years average of precipitation reveals a decrease from 1961 to 2000 (Graph-5.23). The deviation remains negative from 1961 to 1980 and turns to positive during 1981 to 2000 with a -0.04 (-1.02mm) and 0.04inch (1.02mm) respectively (Graph-5.24).

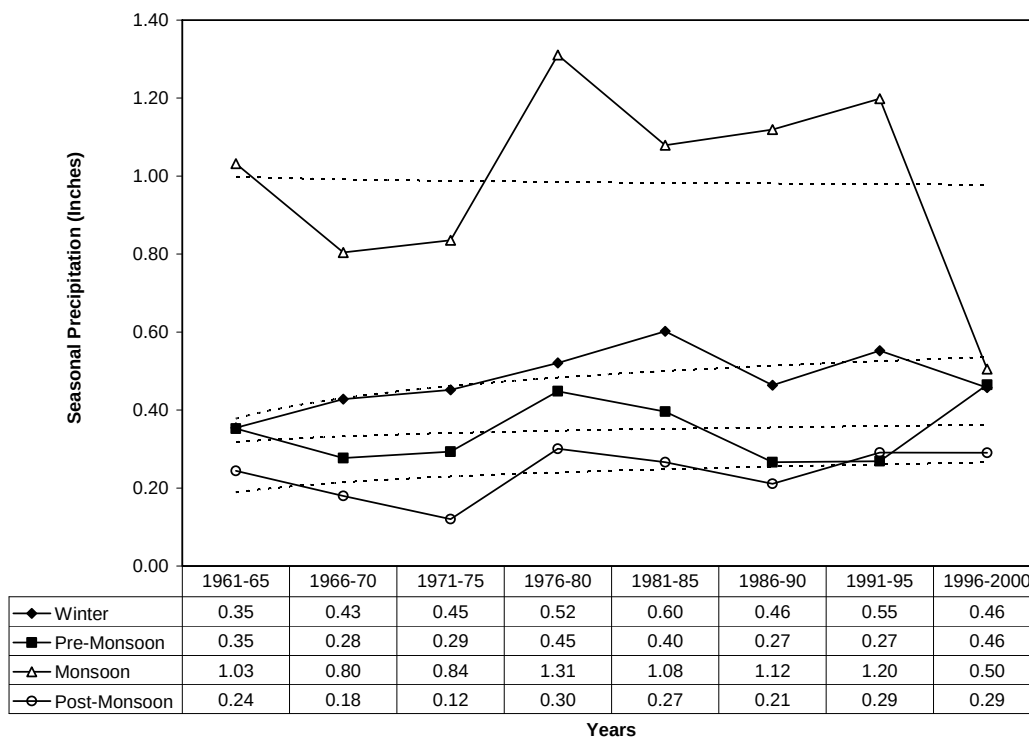
Graph-5.15: Arid Region
Mean annual Precipitation of Sub Seasons (1961-2000)



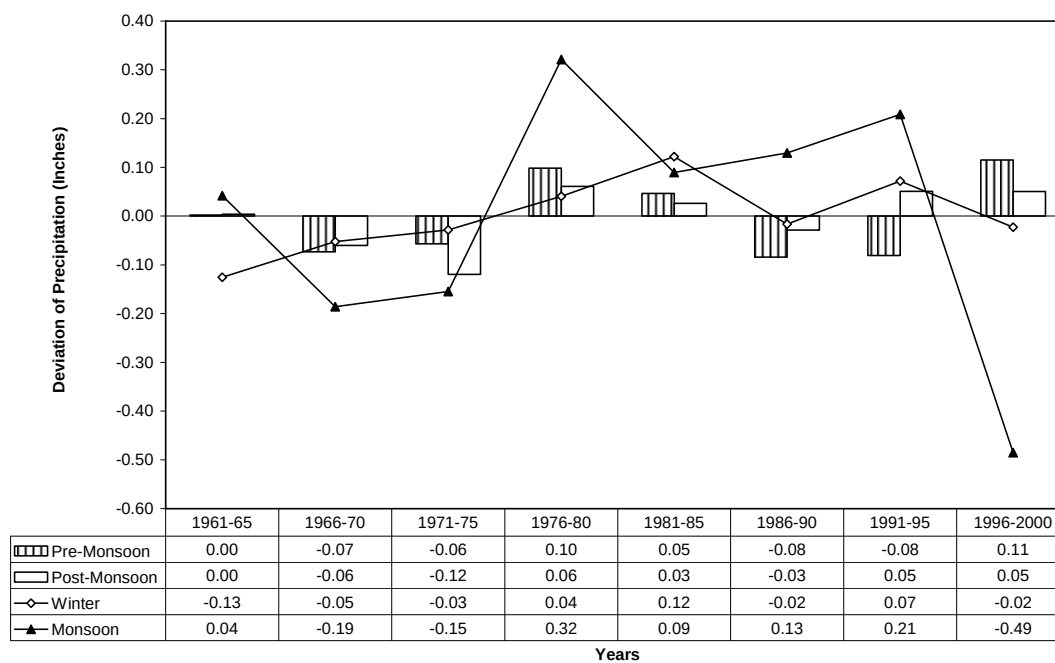
Graph-5.16: Arid Region
Seasonal Deviation of Precipitation (1961-2000)



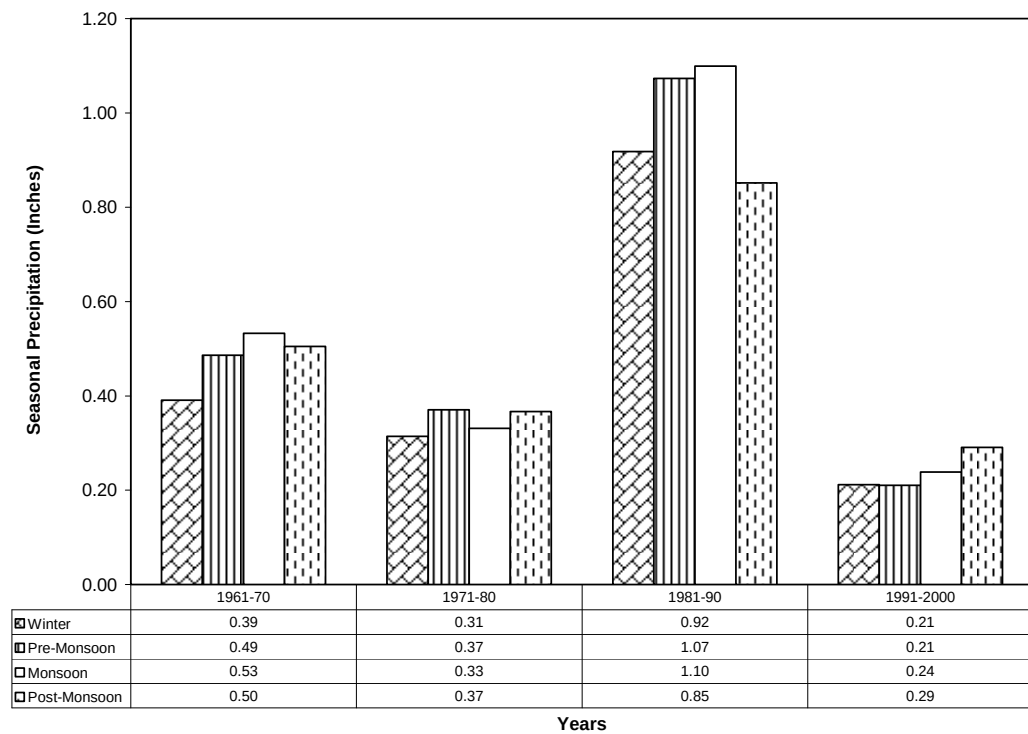
Graph-5.17: Arid Region
Five Years Average Seasonal Precipitation (1961-2000)



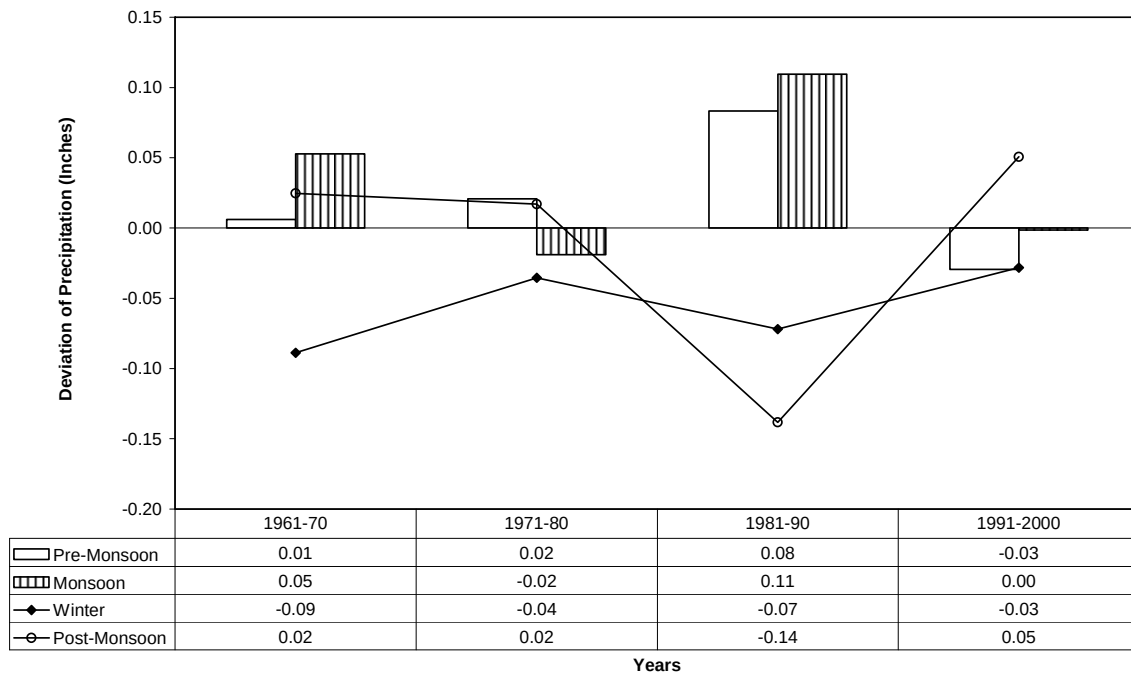
Graph-5.18: Arid Region
Five Years Devitaion of Precipitation (1961-2000)



Graph-5.19: Arid Region
Ten Years Average precipitation (1961-2000)



Graph-5.20: Arid Region
Ten Years Deviation of Precipitation (1961-2000)



The pre-monsoon season varies from mid-April to June and mostly covers the tail of *rabi* season. The total fluctuation of the season is -0.04inch (-1.02mm) having heaviest precipitation of 0.34inch (8.64mm) in 1996 and the lowest of -0.02inch (-0.51mm) in 1988 and 2000 respectively (Table-5.3). The annual trend shows rise and fall after every three years from 1961 to 1975 (Graph-5.15). From 1976 to 2000, there is a slight oscillation after each five years throughout the series. The deviation from the mean reveals that most of the years of the series are below the average with a rise after every five years from 1961 to 2000 (Graph-5.16).

The average of five years interval plotted on graph-5.17 shows that the high concentration of 0.46inch (11.7mm) is in 1996 to 2000 and minimum of 0.27inch (6.86mm) in 1986 to 1990 and 1991 to 1995 respectively. During last five years, precipitation of the season has reached to its climax i.e. 1995 to 2000; the deviation from the mean condition reveals a negative followed by positive trend alternately after an interval of five years (Graph-5.18). The ten years interval gives a clear picture of oscillation in the arid region of Pakistan (Graph-5.19). During 1981 to 1990, the pre-monsoon precipitation was at its climax (1.07inches or 27.2mm) and remained low during 1991 to 2000 (0.21inch or 5.3mm). The trend reveals a change in the precipitation after every ten years.

The deviation from the mean condition indicates that from 1961 to 1990 the precipitation was above the average condition and turn down during 1991 to 2000 (Graph-5.20). The fifteen years interval of the season shows a rise and fall in precipitation after each fifteen years (Graph-5.21). The deviation from the

fifteen years average shows that it was below the mean condition during 1961 to 1975 and carried positive trend onward 1990 (Graph-5.22). The twenty years interval reveals slight variation in both quarters i.e. 1961 to 1980 and 1981 to 2000 (Graph-5.23). The deviation from the mean remains negative throughout the series but in last 20 years, it runs near the average line (Graph-5.24). It shows that the change in the pre-monsoon precipitation remains low in five years, medium in ten, and high in 20 years.

The monsoon season of the arid region ranges from July to mid-September and covers the sowing time of *kharif* crops. The sum of deviation shows an increase of 0.05inch (1.3mm). The heaviest precipitation of 1.56inches (39.6mm) has been recorded in 1978 and the lowest of -0.86inch (-21.8mm) in 1991 (Table-5.3 and Graph-5.15). The deviation from the mean reveals that it remains below the average from 1961 to 1975 with a rise during 1976 to 1978 and slacken up to 1988. From 1989 to 1994, the showers were mostly above the average condition and carried reverse trend during 1995 to 2000 (Graph-5.16).

The five years average of monsoon precipitation plotted on graph-5.17 and 5.18 shows an increase of 0.5inch (12.7mm) in 1996 to 2000. The trend shows a decline during 1961 to 1970, which rise during 1971 to 1980 and slacken in 1981 to 1985. From 1986 to 1995, there is a slight increase and a subsequent decrease in precipitation till 2000. From 1981 to 1990 the average precipitation is 1.1inches (27.9mm), while from 1991 to 2000 the average is 0.24inch or 6.1mm (Graph-5.19 and 5.20). The fifteen years average shows rise and fall from 1961 to 1990) and remains low during 1991 to 2000 (Graph-5.21).

The deviation from the mean indicates that the monsoon precipitation has negative deviation during 1961 to 1975 and positive during 1976-90 (Graph-5.22). The twenty years trend plotted on graph-5.23 and graph-5.24 reveals decrease from 1961 to 1980 and an increase till 2000.

The post monsoon precipitation last from mid-September to November and cover the growing and harvesting period of *kharif* crops. The season shows change of -0.11inch (-2.8mm) having heaviest of 0.41inch (10.4mm) recorded in 1997 and the lowest of -0.6inch (-15.2mm) in 1971 and 1985 respectively (Table-5.3). The annual trend shows decrease in precipitation throughout the series from 1961 to 2000 (Graph-5.15). The deviation reveals that most of the precipitation remains below the mean condition with a positive deviation after each ten years (Graph-5.16).

The five years average indicate decrease from 1961 to 1975 and then rise up during 1976 to 1980 and decline from 1981 to 1991 (Graph-5.17 and 5.18). The precipitation shows an increase in the last ten years i.e. 1991 to 2000. The ten years average plotted on graph-5.19 reveals change in precipitation after each 10 years. The deviation from the mean shows that the precipitation of the area was above the mean condition from 1961 to 1980 and turns negative trend during 1981 to 1990 and rises up from 1991 to 2000 (Graph-5.20).

The fifteen years precipitating remain low from 1961 to 1975 and high during 1978 (Graph-5.21 and 5.22). The deviation of 20 years average shows that after every twenty years there is oscillation in the precipitation of the season (Graph-5.23 and 5.24).

Generally, the seasonal precipitation of the arid region in Pakistan shows that the precipitation decline in winter, pre-monsoon and post monsoon season and increase during summer season. The total decline of the cold season since 1961-2000 is -0.05inch (-1.27mm), -0.04inch (-1mm) in pre-monsoon season, and -0.11inch (-2.8mm) in post monsoon season, while there is an increase of 0.05inch (1.27mm) in monsoon season throughout the series (Graph-5.25).

5.6. Precipitation variation:

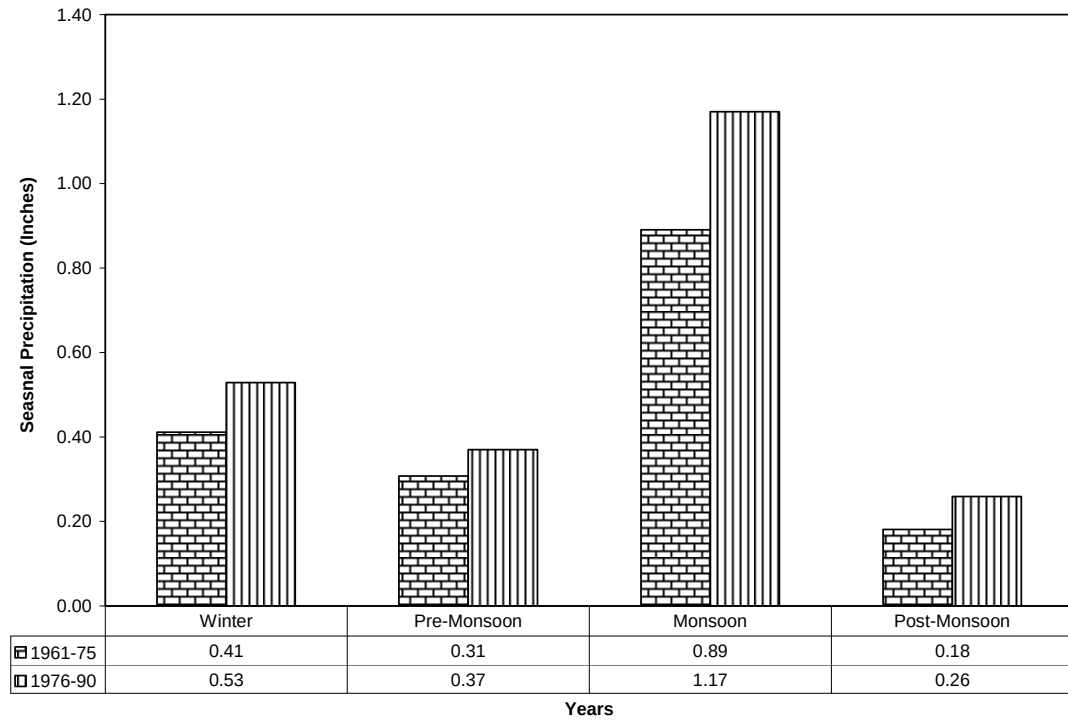
Precipitation variation is the greatest hazard to crop production in the arid region of Pakistan. During rainy season, cultivators may plough and sow large area of their land, but if it is followed by light precipitation with increase in temperature, it will prove disastrous to crop production. On the other hand, very low precipitation will only wet soil surface, which will not have any appreciable effect on the soil moisture requirement.

A comparison of precipitation variation related to different regions is given in table-5.8. As the precipitation of the arid region is not uniform across the region, therefore the area has been divided into the following five regions.

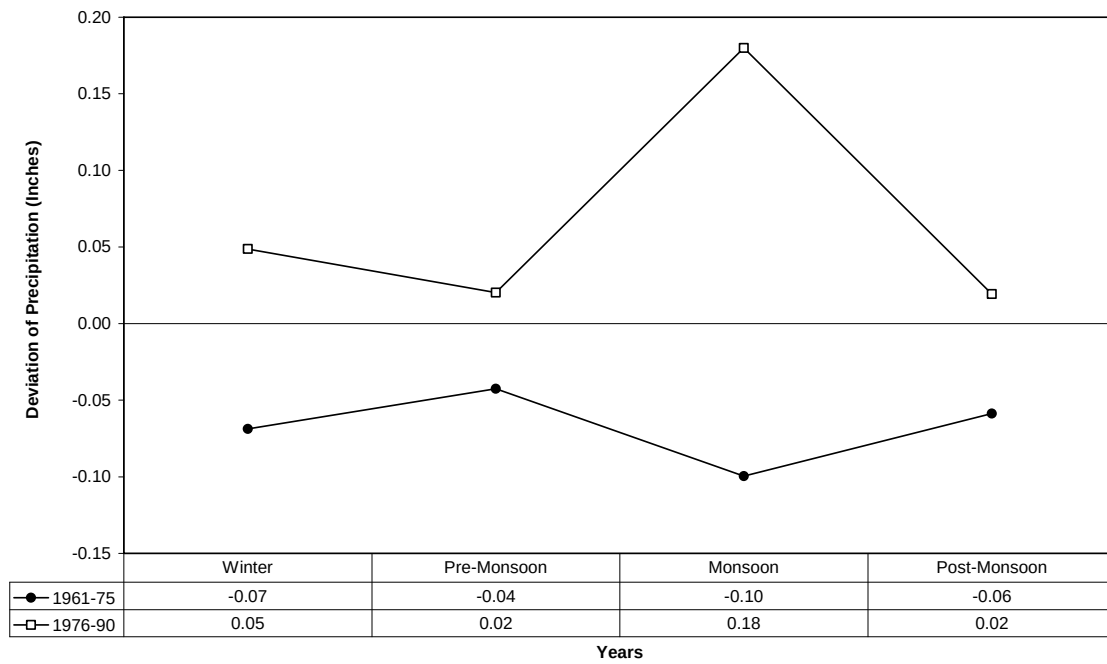
5.6.1. Piedmont/Baluchistan plateau:

The region consists of Dera Ismail Khan in Khyber-Pakhtoonkhwa, Quetta and Chagai districts in Baluchistan. Aridity prevails over considerable parts of the region. The average winter precipitation of the region is 0.54inch (13.7mm) having a sum of deviation of -1.22inch (-31mm). The mean summer precipitation is 0.6inch (15.2mm) with a fall of -0.72inch or -6.9mm (Table-5.8). In sub-seasons, the decline in cold season is -1.32inch (-33.5mm), which is the extreme

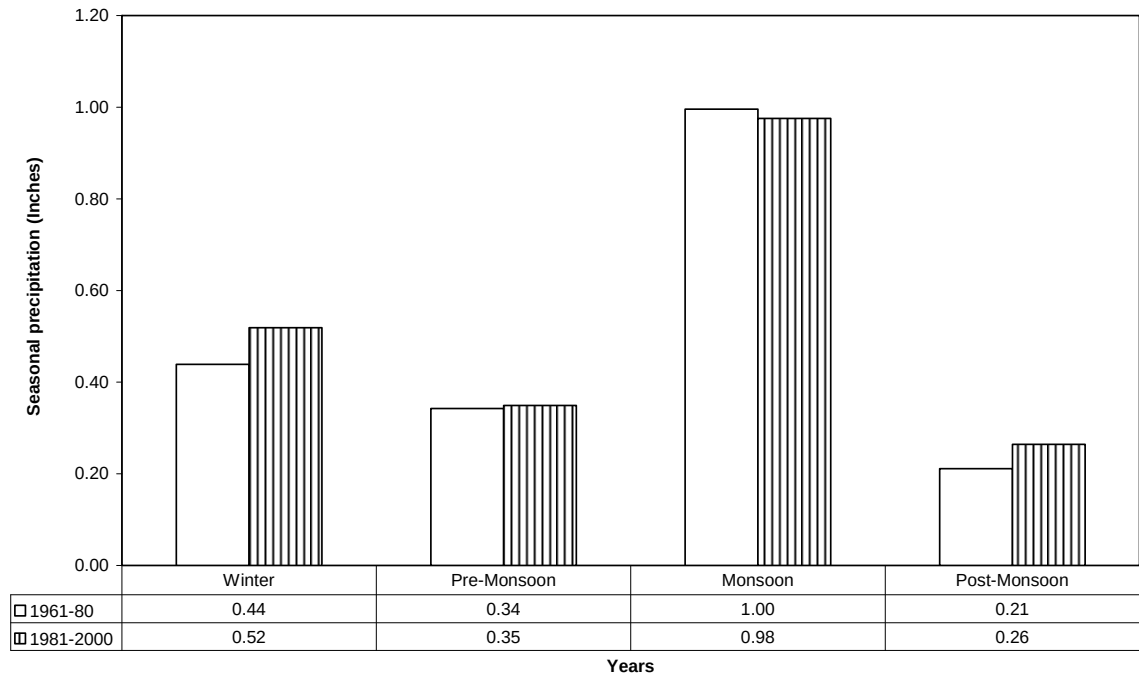
**Graph-5.21: Arid Region
Fifteen Years Average Precipitation (1961-2000)**



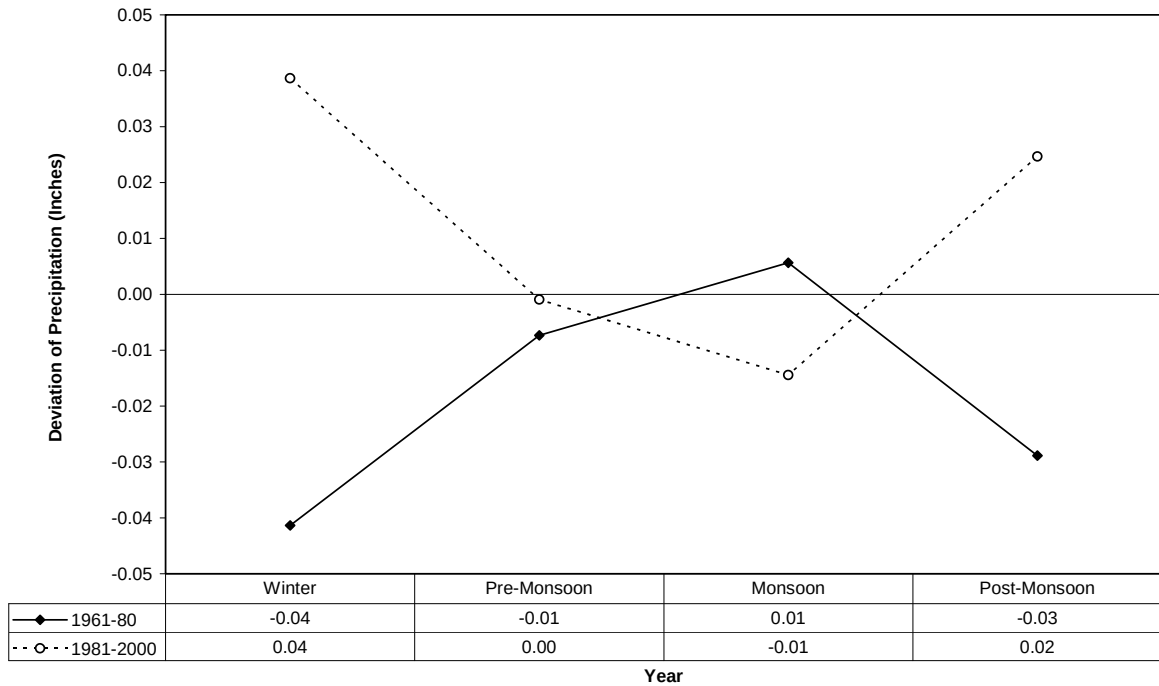
**Graph-5.22: Arid Region
Fifteen Years Deviation of Precipitation (1961-2000)**



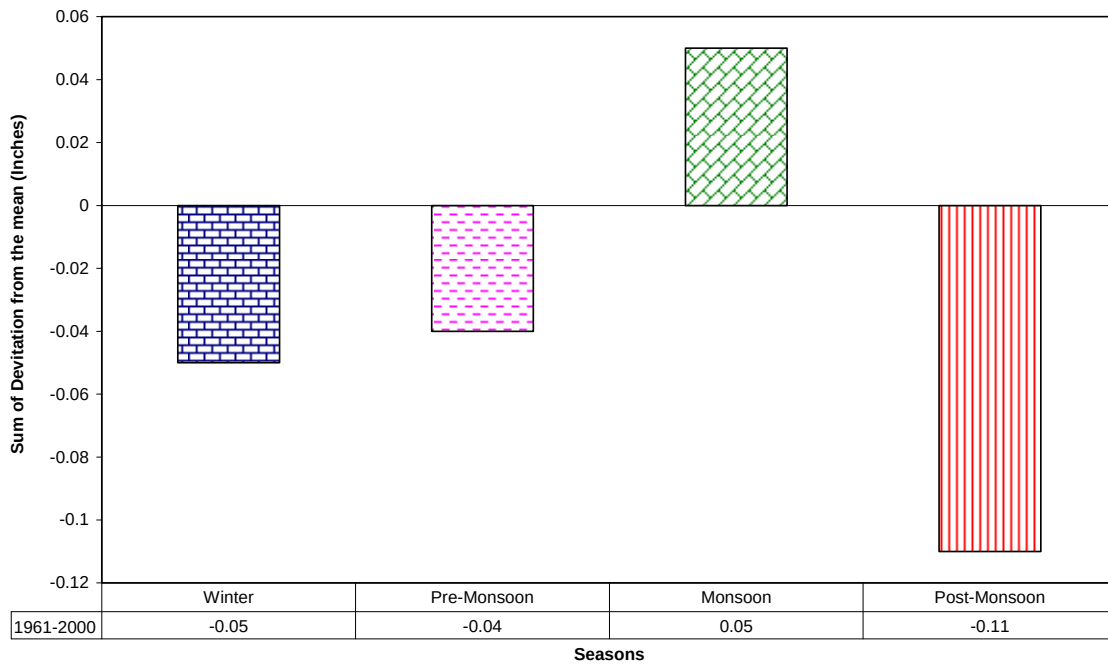
Graph-5.23: Arid Region
Twenty Years Average Precipitation (1961-2000)



Graph-5.24: Arid Region
Twenty Years Deviation of Precipitation from the Mean (1961-2000)



Graph-5.25: Arid Region
Total Oscillation of Seasonal Precipitation (1961-2000)



fluctuation as compared to other seasons. The oscillation in pre-monsoon is - 0.82inch (-7.1mm) and post monsoon season is -0.45inch (-11.4mm) with an increase of 0.2inch (5.1mm) in monsoon season. Consequently, the precipitation of the region is going to decrease in cold, pre-monsoon and post monsoon seasons, whereas in monsoon season, it reveals an increase from 1961 to 2000. This decline in precipitation might decrease the production of *kharif* and *rabi* crops and the area has become more arid.

The annual trend at Dera Ismail Khan (Khyber-Pakhtoonkhwa) indicates that the concentration of the precipitation has increased from 1961 to 2000 (Graph-5.27). At Quetta, the annual precipitation has increased from 1961 to 1982 and decreased onward 2000 (Graph-5.26). It is this long term oscillation that changed the area from semi-arid to arid climate during 1961 to 2000. The pattern of precipitation is different at Dalbandin as compared to Quetta and Dera Ismail Khan. The showers has remained high during 1961 to 1995 and suddenly

slacked till 2000 (Graph-5.28) and then shows a stationary trend throughout the season.

It is concluded, that the precipitation over Dera Ismail Khan and Quetta has decreased with passage of time, whereas, it has remained stable over the southwestern Baluchistan and Kharan desert that effect the production of crops in the region.

5.6.2. Northern arid region:

The region covers Gilgit-Baltistan province and Chitral district in Khyber Pakhtoonkhwa. At Skardu, the annual precipitation shows an increase from 1961 to 1995 and decreasing upto 2000. It is this long term increase that dropped the southern observatories (Chilas and Astore) from arid to semi-arid climates during 1961 to 2000 (Graph-5.29). Gilgit shows a slight rise in precipitation throughout the series. There is a change in the precipitation of the observatory after every six years. The observatory of Drosh shows a high fall from 1961 to 2000 (Graph-5.31). The seasonal oscillation of the Gilgit-Baltistan region indicates that the winter precipitation of the region remained unchanged during 1961 to 2000, whereas the summer precipitation shows an increase of 0.01inch (0.3mm). In sub-seasons, the share of cold, pre-monsoon, and monsoon seasons have declined at the rate of -0.01inch (-03mm) per year, while the concentration of post monsoon has remained stable (Table-5.8). This decrease in the precipitation of the region might affect the crop production and caused shift in the boundaries of growing season towards north.

5.6.3. Coastal region:

The observatories of Pasni and Karachi cover this region. The eastern margin of the coastal region receives heavy precipitation during summer (monsoon), whereas at western tip, it is from western disturbances (winter season). The annual trend of precipitation at Karachi shows a decreasing pattern from 1961 to 2000 (Graph-5.32). At Pasni, the annual trend of precipitation indicates that the area has remained stable throughout the series (Graph-5.33).

The seasonal deviation of precipitation at Karachi shows that during winter it fell to -0.39inch (-9.9mm), while in summer it rose upto 0.27inch or 6.9mm (Table-5.8). In sub- seasons, the precipitation of the area was -0.39inch (-9.9mm) in cold, -0.57inch (-14.5mm) in pre-monsoon and -0.5inch (-12.7mm) in post monsoon seasons. The monsoon season reveals average increase of 1.26inches (32mm) throughout the series. This increase in monsoon precipitation and decrease in the other seasons might shorten the growing season of *kharif* and *rabi* crops.

5.6.4. Thar and Cholistan desert:

The heavy showers in this region are received in monsoon season, whereas the ratio of winter precipitation remains low. The annual trend of precipitation at Chhor shows an increase from 1961 to 2000 (Graph-5.34). At Bahawalpur, the precipitation trend is opposite as compared to Chhor (Graph-5.35). Generally, the rate of precipitation at southern Punjab is decreasing with passage of time, while there is an increasing trend over eastern Sind particularly at Chhor (Thar desert).

The seasonal deviation in Thar and Cholistan deserts indicate a decline of -0.01inch (-0.25mm) in winter with stable precipitation in summer season (Table-5.8). The sub-seasons of the region show an increase of 0.01inch (0.25mm) during pre-monsoon, monsoon, and post monsoon seasons, while it is constant in cold season (Figure-7.4).

Table-5.8: Arid Region
Seasonal Fluctuation of Precipitation (Inches)

Regions	Station	Main Seasons				Sub-Seasons							
		Winter	Devi	Summer	Devi	Winter	Devi	Pre-Monsoon	Devi	Monsoon	Devi	Post-Monsoon	Devi
Western	Dalbandin	0.53	-0.62	0.09	-0.87	0.58	-0.71	0.10	-0.63	0.06	-0.82	0.07	-0.33
	D I Khan	0.56	-0.59	1.11	0.15	0.67	-0.62	0.54	-0.19	1.90	1.02	0.29	-0.11
	Average	0.54	-1.22	0.60	-0.72	1.29	-1.32	0.73	-0.82	0.88	0.20	0.40	-0.45
Northern	Gilgit	0.34	-0.25	0.57	0.03	0.41	-0.29	0.58	-0.04	0.46	0.05	0.18	-0.03
	Skardu	0.85	0.26	0.52	-0.02	0.98	0.28	0.65	0.03	0.35	-0.06	0.25	0.04
	Average	0.59	0.00	0.54	0.01	0.70	-0.01	0.62	-0.01	0.41	-0.01	0.21	0.00
Coastal	Karachi	0.27	-0.39	0.93	0.27	0.27	-0.39	0.09	-0.57	1.92	1.26	0.16	-0.50
Eastern	Chhor	0.09	-0.08	1.20	0.23	0.08	-0.08	0.34	-0.01	2.15	0.50	0.34	0.09
	Bahawalpur	0.24	0.07	0.73	-0.24	0.24	0.08	0.37	0.02	1.16	-0.49	0.17	-0.08
	Average	0.17	-0.01	0.97	0.00	0.16	0.00	0.35	0.01	1.65	0.01	0.25	0.01
Central	Hyderabad	0.11	-0.04	0.86	0.18	0.11	-0.05	0.23	0.06	1.58	0.32	0.19	0.03
	Jacobabad	0.20	0.05	0.50	-0.18	0.20	0.04	0.12	-0.05	0.94	-0.32	0.12	-0.04
	Average	0.15	0.00	0.68	0.01	0.16	-0.01	0.17	0.01	1.26	0.00	0.16	-0.01

Source: PMDC, Karachi, 1961-2000

5.6.5. Central irrigated plain:

This region covers the western part of Sind and Kachhi plain in eastern Baluchistan. The area has received heavy precipitation in winter and post monsoon seasons. Hyderabad and Jacobabad in Sind and Sibi in Baluchistan limit the boundary of the region. At Hyderabad, the annual precipitation reveals a negative trend throughout the series (Graph-5.36). Jacobabad shows a positive trend during 1961 to 2000 excluding 1961 to 1966 and 1995 to 2000, when it turns into negative trend (Graph-5.37). Generally, the precipitation increases over the irrigated plain in Sind and decreases at central Baluchistan.

The deviation from the mean of the region shows that during winter season, the precipitation of the area has remained stable, while in summer there was an average increase of 0.01inch or 0.25mm (Table-5.8). During sub-seasons, there is a fall of -0.01inch (-0.25mm) in cold and post monsoon seasons respectively. The pre-monsoon season shows a rise of 0.01inch (0.25mm), whereas the monsoon precipitation remains stable.

Chapter-6

Impact of Climate Change

on Agriculture and Indus Drainage Basin

Pakistan is an agriculture country and most of its population and economy is based on the agriculture sector. Due to non-availability of water for irrigation and scanty precipitation, a major part of the arid region is unproductive or rainfed. It is therefore, needed to evaluate the impact of climate change on agriculture as well as ecosystem of the arid region.

This chapter explains the impact of climate change on crop productivity, landuse, cropping seasons, and agriculture environment. Temperature and precipitation fluctuation has also been dealt with in relation to water resources, desertification, and severe weather events.

6.1. Impact on crops:

Agriculture has always been dependent on climate and soil. For crop production and adaptation the predictability of climate change is of utmost importance. What is required is an understanding of the effect of the changing climate on agriculture environment.

A temperature rise of 1.6°C (Chapter-4) extends the growing seasons, cultivable area, early maturity of grain and the growing of new crops. *"If on the one hand the rise of temperature is beneficial to the crops, on the other hand the solar radiation also affects the weeds and pests, getting better living conditions*

under higher temperatures. The combination of the weeds, pests and poor herbicide reduces the potential crop yields," (Aggarwal., Sinha, 1993). During the growth cycle of the plant, "water is needed at the initial stages of production, but not during the final stage. Low precipitation has negative effect on the germination of the seed. Dry conditions, frequency, and severity of dust storms all result in decreased production of major grains."

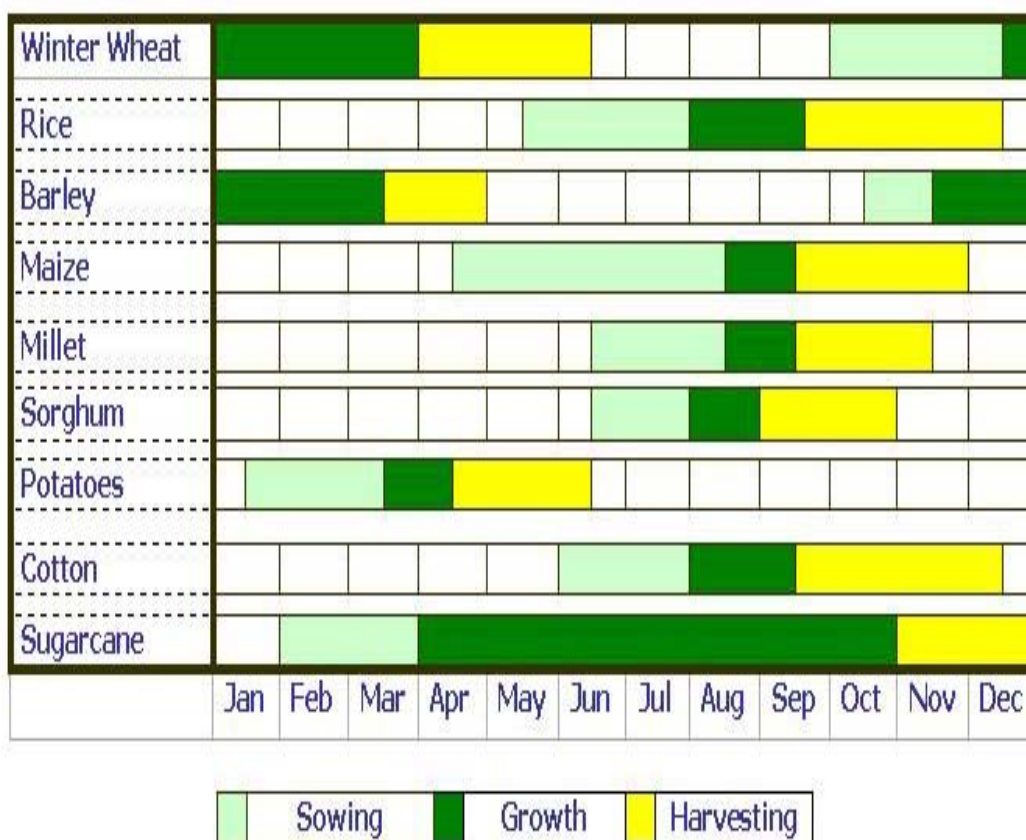
Krishnamurthy (2011) has studied, *"the climate extreme, agriculture and natural resources in India using regression, covariance and quartile distribution. He has evaluated the impact of temperature and precipitation on crop-specific data on district level yield for time period of 1971 to 2006"*. Kienzler (2012) has studied, *"the characteristics of climate change in the remote mountain areas of Khyber- Pakhtoonkhwa in northwestern Pakistan and the possible impacts of temperature and precipitation changes on agriculture, which is the mainstay of food security in the area."*

6.1.1. Cropping seasons:

There are two principal crop seasons in the arid region of Pakistan, namely *"kharif,"* and *"rabi"* (Graph-6.1). The cropping pattern of the arid region has been plotted on map-6.1 and discussed as follow.

6.1.1.1. Kharif crops:

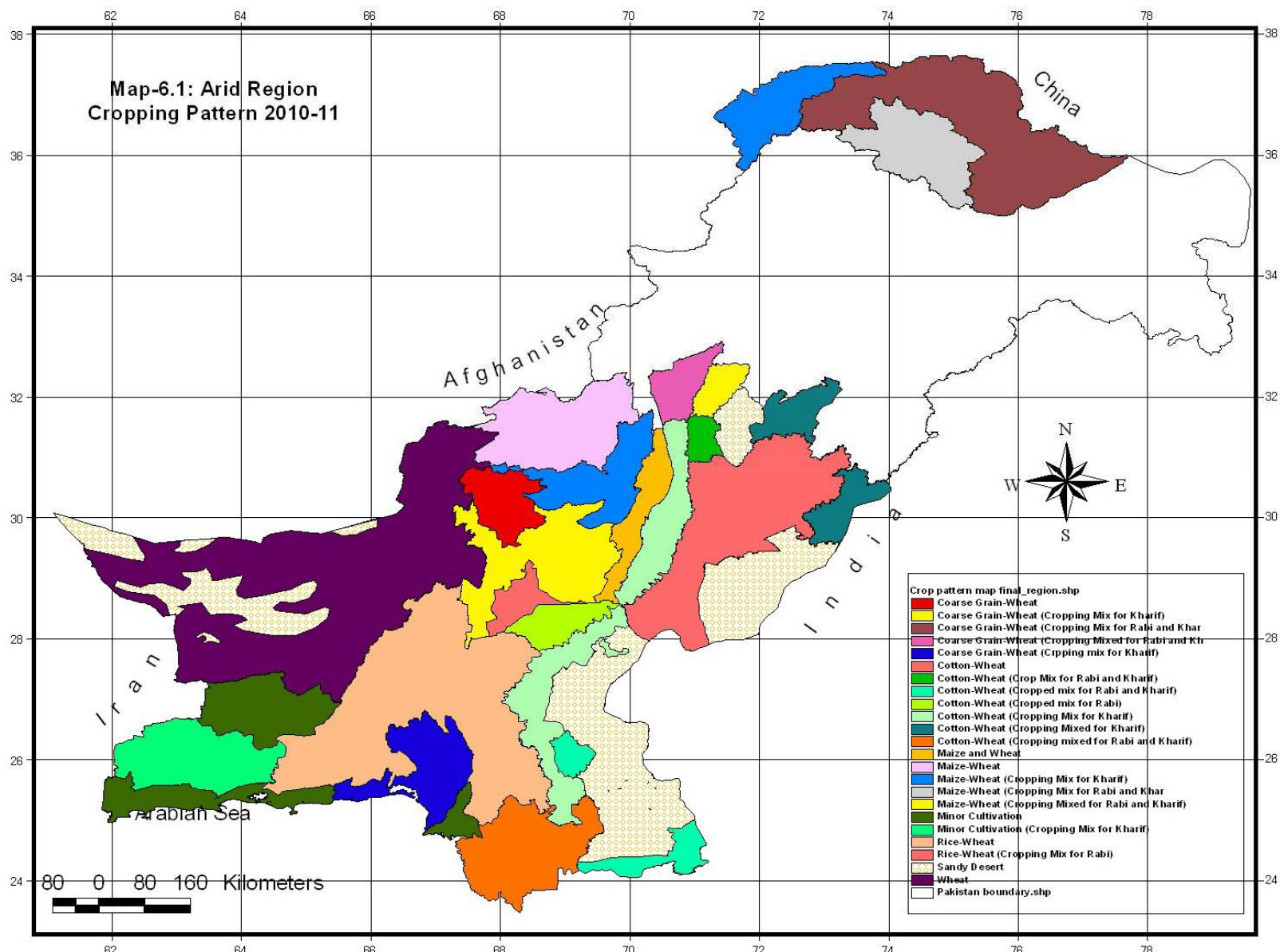
In summer season the crops are sown from April to June and harvested from October to December (Graph-6.1). *Kharif* crops need plenty of water and heat. Main *kharif* crops are cotton, rice, sugarcane, tobacco, maize, and millet. They

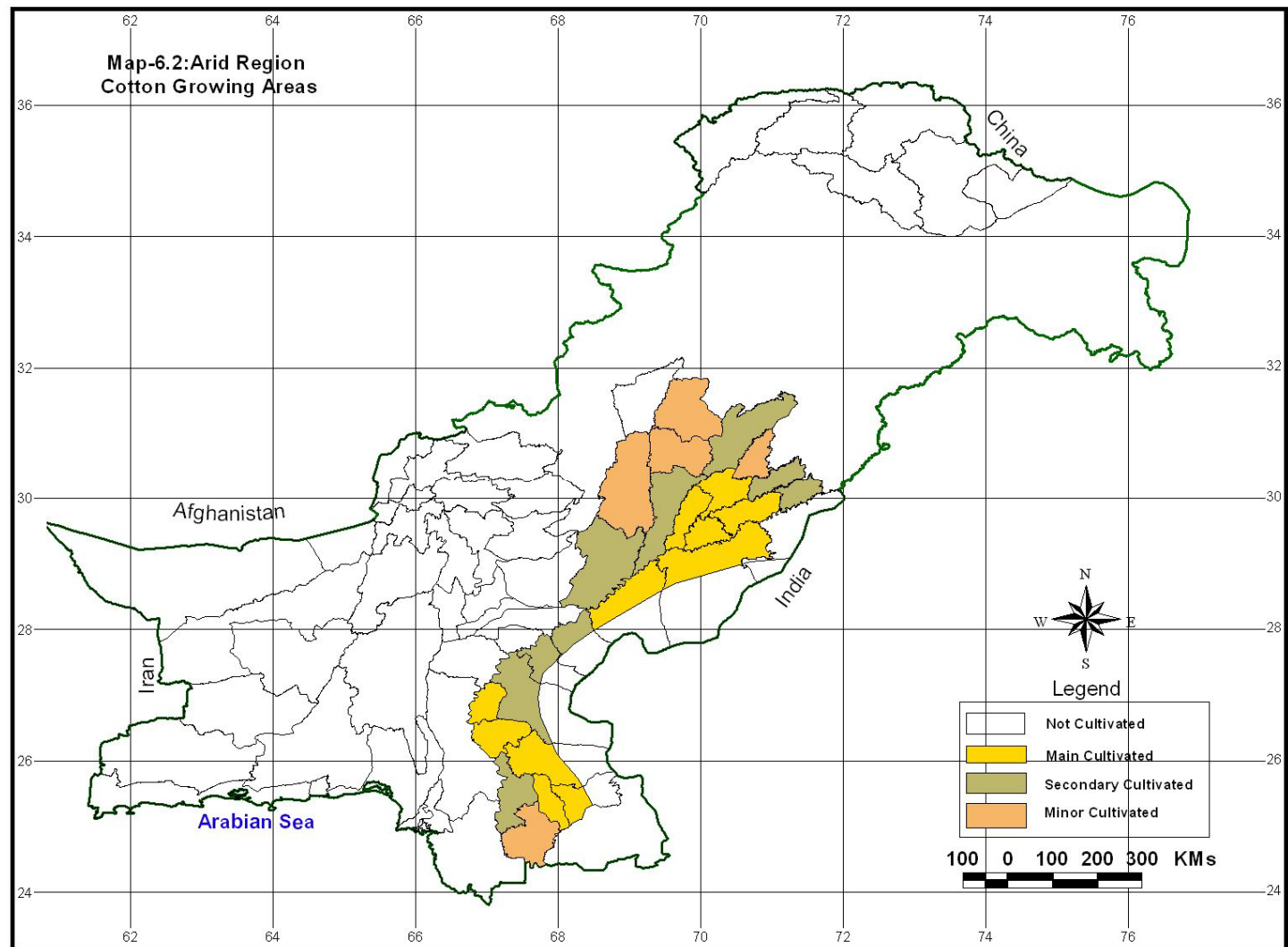


Graph-6.1: Cropping Pattern of Major Crops, by Agriculture Census

Organization, Lahore, 2000.

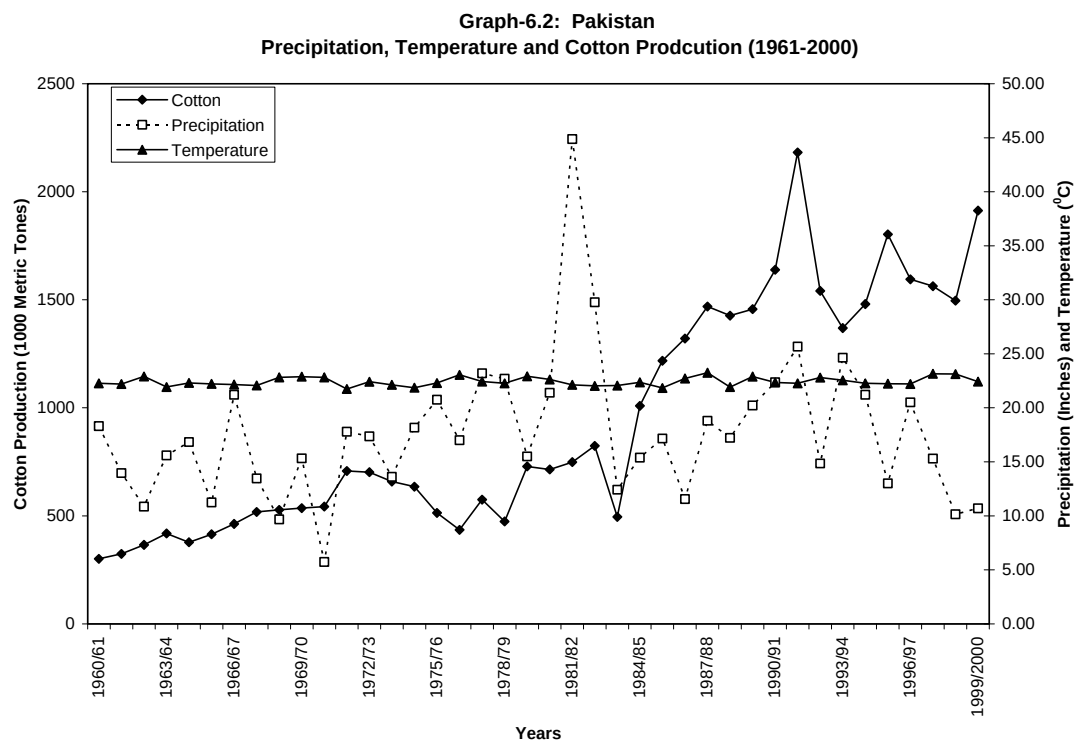
cover 45% of the cultivated land and count for the major cash crops in the arid region of Pakistan. The decline in precipitation has effected the production, while increase in temperature has provided suitable condition for the germination and growth of the crops during *kharif* season.





6.1.1.1.1. Cotton:

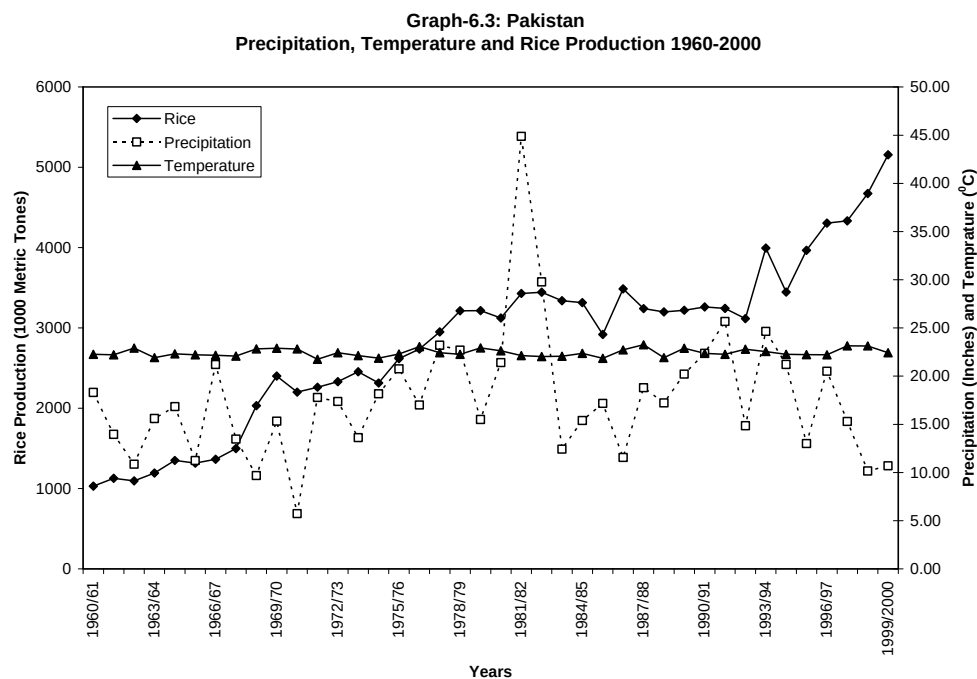
It is one of the main cash crops and an important export commodity. Cotton cultivation requires a long frost free time, moderate rain, and longer shining days. Three fourth of the cotton of Pakistan is grown in the arid region of Punjab, whereas the remaining is grown in the arid irrigated plains of Sind (Map-6.1 and 6.2).



It is evident that the cotton production in the arid region of Pakistan is more vulnerable to the on going climate change. Graph-6.2 shows the comparison of the cotton production, precipitation, and temperature. The cotton production of the region reveals that it is directly proportional to precipitation and temperature from 1961 to 1970 and inversely proportional from 1971-1980. From 1981 to 2000, the trend is again directly proportional with precipitation. The cotton production shows an increase from 1981 to 1990 with an increase in

precipitation and then slackens onward to 2000 with the fall in precipitation of the region. Furthermore, there is a direct proportion between temperature and cotton production throughout the series (1961-2000). It is concluded that the cotton production of the country has declined with passage of time due to fall in precipitation of the region and surface runoff and need adaptation. However, it is expected that it may be recovered with the development of irrigation system and utilization of the advance agriculture technologies and fertilizers (Table-6.4).

6.1.1.1.2. Rice:

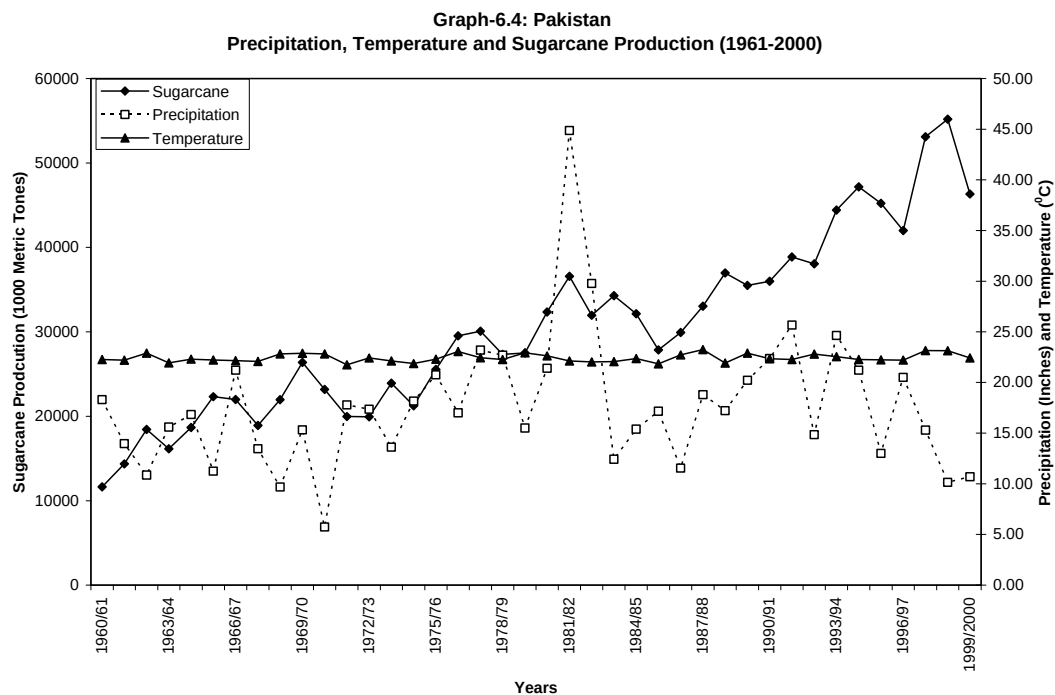


Rice is an important cash as well as food crop that covers one-tenth of the cultivable land in the arid region. The main rice cultivated regions are lower Punjab, Sind, and Nasirabad in Baluchistan (Map-6.3). The comparison of rice production, precipitation, and temperature has been plotted on graph-6.3. The trend reveals that the rice production of the region from 1961 to 2000 increases

with little decline in the years having meteorological drought. Overall, there is no impact of precipitation fluctuation on the rice cultivation in the arid region of Pakistan. The rice production shows an increase with the increase in temperature and directly proportional to each other. It is expected that this stability in the rice production may be because of the availability of surface water in the entire irrigated lands of the lower Punjab and Sind (Table-6.4).

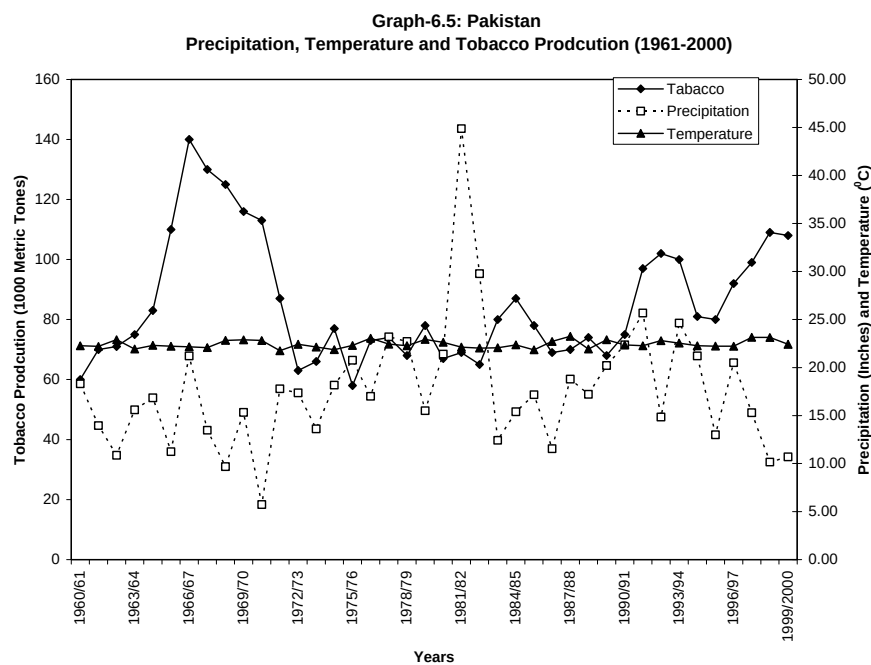
6.1.1.1.3. Sugarcane:

It is a crop native to warm temperature and an important cash crop of the arid region. It requires 16 sessions of irrigation and heavy fertilization for good



growth (Khan, 1991). It is harvested mechanically in lower Punjab and Sind, where sufficient water and high temperature are available for the irrigation and growth (Map-6.4).

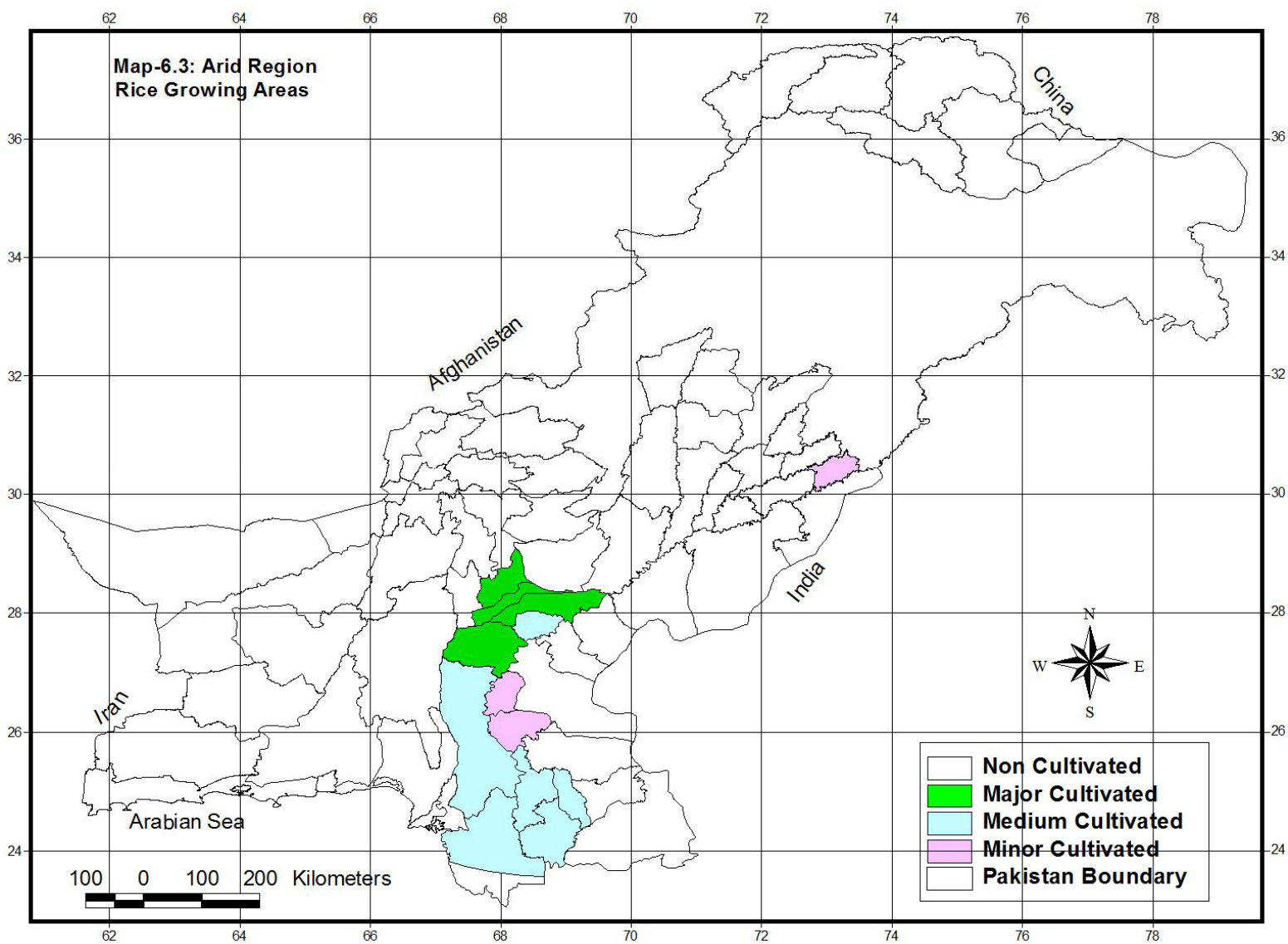
The comparison of sugarcane production and the annual trend of precipitation and temperature reveal that the production of the crop has increased during 1961 to 2000 having rise and fall in the period, where the precipitation decreased (Graph-6.4). Generally, the production of sugarcane indicates an increasing trend throughout the series and this may be the result of the well established canal system and an increase in temperature in the sugarcane grown areas of Sind and lower Punjab (Table-6.4).

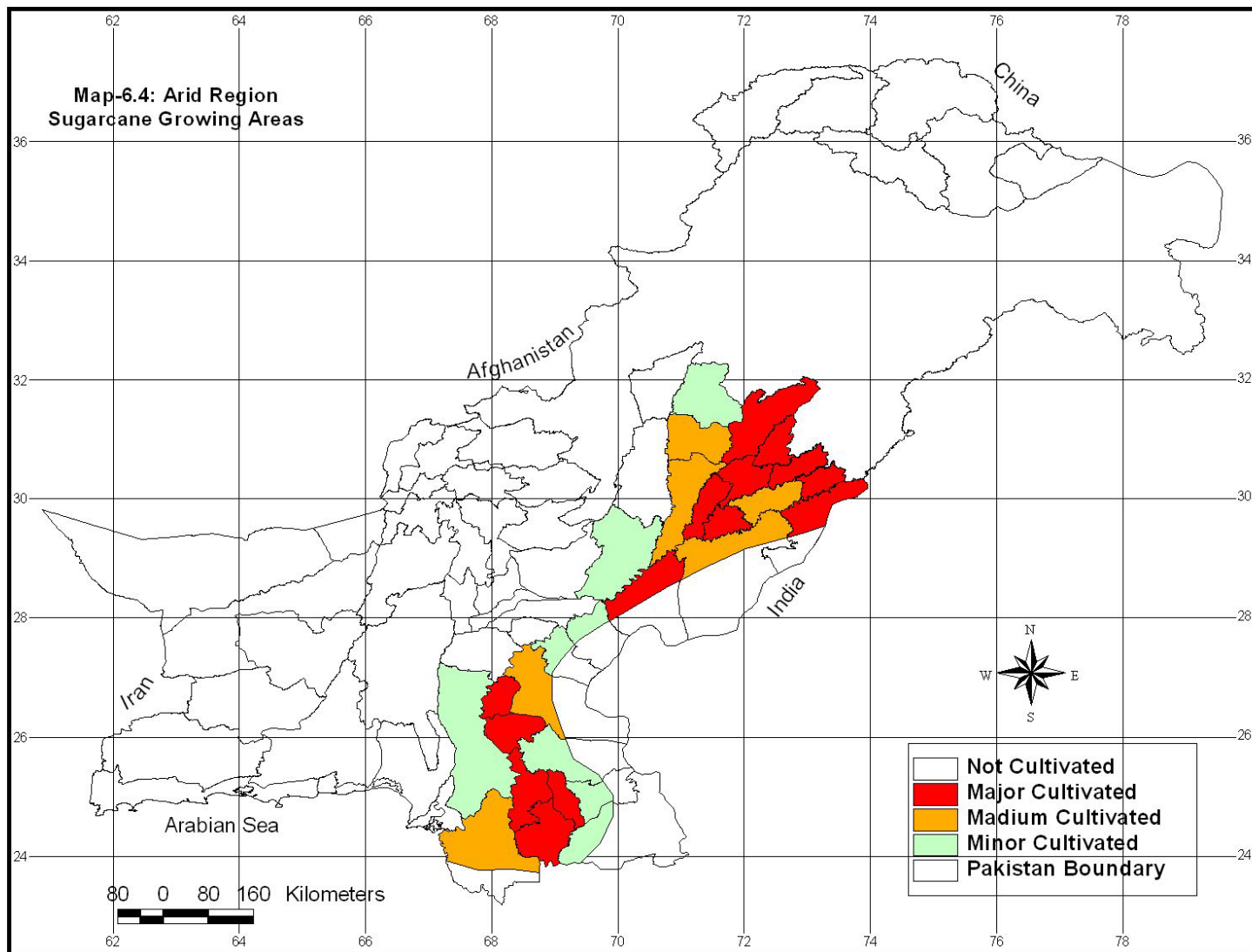


6.1.1.1.4. Tobacco:

Tobacco is a cash crop grown in few areas of Sind and lower Punjab in the arid region of Pakistan.

The annual production of tobacco and trend of precipitation and temperature from 1961 to 2000 shows that it has declined from 1965 to 1995 and then rose up





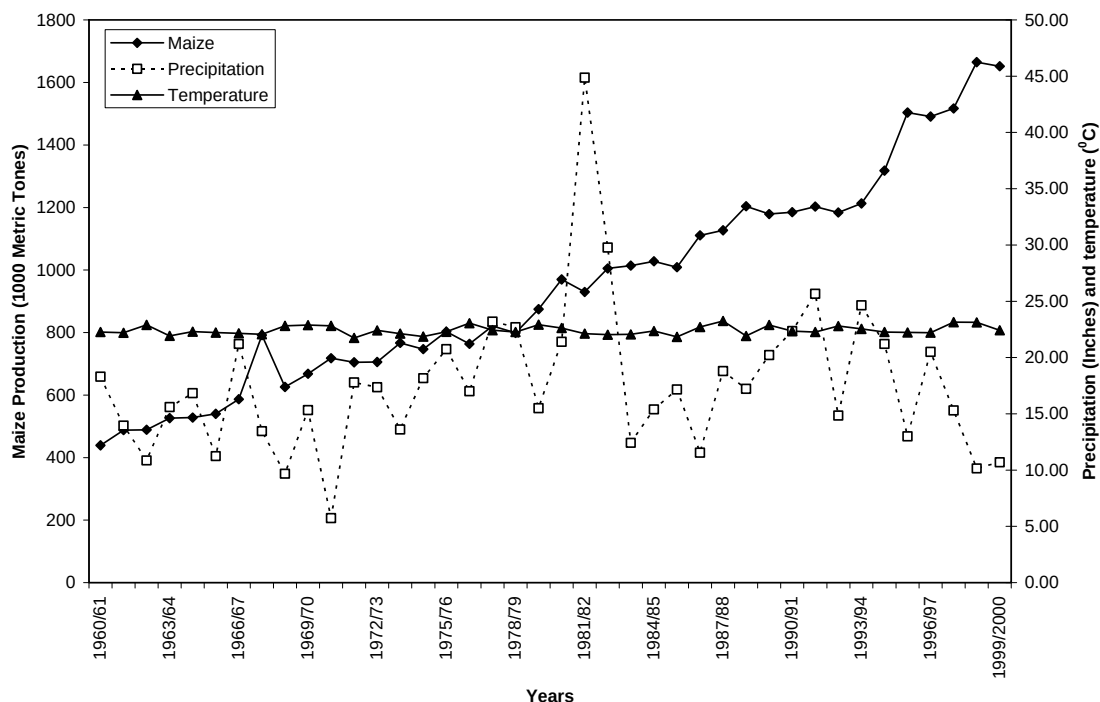
onward to 2000 (Graph-6.5). From 1961-65, the tobacco production and precipitation are inversely proportional to each other. From 1966 to 2000, the trend of tobacco production and precipitation is directly proportional and continuously decreases with passage of time, while there is inverse relationship between tobacco and temperature. The production of the crop shows an increase during the years, where there is high temperature and decline in the cold years. Generally, the production of tobacco shows decrease with increase in temperature throughout the series. The data show that the crop is more vulnerable to the on going climate change and need mitigation and adaptation (Table-6.4). This decrease in the production of tobacco in the arid region of Pakistan might be the result of decrease in the cultivation of tobacco area due to insufficient precipitation or may be the decrease in the tobacco industry.

6.1.1.1.5. Maize:

It is commonly known as corn and ability to grow in diverse climates and cultivated throughout the arid region in Pakistan. It is grown in the moderate precipitation areas even without the irrigation facilities (Map-6.5).

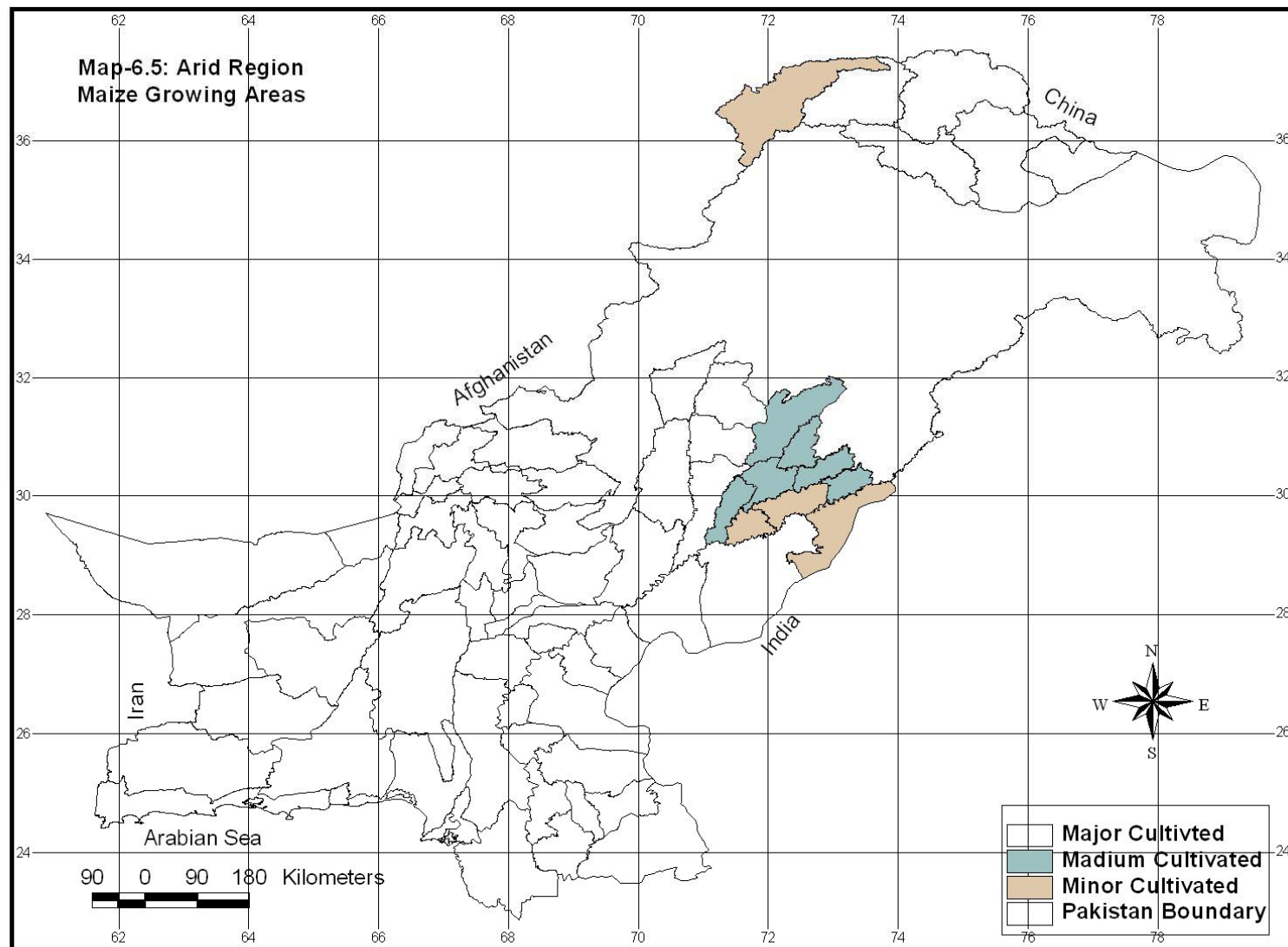
Graph-6.6 shows the maize production, precipitation, and temperature. It reveals that maize production and precipitation are inversely proportional to each other. Thus, production of maize increases as the precipitation decreases, whereas, it is directly proportional to temperature throughout the series. Due to decrease in precipitation the maize grown area increases with passage of time (Table-6.4).

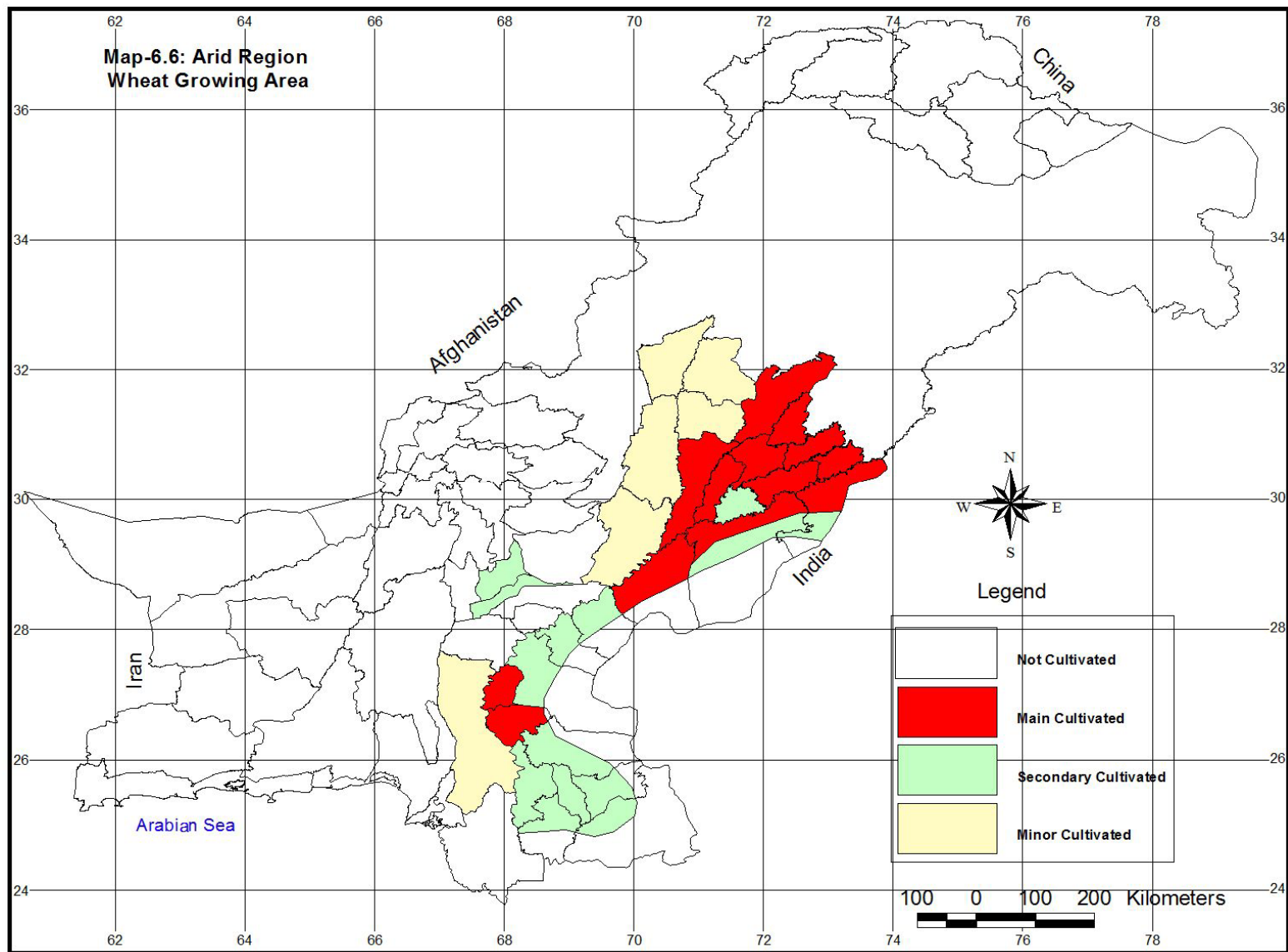
Graph-6.6: Pakistan
Precipitation, Temperature and Maize Production (1961-2000)



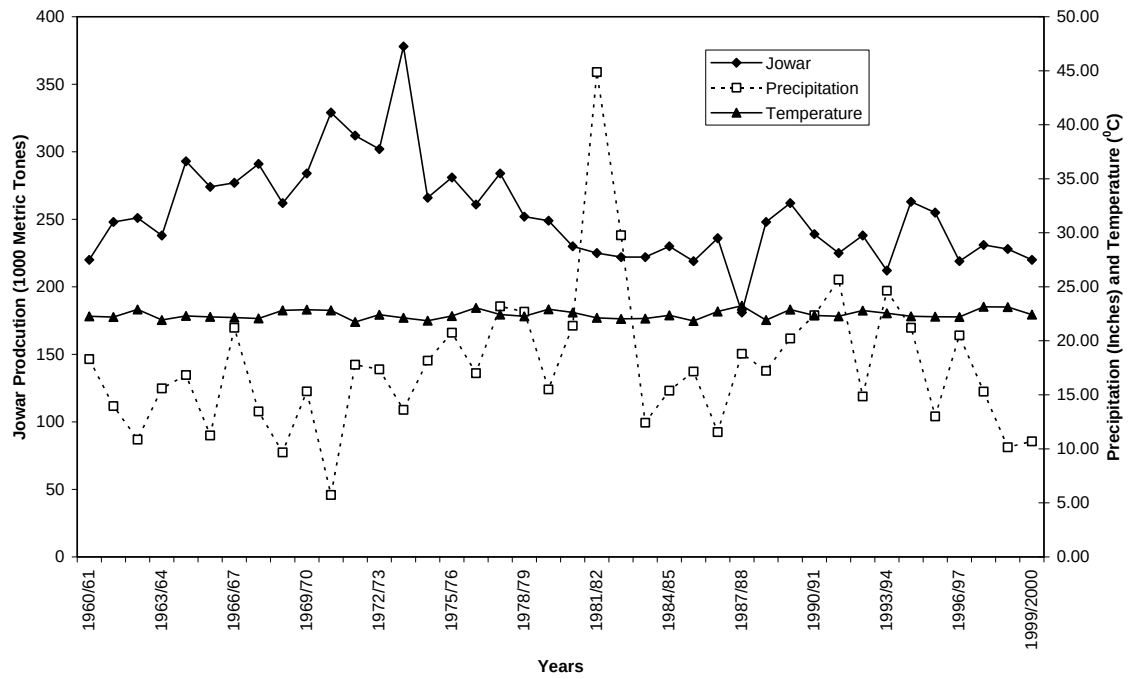
6.1.1.1.6. Millets:

The millets are small seeded species, grown for food and fodder, in dry or rainfed environment. "Out of total area under the millet cultivation, 60.7% is in Punjab, 37.8% in Sind, 0.1% in Baluchistan (Khan, 1991)". Sorghum and Pearl millet are the most important cereal crops in the arid region of Pakistan. The Sorghum production shows an increase from 1961 to 1975 followed by decrease upto 2000. The trend is directly proportional to precipitation and indirectly proportional to temperature (Graph-6.7). The crop is on risk to the on going climate changes in the arid region of Pakistan and need adaptation immediately (Table-6.4).

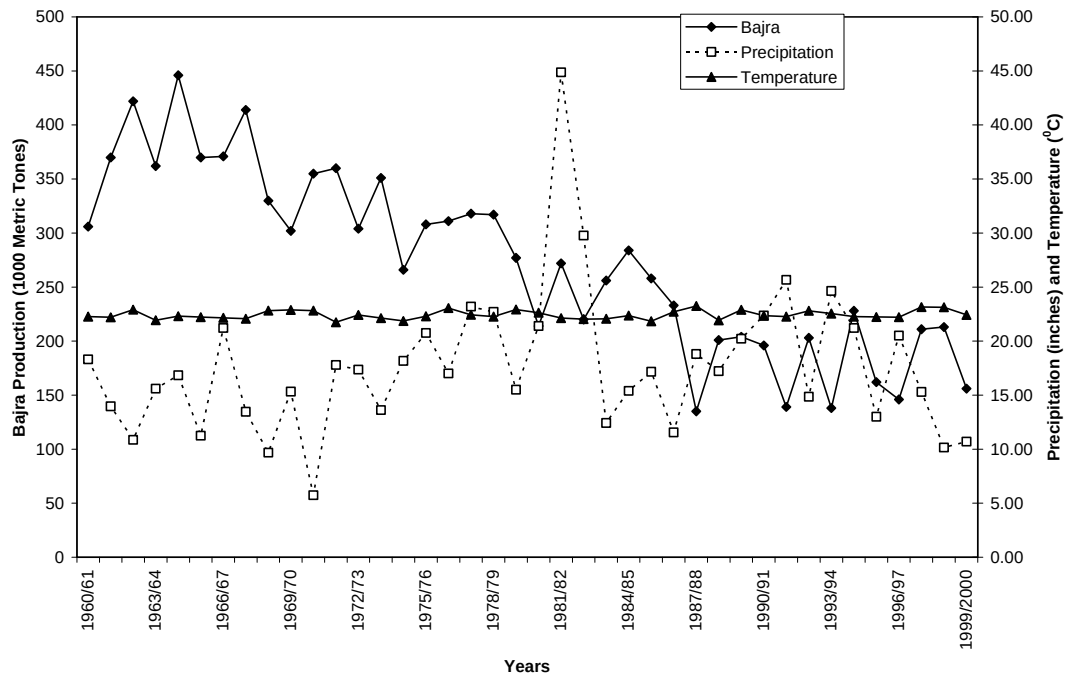




Graph-6.7: Pakistan
Precipitation, Temperature and Jowar Production (1961-2000)



Graph-6.8: Pakistan
Precipitation, Temperature and Bajra Production (1961-2000)



The trend of Pearl millet production and precipitation reveals a very strong direct relationship from 1961 to 2000, while it is converse between the production and temperature (Graph-6.8). It shows that the agriculture activities in the rainfed areas are more vulnerable to the ongoing climate change and need adaptation to cope with the problem.

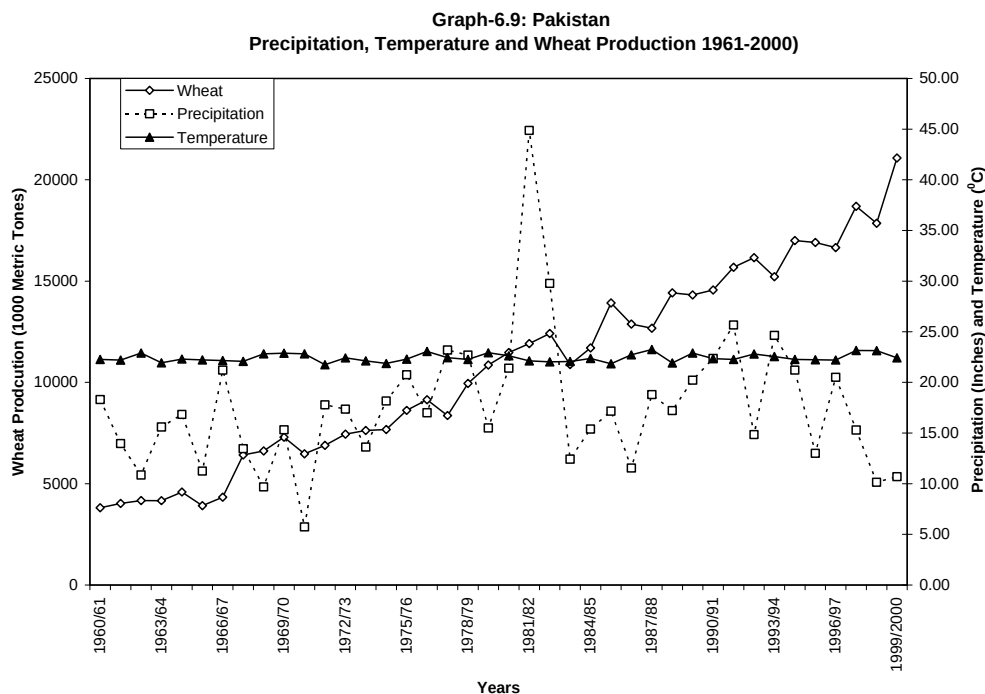
6.1.1.2. *Rabi* crops:

Rabi crops are sown in winter season from October to December and harvested in April and May. These crops including wheat, barley, oil seeds, and gram need less amount of water due to moderate sunshine. They cover about 55% of the total cultivated land of Pakistan (Khan, 1991). The main *rabi* crops in the arid region are as follow.

6.1.1.2.1. *Wheat*:

Wheat is the most important *rabi* and grain crop. It occupies the largest cultivated area throughout the arid region. It can grow under a wide range of conditions as long as the temperature is not very hot. Wheat is grown on rainfed area as well as on irrigated plain of the lower Punjab, Sind, and Nasirabad in Baluchistan (Table-6.4).

According to Khan, 1993, "*Punjab is the main wheat producing area contributing 72% of the total production. Sind is the next largest wheat producer with a share of 17% of the total production of the country*" (Map-6.6).

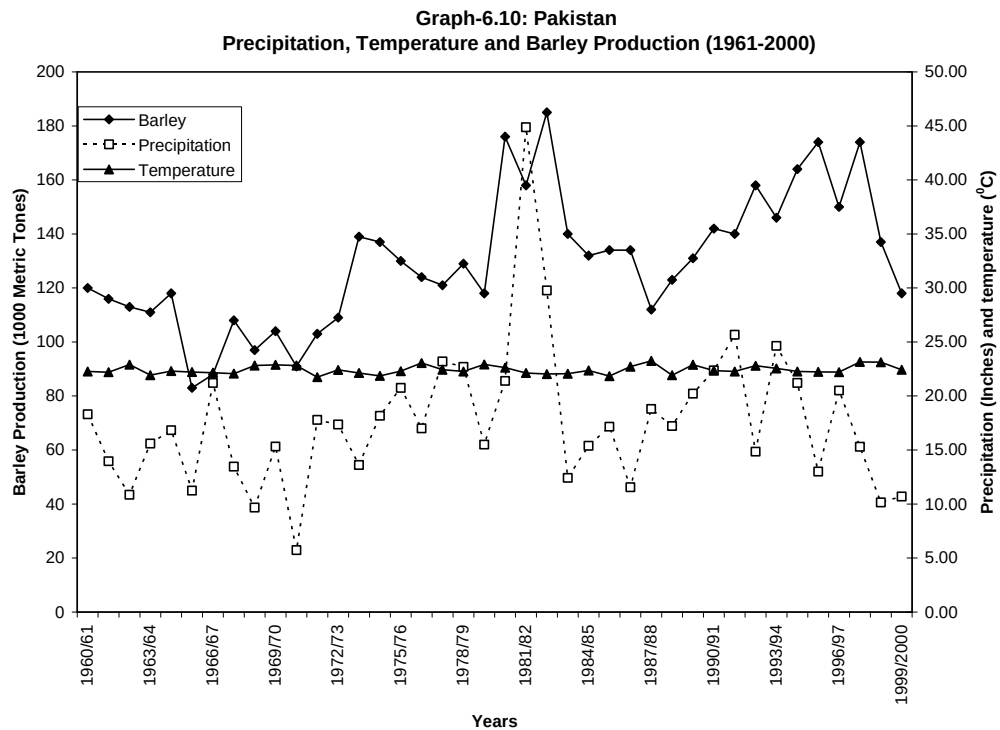


It seems that there is no visible effect of precipitation fluctuation on the wheat cultivation and yield, as is evident from graph-6.9. However, the temperature fluctuation is directly proportional to the wheat production from 1961-2000. This increase in the wheat production might be the result of increase in the wheat cultivated area.

6.1.1.2.2. Barley:

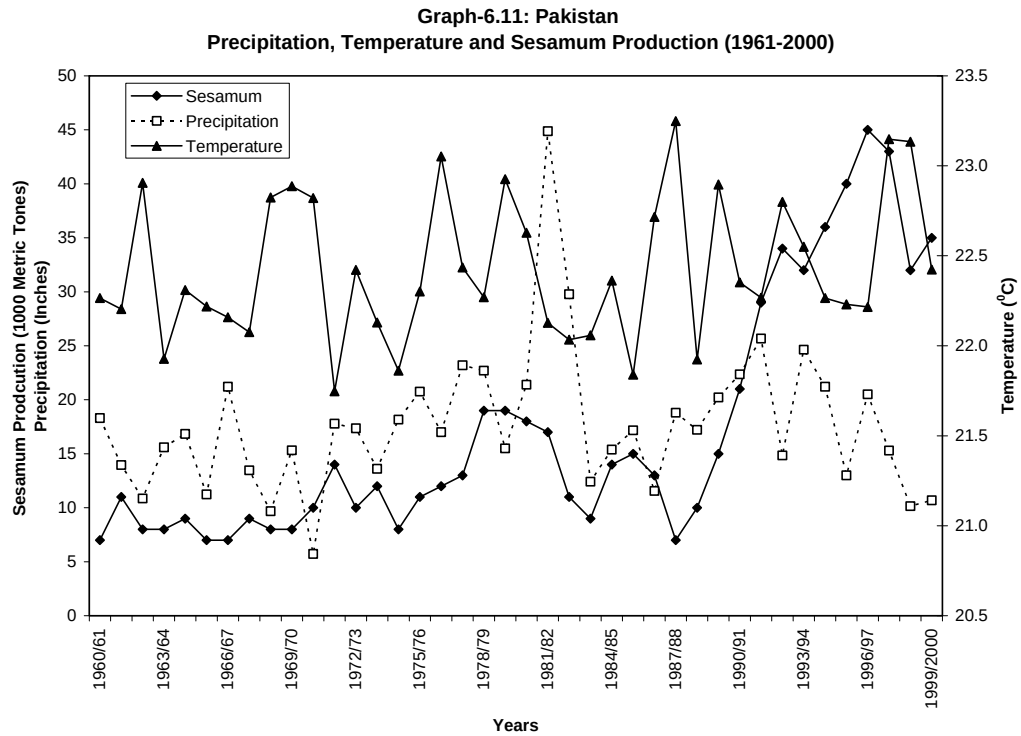
It is grown in cool and dry climate, having a short growing season and is relatively tolerant to drought. The suitable environment for its cultivation is the rainfed areas of Sind, Punjab, and Baluchistan. The cross-matching of temperature, precipitation, and barley production plotted on graph-6.10 reveals that the yield decreases with decrease in precipitation and increase in the temperature from 1961-2000. The production of the crop is directly proportional

to precipitation and inverse to temperature. It seems that because of the ongoing climate change the barely production decreases with passage of time (Table-6.4).



6.1.1.2.3. Oil seeds:

It is liquid materials derived from many plants. Though different parts of plant may give oil but it is primarily extracted from the seeds. Sesame indicum crop has been selected to analyze for the impacts of precipitation and temperature fluctuation on the production of the oil seeds. This is directly proportional to precipitation from 1961-1995 and inversely till 2000, whereas it is directly proportional to temperature throughout the series. The results plotted on graph-6.11 reveal that the production of oil seeds remains stable from 1961 to 2000 (Table-6.4) and this might the

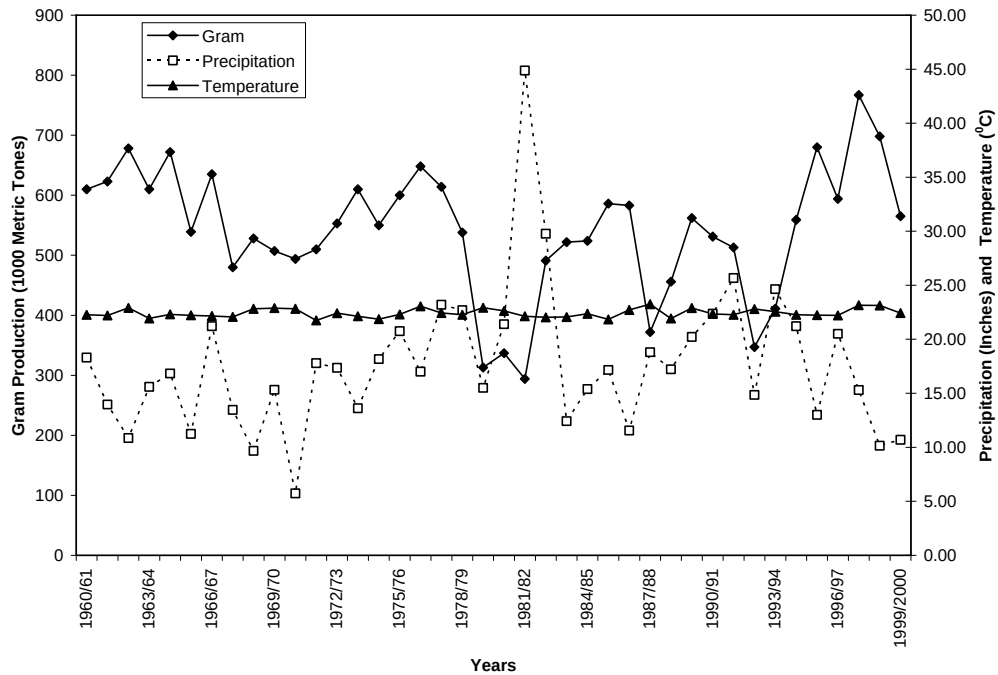


result of increase in temperature. It is expected that due to decrease in precipitation and shortage of irrigated water most of the cultivated land change into the rainfed areas that might have be increased the cultivated land of the sesame crop in the arid region.

6.1.1.2.4. Pulses:

Pulses are important crop with high nutritional value. They include gram and others, grown in the rainfed area on marginal lands. Eastern part of Indus plain in lower Punjab and Sind and parts of Baluchistan are the major production areas.

Graph-6.12: Pakistan
Precipitation, Temperature and Gram Production (1961-2000)

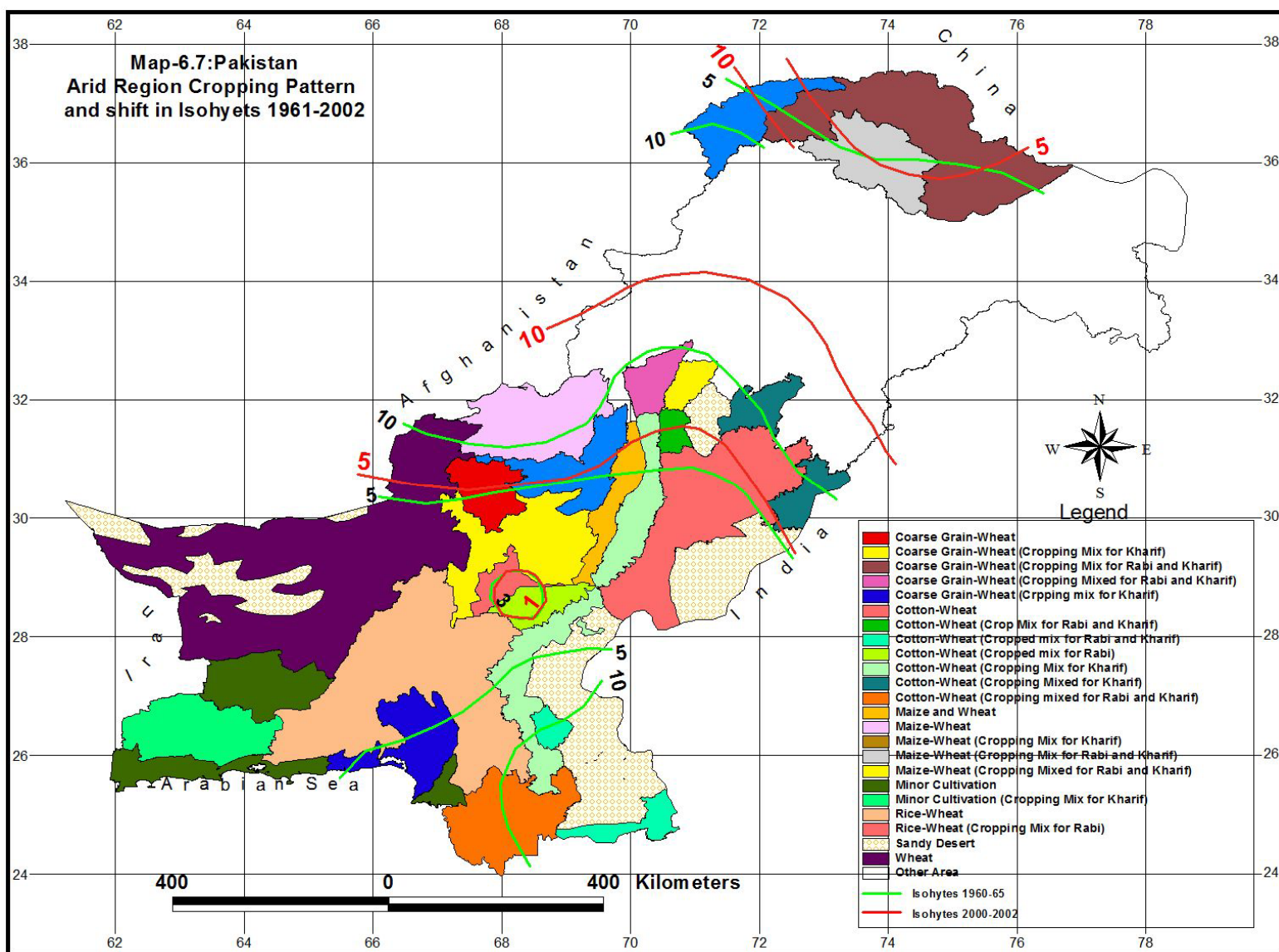


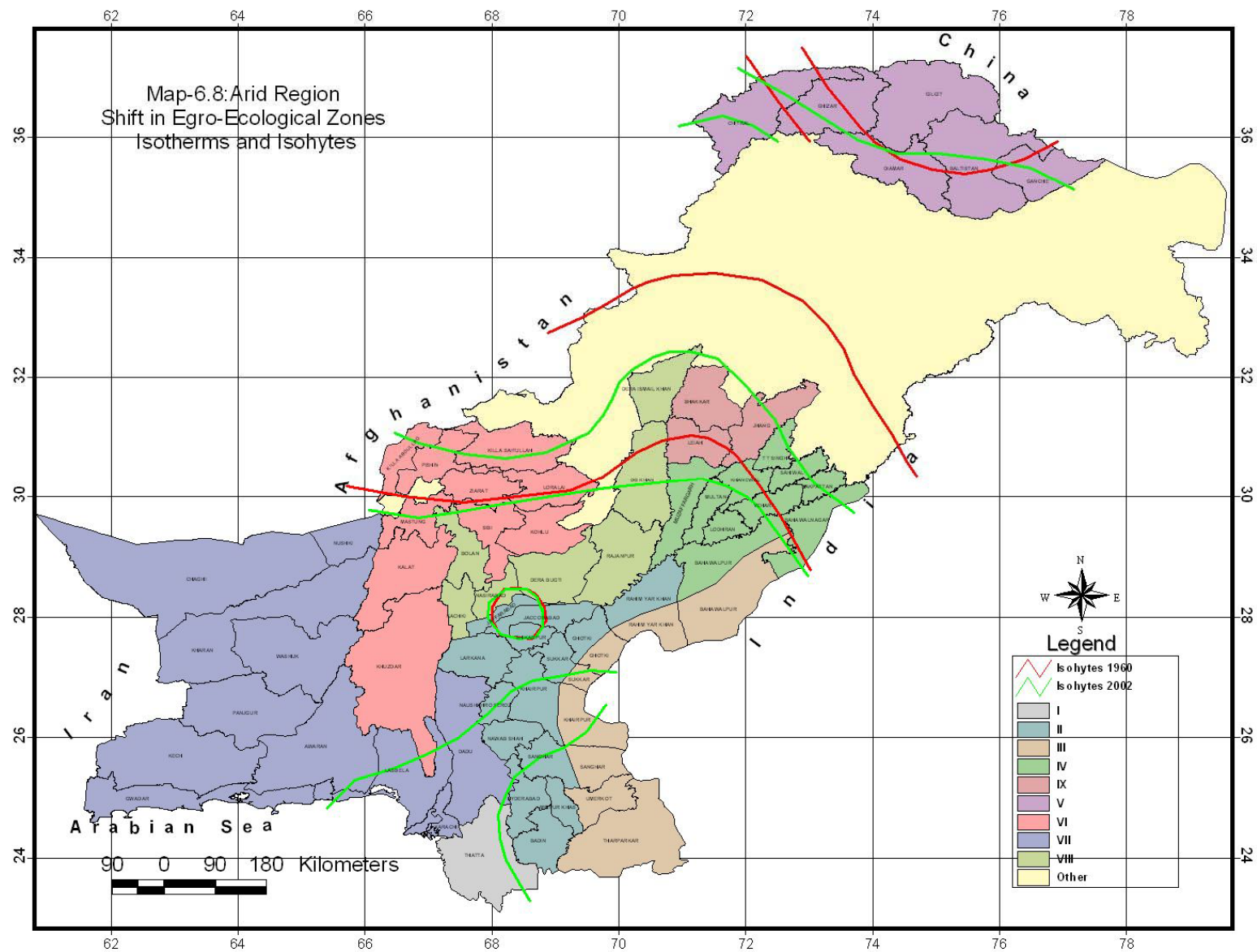
In Pakistan, it is evident that the ongoing decline in precipitation and increase in temperature has decreased the production of pulses. Its cross matching with the precipitation and temperature reveals that from 1961 to 1990, the yield of gram is directly proportional to precipitation (Graph-6.12). But from 1991 to 2000, the production of gram increased, whereas the trend of precipitation decreases. The crop production is inversely proportional to temperature throughout the series. It can also be noted from the graph that the average production of the pulses is decreasing from 1961 to 2000 and more vulnerable to the precipitation and temperature fluctuation (Table-6.4).

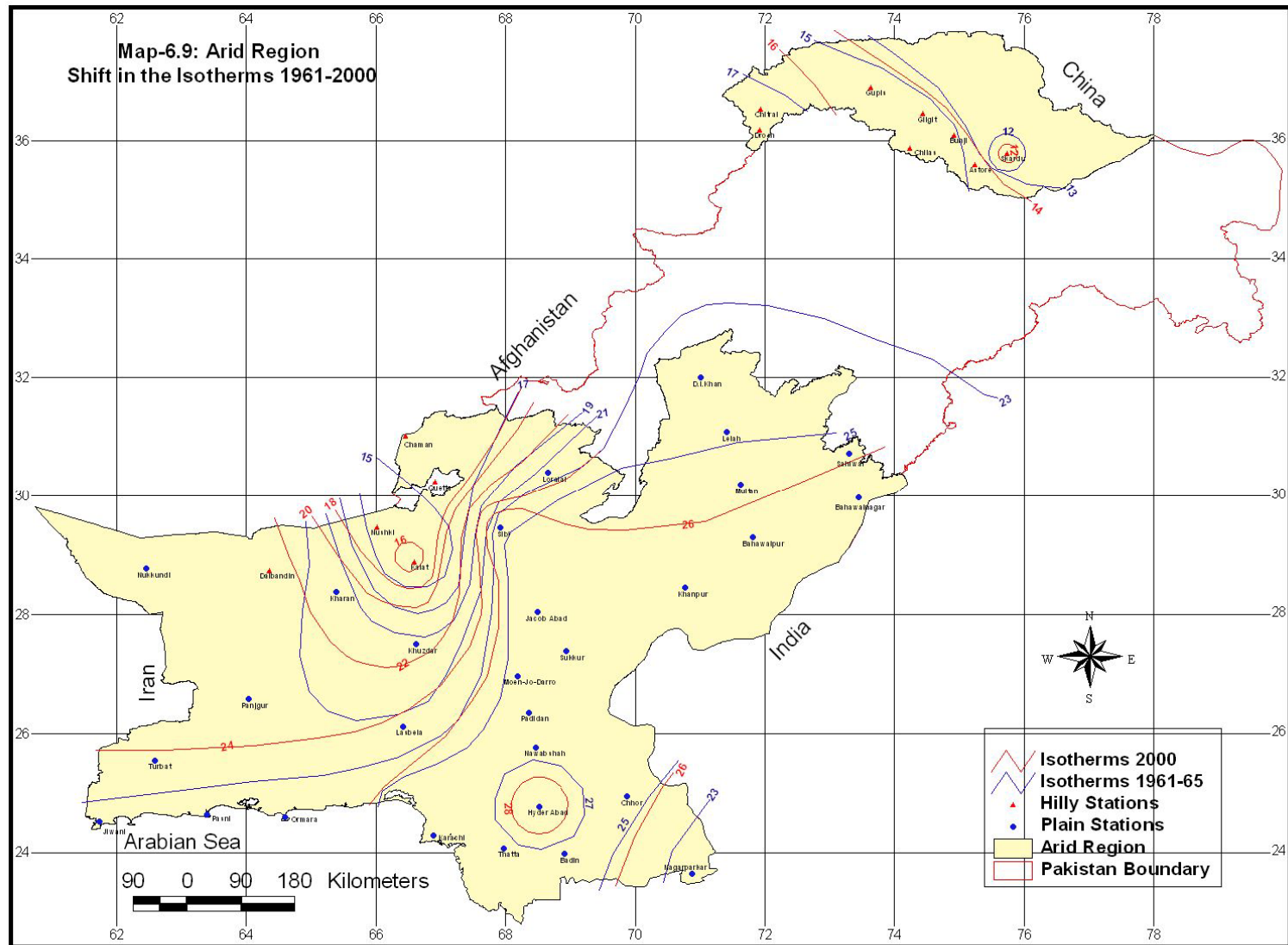
6.1.2. Shift in the growing Season:

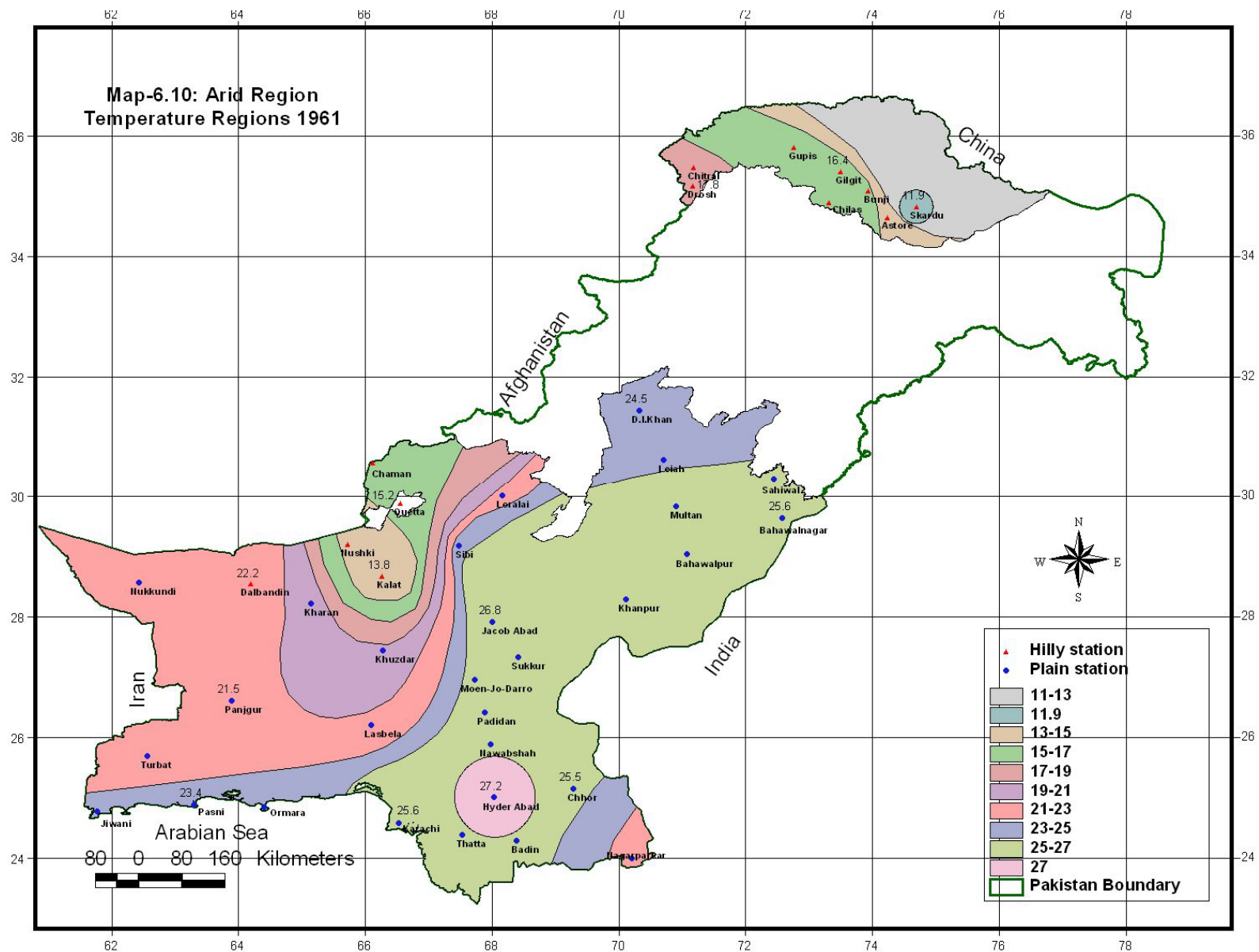
To evaluate the shift in cropping pattern and growing seasons in the arid region of Pakistan, the isohyets of 1960 and 2000 have been drawn on map-6.7 and 6.8. The maps indicate that the boundary of southern arid region has shifted towards northwest upto 100 kilometers, and as a result considerable area of the central Punjab, lower KPK, lower FATA, and Quetta in Baluchistan has become arid in 2000, that was semi-arid region in 1961. In northern arid region (Gilgit-Baltistan), the boundary of aridity has shifted towards China upto 60 kilometers in 2000. The temperature of the arid region also shows an increasing trend from south towards north during 1961 to 2000.

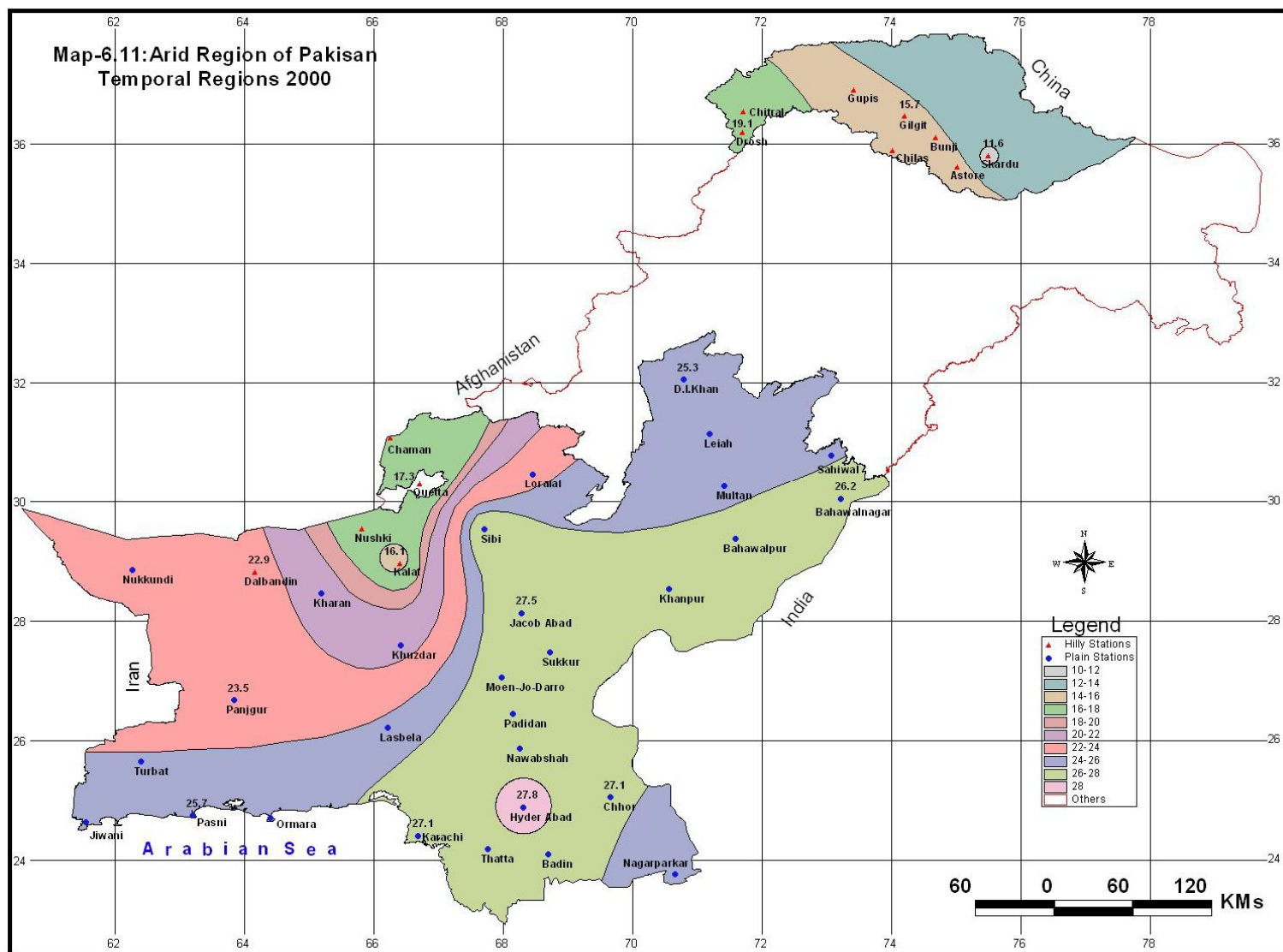
This shift in the boundary of the arid region and an increasing trend in the temperature towards north have affected the cropping pattern and yield, in rainfed areas of the entire arid region (Map-6.9, 6.10, 6.11). The rise in temperature in the other rainy regions (humid and sub-humid) is more suitable for the increase in crop productivity. In most of the mountainous areas of Pakistan where one crop was grown throughout the year are now able to produce two crops as the temperature is suitable for the growth. The best example studied during the field work is the upper Swat area of Kalam where one crop that is potato used to be grown in the past but due to climate changes the area is producing two crops annually. Those areas where two crops were grown are now able to produce three crops annually e.g. Swat, Dir, and Chitral.











6.1.3. Impacts on crop productivity, area, and yield:

Wiebe and Masters in 2000 have studied the climate and agricultural productivity in several countries of the World, using recent climate and resource data to test the determinants of agricultural input used and output level. Hurd, Adams, and McCarl in 2001 have evaluated the global climate change and its impact on agriculture. They have opined that the agriculture can be affected by recent and future climate change in different parts of the World and need adaptation.

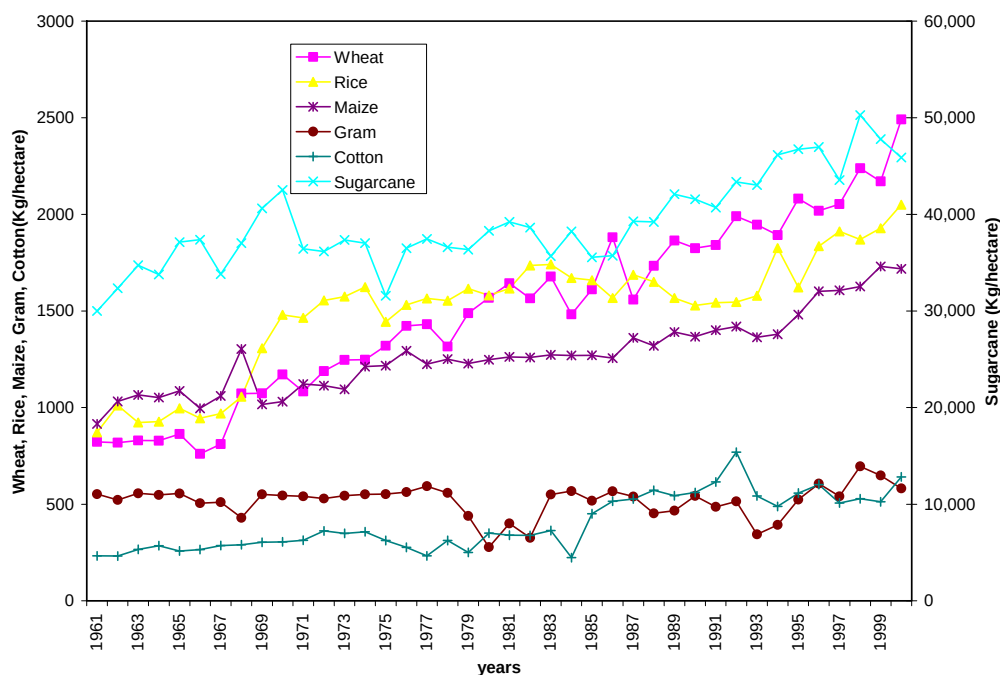
In Pakistan, the lower Punjab generally represents characteristics of the entire arid region as it has irrigated plain, sandy desert, rainfed areas, grasslands, barren mountains and has been considered as a sample area for the climate change and agriculture.

The data of major crops of Pakistan show that the average yield per hectare of sugarcane, gram, and cotton has decreased, but there is an increasing trend noted in the yield of wheat, gram and rice from 1961 to 2000 (Graph-6.13). The analysis of crop productivity, cropping area, and yield per acre for different *kharif* and *rabi* crops in the lower Punjab are as follow:

6.1.3.1. Rice:

The temperature increase of 1.6°C has shifted the boundaries of rice growing areas and the arid region has become hotter than it was before. Generally, the decline in precipitation and increase in the surface temperature

Graph-6.13: Pakistan
Yield per Hectare of Major Agriculture Crops 1961-2000



results into change in the growing degree days in the rice cultivated areas of lower Punjab and Sind. The growing season length has been affected more in the arid region as compared to other rainy regions (sub-humid) because rice cultivation in this area has experienced heat stress and the ongoing increase in temperature and decrease in precipitation would further aggravate it.

Generally, the production of the rice in arid region of the lower Punjab was 1342 thousand tones in 1990 on a total cropped area of 568 thousand acres and average yield of 18 mds/acre or 720Kgs/acre (Table-6.1). Overall, the production of rice shows an increase of 2577 thousand tones in 2000 with an increase in cropped area of 898 thousand acres and decrease of 16.7 mds/acre (668 Kgs/acre) in yield. The production of the rice at district level indicates a negative trend in Multan and Bahawalpur divisions, whereas it remains stable in Faisalabad and Dera Ghazi Khan divisions. The sum of deviation from the mean

shows an increase of 0.05 thousand tones in 2000 as compared to 0.03 thousand tones in 1990 having decreasing trend in all districts excluding Jhang, Pakpathan, and Rahimyar Khan. The sum of deviation of the rice cropped area shows a stable condition during 1990 that dropped to -0.08 thousand acres in 2000. The yield per acre is showing a positive deviation from the mean (1991) in the Multan division, while in other areas it is moving towards negative till 2000. The sum of deviation from the mean in 1990 was 0.03 mds/acre (1.2 Kg/acre) that dropped to 0.02 mds/acre (0.8 Kg/acre) in 2000.

It is concluded that the production of rice in the lower Punjab has increased from 1990 to 2000 but cropped area and yield per acre shows a decrease with passage of time, a result of decline in precipitation, water scarcity, and temperature stress.

6.1.3.2. Wheat:

The effective temperature for wheat growing is 5 to 30⁰C with optimum level of 15 to 20⁰C (Sadiq., Gadiwala, 2008). In wheat growing areas of the arid region, the maximum temperature has exceeded 30⁰C during March and April (Table-4.1). The temperature increase of 1.6⁰C might squeeze the potential zone of wheat crop, where some of the arid region might be outside the potential zone. The increase in temperature have reduced the growing season of wheat in the southern arid region.

The total production of arid region in lower Punjab was 6365.1 thousand tones in 1991 that rose to 9161.8 thousand tones in 2000. The production of wheat in the irrigated lands shows a marked increase, might be the result of

increase in the cultivated area and availability of water resources. The total cropped area in lower punjab was 7445 thousand acres (1991) that increased to 8540 acres in 2000. The yield was 23.2 mds/acre (928Kgs/acre) in 1991 that rose to 29.1 mds/acre (1164Kgs/acre) in 2000. Generally, the wheat production, cropped area, and yield per acres shows a positive trend from 1991 to 2000 in the lower Punjab.

It is observed from table-6.2 that the sum of deviation from the mean of wheat in 1991 was -0.02 thousand tones that rose to positive deviation in the year 2000. The cropped area also shows a negative trend in 1991 that rose to the mean level in 2000. The sum of deviation of yield per acre was -0.06 mds/acres (-2.4Kgs/acre) in 1991 that increased to -0.03 mds/acre(-1.2Kgs/acre) in 2000. Normally, the cropped area under wheat shows a decrease in Multan and Dera Ghazi Khan divisions that might be the result of non-availability of irrigation water and also decrease in precipitation. In some cases the yield per acre has increased at Dera Ghazi Khan and decreased in the Rajanpur district. It is concluded that the wheat production in the irrigated plain is stable but the cropped area has decreased in the districts, where aridity prevails. The crop is vulnerable to the ongoing climate change and non-availability of the surface water.

6.1.3.3. Sugarcane:

The total production of sugarcane was 8325.3 thousand tones in 1991 that went up to 12041.6 thousand tones in 2000. The cropped area was 601 thousand acres (1991) that dropped to 697 thousand acres in 2000. The yield was 13.1

mds/acre (524Kgs/acre) that rose to 16.9 mds/acre in 2000 (Table-6.3). Generally, the production, and cropped area of sugarcane shows an increase during the period of 1991 to 2000 and decrease in the yield per acre. This decrease is the result of the ongoing climate change in the irrigated lands of Punjab and Sind provinces. During this period, the deviation from the mean of cropped area and production was stable, while the yield per acre dropped from 0.7 mds/acre or 28Kgs/acre (1991) to -0.6 mds/acre or -24Kg/acre in 2000. This decrease in the yield of sugarcane per acre shows the water scarcity in the region that need adaptation.

6.1.3.4. Cotton:

The crop is cultivated mostly in the irrigated plain of the lower Punjab and Sind province. The production of cotton in lower Punjab reveals that it was 10658.9 thousand tones in 1991 that dropped to 8366 thousand tones in 2000 (Table-6.3). The total area cultivated with cotton in 1991 was 5175 thousand acres that rose to 5683 thousand acres in 2000 with decrease in the yield from 26.9 mds/acre or 1078Kgs/acre (1991) to 19.4 mds/acre or 776Kgs/acre (2000). It is concluded that the crop is vulnerable to climate change and shows a marked decrease in the production and yield per acre. The change in the crop cultivable area is conspicuous in all districts of the lower Punjab. This change in the cotton production is the result of non-availability of the surface water and also the precipitation fluctuation in the region.

Table-6.1: Arid Region of Punjab
District wise Rice Area, Production and Average Yield (1990-2000)

NAME	Average Yield Mds/Acre				Area (1000 Acres)				Production (1000 Tones)			
	1991-92		2000-01		1991-92		2000-01		1991-92		2000-01	
Punjab	18.07	Deviat	16.76	Deviat	568	Deviat	898	Deviat	1342.24	Deviat	2577	Deviat
Bakkar	0.00	-16.94	0.00	-15.71	0	-35.5	0	-56.13	0	-16.94	0	-34.96
T.T. Singh	15.31	-1.63	14.78	-0.93	33	-2.5	62	5.87	15.31	-1.63	34.2	-0.76
Jhang	47.03	30.09	15.96	0.25	112	76.5	213	156.87	47.03	30.09	126.86	91.9
Sahiwal	21.74	4.80	16.98	1.27	38	2.5	58	1.87	21.74	4.8	36.75	1.79
Pakpattan	21.73	4.79	17.59	1.88	38	2.5	110	53.87	21.73	4.79	72.2	37.24
Multan	5.08	-11.86	16.46	0.75	9	-26.5	23	-33.13	5.08	-11.86	14.13	-20.83
Lodhran	2.21	-14.73	17.92	2.21	4	-31.5	8	-48.13	2.21	-14.73	5.35	-29.61
Khanewal	10.1	-6.84	16.17	0.46	21	-14.5	36	-20.13	10.1	-6.84	21.73	-13.23
Vehari	7.9	-9.04	16.02	0.31	18	-17.5	44	-12.13	7.9	-9.04	26.31	-8.65
Muzaffargarh	24.73	7.79	19.29	3.58	40	4.5	56	-0.13	24.73	7.79	40.32	5.36
Layyah	0	-16.94	15.54	-0.17	0	-35.5	2	-54.13	0	-16.94	1.16	-33.8
D.I.Khan	23.02	6.08	22.76	7.05	51	15.5	63	6.87	23.02	6.08	53.51	18.55
Rajanpur	20.37	3.43	15.13	-0.58	42	6.5	25	-31.13	20.37	3.43	14.12	-20.84
Bahawalpur	14.4	-2.54	16.42	0.71	27	-8.5	18	-38.13	14.4	-2.54	11.03	-23.93
R Y Khan	35.94	19.00	15.09	-0.62	92	56.5	129	72.87	35.94	19	72.68	37.72
Bahawalnagar	21.51	4.57	15.27	-0.44	43	7.5	51	-5.13	21.51	4.57	29.06	-5.9
Average/Sum	16.94	0.03	15.71	0.02	35.5	0	56.125	-0.08	16.94	0.03	34.96	0.05

Source: MINFAL, Manistry of Food, Agriculture, and Livestock, Islamabad (1Mds=40Kgs and 1hectare=2.47acres)

**Table-6.2: Arid Region of Punjab
District wise Wheat Area, Production, and Yield (1990-2000)**

NAME	Area (1000 Acres)				Production (1000 Tones)				Yield (Mds/Acres)			
	1991-92		2000-01		1991-92		2000-01		1991-92		2000-01	
Punjab	7445	Deviat	8540	Deviat	6365.1	Deviat	9161.76	Deviat	23.18	Deviat	29.07	Deviat
Bhakkar	329	-136.31	347	-186.75	233.21	-164.61	314.7	-257.91	18.99	-4.19	24.3	-4.77
T.T. Singh	349	-116.31	358	-175.75	348.61	-49.21	412.89	-159.72	26.76	3.58	30.9	1.83
Jhang	796	330.69	892	358.25	692.01	294.19	919.74	347.13	23.29	0.11	27.63	-1.44
Sahiwal	520	54.69	364	-169.75	566.58	168.76	457.72	-114.89	29.19	6.01	33.69	4.62
Pakpattan	193	-272.31	391	-142.75	210.29	-187.53	582.01	9.4	29.19	6.01	39.88	10.81
Multan	421	-44.31	484	-49.75	330.17	-67.65	501.59	-71.02	21.01	-2.17	27.77	-1.3
Lodhran	341	-124.31	457	-76.75	267.43	-130.39	479.65	-92.96	21.01	-2.17	28.12	-0.95
Khanewal	477	11.69	531	-2.75	409.87	12.05	714.49	141.88	23.02	-0.16	36.05	6.98
Vehari	542	76.69	647	113.25	561.22	163.4	819.13	246.52	27.74	4.56	33.92	4.85
Muzaffargarh	627	161.69	711	177.25	510.91	113.09	703.56	130.95	21.83	-1.35	26.51	-2.56
Layyah	447	-18.31	436	-97.75	306.84	-90.98	390.49	-182.12	18.39	-4.79	24	-5.07
D.I.Khan	319	-146.31	384	-149.75	275.78	-122.04	430.98	-141.63	23.16	-0.02	30.07	1
Rajanpur	255	-210.31	359	-174.75	236.44	-161.38	329.28	-243.33	24.84	1.66	24.57	-4.5
Bahawalpur	528	62.69	672	138.25	438.72	40.9	663.15	90.54	22.26	-0.92	26.44	-2.63
R Y Khan	681	215.69	804	270.25	536.61	138.79	778.48	205.87	21.11	-2.07	25.94	-3.13
Bahawalnagar	620	154.69	703	169.25	440.41	42.59	663.9	91.29	19.03	-4.15	25.3	-3.77
Average/Sum	465.31	0.04	533.75	0	397.82	-0.02	572.61	0.00	23.18	-0.06	29.07	-0.03

Source: MINFAL, Manistry of Food, Agriculture, and Livestock, Islamabad (1hectare=2.47acres and 1Mds=40Kgs)

**Table-6.3: Arid Region of Punjab
District Wise Sugarcane Area, Production, and Yield (1990-2000)**

NAME	Yield (Mds/Acre)				Production (1000 Tones)				Area (1000 Acres)			
	1991-92		2000-01		1991-92		2000-01		1991-92		2000-01	
Punjab	13.1	Deviat	16.9	Deviat	8325.3	Deviat	12041.6	Deviat	600.9	Deviat	696.7	Deviat
Bhakkar	13.1	0.0	17.4	0.5	510.5	-9.8	878.2	125.6	39.1	1.54	50.6	7.06
T.T. Singh	16.1	3.0	19.3	2.4	1247.1	726.8	1803.9	1051.3	77.7	40.14	93.3	49.76
Jhang	14.5	1.4	17.7	0.8	1657.2	1136.9	3129.8	2377.2	114.4	76.84	177.3	133.76
Sahiwal	15.3	2.2	18.9	2.0	642.7	122.4	668.0	-84.6	42	4.44	35.3	-8.24
Pakpattan	15.4	2.3	19.0	2.1	366.0	-154.3	569.9	-182.7	23.8	-13.76	30	-13.54
Multan	12.2	-0.9	16.0	-0.9	68.1	-452.2	153.3	-599.3	5.6	-31.96	9.6	-33.94
Lodhran	12.3	-0.8	18.2	1.3	60.4	-459.9	65.6	-687.0	4.9	-32.66	3.6	-39.94
Khanewal	14.9	1.8	16.1	-0.8	315.0	-205.3	321.0	-431.6	21.1	-16.46	20	-23.54
Vehari	12.3	-0.8	15.9	-1.0	347.3	-173.0	572.7	-179.9	28.2	-9.36	36.1	-7.44
Muzaffargarh	12.5	-0.6	16.2	-0.7	255.7	-264.6	680.2	-72.4	20.5	-17.06	42	-1.54
Layyah	11.5	-1.6	14.9	-2.0	284.9	-235.4	536.7	-215.9	24.7	-12.86	36	-7.54
D.I.Khan	12.0	-1.1	16.4	-0.5	31.2	-489.1	75.5	-677.1	2.6	-34.96	4.6	-38.94
Rajanpur	8.9	-4.2	14.4	-2.5	72.3	-448.0	83.7	-668.9	8.1	-29.46	5.8	-37.74
Bahawalpur	13.0	-0.1	16.8	-0.1	455.2	-65.1	394.7	-357.9	34.9	-2.66	23.5	-20.04
R Y Khan	13.6	0.5	16.5	-0.4	967.3	447.0	1144.2	391.6	71	33.44	69.2	25.66
Bahawalnagar	12.7	-0.4	16.1	-0.8	1044.4	524.1	964.2	211.6	82.3	44.74	59.8	16.26
Average/Sum	13.1	0.7	16.9	-0.6	520.3	0.0	752.6	0.000	37.56	0.00	43.54	0.00

Source: MINFAL, Ministry of Food, Agriculture, and Livestock, Islamabad (1Mds=40Kgs and 1hectare=2.47acres)

**Table-6.4: Arid Region of Punjab
District wise Cotton Area, Production, and Yield (1990-2000)**

NAME	Area (1000 Acres)				Production (1000 Tones)				Average Yield (Mds/Acre)			
	1991-92		2000-01		1991-92		2000-01		1991-92		2000-01	
Punjab	5175	Deviat	5683	Deviat	10658.85	Deviat	8365.89	Deviat	26.95	Deviat	18.39	Deviat
Bhakkar	23	-300.4	13	-342.1	31.5	-634.6	14.4	-508.3	18.7	-8.2	15.2	-3.1
T.T. Singh	144	-179.4	111	-244.1	266.6	-399.5	116.6	-406.2	25.3	-1.6	14.3	-4.0
Jhang	225	-98.4	150	-205.1	419.7	-246.4	141.7	-381.0	25.5	-1.4	12.9	-5.4
Sahiwal	401	77.5	198	-157.1	827.2	161.0	219.9	-302.9	28.2	1.2	15.1	-3.2
Pakpattan	148	-175.4	128	-227.1	309.1	-357.0	139.6	-383.2	28.5	1.6	14.9	-3.4
Multan	420	96.5	424	68.8	924.8	258.6	618.2	95.3	30.1	3.1	19.9	1.5
Lodhran	439	115.5	483	127.8	971.2	305.0	714.0	191.2	30.2	3.2	20.2	1.8
Khanewal	425	101.5	476	120.8	962.2	296.0	674.9	152.0	30.9	4	19.3	0.9
Vehari	603	279.5	588	232.8	1375.5	709.3	1010.2	487.3	31.1	4.2	23.4	5.1
Muzaffargarh	359	35.5	470	114.8	626.6	-39.5	609.4	86.5	23.8	-3.0	17.7	-0.6
Layyah	55	-268.4	109	-246.1	91.0	-575.1	90.9	-431.9	22.6	-4.3	11.4	-6.9
D.I.Khan	119	-204.4	244	-111.1	234.8	-431.3	417.5	-105.3	26.8	0.03	23.3	5
Rajanpur	179	-144.4	369	13.8	366.2	-299.9	674.2	151.3	27.9	1.0	24.9	6.5
Bahawalpur	534	210.5	654	298.8	1078.2	412.0	1118.6	595.7	27.6	0.6	23.3	4.9
R Y Khan	669	345.5	777	421.8	1366.4	700.2	1227.1	704.2	27.9	0.9	21.5	3.2
Bahawalnagar	432	108.5	489	133.8	807.4	141.2	578.0	55.2	25.5	-1.4	16.1	-2.2
Average/Sum	323.44	-0.04	355.19	-0.04	666.1	-0.03	522.8	-0.03	26.9	0.05	18.3	0.01

Source: MINFAL, Manistry of Food, Agriculture, and Livestock, Islamabad (1Mds=40Kgs and 1hectare=2.47acres)

**Table-6.5: Pakistan
Kharif and Rabi Major Crops Production 1961-2000 (1000 tons)**

Year	Rice	Wheat	Sorghum	Peal millet	Barley	Maize
1961	1030	3814	220	306	120	439
1965	1350	4591	293	446	118	528
1970	2401	7295	284	302	104	668
1975	2314	7674	266	266	137	747
1980	3216	10857	249	277	118	875
1985	3315	11703	230	284	132	1028
1990	3220	14316	262	204	131	1179
1995	3447	17002	263	228	164	1318
2000	5156	21079	220	156	118	1652
Year	Sesamum	Rape & Mustard	Sugarcane	Tobacco	Gram	Cotton
1961	7	214	11639	60	610	301
1965	9	214	18669	83	672	378
1970	8	255	26371	116	507	536
1975	8	248	21241	77	550	635
1980	19	247	27498	78	313	729
1985	14	235	32140	87	524	1009
1990	15	233	35494	68	562	1457
1995	36	229	47168	81	559	1480
2000	35	297	46333	108	565	1913

Source: Kurosaki T (2007), and Statistical Supplement of the Economic Survey, 2000.

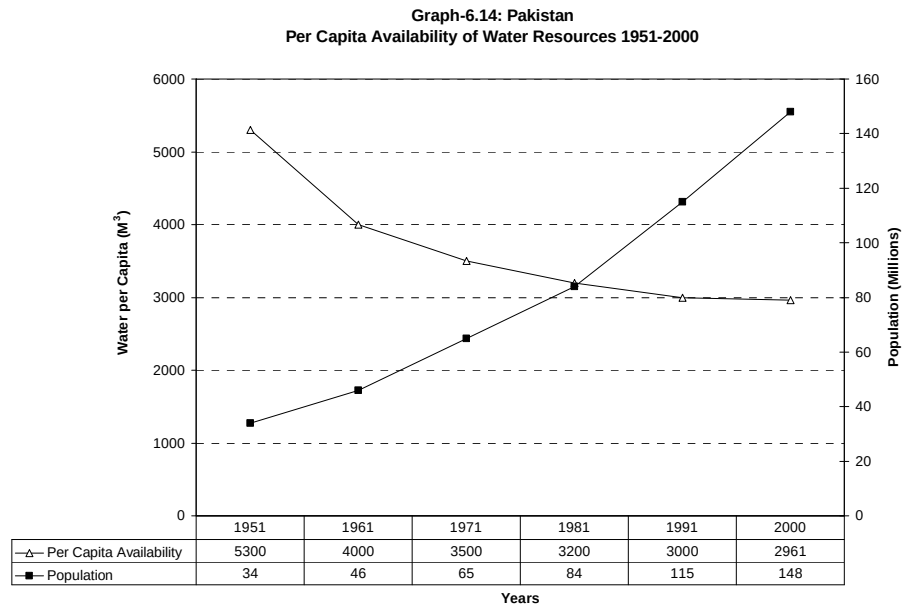
6.2. Impacts on agriculture environment:

IPCC (2009) has opined that in Asia, *"By the 2050s, freshwater availability in large river basins, is projected to decrease. Climate change is going to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization, and economic development."* The climate change has impacts on all the aspects of the agriculture environment including hydrology, soils, forestry, and landuse etc requiring detailed studies.

6.2.1. Water Resources:

The most serious potential threat arising from climate change in the arid region of Pakistan is water scarcity. GoP, 2000 and UNESCO, 2006, "*The gross per capita water availability in Pakistan was 5300 m³/year (1951) that declined to 2900 m³/year*

(2000). The per capita water availability is inversely proportional to the population growth" (Graph-6.14).



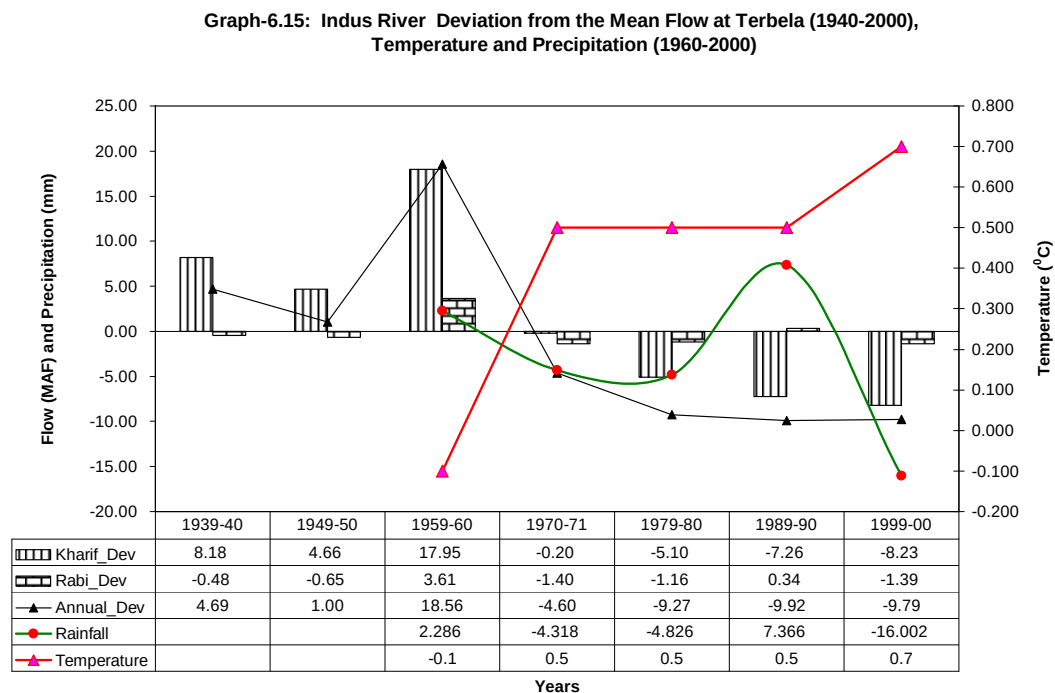
"*The consequences of climate change for water resources depend not only on possible changes in the supply but also on changes in the demand, both human and environmental needs. The water demand has been affected by many factors, including population growth, wealth, and distribution. In Pakistan, it is expected that 60% population of the arid region are already under high water stress, and this number is expected to increase significantly with passage of time, due primarily to population growth, climate change and groundwater"* (GoP, 2005).

6.2.1.1. Rivers Flow:

Water is a precious resource for the existence of the human life and without water availability it is hard to survive. Water sector is playing a vital role in the development of the human societies in the entire arid region. The water flow in Indus and its tributaries are running dry and it is hoped that it will be further affected due to the ongoing climate change and decline the agriculture productivity. The impacts of climate change on the flow of Indus and its tributaries are as follow.

6.2.1.1.1. Indus river:

Indus river is the main source of surface water in Pakistan that passes through the core of the arid region in Gilgit-Baltistan province, lower Punjab, and Sind. The discharge data of the Indus river recorded at Tarbela, plotted on graph-



6.15 and table-6.6, reveal that the annual flow of the Indus river was positive

from 1940 to 1960 and then turned into negative deviation from 1961-90. *Kharif* season, shows a positive deviation during 1940 to 1960 and 1990 to 2000 respectively, while in the remaining years, the trend is negative. In *rabi* season, the water flow indicates a positive deviation from 1950 to 1960 and 1990-2000, whereas it has remained negative during 1961 to 1989.

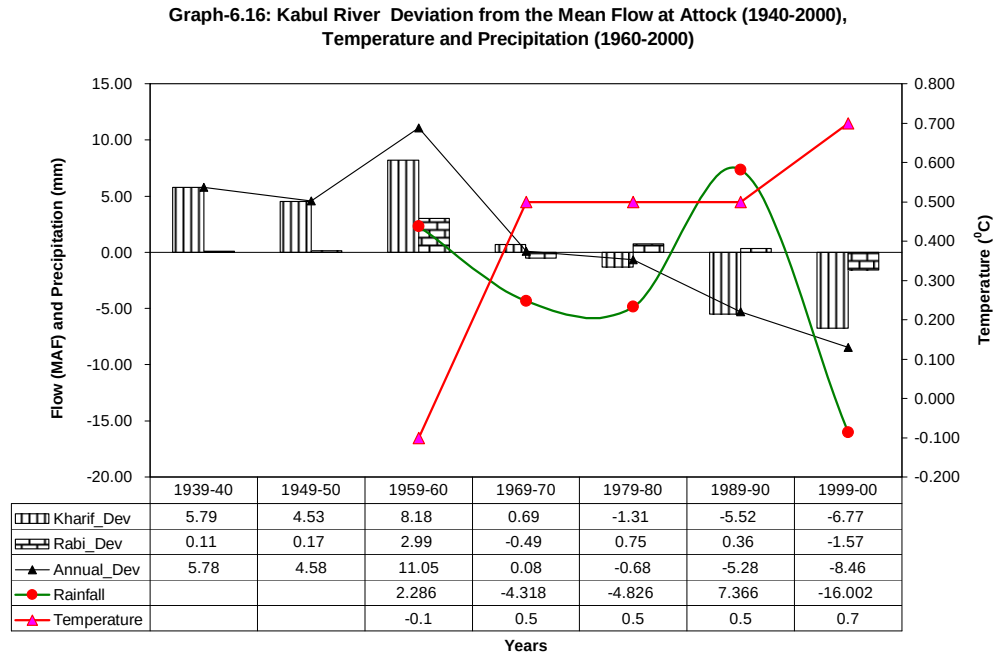
Generally, the annual flow at Tarbela shows a decrease of -0.02MAF (-0.002MAM) during 1941 to 2000. In *kharif* season, the deviation from the mean is 21.01MAF (2.5MAM), while in *rabi* season it is -0.03 MAF (-0.004MAM). It shows that the annual flow of the Indus river decreases with passage of time. This might be the result of precipitation and temperature fluctuation. The impact on water flow is marked in the *rabi* season (winter precipitation), as compared to *kharif* season (monsoon precipitation). The decline of flow in the *rabi* season, has affected the crop productivity in the irrigated plain in Sind and lower Punjab (*rabi* season crop).

6.2.1.1.2. Kabul river:

The discharge at Attock shows that the annual flow of the Kabul river has increased upto 0.02MAF (0.0024 MAM) from 1937 to 2000. During *kharif* season, the water flow is showing an increase of 8.12MAF (0.97MAM), whereas in *rabi* season it is -0.06MAF or 0.007MAM (Table-6.6).

The annual flow of the Kabul river was above the mean condition from 1940 to 1970 and remained below the mean from 1971 to 2000 (Graph-6.16). During *kharif* season, the flow was positive from 1937 to 1970 and remained below the mean condition from 1971 to 2000. The decrease in the flow of the

Kabul river was marked in *kharif* as compared to *rabi* season, when the flow was above the mean condition throughout the series excluding time intervals of 1960 to 1970 and 1990 to 2000.



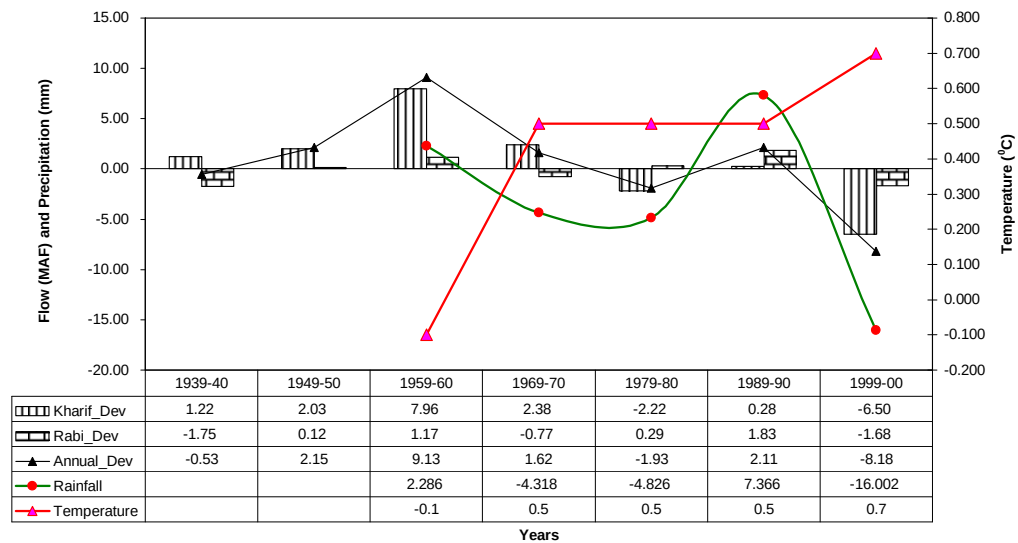
Generally, the flow of Kabul river is stable throughout the series but from 1970 to 2000 it has decreased, indicating the flow to be vulnerable to the ongoing climate change and need adaptation.

6.2.1.1.3. Jhelum river:

Jhelum river mostly covers the irrigated land of the upper Punjab. Its major water reservoir is at Mirpur, with Mangla dam, the main source of electric supply to most of the Punjab and Azad Kashmir. The annual flow of the Jhelum river shows a decrease of -0.12MAF (-0.02MAM), whereas it is 0.14MAF (0.01MAM) in *kharif* season and -0.26MAF (-0.03MAM) in *rabi* season (Table-6.6).

The flow was above the mean condition during 1950 to 1970 and 1981 to 1990, while the trend is negative in the remaining years of the series (Graph-6.17). In *kharif* season, the flow is above the mean during 1940 to 1970 and negative deviation from 1971 to 2000. The flow of Jhelum river reveals ups and downs throughout the series in *rabi* season (Figure-7.3).

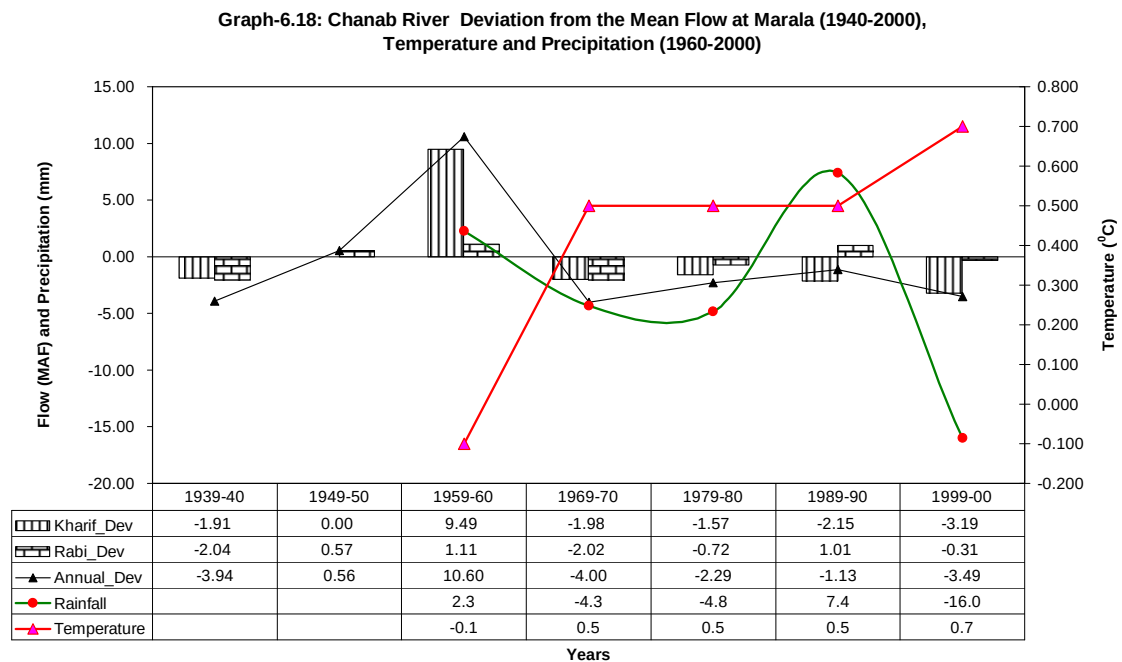
Graph-6.17: Jhelum River Deviation from the Mean Flow at Mangla (1940-2000), Temperature and Precipitation (1960-2000)



The annual flow of the river has decreased due to decline in precipitation and more vulnerable to the ongoing climate changes in Pakistan. The decline in the flow of water is severing during *rabi* season and would result in the decline of agriculture productivity.

6.2.1.1.4. Chenab river:

The river covers the irrigation of the central Punjab especially Gujrat and the surrounding areas. The analysis of flow data collected at Maralla headworks show annual decline of -0.31MAF (-0.04MAM) with -0.21MAF (-0.03MAM) during *kharif* and -0.10MAF (-0.01 MAM) in *rabi* season respectively (Table-6.6).



The deviation indicates that the annual flow of Chenab river was below the mean since 1937 to 2000 excluding 1950 to 1960, when it flowed inversely. Generally, the flows in kharif and rabi seasons were below the mean throughout the period and severely affected by the ongoing climate change (Graph-6.18).

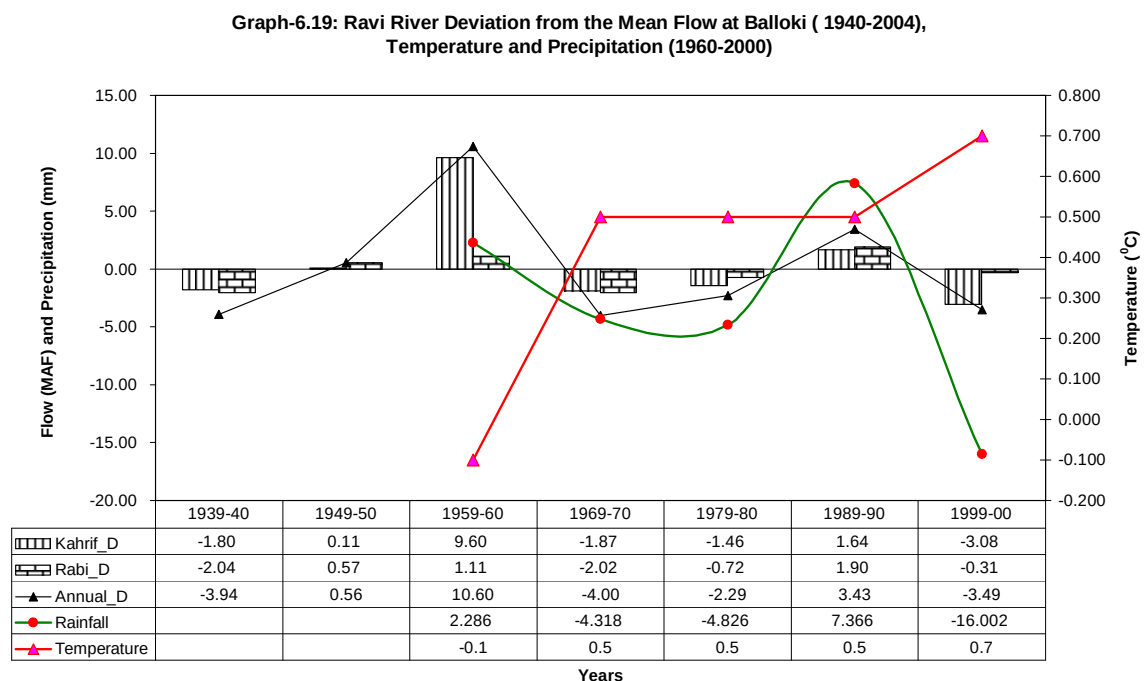
6.2.1.1.5. Ravi river:

The river runs to the northwest of Lahore and covers most of the irrigation system of the lower Punjab. The annual flow of the river reveals a decline of -0.31MAF (-0.04MAM) with an increase of 7.16MAF (0.9MAM) in *kharif* and a

decrease of -0.10MAF (-0.1MAM) during *rabi* season in between 1937 and 2000 (Table-6.6).

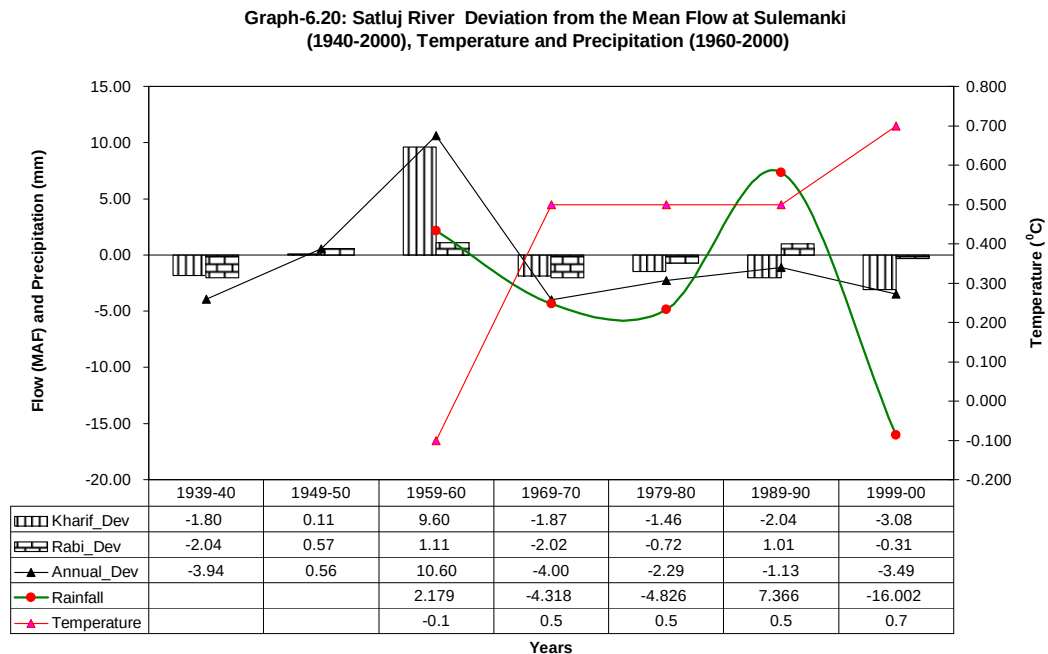
The annual and seasonal trend of Ravi flow plotted on graph-6.19 shows that it was above the mean during 1950 to 1960 and 1980 to 1990, but it remained below the mean from 1961 to 1979 and 1991 to 2000. The decrease in annual discharge seems to have been affected by the decline in precipitation and the measures taken by India as a result of the Indus Water Treaty 1960.

The river is vulnerable to the ongoing climate changes and need adaptation. Due to decrease in the flow, it is also expected that it will deteriorate the crop productivity severely in the lower Punjab and change landuse and cropping pattern.



6.2.1.1.6. Sutlej river:

Sutlej river is one of the major tributaries of the Indus river that flows in the arid region of the lower Punjab. The river covers the irrigation system of Bahawalpur, Bahawalnagar, and Rahimyar Khan district. According to the Indus Water Treaty 1960, the river has also been handed over to India. The deviation from the mean condition of the annual flow shows a decrease of -0.31MAF (-0.04MAM) with -0.52MAF (-0.06MAM) in *kharif* and -0.10MAF (-0.01MAM) in *rabi* season (Table-6.6).



The annual flow of the river has remained above the mean from 1950 to 2000 and below during 1940 to 1950 and 1961 to 2000 with same pattern during *kharif* and *rabi* seasons (Graph-6.20). The trend of flow indicates that it is more vulnerable to the ongoing climate change and anthropogenic changes in the region and need adaptation. It is expected that the decrease in the flow of water will reduce the agriculture productivity in the lower Punjab (Figure-7.3).

6.2.1.1.7. Baluchistan rivers:

Area wise Baluchistan is the largest province and covers almost half of the arid region in Pakistan. The area is a network of natural drainage system but most of the torrents remain dry or seasonal throughout the year. Baluchistan can be divided into four very conspicuous drainage basins. The northern Baluchistan forms part of the Indus drainage system as the main river Zhob flows from southwest to northeast and drains into the Gomol river near Gulkach that drains into the Indus south of Dera Ismail Khan. The rivers of southern Baluchistan along the Makran coast drain into the *Arabian* Sea and the area does not form part of the Indus drainage basin. They include the Hub, Porali, Nal, Mushkai, Hingol, Kech, Nihing, and Dasht river. There is a considerable area of western Baluchistan in Chagai, Kharan and Panjgur district, where there has developed the inland drainage system converging mainly on the Hamun-e-Mashkhel, near Iran border in Kharan district and Hamun-I-Lora in eastern Chagai district. Another very important hydrological zone is the Bolan-Kachhi plain, where the non-perennial streams coming-out of the mountainous region are absorbed in the Kachhi plain and do not reach the Indus. Due to aridity, the water discharge is low and because of the mountainous nature of the province most of these rivers flow in deep narrow valleys where little land area is available for agriculture. Therefore, most of the rivers in Baluchistan are not as beneficial for crops as in the Indus plain.

**Table-6.6: Arid Region
Flow of Main Rivers (MAF) 1940-2000**

Indus at Tarbela							Kabul River at Attock					
Year	Kharif	Deviat	Rabi	Deviat	Annual	Deviat	Kharif	Deviat	Rabi	Deviat	Annual	Deviat
1939-40	61.5	8.2	8.6	-0.5	70.2	4.7	25.4	5.8	4.1	0.1	29.5	5.8
1949-50	58.0	4.7	8.4	-0.7	66.5	1.0	24.1	4.5	4.2	0.2	28.3	4.6
1959-60	71.3	17.9	12.7	3.6	84.0	18.6	27.8	8.2	7.0	3.0	34.8	11.1
1970-71	53.2	-0.2	7.7	-1.4	60.9	-4.6	20.3	0.7	3.5	-0.5	23.8	0.1
1979-80	48.3	-5.1	7.9	-1.2	56.2	-9.3	18.3	-1.3	4.8	0.7	23.0	-0.7
1989-90	46.1	-7.3	9.4	0.3	55.5	-9.9	14.1	-5.5	4.4	0.4	18.4	-5.3
1999-00	56.2	2.8	8.8	-0.3	65.0	-0.5	12.8	-6.8	2.5	-1.6	15.2	-8.5
Average/Sum	56.4	21.0	9.1	0.0	65.5	0.0	19.6	8.1	4.0	-0.1	23.7	0.0
Jhelum at Mirpur							Chenab at Maralla					
1939-40	18.9	1.2	3.1	-1.7	22.1	-0.5	20.0	-1.9	2.6	-2.0	22.6	-3.9
1949-50	19.8	2.0	5.0	0.1	24.8	2.2	21.9	0.0	5.2	0.6	27.1	0.6
1959-60	25.7	8.0	6.0	1.2	31.7	9.1	31.4	9.5	5.8	1.1	37.2	10.6
1969-70	20.1	2.4	4.1	-0.8	24.2	1.6	19.9	-2.0	2.6	-2.0	22.6	-4.0
1979-80	15.5	-2.2	5.2	0.3	20.7	-1.9	20.3	-1.6	3.9	-0.7	24.3	-2.3
1989-90	18.0	0.3	6.7	1.8	24.7	2.1	19.7	-2.1	5.7	1.0	25.4	-1.1
1999-00	11.2	-6.5	3.2	-1.7	14.4	-8.2	18.7	-3.2	4.4	-0.3	23.1	-3.5
Average/Sum	17.7	0.1	4.9	-0.3	22.6	-0.1	21.9	-0.2	4.7	-0.1	26.5	-0.3
Ravi at Balloki							Sutlej at Sulemanki					
1939-40	20.0	-1.8	2.6	-2.0	22.6	-3.9	20.0	-1.8	2.6	-2.0	22.6	-3.9
1949-50	21.9	0.1	5.2	0.6	27.1	0.6	21.9	0.1	5.2	0.6	27.1	0.6
1959-60	31.4	9.6	5.8	1.1	37.2	10.6	31.4	9.6	5.8	1.1	37.2	10.6
1969-70	19.9	-1.9	2.6	-2.0	22.6	-4.0	19.9	-1.9	2.6	-2.0	22.6	-4.0
1979-80	20.3	-1.5	3.9	-0.7	24.3	-2.3	20.3	-1.5	3.9	-0.7	24.3	-2.3
1990-91	23.4	1.6	6.6	1.9	30.0	3.4	19.7	-2.0	5.7	1.0	25.4	-1.1
1999-00	18.7	-3.1	4.4	-0.3	23.1	-3.5	18.7	-3.1	4.4	-0.3	23.1	-3.5
Average/Sum	21.8	7.2	4.7	-0.1	26.5	-0.3	21.8	-0.5	4.7	-0.1	26.5	-0.3

Source: WAPDA, Lahore and PARC, Islamabad 1937-2005 (1MAF=0.12MAM)

Due to the non-availability of data regarding the discharge, crop productivity in the remote valleys of Baluchistan and the precipitation and temperature, it is difficult or rather impossible to find out the relationship between these variables. Whatever data were available about the discharge of the three rivers of Khost, Hub and Porali have been analyzed and the results have been given as follow.

The Khost river in northern Baluchistan near Khost and Harnai is a small tributary of the Nari river of the Bolan Pass. It has shown decrease in the flow from 14MAF (1.7MAM) in 1968 to 6MAF (0.7MAM) in 1972 and the river changed into non-perennial with passage of time. The Hub and Porali river in the southeast of Baluchistan have shown an increasing trend during 1968 to 1972 but due to ongoing climate change, the flow has decreased till 2000 (Table-6.7). It seems that the rivers in Baluchistan are more vulnerable to the ongoing climate changes and affected the crop productivity during *kharif* and *rabi* seasons.

6.2.2. Expansion in aridity:

Climatically, most of the southern Pakistan is arid as it receives less than 10inches (254mm) precipitation annually which is insufficient for the agriculture growth. It changes gradually to semi-arid and hyper-arid in the northern Indus plain and there is no sharp boundary where arid region can be distinguished from semi-arid.

Table-6.7: Arid Region
Rivers flow 1968-1972 (MAF)

Name		Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Khost	1968	8	49	55	12	6	5	4	5	4	4	5	7	14
	1969	6	6	6	7	5	4	30	13	4	3	3	4	7
	1972	3	3	15	11	6	5	3	5	3	3	4	8	6
	Average	6	19	25	10	6	5	12	7	3	3	4	6	9
Hub	1968	62	32	15	1	0	0	61	60	5	0	0	0	20
	1969	0	0	0	0	0	0	193	194	38	6	0	0	36
	1972	0	191	0	27	0	70	446	171	2	0	0	0	76
	Average	21	74	5	9	0	23	233	142	15	2	0	0	44
Porali	1968	0	0	49	59	140	66	282	314	20	19	16	39	84
	1969	13	15	26	28	117	151	660	93	5	12	8	11	95
	1972	0	0	0	2000	10	347	1240	90	80	10	11	8	316
	Average	4	5	25	696	89	188	727	166	35	14	12	19	165

Source: NOAA, online (1MAF=0.12MAM)

arid region in 1960. It included, 2749 sq.kms area of Baluchistan (Quetta and its surroundings), and 54360 sq.kms of southeastern Sind. Northern arid region has reduced by 6594 sq.kms towards north (China). The total area of the arid region increased to 668300 sq.kms by 2000. The total addition into the arid region from 1961 to 2000 is 106,600 sq.kms, revealing that on the average 2665 sq.kms of semi-arid area has converted into the arid region per year (Map-6.12 and Table-6.8). It also shows that the area is vulnerable to the ongoing climate change and need significant adaptation and further research.

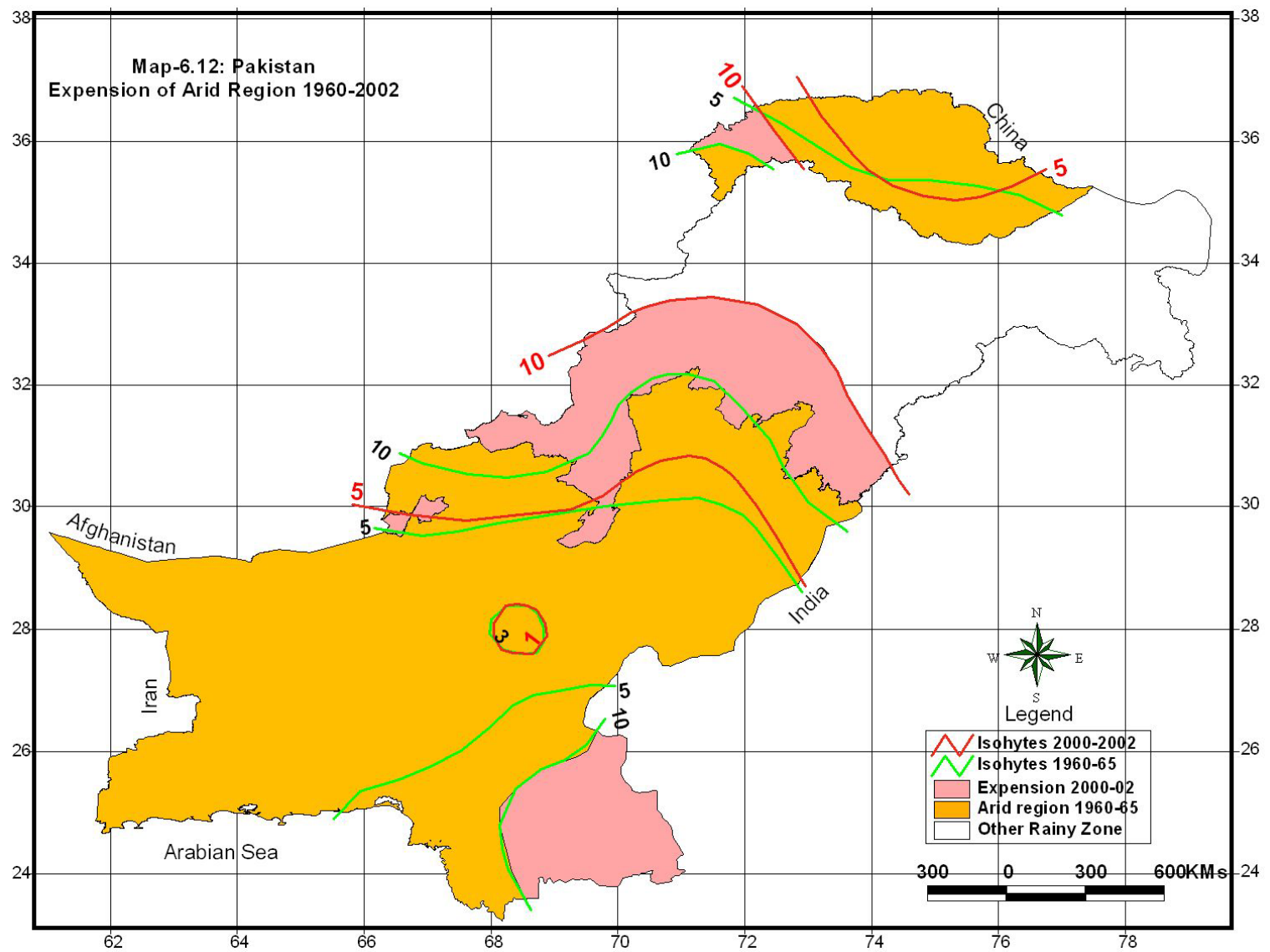
According to this research, aridity prevailed over 668,300 sq.kms area in Pakistan (1960) that showed a net increase of about 106,600 sq.kms towards north and most of the areas of the central Punjab, lower Khyber-Pakhtoonkhwa, and northern Baluchistan were became arid in 2000. This area was part of the semi-

**Table-6.8: Pakistan
Expansion of the Arid Region 1961-2000**

Location	Expansion Area (sq.km)
Total Arid Area 1960	668,300
Punjab, KPK, Baluchistan Expansion	106,600
Total Decrease in the North	-6954
Sum of Arid region in 2000	768,306

Source: Primary Data, digitized from 1:50K toposheets

arid region in 1960. It included, 2749 sq.kms area of Baluchistan (Quetta and its surroundings), and 54360 sq.kms of southeastern Sind. Northern arid region has reduced by 6594 sq.kms towards north (China). The total area of the arid region increased to 768,306 sq.kms by 2000. The total addition into the arid region from 1961 to 2000 is 99,646 sq.kms, revealing that on the average 2488 sq.kms of semi-arid area has converted into the arid region per year (Map-6.12 and Table-6.8). It also shows that the area is vulnerable to the ongoing climate change and need significant adaptation and further research.



6.2.3. Drought:

Pakistan frequently experiences droughts in the arid region. The Punjab province underwent the worst droughts in 1899, 1920 and 1935. The Khyber-Pakhtoonkhwa province experienced such droughts in 1902 and 1951, while Sind had its worst droughts in 1871, 1881, 1899, 1931, 1947, and 1999 (Kulshreshta and Sikka, 1989). The most severe droughts at the national scale were perhaps the most recent which occurred in 1999 to 2000 prolonging upto 2002 in certain areas (Table-6.6). The precipitation was erratic and river flows had dropped. The water in the Tarbela dam reached to dead level in late February or early March almost every year. The recent drought (1999-2002) has also exposed the vulnerability of the Indus basin irrigation system and environmental issues in deltaic areas.

**Table-6.9: Historical Droughts in India and Pakistan,
1802-2002**

Class range	Drought Years	No. of Years
1801-1825	1801,04,08,12,19,25	6
1826-1850	1832,33,37	3
1851-1875	1853,60,62,66,68,73	6
1876-1900	1877,91,99	3
1901-1925	1901,04,05,07,11,13,15,18,20,25	10
1926-1950	1939,41	2
1951-1975	1951,65,68,72,74	6
1976-2002	1979,82,85,87,2002	5
1801-2002	Sum	41

Source: Kulshreshta and Sikka, 1989.

Although the physical causes of drought are not fully understood, however several partial explanations of droughts in the arid region of Pakistan have been put forward based on theoretical grounds as well as on the past synoptic situations related to monsoon failures. *"Among the major factors*

cited are, weaker meridional pressure gradient, larger northward shifts of the monsoon, smaller frequencies of depressions and shorter westward extent of depressions tracks, shift in the western depressions towards northwest, deforestation, soil degradation, increase in temperature and decrease in precipitation (Kulshreshta., Sikka, 1989)". The situation is particularly serious in areas, where groundwater is either deep or brackish and no surface-water resources are available. Other factors that intensified the adverse impact of droughts include over-exploitation of groundwater in violation of groundwater regulations, deforestation, depletion of grazing pastures due to lack of management, poor farm water management and lack of controlled cropping patterns (Figure-7.1 and 7.4). These factors need further research to elaborate each and every aspect in view how to reduce the impact of the drought in the arid region of Pakistan.

6.2.4. Floods:

Pakistan is one of the five South Asian countries with the highest annual average number of people physically exposed to floods, which occur normally due to storm systems that originate from Bay of Bengal during the monsoon from July to September. Floods particularly hit Punjab and Sind, while hill torrents tend to affect the hilly areas of Khyber-Pakhtoonkhwa province, Baluchistan and the Gilgit-Baltistan province. Flood events of 1950, 1992, and 1998 caused many deaths and huge losses to the national economy. According to official sources, floods in Pakistan during the decade 1991 to 2001 caused an estimated damage of over Pak Rs. 78,000 million to property. During the flood of 2010, the fatalities were above 1781 and the total number of villages affected was 20 millions. This flood also caused damages to

transportation system, agriculture, power supply, power resources, natural vegetation, and cause a soil erosion at very high level (Table-6.10).

Table-6.10: Major Flood Events in Pakistan

Year	Fatalities	Villages affected
1950	2,190	10,000
1956	160	11,609
1957	83	4,498
1973	474	9,719
1976	425	18,390
1978	393	9,199
1988	508	1,000
1992	1,008	13,208
1995	591	6,85
2001	219	50
2003	484	4,376
2004	85	47
2005	59	1,931
2007	918	2 million+
2010	1,781+	20 million

Source: GOP, WCDR, 2005.

Chapter-7

Adaptation to Climate Change

The chapter discusses the short and long-term adaptation to the temperature and precipitation fluctuation noted in the previous chapters with reference to agriculture sector. The main factor is the rising temperature, which would affect the duration of growing season, requirement of water resources, enhanced plant, and livestock diseases. Agricultural production losses may also occur due to enhanced frequency and intensity of extreme weather events such as floods and droughts due to climate change. Considerable efforts would be needed to combat these climate-related impacts particularly in view of the time required for crop and livestock production systems to adapt. The next section discusses some of the measures that could be adapted in relation to climate change. One of the most important in this connection is the awareness and information on which the success will hinge. It was for this reason that a survey was conducted to find out the perception and level of awareness of people to climate change and related adaptation measures.

Adaptation to climate change is defined as, “*Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Darkin, 2008)*”. The adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damage, to take advantage of opportunities or to cope with the

consequences. Adaptation is processes through which societies in the arid region of Pakistan make themselves better able to cope with an uncertain future. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes. There are many options and opportunities to adapt. Based on the current research (chapter-3 to 6), the following adaptation strategies has been made to cope with the problem of climate change and its impact on agriculture sector in the arid region of Pakistan.

7.1. Adaptation Measures:

The climate related impacts could only be reduced through adaptation. A number of measures are needed for the same. Communities in arid region themselves are the key in adaptation to climate change as they are the ones who know and are aware of the changes that are happening in their environment, and how these are impacting them whether it concerns agriculture or other sources of livelihood. Nevertheless, the government assistance is also indispensable as communities in arid region are mostly vulnerable communities with lack of resources.

7.1.1. Agriculture and Growing Seasons:

The analysis shows a considerable dependence of the agricultural sector on climate conditions and their fluctuation. The arid region of Pakistan contains irrigated, rainfed, pure desert, and mountainous areas. Due to precipitation deficiency and temperature rise (Chapter-4 and 5), the rainfed land has subjected to increase and the crops production and yield per acre reduced in lower Punjab and Sind province.

7.1.1.1. Basic technology needs:

- o The government is needed to consider the development of supporting facilities in large-scale keeping in view the available surface water.
- o To build new small-scale dams in the rainfed areas of the arid region especially in Baluchistan.
- o To control the expansion of middle-and low-productivity agricultural zones and strengthen the restoration of degraded farmlands.
- o To utilize advance agricultural tools and technologies to improve crop productivity.
- o To provide scientific and technological facilities for agriculture, including a long-term weather forecasting.
- o To implement combined agro-technical and land reclamation measures to improve the area under crops.
- o To develop program to prevent soil salinization and swamping in agriculture land located on both sides of Indus and its tributaries.
- o To provide financial support and insurance to agricultural farms at government and private levels and to create awareness among people about the farm cultivation system.
- o To improve selection of growing drought resisting and high-yielding agricultural crop varieties, require less water.
- o To create and introduce fast growing, disease and heat-resisting varieties.
- o To forecast and take timely measures to prevent crop pests and diseases related to climate conditions.

- o To increase the efficiency of crops irrigation by applying water-saving technologies.

7.1.1.2. Crop yield and Production:

The cultivation of water sensitive crops like maize, sorghum, sunflower, and soybean would be required to adjust for shortage in water supplies and for sustainable crop yield and lengthening of the growing seasons in rainfed areas of Baluchistan, Sind, and lower Punjab.

- o Precise land leveling using advance technologies is a good option for rice crop to have better yield and efficient water use, in addition to salinity management. The increase in air temperature would increase the temperature of standing water in rice fields and adversely affect the growth and yield of paddy rice. The land leveling would help in effective drainage of warm water in dry climate and excess rain water.
- o In arid region of Pakistan where there are limited irrigation facilities, the groundwater is a major source of irrigation. Groundwater in these areas is facing problems of scarcity throughout the year. Due to recent precipitation and temperature fluctuation, limited irrigation through *tubewells/Karez* will be more suitable to increase the crop production especially in the arid Baluchistan.

7.1.1.3. Expansion in irrigation system:

Due to the recent climate change, aridity has increased and there is need of the improvement in the irrigation requirements. The increase in population and irrigation water demand would affect the water availability in the lower Punjab and Sind province. Therefore, it is needed to extend the irrigation facilities to new rainfed areas. The main factors to cope with the problem of

climate change and expansion of irrigation system in the arid region are as follow.

- o The surface water supplies from the adjacent watersheds can be managed for diversion to agriculture lands, if flows are perennial. Incase flows are non-perennial; the runoff can be stored in reservoirs and dams and then regulated to provide irrigation. There is a great potential of storing runoff areas within or outside the Indus basin in lower Punjab and Baluchistan, which will also reduce the flood hazard.
- o The increase in irrigation water requirements due to climate change would force the farmers to start using low quality of water in fragile environments.
- o To invest more in the irrigation facilities, especially in rainfed areas of the Baluchistan already facing dearth of surface water because of aridity and climate fluctuation.
- o In Baluchistan most of the farmers have turned to use groundwater to maintain crop productivity that is adversely affecting the watertable, observed in 2000 in most of Baluchistan, Sind, and lower Punjab. The introduction of irrigation facilities in the arid region will not only help to increase the crop productivity but will also increase the recharging capacity of watertable.
- o The government of Pakistan should develop and improve the canal irrigation system along with the other water resources like tubewells, *Karez*, and wells etc.
- o The government of Pakistan is needed to invest more in the development of the rainy or flood water irrigation system in the entire

area of Baluchistan. This will also decrease the process of desertification in the area. The airborne precipitation (artificial rain) is more suitable for the areas located closer to the Arabian Sea for the farms cultivation. Private sector should also be invited to invest in the irrigation projects of the country for the improvement and utilization of the flood water for the development of agriculture in the arid region of Pakistan.

7.1.2. Adaptation to water sector:

The water sector is more vulnerable to the climate change and is counted as major environmental problem. Adaptation to the adverse effects of climate change on surface and sub-surface hydrology, therefore, will be a part of the overall comprehensive strategy to overcome the current as well as future environmental changes.

Under almost all the circumstances the water sector shows that the system could not meet the entire demand of the agriculture sector in the future. Adaptation measures, therefore, would be required to overcome the adverse effects or to obtain the benefits of the positive impacts.

The current flow of water and its storage is not fulfilling the need of agriculture in the arid region. It is evident from the analysis of the water flow in the Indus system that if extra flow or extra storage is not added to the current capacity then there will be serious water related crises in the dry years not only in the arid region but also on national level (Chapter-6). Major changes will take place in the rivers' flows and as a result the economy of the country will suffer.

The environment and economy of arid region is highly dependent on the onset and retreat of monsoons, western disturbances, and water supplies from glaciers and snowmelts. Excessive and inadequate precipitation causes floods and droughts respectively, having damaging effects on the crops in the lower Punjab and Sind. The current climate change can cause serious impacts on the monsoons and western disturbances, frequency and distribution of rain spells, accelerating the melting of glaciers and increasing the frequency of floods and droughts. The major adaptive steps to the ongoing climate change and its impacts on the water sector in the arid region of Pakistan are summarized as follow:

7.1.2.1. Water conservation:

The most important factor to cope with the impact of climate change on water sector is the conservation of water resources and building new water reservoirs. It is also needed to introduce new approaches for planning and management for the water resources in the arid region. The following are the key adaptive steps.

a. To overcome the insufficiency of running water, caused by climate change, it is needed to construct additional water reservoirs that will help in the shortage of the water resources in future supplies to different parts of the arid region in Pakistan.

b. Every year Pakistan faces the problem of flood in Indus water system that causes damages to national economy through destruction of properties, crops, human residence, and livestock. As there is no facility to store the flood water in the country, it is therefore, recommended to construct by pass reservoirs on Indus and its tributaries. The major function of these

reservoirs will be the storage of flood water during flood or rainy season and maintaining normal flow in the Indus system. The excess water stored can be added to the normal flow during dry months to fulfill the requirements of the irrigation system in the arid region. This will not only reduce the damages caused by flood every year in Pakistan but will also help to store the extra flow and to utilize it for the sustainable agriculture. The suitable areas for such reservoirs are mountainous areas of KP, Baluchistan, central Punjab, and upper Sind.

c. In addition to major water reservoirs, small dams are the second option to overcome the shortage of water and to mitigate the adverse impacts of the climate change especially in the seasonal torrents of Baluchistan and the Indus river tributaries.

d. There are a large number of seasonal streams in Baluchistan and Gilgit-Baltistan province, suitable for the storage of small inland dams (Figure-7.1). They will not only supply water for the human and agriculture needs of the local communities but will also help in the recharging of watertable. During wet years or flood, these inland dams will be more suitable for storage of flood water,



Figure-7.1: Wet (before 2000) and Dry view (2000) of Lake Hina, Quetta Baluchistan.

while in dry years these will be the only source of irrigation system and will also help in the domestic use.

e. This is also helpful for the storage of water near residential areas. It is needed to dig land near the residential area and stored the rainy water as well as domestic used water (polluted) in it. This will be more suitable in areas where the watertable is deeper and located far and wide from the rivers or canals especially in the entire arid region of Baluchistan and Sind provinces.

7.1.2.2. Construction of river embankments:

The banks of Indus and its tributaries are not in the position to face the pressure of high flow during rainy season. Most of the river banks are exposed to the river erosion. This problem not only results in the high damages during flood or rainy season but is also widening the river bed and occupies most of the cultivated land converting it into waterlogged areas (Figure-7.3). It is therefore, needed to construct river embankments and to restrict the river bed upto the water flow capacity. A major example is the construction of Ghazi Barotha project that controls the flow of the Indus river in a bypass canal (Figure-7.2). These embankments will not only help to save the land from waterlogging but will also provide base for the meaningful use of the water resources.



Figure-7.2: Ghazi Barotha dam and bypass canal



Figure-7.3: Exposed banks, base widening, and waterlogging of Jhelum and Sutlej river.

7.1.2.3. Improvement in the irrigation system:

Being an agriculture economy, Pakistan is extraordinarily dependent on its water infrastructure, and it has invested in it massively. Due to time factor much of the infrastructure in Pakistan is collapsing. This is true even for some of the major barrages, which serve millions of hectares and where failure would be disastrous.

7.1.2.4. Policy for water management:

The government of Pakistan has to improve the policy of the water sector management keeping in view the needs of nationals, agriculture, disasters, watertable, power resources, national economy, and the current climate change.

7.1.2.5. Planning for water resources:

The adaptation strategy of any issue in the future and for the vital issue of water resources planning, development, and management in particular has to be sustainable, technologically advanced, and visionary. Water resources planning, development and management in the Indus is ecologically, technologically, and sociologically complex. Adjustment to climate change impacts will only be effective if these complexities are properly understood. Water planning should concentrate on the dynamics of the water resource system. Impacts on flood, deposition, and whether represent high priorities for additional investigation and planning. Climate imposed considerations can be incorporated within medium and long term water investment planning and projects appraisals. Given the importance of Indus river, it would be advisable to broaden the scope of water planning to address the long term impacts of climate change in conjunction with pressing water problems in the arid region.

7.1.3. Early warning system and monitoring:

Due to increase in climatic hazards in the arid region, Pakistan has to improve its early warning system and monitoring network to enhance adaptive capacity in vulnerable sectors such as agriculture, natural disasters, water

scarcity, and aridity etc. The following are some factors to cope with impacts of climate change by using early warning and monitoring system.

- o To counter flood and storms, local governments are required to develop city flood control and water drainage plans.
- o To introduce advance technologies for the monitoring and early warning system for flood, surface water, earthquakes, cyclones etc.
- o To improve the forecasting of weather for agriculture and also to develop new forecasting centers throughout the arid region to control drought, desertification, and water flow etc.

7.1.4. Raising public awareness:

The public needs to be made aware of the climate issues with respect to the impacts on the locals, cultural and economic environment. Pakistan strategies to raise public awareness can be summarized as follows:

- o All the concerned officials and decision-makers should be well aware of the matters related to climate change and their impacts.
- o Public should be educated through media about climate change, its impacts on agriculture and water resources. Government is needed to introduce knowledge about climate change in the education curriculum of educational institutions in the country.
- o To encourage public and private participation, increase the transparency of decision-making processes related to climate change issues, public awareness, social groups, and NGOs to play active roles in the adaptation of climate change especially in Baluchistan.
- o To strengthen international cooperation on public awareness especially good practices on climate change education.

7.1.5. Improving R&D facilities:

There is need for research and development to meet with the challenge of the climate change as it will affect almost all the aspects of life in Pakistan. Some of the recommendations to enhance climate change-related R&D are as follows.

- o There is need to establish Dry Land Research and Development Funds (DLRDF) on federal and provincial level for the control of drought, desertification, and land degradation. It should be run independently through experts and highly specialized people in the field of climate change and desertification.
- o Pakistan has to promote scientific and technological research to examine impacts of climate change on the socio-economic development, analysis of the effectiveness of socio-economic benefits and costs in response to climate change, surface water, agriculture yield, deforestation, ways of artificial precipitation, waterlogging, and salinity, alternate resources of energy, and advance technology.
- o The federal and local governments have to establish effective incentive and competition mechanism and a favorable academic environment for researchers with international vision and ability to carry out climate change studies, and encourage research activities.
- o The government should develop a mechanism for the transfer of advance technologies to the farmers in the arid region.
- o To identify and develop variety of seeds for drought prone areas of Baluchistan and Sind.

7.1.6. Adaptation to aridity:

The government plans should contain provision for the implementation of specific actions to detect drought and to mitigate its effects on agriculture production. Some of the major steps to combat aridity in the arid region of Pakistan are as follow.

- o To be aware of the serious deterioration of the natural resources in the surrounding of arid region and of the need to find ways of improving the life standards of the locals.
- o To channelize water resources in different parts of the arid region and to findout new areas and irrigation resources for the agriculture, locals and livestock.
- o Development in agriculture and water resources should be in accordance with each other for the socio-economic benefits such as jobs, income etc.
- o To control the far reaching change in the landuse of the arid region that is caused by the scarcity of water and population growth.
- o To establish emergency response plan to save the human life and livestock during drought period in the arid region of Pakistan.
- o To introduce comprehensive soil management techniques and technologies.
- o To grow plantation forest, especially the acacia tree, in the surroundings of the arid region to control the expansion of desertification.



Figure-7.4: Dry distributary of Indus river at Eastern Sind, 2000

7.2. Perception of Communities on climate change:

The main objective of comprehending people's perception was to assess the level of public awareness to climate change and needed adaptation measures. The questionnaire survey was conducted in the arid region of lower Punjab, parts of Baluchistan, Sind, and Gilgit-Baltistan, upper and lower Khyber-Pakhtoonkhwa province using random sampling method. The sample area covered 25 districts having different kind of landforms (Map-1.1).

The result of the survey showed a high level of awareness as all the respondents pointed out that the climate was changing; 40 percent believed that it had changed moderately, while 80% were of the opinion that it had changed severely with the passage of time. About 73% of the respondents believed that climate of the arid region in lower Punjab were hot; while in some areas it was moderate and warm. Moreover, 55% of the people

believed that climate of the arid region was warm before 2000, and was continuously changing to hot climate. They were also of the opinion that this change of climate is due to the increasing temperature (80%) and decreasing precipitation (90%) from 1990 to 2011.

7.2.1. Perception on Causes of climate change:

About, 57% of the participants believe that this change in the climate of the area is due to anthropogenic activities like overpopulation, over cropping, deforestation, overgrazing, land degradation, atmospheric pollution, and wars. Most of the people believe that government was not acting adequately to address the problems, while 84% believed climate change poses a serious challenge to the entire arid region. Over 94% has opined that the exhaust gases are mostly added to atmosphere from vehicle emission, while in some cases it is by industries. More than 90% were willing to take part in the campaigns if launched to mitigate harmful impacts of the climate change in the area.

7.2.2. Perception on Impacts:

The respondents were asked to choose sectors where climate change has a major impact. Almost all of the respondents agreed upon the climate change and its impacts on all aspects of the human life and call for adaptation and mitigation strategies. The majority gave priority to drinking water, agriculture, forest fires, drought, desertification, health, economy, and decline in the market values of livestock in drought prone areas. Majority of those who answered believe that they will feel the impacts of climate change within 5 to 10 years (2000 and onward). Those surveyed, were also asked to choose the three most important measures to mitigate the causes and to adapt to the

effects of climate change. Changing consumption patterns or increase in poverty and reducing agriculture production was the main measure chosen, followed by education and awareness. For watertable, 44% of the respondents suggested to reduce the use of tubewells and to introduce most advanced agriculture and irrigation technologies. Most of them are willing to take community based action for the reforestation on the barren land of the arid region. About, 90% of the people took decrease in the forests area to be a major cause, as according to them there had been sever cutting of natural vegetation for domestic and agriculture use and recommended forestation, alternate energy sources, and materials for the construction of houses to save the existing forest life.

7.2.3. Drought and desertification:

The arid region of Pakistan has passed through a sever drought many times since 1960. About 36% believe that the sever drought of the area was recorded in 1971, while some of them vote for 2000, when the market value of the livestock dropped to almost half as compared to normal years. Among the participants, 28% have opined that these droughts were hydrological, while 62% believe that it was agriculture drought, which affected the fauna, human lives, and agriculture (winter and summer crops) in the rainfed areas of the lower Punjab. About, 70% believe that the droughts were the result of decrease in precipitation that declined the flow of water and caused damages to crops, human, and animal lives (Figure-7.3 and 7.4). The most affected areas during 1971 and 2000 droughts were Baluchistan, lower Khyber-Pakhtoonkhwa, Lower Punjab, and entire region of Federal Administrative Tribal Areas (Figure-7.1). Besides, 50% of the people believe that the climate

change in the arid region not only effected the human lives but also pushed the birds to migrate into the near by lands for breeding, shelter, and food. Moreover, 57% of the respondents mentioned that less than 25% residents of the lower Punjab migrated to nearby cities in search of jobs, foods, shelters, and drinking water during drought years. This migration took place because of non-availability of timely government support to the people of the arid region.

7.2.4. Agriculture sector:

Generally, 67% of the participants believe that the recent climate change mostly affected the *rabi* crops (October to May) in the region. Among the surveyed, 70% have opined that this has not only changed the production of crops but it has also changed the sowing and harvesting period of the *rabi* (winter) and *kharif* (summer) crops in the area by 21 to 30 days. The total of 59% of the people was of the view that the crop production has decreased causing food scarcity, affecting the national economy. Furthermore, 62% of the respondents believed that the climate change has shifted the boundaries of the agriculture zones towards north and northwest during 1990 to 2011. According to the people, the production of the *rabi* (winter) as well as *kharif* (summer) crops declined from 10 to 15 kilograms per acre.

7.2.5. Water resources:

Most of the respondents have the opinion that people are using tubewells as water resource for agriculture (48%), whereas 36% are in irrigated plains and 15% into rainfed area. About 96% have mentioned that the flow in canals and rivers decreased between 1980 and 1995, with impacts on the agriculture production, human lives, national economy, and

desertification. The respondents believed that this happened because of decrease in precipitation (62%), while according to 24% it is the result of deforestation. Asking about the control of desertification, forty five percent of the surveyed people have suggested forestation, while 55% identified canal system as the main factor to control desertification in the region.

As glacier is the main source of surface water, and it is necessary to know about the public perception regarding the impact of climate change on glaciers in the northern arid region (Gilgit-Baltistan). The 67% of participants have opined that the glaciers are going to melt and retreat with passage of time, Most of the respondents believed this to be the consequence of the global warming. Among the people, 38% believed that it could be controlled by the plantation of trees on mountains, while the remaining have suggested for the control of atmospheric pollution. Asking about the impact of climate change on coastal region in Pakistan, 85% of the residents believed that the ongoing climate change was affecting the coastal region by means of change sea level, cyclones, and floods.

7.3. Adaptation Implementation:

Implementing adaptation plans and strategies in the arid region is a vital next step for Pakistan. As highlighted in this chapter, many plans and strategies have been made and a number of capacity-building steps have been suggested. Now, it is important to bridge the gap between adaptation assessment and planning and adaptation implementation, and to build on knowledge from capacity building strategies. Adaptation options need to be matched to priority needs both in the context of community-based action and in national and sectoral planning as well as disaster risk reduction in the arid

region. Adaptation plans must be integrated into top-down and bottom up approaches for planning to enable sustainable development and the efficient use of resources for adaptation in the arid region of Pakistan.

Chapter-8

Conclusions, Recommendations and Further Research

Following are the conclusions drawn from the study of temperature and precipitation distribution pattern and trends for the identification of hot/dry and wet/cold periods and its impact on agriculture sector and adaptation from 1961 to 2000. The research hypothesis, "*the Changes in the temperature and precipitation in Pakistan have affected agriculture in arid lands of Pakistan severely and adaptation strategies are needed to cope with the situation,*" has been tested using statistical techniques and public opinion. The impacts of climate change on the *rabi* crops (winter) are more visible as compared to *kharif* crops (summer). Both of the seasons show decline in the crop production except rice, wheat, sugarcane, and cotton that has increased due to expansion of agriculture landuse, food demand, and market value. Generally, the temperature and precipitation fluctuation has caused change in the agriculture productivity, yield per acre, and landuse that affected the national economy by increasing demand for food and vegetable. Generally, the water resources have declined due to precipitation fluctuation resulting in the increase of the rainfed area, expansion in the arid region, and shift in the growing season, and depletion of the watertable. It is these outstanding results that provide a base for the acceptance of the research hypothesis.

8.1. Conclusions:

About 700 papers and books regarding climate change, impact, and adaptation were collected on national as well as international level, in which 208 papers were considered for the current work. Most of the papers are

about climate change, fluctuation, and variation in the different parts of Pakistan and the World as a whole. Among them, a few papers discuss the climate change in the arid region.

From the literature review regarding the climate change, adaptation and mitigation it is evident that it is not only an issue in the arid region of Pakistan but it has effected different parts of the world including Asia, Africa, Europe, America, and Australia etc. The negative impacts of climate change are more visible in the Eastern and South Asia as well as Middle East in the form of floods, cyclones, droughts, landsliding, and agriculture production etc.

8.1.1. Environment and agriculture:

The relationship between physiography, human pressure on land, vegetation, landuse, marine influence, and agriculture shows that these are the key factors that control the climate and cropping pattern in the arid region of Pakistan. Most of the forests have been cleared for agriculture and domestic use to overcome the food demand and human stress.

The soils of flood plain and bar upland in lower Punjab and Sind province are more suitable for agriculture activities having high productivity as compared to other parts. The Baluchistan soils are suitable for the agriculture but because of non-availability of surface water and low precipitation, it remains un-cultivated.

Due to shift in isotherms and isohyets, the boundaries of the agro-ecological zones have extended towards northwest. This shift in the boundaries of agro-ecological zones has caused adverse effects on the landuse, cropping area, growing seasons, and production. Certain decrease in the agriculture land, forests/scrub covered area, irrigated land, grassland,

sandy desert, waterlogged area, while an increase in the barren land, rainfed areas, and human pressure on land from 1961 to 2000 has been noted.

8.1.2. Temperature distribution and fluctuation:

The mean monthly temperature of the arid region shows rising trend from 1961 to 2000. The highest temperature of the region has been recorded at Sind, while the lowest is at the northern arid region. The mean monthly temperature of the arid region in Pakistan increases from northwest to southeast.

In hilly areas, the winters are longer with short summers, while in plain, the trend is reverse as compared to highlands. It is this variation that provides base for the growing season of crops throughout the year. The mean monthly temperature of summer season indicates a decreasing trend because of an increase in the monsoon precipitation, while the trend remains high in winters.

Five temperature zones have been identified in the arid region including hot, warm, mild, cool, and cold. There is a slight increase in temperature in cold, pre-monsoon, monsoon season, and decrease in the post-monsoon season that adversely affected the agriculture sector in the southern arid region.

The rising trend of mean monthly temperature in the Gilgit-Baltistan and lower Khyber-Pakhtoonkhwa provinces have caused melting of glaciers and retreat of ice sheets in the Himalayas. The recent avalanche at Gayari valley Siachin area (2012) near Skardu and catastrophic landslide near Attabad in Hunza Valley are the result of such changes. The trend of temperature is also negative in the lower Punjab and coastal region.

The mean monthly temperature showed change after an interval of five, ten, fifteen, and twenty years. The current increase of 1.6degree Celsius in temperature has caused change in the sowing and harvesting time period of crops (cropping season) and agro-ecological zones of the country. It has nourished the pests in the lower Punjab and Sind especially in the cotton and rice growing areas. The increase in temperature has also affected the crop production and caused increase in the rainfed area.

8.1.3. Precipitation distribution and fluctuation:

The annual precipitation of the arid region in Pakistan revealed a decreasing trend during 1961 to 2000 that caused negative affects on the agriculture sector. The average precipitation of 1.48inches (37.6mm) and total precipitation of 6.53inches (165.9mm) was insufficient for the crop growth and production. Moreover, the decrease of -0.05inch (-1.27mm) precipitation has dropped the flow in the Indus and its tributaries that caused change in landuse pattern, growing season, yield per acre, and make the agriculture sector more vulnerable to climate change.

The winter precipitation of the arid region decreased, whereas it increased in the summer season. The decrease in winter precipitation reveals that the *rabi* crops are on risk in the rainfed as well as in the irrigated plain of lower Punjab and Sind, while the production of the *kharif* crops remained stable due to increase in the monsoon lows, cultivated area, and human demand. The precipitation showed decrease in cold and pre-monsoon season, whereas it is increased in monsoon and post monsoon season.

According to Palmer Drought Severity Index, the dry condition prevailed over the arid region of Pakistan from 1871 to 2000. The

meteorological data from 1961 to 2000 revealed a slight change after every five years, medium in ten and fifteen years and long term oscillation after 20 years. The isohyets revealed heavy rains in the southern Sind in monsoon season, while in winter, it shifted towards northwest Baluchistan. The Gilgit-Baltistan province has high precipitation from local thunderstorms (pre-monsoon season), while at central Sind and adjoining areas of Baluchistan, it was in the post monsoon season. The precipitation over Dera Ismail Khan, Drosh, and Quetta decreased with passage of time, whereas it remained stable over the southwestern Baluchistan and Kharan desert.

The seasonal oscillation of the Gilgit-Baltistan region indicated that the winter precipitation has remained stable, whereas the summer precipitation showed an increase during 1961 to 2000. In the coastal region, southern Punjab, irrigated plain of Sind, Kachhi plain in Baluchistan, Thar and Cholistan desert, it has been noted that the precipitation has declined during cold, pre-monsoon and post monsoon seasons having a slight increase in the monsoon season. This decrease in the precipitation has converted most of the cultivated land into rainfed areas and affected the agriculture productivity. Generally, the isohyets revealed that the boundary of semi-arid climate has shifted from Nagar Parkar towards the northwest (central Sind).

Generally, the isohyets of the southern arid region revealed a shift in the boundary towards northwest. Resultantly, Quetta and the adjoining areas of Afghanistan fell into arid climate during 1961 to 2000 and aridity prevailed over most area of Baluchistan, Sind, and lower Punjab.

8.1.4. Impact on agriculture and Water resources:

The flow of the Indus and its tributaries seem to have direct relationship with the precipitation fluctuation. However, the impact is not visible on the flow of the Kabul River as it is prominent on the Indus and its tributaries and Baluchistan rivers. The Indus water treaty of 1960 has also played a role in the change of the flow in Sutlej and Ravi rivers.

The agriculture in the rainfed area depended on the climate particularly precipitation and temperature fluctuation as it is evident from the case of the barley, sesamum, gram in *rabi* season and pearl millet, sorghum, maize, and tobacco in *kharif* season. The crops grown on the irrigated area have no apparent relation with the precipitation fluctuation because a number of other factors seem to have affected the production like the increase in the cultivated area, improved irrigation system, market value, human demand etc. In order to protect our crops from the climate hazards in the arid region the irrigation facilities should be extended to the rainfed areas.

The production of cotton, tobacco, Sorghum and Pearl millet, millet, barely, and gram has decreased from 1961 to 2000. These crops are vulnerable to the ongoing climate change in the arid region of Pakistan. Furthermore, the production of rice, sugarcane, maize, wheat, and sesamum has shown an increase from 1961 to 2000 and remained stable. This stability is the result of increase in the cultivated land, better irrigation facilities, and market value etc.

The southern arid region has extended towards northwest, while it is towards north in the northern arid region (China). The agro-ecological zones and cropping pattern have shifted towards northwest. Due to increase in temperature and change in the growing seasons, most of the mountainous

areas that grew single crop throughout the year are now able for cultivation of two crops.

8.1.5. Adaptation to Climate change:

The water sector is more vulnerable to the impacts of climate change. These impacts could be minimized with the help of construction of new water reservoirs and inland dams, river embankments, improvement in the water supply and irrigation system, planning for the use of water resources and utilization of the flood water, revise policy of the water management, implementation, and establishment of research and development funds.

Agriculture also requires improvement in the infrastructure, new technologies, crop choice, extension of irrigation system to rainfed areas, water saving technologies, legislation for landuse change, and human stress on land.

The techniques of the early warning system and monitoring of weather, natural disasters, agriculture, and surface flow are very old and traditional and the introduction of the advance technologies are the need of the time. The government and the private sector should create awareness among the locals about the impacts of climate change using mass media, (news papers, TV, pamphlets etc) and to educate the farmers.

It is required to promote the research institutes and to utilize the international funds with more proper ways. It will be appreciated if the government extends their linkages with different international organizations and to devise a national adaptation strategy for the arid region.

8.2. Recommendations:

Following are the recommendations to cope with the environmental hazards and to minimize the negative impacts of climate change on the agriculture and crop productivity in the country particularly in the arid region.

- o To establish climate change research center at university level to encourage research in this field and to produce specialized manpower. For this purpose it is of utmost importance to develop centralized data centers with easy access to the researchers for the study of the climate change particularly in the arid region of Pakistan.
- o To control deforestation by providing alternate sources of energy for the domestic and commercial use to the inhabitants of the arid region and to prevent the people strictly to change the forest area into agriculture land.
- o Population growth in the arid region of Pakistan is one of the major problems and the Government is needed to control birth rates in the area by means of literacy, awareness of the people through mass media, rural health centers, and medical specialists.
- o Due to fluctuation in winter and pre-monsoon precipitation it is suggested that the Government should control the use of underground water so that it should not affect the watertable in the arid region.
- o Most of the forests in the Thar and Cholistan desert are cleared by the locals for agriculture, domestic use, and expansion in residential area that will accelerate the process of desertification. The federal and local government is needed to take action against forest mafia on urgent

basis and also to make changes in the forest laws to give protection to wild life in these deserts by legal means.

- o Natural as well as anthropogenic activities have caused change in the climate of the arid region. It is hard to control the natural processes but easy to control the human activities causing variation in the climate of the region. It is suggested to control population growth, deforestation, degradation of soil, urban sprawl, wars, use of explosive materials, and atmospheric pollution etc.
- o The need of land for agriculture and food demand force the people for the cutting of forests in the highlands. It is therefore, recommended to carryout the forestation of the *Shamilat* land at any cost and in this regard strict policies should be formulated and implemented. The government should also make sure the meaningful use of the international funds for the forest restoration in the area.

8.3. Further research:

A research study opens the ways and identifies the problems and topics for further research. During this research the following problems have been identified that need detail study.

- o To analyze the impact of natural vegetation, natural disasters, soil degradation and marine influence on temperature and precipitation variation and fluctuation in the arid region of Pakistan.
- o To study the impacts of temperature fluctuation on the glaciers and permafrost in the upper catchment area of the Indus drainage basin and its adaptation to climate change.

- o To conduct research on the expansion of desertification caused by deforestation and landuse change in Thar, Cholistan, and Kharan deserts.
- o To update the adaptation measures, policies, and strategies for the impact of climate change in the arid region of Pakistan regularly.

8.4. References:

ADB.; **2009.a**, Climate Change and Migration in Asia and Pacific, Executive Summary: ADB Avenue, Mandaluyong City 1550 Metro Manila, Philippines, p. 44.

ADB.; **2009.b**, Understanding and Responding to Climate Change in Developing Asia, Asian Development Bank 6 ADB Avenue, Mandaluyong City 1550 Metro Manila, Philippines. p. 84.

Adger, W. N.; Barnett J., **2007**, Climate change, human security and violent conflict, *ELSEVIER, Political Geography* 26, pp. 639-655. "(Online)" www.elsevier.com/locate/polgeo.

AEA.; **2007**, Adaptation to Climate Change in the Agricultural Sector. *ED05334, Issue Number 1*, p. 10.

Agboola, P.; *et al.*, **2002**, Global warming: Solar variation effects. A Publication of Department of Engineering Eastern Mediterranean University, Gasimausa, visa Mersin 10., Northern Cyprus, Turkey. P. 5.

Aggarwal, P. K.; Sinha, S. K., **1993**, Effect Of Probable Increase in Carbon Dioxide and Temperature on Wheat Yields In India. *J. Agric. Meteorol.* 48, pp. 811–814.

Ahmad, A. U., **2006**, Bangladesh Climate Change Impacts and Vulnerability. A Synthesis: Climate Change Cell, Department of Environment Component 4b, Comprehensive Disaster Management Programme, Bangladesh Room 403, Paribesh Bhabhan, Agargaon, Dhaka-1207, Bangladesh. p. 49.

Ahmad, R.; Rafi Z.; Wheat Crop Model Based On Water Balance For Agrometeorological Crop Monitoring. *Pakistan Journal of Meteorology*. Vol. 2: Issue 3: (**March 2005**), p. 23-33.

Ai, L.; *et al.* Precipitation variations of Longxi, northeast margin of Tibetan plateau since AD 960 and its relationship with solar activity, *Clim. Past discuss*. Vol. 3. pp. 1037–1061. **2007**, "(Online)" www.clim-past-discuss.net/3/1037/2007/.

AKhtar, T.; **2009**, Climate Change and Flow of Environmental Displacement in Bangladesh, Unnayan Onneshan-The Innovators House-19/A, Road-16 (New), Dhanmondi, Dhaka, Bangladesh. p. 18.

Alam, A.T.M.J.; *et al.* **2011**, Spatial Analysis of Precipitation Distribution and Its Impact on Agricultural Drought at Barind Region, Bangladesh., *Rajshahi University Journal of Environmental Science*. ISSN 2227-1015. Vol. 1, pp. 40-50

Ali, Z. **2003**, Climate Change Influence on Avian Diversity of Wetlands. A Study with Management Options on A Ramsar Site from Pakistan. 121 M, Marghzar Peco Colony, P O Awan Town, Lahore, Pakistan. p. 25.

Arnell, N. W.; **2004**, Climate Change and Global Water Resources: SRES emissions and socio-economic scenarios, *Global Environmental Change*, 14. pp. 31–52.

Avissar, R.; Pielke, R. A. **1990**, Influence of Landscape Structure on Local and Regional Climate. *Landscape Ecology*. vol. 4. No. 2/3. SPB Academic Publishing, The Hague. pp. 133-155.

Ayaz, M.; Iqbal, M.; Siddiqui, K. M. **1999**, Forest ecosystem climate change impact assessment and adaptation strategies for Pakistan, *Climate Research*, Vol. 12: pp. 195–203.

Arshad A, Ahmad S, and Rohi R., characterization and classification of agro climates of Pakistan., Pakistan Journal of Agriculture. Res. Vol. 17. No. 3. **2002**.

Baas, S.; Ramamasy, S. **2007**, Climate variability and change: adaptation to drought in Bangladesh. A resource book and training guide, Asian Disaster Preparedness Center Food and Agriculture Organization of The United Nations Rome. p. 66.

Bashir, F.; Butt, M. J. **2005**, Satellite Snow Monitoring in Northern Pakistan. Publication of Department of Meteorology COMSATS Institute of Information Technology Islamabad, Pakistan. p-5.

Beg, M. A.; **2001**, Is Global Warming Changing Pakistan Climate. Science.com, Friday Magazine of *Daily DAWN*. July 6th. pp. 1-8.

Beniston, M.; **2003**, Climatic Change in Mountain Regions: A Review of Possible Impacts, *Kluwer Academic Publishers, Climatic Change*, 59: pp. 5–31.

Barret, W.J.; Manual for the Geography of Natural Resources.; Burgess Publishing Company, Minnesota, **1963**, p. 48.

Bizikova, L. T.; Neale; Burton, I.; **2008**, Canadian Communities Guidebook for Adaptation to Climate Change, Including an approach to generate mitigation co-benefits in the context of sustainable development, First Edition, Environment Canada and University of British Columbia, Vancouver. Catalogue N°: En56-226/2008E. ISBN: 978-1-100-10839-1. p. 104.

Blanco, E. I.; **2008**, Climate Change Impacts on the Water Resources. An overview of global Impacts and techniques to assess at local scale. Literature Review. The University Of Texas At Austin. p. 27.

Bliunas, S.; Soon, W.; **2003**, Re-constructing Climatic and Environmental Changes of the Past 1000 years. *a re-Appraisal.*, *Energy & Environment* · Vol. 14, No. 2 & 3. pp. 233-298.

Burbank, W. D.; and Brozovic, N.; **2000**, Dynamic Fluvial Systems and Gravel Pro-Gradation in the Himalayan Foreland, *GSA Bulletin*. V. 112, No. 3, p. 394–412.

Bush, A. B. G.; **2004**, Modeling of late Quaternary climate over Asia: a synthesis, *Boreas*, Oslo, ISSN 0300-9483. Vol. 33, pp. 155–163.

CARES.; **2009**, Humanitarian Implications of Climate Change: Mapping emerging trends and risk hotspots, *Second Edition*. Noel Creative Media Ltd, Nairobi, p. 36.

Carter, R. M.; Human-Caused Global Warming, The Center for Science and Public Policy Washington, D.C. 202-454-5249. **February 2007**, p. 39. "(Online)", <http://www.scienceandpolicy.org>.

Catoire, S. M.; *et al.*; **2011**, Through the Decade: Extreme Weather's Impact on Agriculture. Governor's School for Agriculture, Virginia Tech, Blacksburg, VA, 24061. p. 200.

Changnon, A.; *et al.*; **1999**, Temporal Fluctuations in Weather and Climate Extremes that Cause Economic and Human Health Impacts, A Review. *Bulletin of the American Meteorological Society, USA*, p. 22.

Chaudary, Z. Q.; Impact of Climate Change on Agriculture and Forests in Pakistan, *Science Technology and Development*, Vol. 13. No.2. **April-June, 1994**. pp. 44-46.

Chaudhari, H. S.; **2007**; South Asian Summer Monsoon Precipitation Variability: Couple climate model simulations and projections under IPCC AR4. *Appl. Climatol.* DOI 10.1007/s00704-006-0282-0. Printed in The Netherlands, 90. pp. 133–159.

Chen, B.; Liu, X.; **2000**, Climatic Warming in the Tibetan Plateau During Recent Decades, *International Journal of Climatology, Royal Meteorological Society ,Int. J. Climatol. Vol, 20*. pp. 1729-1724.

Chen, C. C.; McCarl, B. A.; Schimmelpfennig, D. E.; **2010**, Yield Variability as Influenced by Climate: A Statistical Investigation, Economic Research Service United States Department of Agriculture Washington D.C. p. 27.

Chivian, E.; *et al.*; **2001**, Climate change and extreme weather events-Implications for food production, Plant diseases and pests. NASA Publications. Paper. 24. pp. 230-245. "(Online)", <http://digitalcommons.unl.edu/nasapub/24>.

Chowdhury, A. M.; *et al.*; **2004**, Water Resources in South Asia: An Assessment of Climate Change-associated Vulnerabilities and Coping Mechanisms, Final report for APN project 2004-02-CMY-Muhammed. Asia Pacific Network for Global Change Research, p.64.

Clark, J. S.; Yiridoe, E. K.; Astatki, T.; **2006**, Testing for trend in the variability of monthly and seasonal temperature using the range and the

standard deviation as measures of variability, Nova Scotia Agricultural College, P. O. Box 550, Truro, Nova Scotia, Canada, B2N 5E. p. 5.

Clark, M. P.; Serreze, M. C.; **2000**, At least four different modeling studies indicate that variability in snow cover over Asia may modulate atmospheric circulation over the North Pacific Ocean during winter, *Journal of climate*. Vol. 13. pp. 3700-3710.

Cole, E.; Overpeck, J. T.; Morrill, C.; **2002**, A synthesis of abrupt changes in the Asian summer monsoon since the last deglaciation, *the Holocene* 13, Vol. 4. pp. 465–476.

Crowley, T. J.; **2000**, Causes of Climate Change Over the Past 1000 Years, *289 Science*. Vol. 270, pp.28-45.

Darkin B., **2008**, Climate Resilience in China and the European Union: Managing Impacts and Adaptation, Chatham House, London SY1Y 4EL, p. 26.

Daniel, H. D.; Cynthia, R.; **1995**; Potential Impacts of Climate Change on Agriculture and Food Supply, *Consequences*. Vol. 1. No. 2. "(Online)" <http://www.gcric.org/CONSEQUENCES/summer95/rosenzweig.html>.

DEFRA.; **2005**, The impacts of Climate Change on Agriculture A vision for our rural landscape, Final Report, Jurys Great Russell Street, London. p. 59.

DFID.; **2006**; Energy Efficiency and Climate Change Considerations, for On-road Transport in Asia. Asian Development Bank, Philippines. p. 76.

Dobermann, A.; Wassmann. R.; **2007**, Climate Change Adaptation through Rice Production in Regions with High Poverty Levels. *SAT eJournal*. Volume 4. pp. 1-24.

Dregne, H. E.; **1986**, Desertification of arid lands, In Physics of desertification, ed. F. El-Baz and M. H. A. Hassan. Dordrecht, The Netherlands, p. 20.

Duffy, P. B.; Mauren, E. P.; **2005**, Uncertainty in projections of stream flow changes due to climate change in California. *Geophysical Research Letters*. Vol. 32. L03704, doi:10.1029/2004GL021462. p.13.

Dutta, K.; Agnihotri, R.; **2003**, Centennial scale variations in monsoonal rainfall (Indian, east equatorial and Chinese monsoons): Manifestations of solar variability, *Review Article, Current Science, Vol. 85, No. 4*. pp. 459-463.

EEPSEA.; **2008**, Climate Change: Impacts, Adaptation and Policy in South East Asia, International Development Research Centre, 22 Cross Street, #02-55, South Bridge Court, Singapore, p. 79. "(Online)", www.eepsea.org and eepsea@idrc.org.sg.

Esplen, E.; Demetriades, D.; Brody, A.; **2008**, Gender and climate change: *Mapping the linkages A scoping study on knowledge and gaps*. DRAFT. DFID. IDS, UK. p. 27.

Estiarte, M.; *et al.*; **2007**; Valuation of Climate-Change Effects on Mediterranean Shrublands. Ecological Applications. *Ecological Society of America*. Vol. 17(1). pp. 91–100.

FAO.; **2002**, Long term plans for drought mitigation and management in the Near East region, Twenty-Sixth FAO Regional Conference for the Near East Tehran, Islamic Republic of Iran. p. 65.

Farquharson, F. A. K.; Tate, K. J. S. E. L.; **2001**, Sensitivity Studies of the Impacts of Climate Change on White Nile Flows, *Journal of Climate Change*, Vol. 50. Kaluwer Academic Publishers, Netherland. pp. 177-208.

Finan, T. J.; West, C. T.; Leon. M. V.; **2003**, A comparative assessment of climate vulnerability: agriculture and ranching on both sides of the US–Mexico border, *Global Environmental Change*. Vol. 13, 159–173.

Foley, A.; *et al.*; **2005**, Impact of regional climate change on human health. Vol. 438. doi:10. 1038/nature04188. p.20.

Franks, S. W.; **2002**, Identification of a Change in Climate State Using Regional Flood Data, *Hydrology and Earth System Sciences*, 6(1). pp. 11–16.

Fresco, L.O.; Gomes, R.; **1998**, What Can Agricultural Science and The CGIAR Do About It? Research, Extension and Training Division, Sustainable Development Department. FAO. Rome, p. 32.

Gadema, Z.; and Rajaryal, K.; **2008**, Climate change and disaster impact reduction. British Council, DFID, Del:PHE. Northumbria University, School of Applied Sciences, Disaster and Development Center, p.114.

Geijn, S. C. V. D.; Rotter, R.; **1999**, Climate Change Effects on Plant Growth, *Crop Yield and Livestock*. Climate Change. Vol. 43; 651-681, *Kluwer Academic Publishers, Netherlands*.

Glantz, M.; **2002**, Water, Climate, and Development Issues in the Amudarya Basin. Informal Planning Meeting, Workshop Report. Environmental and Societal Impacts Group National Center for Atmospheric Research PO Box 3000 Boulder, CO 80307 USA. p. 52.

GoBangladesh.; Bangladesh Climate Change Strategy and Action Plan 2008. Ministry of Environment and Forests Government of the People's Republic of Bangladesh. **September 2008** Dhaka, Bangladesh. p. 86.

GoChina.; **2009**, Impact of Climate Change to 2030; A Commissioned Research Report. *Special Report*, NIC 2009-02D. Joint Global Change

Research Institute and Battelle Memorial Institute, Pacific Northwest Division.
p.53.

Goheer, M. A.; **2009**, Current capabilities in the analysis of climate risks and adaptation strategies in critical areas. Global Change Impact Studies Centre (GCISC) Islamabad- 44000, Pakistan. p. 24.

GoJapan.; **2007**, International Cooperation for Adaptation to Climate Change in Developing Countries, (Recommendations By Experts Committee). A report of Ministry of Foreign Affairs Govt of Japan, p. 18.

Golkany, M. I.; **1997**, Adapting to Climate Change, Department of science & Engineering, Office of Policy Analysis, Department of the Interior, USA. p.30.

GoNorway.; Climate Change Adaptation and Poverty Reduction: Key interactions and critical measures, *GECHS*: Global Environmental Change and Human Security: Report **2007**:1. NORAD. p.44.

GoP.; **1972**, Agro-Ecological Zones of Pakistan, Pakistan Agriculture Research Council, Islamabad, p.70.

GoP.; **2003**, Pakistan's Initial National Communication on Climate Change. Government of Islamic Republic of Pakistan Ministry of Environment Islamabad-Pakistan, p. 92.

GoP.; **2004**, Climate Change Vulnerabilities in Agriculture in Pakistan. A joint report of the Ministry of Environment and IUCN, Islamabad. p. 6.

GoP.; **2005**, A Review of Disaster Management Policies and Systems in Pakistan, *WCDR*. p.44.

GoP.; **2008.a**, Statistical Supplement of the Economic Survey. *Chapter-2*. Ministry of Finance, Govt of Pakistan, Islamabad. pp.21-60. (Online), http://www.finance.gov.pk/s_survey_0708.html.

GoP.; **2008-09.b**, Statistical Supplement of the Economic Survey. Chapter-2. Ministry of Finance, Govt of Pakistan, Islamabad, pp.21-60. "(Online)", http://www.finance.gov.pk/s_survey_0708.html.

GoP.; **2009**, Climate Change Vulnerabilities in Agriculture in Pakistan, with collaboration with IUCN and DFID, Ministry of Environment, Islamabad. p. 7.

GoP.; Agriculture Census of Pakistan, **1960; 1970; 1980; 1990; 2000**; Agriculture Census Organization Govt. of the Punjab, Lahore. p. 3000; 4000; 5000; 6000; 8000. "(Online)", <http://www.statpak.gov.pk/aco/content/publications>.

GoP.; Economical Year Books, **1982, 2000**, Statistical Division Govt. of Pakistan Islamabad, p. 600.

GoUK.; **2005**, Impacts of climate change on soil functions, National Soil Resources Institute Cranfield Univeristy Silsoe, Bedfordshire, MK45 4DT, UK. p. 28.

GoUK.; **2007**, Civil Society Coalition on Climate Change. International Policy Press Third Floor, Bedford Chambers the Piazza London WC2E 8HA UK. p. 106.

GoUSA.; **1955**, India and Pakistan 1:250,000 Series U502, U.S. Army Map Service, University of Texas at Austin, USA. "(Online)", <http://www.lib.utexas.edu/maps/ams/india/>.

GoUSA.; **2000**, An Annotated Summary Of Climate Change Related Resources, A Report of U.S. Environmental Protection Agency Office of Policy Washington, D.C. USA. p. 120.

GoUSA.; **2009.a**, Impact of Animal Agriculture on Global Warming and Climate Change, the Human Society of the United States. p. 28.

GoUSA.; **2009.b**, The Effects Of Climate Change On Florida's Ocean & Coastal Resources, A special report to the Florida energy and climate commission and the people of Florida. p. 40.

Handwerk, B.; **2006**, Some Glaciers Growing Due to Climate Change, Study Suggests. *National Geographic News*. p. 2.

Hansen, J. W.; **2005**, Integrating seasonal climate prediction and agricultural models for insights into agricultural practice, *Phil. Trans. R. Soc. B* 29. Vol. 360 No. 1463. pp. 2037-2047.

Hasan, M.; Khan, S.; **2001**, Temperature and Rainfall Fluctuation: A Case Study of Udigram, Swat Valley, Northwest Pakistan. *PGR*. Vol. 56. No. 1 & 2. pp. 73-89.

Hashmi, H. N.; Ghumman, A. R.; Hasan.; **2011**, Impact of Environmental Changes and Global Warming on Temperature in Pakistan, *Mehran University Research Journal Of Engineering & Technology*, Vol. 30. NO. 1, p.15.

Hayat, A.; Bari, A.; Sheikh, M. M.; Chaudhry, Q. Z.; **2001**, History's Worst Drought Conditions Prevailed over Pakistan, PMD, Islamabad. p. 12.

Hewitt, J. A.; *et al.*; **1999**, Testing Hypotheses in Integrated Impact Assessments: Climate Variability and Economic Adaptation in Great Plains

Agriculture, Annual Report to the National Institute for Global Environment Change (NIGEC). P.35.

Hewitt, K.; **2009**, Glaciers and climate change in the Karakoram Himalaya: Developments affecting water resources and environmental hazards. Outline of Presentation at China Environment Forum. Cold Regions Research Centre, Wilfrid Laurier University, Waterloo, Ontario, N2L 3Z9, Toronto. p.3.

Ho, C. H.; Gong, D. Y.; **2001**, Siberian High and climate change over middle to high latitude Asia, Institute of Resources Science Beijing Normal University Beijing, 100875, P.R. China. p. 17.

Houerou, H. N. L.; **1996**, Climate change, drought and desertification, Review. Academic Press Limited, *Journal of Arid Environments*. Vol. 34: pp. 133–185.

Hulme, M.; et al.; **2003**, Adaptation to climate change in the developing world, *Progress in Development Studies*. Vol. 3. No. 3. pp. 179–195.

Hurd, B. H.; Adams, R.M.; McCarl, B.A.; **2001**, Global Climate Change and Its Impact On Agriculture. Texas A&M University, TX. p. 19.

IPCC.; **2007**; Climate Change, Synthesis Report., *Summary for Policymakers*, An Assessment of the Intergovernmental Panel on Climate Change, p. 22.

Irani, D.; et al.; **2008**, Economic Impacts of Climate Change on North Carolina. A Review and Assessment Conducted by the Center for Integrative Environmental Research (CIER). University of Maryland, p. 20. "(Online)", www.cier.umd.edu/climateadaptation.

ISET.; **2007**, Climate Adaptation in Asia: *Knowledge Gaps and Research Issues in South Asia*. Full Report of the South Asia Team. Design And Typesetting Digiscan Pre-press, Kathmandu, Nepal. p.54.

Issar, S. A.; *et al.*; **1995**; Impacts of climate variations on water management and related socio-economic systems. A review and reinterpretation of existing information/ International Hydrological Programme United Nations Educational/ Scientific and Cultural Organization, *UNESCO*, Paris. p. 60.

IUCN.; **2005**, Community Perceptions on Climate Change in Bagrote Valley, Pakistan. *A case study report of IUCN*. P. 51.

Jabbour, J.; and McMullen, C. P.; Climate change: Science and Compendium, Earth System. A report of UN Under-Secretary General and Executive Director, United Nations Environment Programme, **September 2009**. p. 72.

Jiawu, Z.; *et al.*; **2003**, Temperature variations on the Tibetan Plateau over the last two millennia, *Chinese Science Bulletin*. Vol. 48, No.14: 1446-1450.

Jilani, R.; Khan, F. A.; Khan T. M. A.; **2008**, Sea surface temperature variability along Pakistan coast and its relation to el nino-southern oscillation, *Journal of Basic and Applied Sciences*. Vol. 4. No. 2. p. 67-72.

Jones, G. V.; Climate Change in the Western United States Grape Growing Regions, *Acta Hort*. 689. *ISHS*, **2005**. p. 20.

Jun, W. H.; The Weakening of the Asian Monsoon Circulation after the End of 1970's. *Advances in Atmospheric Sciences*, **2001**. Vol.18 (3). pp. 376-386.

Jung, S. H.; *et al.*; **2003**, Monsoonal precipitation variation in the East Asia since A.D. 1840. Tree-ring evidences from China and Korea. *Science in China (Series D)*. Vol. 46. No. 10. p.15.

Kaiser, H. M. Climate Change and Agriculture. *Invited Presentation*. *NJARE*, **1991**, pp. 151-163.

Kalnicky, R. A.; **1987**, Seasons, Singularities, and Climatic Changes over the Mid-Latitudes of the Northern Hemisphere during 1899-1969. *Journal of Climate and Applied Meteorology. A Publication of the American Meteorological Society*. Vol. 26. ISSN 0733-3021: pp. 1496-1509.

Kao, C. W.; **2009**, A White Paper on the Impacts of Climate Change on Drylands, Seminar on Climate Change Department of Geography University of Florida, p. 8.

Karoon, D.; *et al.*; **2003**, Variations in Tropical Convection as an Amplifier of Global Climate Change at the Millennial Scale, NERC Radiocarbon Laboratory, East Kilbride, Scotland. pp. 50-65.

Kato, H.; **2003**, Climate Changes in Asia Due to Global Warming, Research Fellow, Atmospheric Science Department, Komae Research Laboratory, p. 6.

Kauffman, J. M.; **2007**, Climate Change Re_examined, *Journal of Scientific Exploration*. Vol. 21. No. 4. pp. 723–749.

Keefe, W. O.; **2003**, Climate Change Skepticism: A Virtue or Vice. George C. Marshall Institute Remarks before the Johns Hopkins Transatlantic, USA. p. 6.

Khan, A. R.; **2001**, Analysis of hydro-meteorological time series: Searching evidence for climatic change in the Upper Indus Basin. Lahore,

Pakistan: International Water Management Institute. (IWMI working paper 23).
p. 60.

Khan, F. K.; **1989**, Economic Geography. *9th Edition*, Saleem Publishing House, Karachi. p. 268.

Khan, F. K.; **1991-93**, A Geography of Pakistan. Environment, People Economy., Oxford University Press Karachi, Pakistan. p. 245.

Khan, L. M.; Kazi, S. A.; **1959**, Variations of Moisture Types and Their Bearing on Soil Erosion in West Pakistan. *Pakistan Geographical Review.*, Vol. XIV. No.1. pp. 1-19.

Khan, M. L.; **1960**, Recent Climatic Fluctuation over South Asia and the Indian Ocean. *Pakistan Geographical Review. Vol. 15. No.2.* pp. 18-33.

Kienzler, M.; **2012**; Linking Climate Change with Food Security in the highlands of Khyber Pakhtunkhwa, Northwest Pakistan. *Diploma Thesis*. Faculty of Philosophy Institute of Geography and Geology Physical Geography. Friedrichstr. 15 D - 97082 Wurzburg. p. 84.

Kohlin, G.; *et al.*; **2008**, The Impact of Climate Change and Adaptation on Food Production in Low-Income Countries, Evidence from the Nile Basin, Ethiopia, IFPRI Discussion Paper 00828. p. 24.

Krishnamurthy, C. K. B.; **2011**, Essays on Climatic Extremes, Agriculture and Natural Resource Management, *Ph.D dissertation*, Graduate School of Arts and Sciences, Columbia University. P.20.

Kulshreshta, S. M.; Sikka, D.R.; **1989**, Monsoon and Drought in India: long term trends and policy choices. National Workshop on drought management New Delhi. p. 25.

Kumar, D.; **2001**, Monthly Mean Sea Level Variations at Cochin, Southwest Coast of India. National Institute of Oceanography, Regional Centre, P.B. No. 1913, Cochin - 682014 (Kerala), India. P.25.

Kurosaki, T.; **2007**, Compilation of Agriculture Production Data for India and Pakistan Areas. C.1900-1990. CEO Discussion. Paper No. D9924. Hitotsubashi University, 21 Naka, Kunitachi, Tokyo 1868603 JAPAN, p.38.

Lammers, R. B.; *et al.*; **2000**, Global Water Resources: Vulnerability from Climate Change and Population Growth, *Vol. 289. SCIENCE. p. 5.* "(Online)", www.sciencemag.org.

Leduc, B.; **2008**, Climate Change in the Himalayas: the Women's Perspective. *ICIMOD*, Nepal. p. 54.

Lezine, A. M.; Ivory, S. J.; **2009**, Climate and environmental change at the end of the Holocene Humid Period: A pollen record off Pakistan. *Science Direct., C. R. Geoscience 341, Elsevier Masson SAS. pp. 760–769.*

Ligates, D. R.; *et al.*; **2003**, Reconstructing Climatic And Environmental Changes Of The Past 1000 Years: A Reappraisal. *Energy & Environment · Vol. 14. No. 2 & 3. pp. 1-67.*

Livermore, M.; *et al.*; **1999**, Climate change and world food security: a new assessment. *Global Environmental Change S51-67. pp. 1-17.*

Madal, S.; Gajbhiye, K. S.; **2000**, Agro-Ecological Zones, their Soil Resource and Cropping Systems, Status of Farm Mechanization in India, National Bureau of Soil Survey and Land Use Planning, Nagpur. p. 32.

Markham, V. D.; **2008**, U.S. Population, Energy & Climate Change. Center for Environment and Population (CEP). p. 30.

McAneney, J.; Narisma, G. T.; Pitman, A. J.; **2007**, The impact of climate change on the risk of forest and grassland fires in Australia. *Climatic Change* DOI 10.1007/s10584-007-9243-6. Vol. 84. p. 383–401.

McLoed, A.; Kerr, A.; **2001**, Potential Adaptation Strategies Climate Change In Scotland, The Stationery 71 Lothian Road Edinburg, EH39AZ. p. 82.

Mehdi, B. B.; **2006**, Hydropower and Climate Change, Inn at the Forks. Winnipeg, Manitoba. p. 52.

Mendelsohn, R.; **2005**, Climate Change Impacts on Southeast Asian Agriculture, Yale University. p. 10.

Mir, H.; Khan, A. H.; Farooqi, A.B.; **2005**, Climate Change Perspective in Pakistan, *Pakistan Journal of Meteorology*, ISSN - 1810 – 3979. Pakistan Meteorological Department P.O. Box No. 1214, Sector H-8/2, Islamabad–Pakistan. Vol. 2. Issue: 3. pp. 11-23.

Mondal, P.; Shaw, R.; Svrk, P.; Huy, N. N.; **2007**, Adaptation to drought: A case study of Ninh Thuan province, Vietnam, Humanitarian Programme, Oxfam GB in Vietnam. p. 11.

Moore, B.; Vorosmarty, C. J.; Sharma, K. P.; **2002**, Sensitivity of the Himalayan Hydrology to Landuse and Climatic Changes, *Journal of Climate Change*. Vol. 52 (3). Kaluwer Academic Publishers, Netherland. pp. 315-330.

Moseley, R. K.; and Baker, B. B.; **2007**, Advancing Treeline and Retreating Glaciers: Implications for Conservatorium in Yunnan. P.R. China, *Arctic, Antarctic and Alpine Research*. Vol. 39. No. 2. pp. 200–209.

Muhammad, A.; **2002**, Water Resources in South Asia: An Assessment of Climate Change-associated Vulnerabilities and Coping Mechanisms.

National University for Computer and Emerging Sciences FAST House, Rohtas, Road G-N/4, Islamabad Pakistan. p. 3.

Narayanan, K.; Patnaik, U. Vulnerability and Climate Change: An analysis of the Eastern coastal districts of India, An International Workshop Holmen Fjord Hotel, Asker, near Oslo, pp. 21–23: **June 2005**.

Neill, J. C. and Huff, F. A.; **1982**, Effects of natural climatic fluctuation on the temporal and spatial variation in crop yields. *Journal of Applied Meteorology. A Publication of the American Meteorological Society. Vol. 21. No.4. ISSN. 0021-8952.* pp. 540-549.

Nerlander, L.; **2009**, Climate Change and Health, Commission on Climate Change and Development, Secretariat of the Commission Johan Schaar, Sweden., "(Online)", http://docs.lib.noaa.gov/rescue/data_rescue_pakistan.html. p.12.

NIC.; **2009**, China: The Impact of Climate Change to 2030, A Commissioned Research Report. Joint Global Change Research Institute and Battelle Memorial Institute, Pacific Northwest Division, USA. P. 44.

OECD.; **2002**, climate change and sustainable development strategies: A Brazilian perspective. A report of seminar of OECD countries. p. 32.

Onsgaard, G.; Vasepalli, R.; **2004**, Literature review of the socio-Economic consequences of global Warming and abrupt climate change in the Pacific Northwest. Institute for a Sustainable Environment University of Oregon. p. 60.

Overpeck, T. J.; Anderson, M. D.; Gupta, K. A.; **2003**, Abrupt changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean. *NATURE. Vol. 421.* pp. 354-357.

OXFAM's. Climate change: The Implications for Oxfam's Programme, Policies and Advocacy. Oxfam GB, Policy Department , **October 2000**. p. 57.

Pal, S. K.; **2010**, Assessing Climate Change and Adaptation from Poor Peoples Perspective: A Case Study of Bangladesh, *BALWOIS 2010* - Ohrid, Republic of Macedonia. p. 8.

Palmer, W. C.; **1965**, Meteorological Drought. Paper No.45, Dept. of Commerce, Washington, DC. P. 58. "(Online)",
<http://www.egd.ucar.edu/cas/catalog/climind/pdsi.html>.

Panagariya, A.; **2009**; Climate Change and India: Implications and Policy Options. Sixth India Policy Forum conference, New Delhi. p. 70.

Pandey, N.; **2005**, Societal Adaptation to Abrupt Climate Change and Monsoon Variability: Implications for Sustainable Livelihoods of Rural Communities, Winrock International-India, New Delhi. p. 228.

Pant, G. B.; **2003**, Long term Climate Variability and Changes over Monsoon Asia. *J. Ind. Geophys.Union*. V. 7. No. 3. pp. 125-134.

Pesu, M.; Berghall, J.; **2008**, Climate Change and the Cultural Environment; Recognized Impacts and Challenges in Finland, Ministry of the Environment Department for the Built Environment, Edita Prima Ltd, Helsinki. p. 38.

Prasad, P. V. V.; *et al.*; **2008**, Impacts of Drought and/or Heat Stress on Physiological, Developmental, Growth, and Yield Processes of Crop Plants. Advances in Agricultural Systems Modeling Series 1, Segoe Rd., Madison, WI 53711, USA. pp, 301-255.

Qamar, U.; Briscoe, J.; **2005**, Pakistan's Water Economy Running Dry, A report of the World Bank. P. 155.

Rabbani, M. M.; Khan, T. M. A.; **2005**, Sea Level Monitoring And Study Of Sea Level Variations Along Pakistan Coast: A Component Of Integrated Coastal Zone Management. National Institute of Oceanography St-47, Block-1, Clifton, Karachi, Pakistan. p. 6.

Rana, A.; Shukla, P. R.; and Nasir, R.; **2003**, Energy Use and Climate Change: A Policy Analysis for India. Manuscript of Chapter in Climate Change Scenario in India by SK Dash (Ed.). World Wide Fund–India, Delhi (Forthcoming). p.22.

Randall, D.; Schwartz, P.; **2003**, An Abrupt Climate Change Scenario and Its Implications for United States National Security, USA. p. 22.

Rehman, A. Z.; **2010**, Effect Of Temperature on Development and Grain Formation In Spring Wheat, *Pak. J. Bot. Vol. 42(2)*. pp. 899-906.

Reiter, P.; **2001**, Climate Change and Mosquito-Borne Disease. *Environ Health Prospect 109 (suppl 1)*. p. 141–161.

Revi, R.; **2008**, Climate change risk: an adaptation and mitigation agenda for Indian cities. *International Institute for Environment and Development (IIED). Vol. 20(1)*. pp. 207–229.

Rhodes, S.; Mearns, L.; Miller, K.; Trenberth, K. E.; **2000**, Effects Of Changing Climate On Weather And Human Activities. University Corporation for Atmospheric Research, USA. p. 50.

Rozelle, S.; Huang, J.; and Wang, J.; **2010**, Climate Change and China's Agricultural Sector: An Overview of Impacts, Adaptation and Mitigation. A report of ICTSD-IPC Platform on Climate Change, Agriculture and Trade, 7 Chemin de Balexert, 1219 Geneva, Switzerland, Issue Brief No-5, p. 32.

Saab, N. W.; Tolba, M. K.; **2009**, Arab Environment: Climate Change Impact of Climate Change on Arab Countries: 2009 Arab Forum for Environment and Development (AFED). Published with Technical Publications and Environment & Development magazine P.O.Box 113-5474, Beirut, Lebanon. p. 181.

Saab, N.; **2009**, Arab Public Opinion and Climate Change. Selected Chapter. p. 12.

Sadiq, N.; **2010**, Climatic variability and linear trend models for the five major cities of Pakistan. *Journal of Geography and Geology, Canadian center of science and education*. Vol. 2, No. 1. pp. 83-92.

Sadiq, N.; Gadiwala, M.S.; **2008**, The apparent temperature analysis of Pakistan using Bio-meteorological indices. *Pakistan Journal of Meteorology*. Vol. 4. Issue. 8. pp. 15-26.

Savonis, M.; Burkett, V.; **2006**, Impacts of Climate Variability and Change on Transportation Systems and Infrastructure—Gulf Coast Study, U.S. Climate Change Science Program 1717 Pennsylvania Avenue, NW, Suite 250 Washington, DC 20006 USA. p. 17.

Schneider, H. S.; *et al.*; **2009**, Ecological Impacts Of Climate Change. A report of the Geological Survey, Of USA. p. 32.

Segal, M.; *et al.*; **2003**, Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability. *Geophysical Research Letters*. Vol. 30. No. 8. 1425, doi:10.1029/2002GL016822. p.16.

Seymour, F.; **2008**, Forests, Climate Change, and Human Rights: *Managing Risk and Trade-offs*. Center for International Forestry Research (CIFOR), Bogor, Indonesia. p. 23.

Shaowu, W.; Jianbin, H.; **2007**, Variations of geographical latitude of summer rain belts over eastern China during the last millennium. *Advances in Climate Change Research*. Department of Atmospheric Science, School of Physics, Peking University, Beijing 100871, China. P. 13.

Shaw, R., **2006**, Community-based climate change adaptation in Vietnam: inter-linkages of environment, disaster, and human security. Multiple Dimension of Global Environmental Changes, edited by S. Sonak, *TERI publication*, pp. 521-547.

Singh, N.; Sontakee, N. A.; **2000**, On Climatic Fluctuations and Environmental Changes of the Indo-Gangetic Plains, India. *Journal of Climate Change*. Vol. 52 (3). *Kluwer Academic Publishers, Netherland*. pp. 287-313.

Sirocko, F.; *et al.*; **1999**, A 5000-yr Record of Climate Change in Varved Sediments from the Oxygen Minimum Zone off Pakistan, Northeastern Arabian Sea. *Quaternary Research* 51, pp. 39–53, "(Online)", <http://www.idealibrary.com>.

Smajda, J.; **1992**, Studies of Climatic and Human Impacts and their Relationship on a Mountain Slope Above Salme in the Himalayan Middle Mountains, Nepal. *Journal of Mountain Research and Development*. Vol. 12. No. 1. pp. 1-28.

Smakhtin, V. U.; Kaluarachi, J.J.; and Kim, U.; **2008**, Climate change impacts on hydrology and water resources of the Upper Blue Nile River Basin,

Ethiopia. Colombo, Sri Lanka: International Water Management Institute. (IWMI Research Report 126). P. 27.

Solomina, O. N.; Serebryanny, L. R.; Kotlyko, V. M.; **1991**, Climate Change and Glacier Fluctuation during the Last 1000 Years in the Southern Mountains of the USSR. *Journal of Mountain Research and Development*. Vol. 11. No. 1. pp. 1-12.

Spektorman, T.; *et al.*; **2006**, Changes in daily temperature and precipitation extremes in central and south Asia., *Journal Of Geophysical Research*, Vol. 111, D16105, doi:10.1029/2005JD006316. p.12.

Sterrett, C.; **2011**, Review of Climate Change Adaptation Practices in South Asia. Oxfam Research Reports. Climate Concern, Melbourne, Australia. p.100.

Stevenson, C.; *et al.*; **2008**, Consequences of Climate Change on the Ecogeomorphology of Coastal Wetlands, *Estuaries and Coasts*. DOI 10.1007/s12237-008-9047-6. Vol. 31. pp. 477–491.

Strem, E.; Miller, N. L.; Bashford, K. E.; **2003**, Potential Impacts Of Climate Change on California Hydrology. *Journal of the American Water Resources Association*, USA. p. 14.

Sunstein, C. R.; **2007**, Essay on the Divergent American Reactions To Terrorism And Climate Change, *Columbia Law Review*, USA. p, 56.

Tay, S.; Stevenson, A.; Loh, C.; **2008**, Climate Change Negotiations: Can Asia change The game?. Published by Civic Exchange. P.17.

Trobe, S. L.; **2002**, Climate Change and Poverty. A Discussion Paper. Tearfund, 100 Church Road, Teddington, Middlesex TW11 8QE, UK. p. 56.

Trobe, S. L.; and Vanton, P.; Linking climate change adaptation and disaster risk reduction, Wingfinger © Tearfund, **July 2008**, p.19.

Tucker, G. E.; **1997**, Drainage Basin Responses to Climate Change, *Water Resources. Vol. 33, No. 8*, pp 2031–2047.

UNFCCC.; Decision -/CP.15, Advance unedited version. *The Conference of the Parties*. Takes note of the Copenhagen Accord of 18: **December 2009**. p. 6.

UNESCO., **2006-08**, The 2nd UN World Water Development Report: Water, a Share responsibility. New York, p.134, Online, http://www.unesco.org/bpi/wwdr/WWDR_chart1_eng.pdf.

UNO.; **2008**, Climate Change and The Most Vulnerable Countries: The Imperative To Act. Background Paper, UNO. p. 8.

Urdal, H.; Raleigh, C.; **2008-09**, Climate Change, demography, Environmental degradation, and armed Conflict. New Directions in Demographic Security. *ECSP Report. Issue. 13*. p. 7.

USAID/ASIA.; **2008**, Global Climate Change in the Asia-Pacific Region: An Analysis and Road Map for the USAID Regional Development Mission for Asia, Regional Development Mission for Asia US Agency for International Development Bangkok. p. 116.

Viet, N. V.; *et al.*; **2003**, Climate change and strategies to be adapted in agriculture for sustainable development in Vietnam. *Publication of Agro-Meteorological Research Center of Vietnam*. P. 13.

Vose, R. S.; Peterson, T. C.; **1997**, An Overview of the Global Historical Climatology Network Temperature Database, *Bulletin of the American Meteorological Society*. pp. 2837-2849.

Wang, X.; et al.; **2003**, Detection and projection of climate changes in Jianghuai Valley in China, Meteorological Administration of Anhui Province, Hefei, Anhui, China 230061. p.6.

Warner, K.; Freeman, P.; **2001**, Vulnerability of Infrastructure to Climate Variability: How Does This Affect Infrastructure Lending Policies?. Report Commissioned by the Disaster Management Facility of the World Bank and the Prevention Consortium Washington. p. 42.

Weare, B.; et al.; **2008**, Seasonal temperature responses to land-use change in the western United States. *Science Direct, Global and Planetary Change*. Vol. 60. pp. 250–264.

WHO.; Floods: Climate Change and Adaptation Strategies for Human Health. Report on a WHO meeting London, United Kingdom **30 June – 2 July 2002**. p. 52.

WHO; **2005**, Health and Climate Change: the “now and how” A policy action guide, WHO Regional Office for Europe Scherfigsvej 8 DK-2100 Copenhagen, Denmark. p.35.

Wiebe, K. D.; Masters, W. A.; **2000**, Climate and Agricultural Productivity. Center for International Development 79 John F. Kennedy Street Cambridge MA 02138. p.36.

Yadav, R. R.; **2007**, Basin specificity of climate change in Western Himalaya, India: tree-ring evidences. *Current science*. Vol. 92, No. 10. p. 22.

Yafeng, S.; et al.; **2002**, General characteristics of temperature variation in China during the last two millennia, *Geophysical Research Letters*, Vol. 29, No. 9, 1324, 10.1029/2001GL014485. p.22.

Yee, D.; et al.; **2000**, Trends in Extreme Daily Rainfall and Temperature In Southeast Asia and The South Pacific: **1961–1998**. *International Journal Of Climatology Int. J. Climatol.* Bureau of Meteorology, PO Box 1289K, Melbourne, Victoria 3001, Australia. p. 16.

Yi, W.; et al.; Response of Glacier and Lake Co variations to Climate Change in Mapam Yumco Basin on Tibetan Plateau during 1974–2003. *Journal of China University of Geosciences*, Vol. 19, No. 2, p. 135–145, **April 2008**.

Yiyong, R.; et al.; **2008**, Snow Cover Variation in the Past 45 Years (1959 to 2003) in the Tianshan Mountains, China, *Advances in Climate Change Research, Scientific Basis*, Article ID: 1673-1719, Suppl.-0013-05. p. 23.

Yue, L.; et al.; **2008**, Impacts of Climate Change on Chinese Agriculture-Phase II, Climate and Livelihoods in Rural Ningxia: Final Report, AEA the Gemini Building Fermi Avenue Harwell International Business Centre Didcot OX11 0QR United Kingdom. p. 38.

Zell, R.; **2004**, Global climate change and the emergence/re-emergence of infectious diseases, Mini Review. *Int. J. Med. Microbiol* © Urban & Fischer Verlag. Vol. 293, Suppl. 37, pp.16-26. "(Online)", <http://www.urbanfischer.de/journals/ijmm>.

Zhang, Q.; et al.; **1999**, Changes of Climate Extreme in China, *Journal of Climate Change*. Vol. 42 (1). Kluwer Academic Publishers, Netherland. pp. 203-218.

Zhu, Y.; Qian, W.; **2001**, Climate Change in China from 1880 to 1998 and its impact on the environmental condition. *Journal of Climate Change*, Kluwer Academic Publishers, Netherland. Vol. 50. pp. 419-444.

Appendix-A: Questionnaire:

The following questionnaire has been prepared to study the "*Climate Change and its Impact on the Agriculture in Arid Land of Pakistan (1961-2000)*," at Ph.D level in the Institute of Geography, Urban and Regional Planning, University of Peshawar, Khyber-Pakhtoonkhwa. Your response will help us with our ongoing study of climate change in Pakistan. All questions are optional to answer, chose/encircle multiple options where required. Your responses will be anonymous during course of study.

Name.....Profession/Class.....Designation.....

Education.....Sex: Male/Female

District.....Contact No (Mobile/Fixed).....

Province/University.....

1. Pakistan climate is changing.
a. Agree b. Disagree c. Strongly Agree
2. How serious is climate change in your area?
a. Weak b. Moderate c. Severe
3. How is the climate of your native place?
a. Hot b. Warm c. Moderate d. Cool e. Cold
4. How was climate of your area before 2000?
a. Hot b. Warm c. Cool d. Cold.
5. Is there any change in temperature of your area?
a. Yes b. No
6. If yes then, the change has made temperature;
a. Warmer b. Colder c. Moderate

7. For how many years have you observed this change.
a. 10 b.20 c.30 d. 40 e. 50
8. Is there any change in the rainfall of your area?
a. Yes b. No
9. If yes, then has it;
a. Decreased b. Increased c. No Change
10. Since how many years have you noted this change;
a. 10 b.20 c.30 d. 40 e. >50
11. What part of Pakistan has been most affected by climate change?
a. Baluchistan b. Sind c. Punjab d. KPK e.
Northern Areas f. FATA g. Azad Jammu and Kashmir h.
All of 'a' to 'g'
12. What you think is Climate change a result of;
a. Human activities b. Natural Processes c. Carbon
emission
d. Deforestation e. Land Degradation f. all of "a" to "e"
g. Any other.....
13. What are the main activities of humans that effected climate?
a. Deforestation b. Over Population c. Mining d. Wars
e. Carbon emission f. All 'a' to 'e' g. Any other.....
14. What do you suggest to control these activities?.....
15. Which natural processes do you think has changed the climate of Pakistan?
a, Floods b, Forest fires c, Tectonic moment
d, Deforestation e. Global warming f. Degradation of soil

- g. Temperature fluctuation h. Precipitation Fluctuation
- i. All 'a' to 'l' j. Any other.....
16. Is there any solution to control it, if yes then give your opinion?.....
17. What are the main sources of Carbon emission in Pakistan?
- a. Vehicles b. Industry c. Volcanic eruption e. Air
crafts f. All "a" to "e" g. other.....
18. What are the impacts of the climate change in your area?
- a. Water Scarcity b. Forests fires c. Decline Economic
growth d. Caused drought and desertification e.
Reduced crops production f. Decrease in market value g.
other
19. We will feel the impacts of climate change?
- a. With in five years b. 5-10 years c. 11-20
years d. >20 years
20. What change have you observed in the Underground/Drinking water in the last 40 years?
- a. Decrease b. Increase
21. For how many years have you observed this change in the underground/drinking water.
- a. 10 b. 20 c. 30 d. 40 e. 50 and above
22. What are the main causes of decline in watertable?
- a. Decrease in rainfall b. Deforestation c. Population growth
d. Tubewells e. All of the above f. Any other.....

23. What are you suggesting for the stability of the watertable/underground water?
- a. Decrease use of tubewells b. Forestation c. Decrease in population d. Any other.....
24. What changes have you observed in the forests of your area since 1960?
- a. Decrease b. Increase c. Other.....
25. What are the main causes of deforestation in your area?
- a. Sever cutting b. Domestic use c. Forest fires d. other.....
26. What do you suggest for the stability of forests?
- a. Plantation b. Decrease in domestic use c. Provision of alternate energy d. all "a" to "c" e. Other.....
27. How much times your area has passed from drought condition since 1960?
- a. One b. Two c. Three d. Four e. Above five
28. When was the last time there was severe drought in your area?
- a. 1961 b. 1971 c. 1981 d. 1991 e. 2000
- f. Any other.....
29. What type of drought it was?
- a. Hydrological b. Meteorological c. Agriculture
30. What are the main causes of drought in your area?
- a. Decrease in rainfall b. Decrease in river flow

c. Cutting of forests d. Any other.....

31. Has it affected the human lives?

a. Yes b. No

32. If yes, is it in terms of ;

a. Caused diseases b. Damage to human lives c. Damage to
agriculture d. Decrease in drinking water e. Food Scarcity
f. Damage to livestock g. All "a" to "e" h. Any other.....

33. What part of Pakistan has most effected by the drought condition?

a. Baluchistan b. Sind c. Punjab d. NWFP e.
Northern Areas f. FATA g. Azad Jammu and Kashmir h.
All of 'a' to 'g'

34. What kind of support was provided by Govt of Pakistan to the
drought effectives?

a. Financial b. shelters c. Drinking water d. food
b. e. Medicine f. All "a" to "e" f. Any other.....

35. Has the drought affected the animal life in your area?

a. Yes b. No

36. Reference question No. 35, What kind of affects you observed on
animal lives?

a. Deaths b. Decrease in Market price c. Increase in
animal diseases d. Change in animals lay before time e.
All "a" to "e" f. Any other.....

37. What was the market value of the following animals at the time of
drought and before drought (Mentioned price in PKR)?

Name	before Drought	Drought Period
------	----------------	----------------

- a) Goat
- b) Sheep
- c) Ox
- d) Cow
- e) Asses
- f) Donkeys
- g) Buffalos.....
- h) Moll
- i) Cattle

38. Have there been any impacts of drought on the lives of Aves (Birds)?

- a. Yes b. No

39. What are the main impacts of drought on birds? Please tick mark.

- a. Increase in Diseases b. Shelter c. Increase in death
d. Increase in migration e. Any other.....

40. How many people have migrated from your village/town during drought period?

- a. Less than 25% b. 25-50% c. 51-75% d. Above 75%

41. What was the impact of drought on agriculture/crops?

- a. Mostly damaged b. Low production c. Low Market price d.
Any other.....

42. What crops were mostly affected by drought?

- a. Rabbi b. Kharif

43. What are the dates of sown and harvesting of Kharif and Rabbi crops in your area?

Crop Name	Swan Month/Date	Harvest
Month/Date		

a) Rabbi

.....

b) Kharif

44. Is there any change in the sowing and harvesting of Rabbi or Kharif crops since last 40 years?

a. Yes b. No

45. If yes, what is the range of change?

a. 5-10 days b. 11-20 day c. 21-30 days d. > 30 days

46. Has this change led to sown or harvest the *rabi* and *kharif* crops?

a. Before due time b. After due time

47. Reference question 46, has the production of crops going to;

a. Increased b. Decreased c. Remain stable d. other...

48. Is there any change in the agriculture zones because of climate change?

a. Yes b. No

49. If yes, is the agriculture zones boundaries shifted towards;

a. North b. South c. East d. West e. No

change

50. When you have observed this shift in the agriculture zones? Please mentioned the approximate date/Year.....

51. Is there any change in the crops yield per acres in your area?

a. Yes b. No

52. If yes, what is the range of decline in crops yield per acre?

- a. 0-5KG b. 5-10KG c. 10-15 KG d. Any other.....
53. Is this decline related to;
- a. *kharif* crops b. *rabi* crops c. Any other
54. What are the main sources of irrigation in the surrounding of your native village/towns?
- a. Karez b. Tubewells c. Canal system d. Rainfed
55. Is there any change in the flow of water in canals and rivers of your area?
- a. Yes b. No
56. Since when, have you observed this change in flow of water. Please mention the year.....
57. Which are the main rivers passing closer to your native village/town, please highlight the names.....
58. Is there any change in the flow of these rivers?
- a. Yes b. No
59. If yes, since when you have observed it. Please mentioned the year.....
60. Has this decreased in flow of water affected?
- a. Agriculture b. Economy C. Human lives d. all "a" to "c"
- d. Any other.....
61. What type of soil you have in your native town/village?
- a. Loess b. Gravels c. sandy d. Loamy e. Any other.....
62. What caused desertification in your area?
- a. Decrease in rainfall b. Decrease in rivers flow c. Deforestation

- d. Any other.....
63. Has your area change into pure desert with passage of time?
- a. Yes b. No
64. What type of desert it is;
- a. Rocky b. Stony c. Badlands d. Sandy e. Mountain f. other.....
65. What is the maximum height of trees in your area?
- a. 1-2` b. 3-4` c. 5-6` d. above 6`
66. How to control desertification in your area.
- a. Afforestation b. Well canal system c. Any other.....
67. Are there any glaciers in your area? (If no then go to Question no 72)
- a. Yes b. No
68. If yes, then what kind of change have you observed in the last 40 years in the Glaciers?
- a. Increase in glaciers b. Decrease In glaciers c. Sever Melting
- d. Any other.....
69. Are these glaciers melting more rapidly?
- a. Yes b. No
70. What are the main causes of melting of Glaciers?
- a. Increase in temperature b. Atmospheric pollution
- c. Cutting of Forests d. Global warming e. Any other.....
71. What are you suggestions to control high melting of glaciers?

- a. Planting of trees b. Control of atmospheric pollution c. Control of global warming
- d. Any other.....

72. Has the on going climate change effected coastal region in Pakistan?

- a. Yes b. No

73. If yes, then is the sea level;

- a. Rising b. Declining c. No change d. Any other.....

74. What are the main impacts of rise on the coastal region in Pakistan?

- a. Damages to crops b. Damages to ships c. Decrease in sea trade
- d. Damages to sea forts e. Damages to human
- f. Any other

75. The way to control climate change is;

- a. We all need to take action b. Govt should take step for this
- c. Ministries should make proper policy d. all of the above
- e. Any other.....

76. What action would you encourage to take action on climate change?

- a. Clubs b. Organization c. Govt
- d. Each Individual of the country e. other.....

77. What do we need to do for the reduction of carbon emission to atmosphere?

- a. Control on Vehicles b. control emission of CFCs c.

Control

- on wars d. Control on Nuclear weapons e. Any other.....

79. What action do you think is required to reduce the impact of climate change on the economy of Pakistan? Please highlight your suggestions/Comments that have not been mention in the questions stated above (Attached an extra sheet if necessary).

Thank you for your valuable
response.

Khan Saifullah

Ph.D (Scholar)

Appendix-B

ADAPTATION TO CLIMATE CHANGE AND MITIGATION OF ITS EFFECTS IN THE ARID REGION OF PAKISTAN 1961-2000

**Saif Ullah Khan, Prof. Dr. Mahmood-Ul-Hasan,
and Prof. Dr. Muhammad Aslam Khan**

Institute of Geography, Urban and Regional Planning, Disaster Management
University of Peshawar KPK, Pakistan

Emails: saifullahkhan33@gmail.com, makhan40@hotmail.com

ABSTRACT

This paper on climate change in arid zone of Pakistan is based on data derived from various meteorological stations over the period of forty years (1960-2000). The arid region in Pakistan covers about 77.1% of the country (676400Km²). The research analyzes the climate change adaptation and mitigation in the arid region of Pakistan.

Since many years Pakistan is active on national and international levels to adopt a more suitable policy for the reduction of impacts of climate changes in the arid region of Pakistan. Current policy of the country, regarding adaptation to climate change in the arid region of Pakistan, does not fulfill the requirements and it is required to review it periodically as per country economical desires. The main sectors that need adaptation in the arid region of Pakistan are; surface water, coastal management, overgrazing, deforestation, agriculture and livestock, drought and desertification, public awareness, emergency response, early warning system and monitoring, landuse change, waterlogging, and sources of energy.

The water sector is more vulnerable to the impacts of climate change in the arid region. These impacts can be minimized with the help of construction of new water reservoirs and inland dams, river embankments to save the current water from waterlogging, improvement in the water supply and irrigation system, planning for the use of water resources and utilization of the flood water, revision of water management policy, implementation, and establishment of research and development funds.

Keywords

Arid region, Climate change, Adaptation, Policy, Water Management, Deforestation, Overgrazing, Public Awareness.

Proceedings, Protection and Restoration of the Environment XI, Aristotle University of
Thessaloniki, Greece, July 3, 2012 – July 6, 2012,
<http://www.pre11.org/ocs/index.php/pre/pre11>. pp. 98-107.

Appendix-C:

Precipitation Fluctuation and its Impact on the Flow of Indus Water System and Adaptation in the Arid Region of Pakistan (1937-2004)

Saif Ullah Khan¹
Ph.D Scholar

saifullahkhan33@gmail.com

Prof. Dr. Mahmood-Ul-Hasan²
Profdrmahmoodulhasan@yahoo.com

Prof. Dr. Muhammad Aslam Khan³
makhn40@hotmail.com

Abstract:

The paper analyzes the flow of water in the Indus and its tributaries in the arid region of Pakistan from 1937-2004 in terms of average variations as well as seasonal fluctuation and anomalies in intensities of the flow.

The gross per capita water availability in Pakistan was 5300 m³/year (1951) that decline to 1200 m³/year (2000). Due to decrease in precipitation of about 0.6 inches and increase in temperature of 1.6 °C (1960-2000), the flow of water sector in Pakistan shows a more vulnerable condition from 1937-2004. The decline in the flow of the Indus and its main tributaries shows a drastic change in the *Rabi* season while it remain stable in *Kharif* season and need adaptation on an urgent basis. The annual flow of water shows a positive deviation in the Kabul River while it is negative in Indus, Jhelum, Chanab, Ravi, and Satluj rivers. Most of the rivers in Baluchistan are converted into seasonal torrents and the water scarcity for agriculture sector and domestic use will be at climax in the future. The decline in flow of the water in Indus water system will affect the agriculture growth and production in the irrigated area of the arid region in lower Punjab and Sind Provinces. The main adaptations to cope with the problem are, improvement in irrigation system, construction of water reservoirs, river embankments, improvement in drinking water supply, public awareness, policy and implementation, establishment of R&D, crop choices, and planning for water resources.

The major causes are the decrease in winter quota of precipitation, deforestation, overgrazing, drought, desertification, tectonic movements, change in the earth geography, wars in Middle East and Afghanistan, change in pressure pattern, population growth, construction of water reservoirs in India on the main rivers etc.

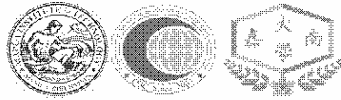
Key Words: Arid region, Rabi Season, Kharif Season, Tectonic movements, Human Pressure. Desertification, Deforestation, Indus water system.

Saifullah Khan, Ph.D Scholar, Department of Geography University of Peshawar, Manager GIS and Mapping USF CO 5th Floor HBL Tower Blue Area Islamabad, Pakistan.

Mahmood-ul-Hasan, Supervisor and Professor, Department of Geography, Urban and Regional Planning Peshawar University, KPK, Pakistan.

Muhammad Aslam Khan, Co-Supervisor, Ex-Chairman and HEC Professor, Department of Geography, Urban and Regional Planning University of Peshawar.

Appendix-D:



2013 International Conference on
Sustainable Environmental Technologies,
30 September – 01 October 2013, Manila, Philippines

People Perception about Climate Change and Adaptation in the Arid Region of Pakistan

Saifullah Khan, Prof. Dr. Muhammad Aslam Khan, Prof. Dr. Mahmood-UI-Hasan

Institute of Geography, Urban and Regional Planning University of Peshawar KPK Pakistan

*Corresponding author
saifullahkhan33@gmail.com

ABSTRACT

The paper analyzes the people perception regarding climate change and adaptation in the arid region of Pakistan in terms of temperature and precipitation fluctuation, drought and desertification, food scarcity, impact on agriculture, river flow, as well as seasonal fluctuation.

According to Khan and Hasan (2012) the arid region of Pakistan shows 0.6 inches decrease in precipitation and 1.6 degree Celsius increase in temperature during 1960-2011. The flow of water sector in Pakistan shows a more vulnerable condition from 1937-2004 that will cause a drastic change in *Rabi* (Winter) as well as *Kharif* (Summer) cultivation and needs adaptation. The decline in flow of the water in Indus water system will affect the agriculture growth and production in the irrigated areas of the arid region in lower *Punjab* and *Sind* Provinces. The main purpose of the work is to know that what is the public opinion regarding climate change, its impacts and how to cope with the problem. Therefore, a questionnaire survey has been conducted in the lower *Punjab* to know the public opinion about the on going climate change and its impacts on social, economic, demographic, and agriculture sectors. The major questions in the questionnaire are about temperature and precipitation fluctuation, deforestation, overgrazing, drought, desertification, change in the earth geography, wars, change in pressure pattern, population increase, construction of water reservoirs, water resources, current government policies.

Key Words: Climate change, Adaptation, People perception, Rabi season, Kharif season, Water resources, Population growth.

11th International Precipitation Conference 2013 30 June - 3 July 2013 Ede-Wageningen The Netherlands

http://www.wageningenur.nl/upload_mm/7/5/e/a72f004a-8e66-445c-bb0b-f489ed0ff0d4_Abstract%20book_TotaalLR-SEC.pdf
<http://www.sciforum.net/conference/wsf2/paper/858/paper>

Appendix-E:

PRECIPITATION FLUCTUATION OF THE ARID REGION IN PAKISTAN (1961-2000)

Saif Ullah Khan¹

saifullahkhan33@gmail.com

Prof. Dr. Mahmood-UI-Hasan²

Profdrmahmoodulhasan@yahoo.com

Prof. Dr. Muhammad Aslam Khan³

makhan40@hotmail.com

Abstract:

This paper on precipitation variation in arid zone of Pakistan is based on data derived from various meteorological stations over the period of forty years (1966-2000). The arid region in Pakistan covers about 77.1 percent of the country (676400 Sq.Kms). The research analyzes the precipitation pattern in terms of average, variations from the average as well as seasonal variations and anomalies in intensities of rainfall.

The Palmer Drought Severity Index (PDSI) at latitude 25° to 30° North and longitude 62°-5' to 72°-5' East (1871-2000) reveals that there is an average reduction in precipitation by 0.1 inches per year and total fall in the last 140 years is around 7.7 inches. It is expected that there will be ups and downs in precipitation for the period of 2001-2040 having wet and dry spells after each five years. The trend will shift to positive till 2015 with little decline in 2030. Beside, in 2020 the precipitation of the region will touch the average line and will remain above the mean condition till 2060 and then vice versa till 2120 with minor oscillation after each 30 years.

As precipitation of the arid region is not uniform in all parts of the area, therefore the region is further divided into five zones that is Western, Northern, Coastal, Eastern, and Central regions. The concentration of precipitation of the series reveals heavy showers in the southern Sind in Monsoon season, while in winter it shifts to Northwest Baluchistan. The Gilgit-Baltistan province has high rains due to local thunderstorms (Pre-Monsoon season) and the intensity of precipitation remains high at central Sind and adjoining areas of Baluchistan in Post Monsoon season.

Generally, the isohyets of the southern arid zone of Pakistan reveal a shift in the boundary of the arid region towards northwest. Thus the area of Quetta and surrounding areas of Afghanistan fall into arid climate. The major causes of this shift in the boundary of the arid region is the decrease in winter quota of precipitation (shift in the westerly currents towards central Asia), deforestation, overgrazing, tectonic movements, change in the earth geography, volcanic eruption, wars in Middle East and Afghanistan, change in atmospheric circulation, shift in the pressure pattern, population increase and other natural/anthropogenic activities that need further research on national as well as international level.

Key Words: Palmer Drought Severity Index, winter precipitation, Summer Precipitation, tectonic movements, pressure pattern.

1. Ph.D Scholar, Department of Geography, Urban and Regional Planning, University of Peshawar, KPK..

2. Supervisor and Professor, Department of Geography, Urban and Regional Planning Peshawar University, KPK, Pakistan.

3. Co-Supervisor, Ex-Chairman and HEC Professor, Department of Geography, Urban and Regional Planning University of Peshawar.

The paper submitted to; International Geo-Science Conference on Mineral Resources and Their Perspective (GeoAlb2011) 27-30 September 2011, Mitrovicë, Republic of Kosovo.

1. GeoAlb 2011, Kosovo, International Geo-Science Conference 27-30 September 2011 Mitrovicë, Republic of Kosovo, <http://www.geoalb.org>.

2. CEST 2011 - 12th International Conference on Environmental Science and Technology, [08-10 Sep. 2011], Rhodes Island, Greece, <http://www.certh.gr/A6461CA8.el.aspx>.

Appendix-F:

SEASONAL FLUCTUATION OF PRECIPITATION IN THE ARID REGION OF PAKISTAN (1960-2000)

Saif Ullah Khan¹

Ph.D Scholar

saifullahkhan33@gmail.com

Prof. Dr. Mahmood-Ul-Hasan²

Prof. Dr. Mahmood-Ul-Hasan

Prof. Dr. Muhammad Aslam Khan³

Prof. Dr. Muhammad Aslam Khan

Abstract:

The arid region in Pakistan covers about 77.1 percent of the country (676400 Sq.Kms). The paper analyzes the precipitation pattern in terms of average, variations as well as seasonal fluctuation and anomalies in intensities of rainfall.

The Palmer Drought Severity Index at latitude 25° to 30° North and longitude 62°-5' to 72°-5' East (1871-2000) reveals that there is a reduction in precipitation by 0.1 inches per year and total fall in the last 140 years is around 7.7 inches. It is expected that there will be ups and downs in precipitation for the period of 2001-2040 having wet and dry spells after each five years. The trend will be reversed to positive till 2015 with little decline in 2030. Beside, in 2020 the precipitation of the region will touch the average line and will remain above the mean condition till 2060 and then vice versa till 2120 with minor oscillation after each 30 years.

As precipitation of the arid region is not uniform in all parts of the area, therefore the region is further divided into five zones that is Western, Northern, Coastal, Eastern, and Central regions. The concentration of precipitation of the series reveals heavy showers in the southern Sind in Monsoon season, while in winter it shifts to Northwest Baluchistan. The Gilgit-Baltistan province has high rains due local thunderstorms (Pre-Monsoon season) and the intensity of precipitation remains high at central Sind and adjoining areas of Baluchistan in Post Monsoon season.

Key Words: Palmer Drought Severity Index (PSDI), Winter Season, Monsoon Season, Pre-Monsoon Season, Post Monsoon Season, Tectonic moments, Pressure Pattern.

1. Ph.D Scholar, Department of Geography University of Peshawar, Manager GIS and Mapping USF CO 5th Floor HBL Tower Blue Area Islamabad, Pakistan.

2. Supervisor and Professor, Department of Geography, Urban and Regional Planning Peshawar University, KPK, Pakistan.

3. Co-Supervisor, Ex-Chairman and HEC Professor, Department of Geography, Urban and Regional Planning University of Peshawar.

Appendix-G: List of Graphs:

Graph-4.19: Chhor
Annual Trend of Mean Monthly Temperature (1961-2000)

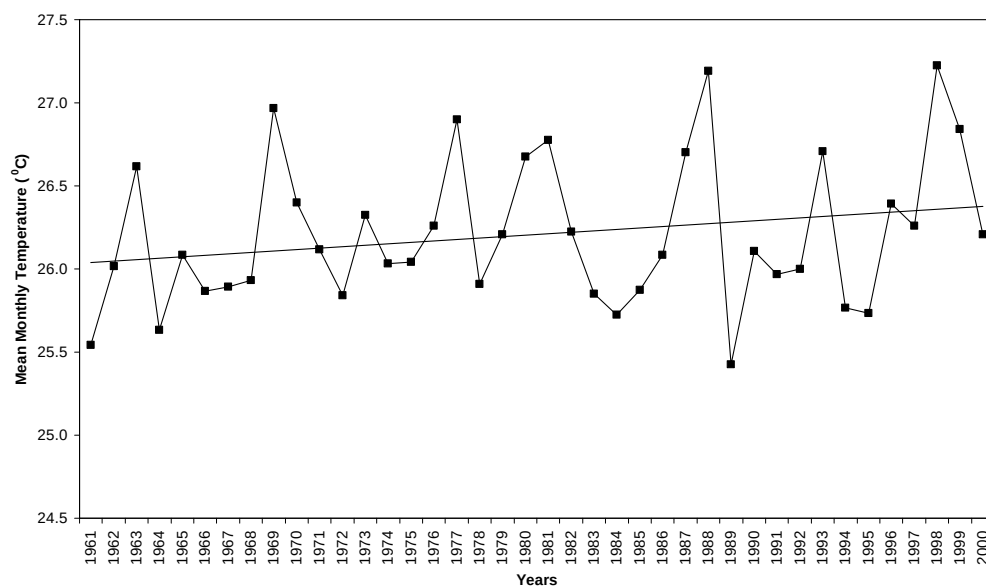
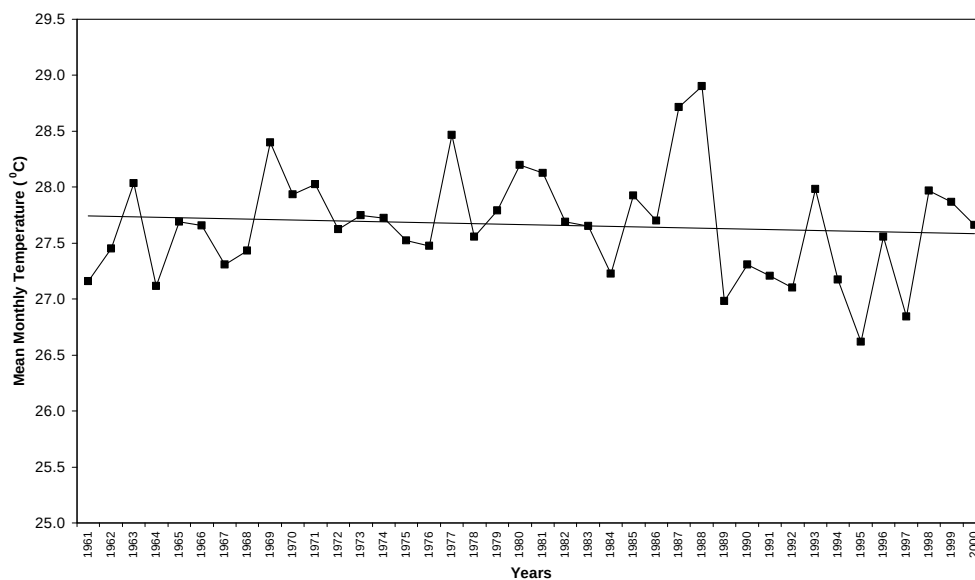
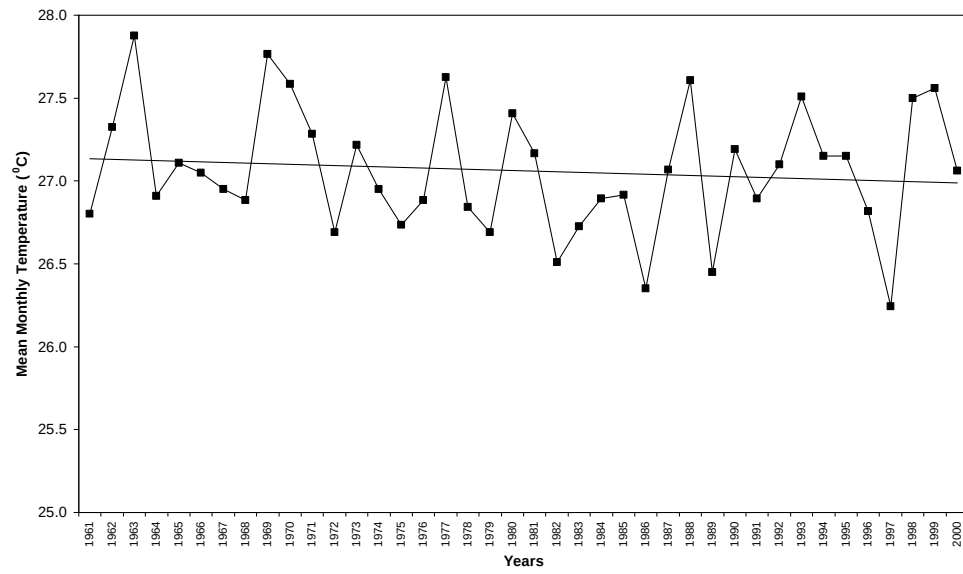


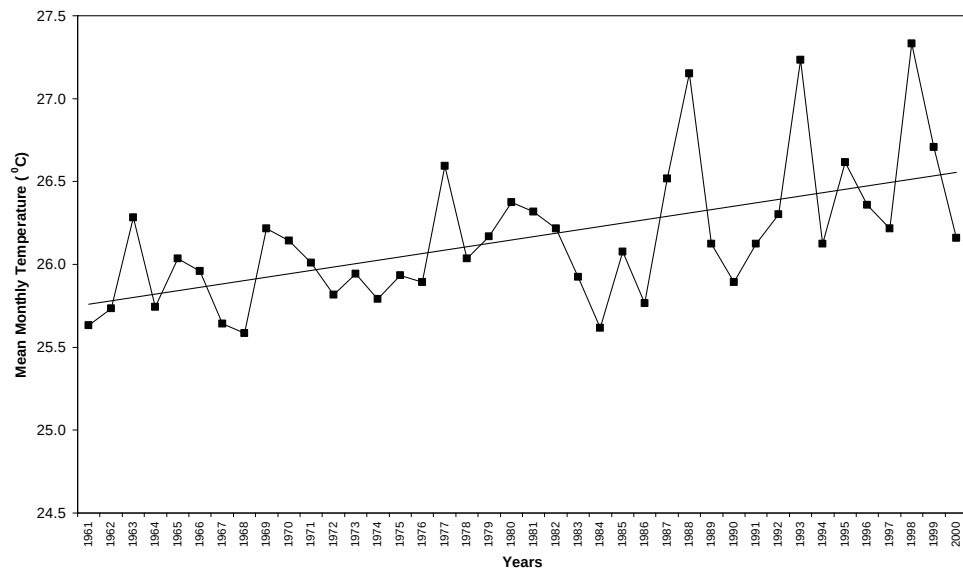
Table-4.20: Hyderabad
Annual Trend of Mean Monthly Temperature (1961-2000)



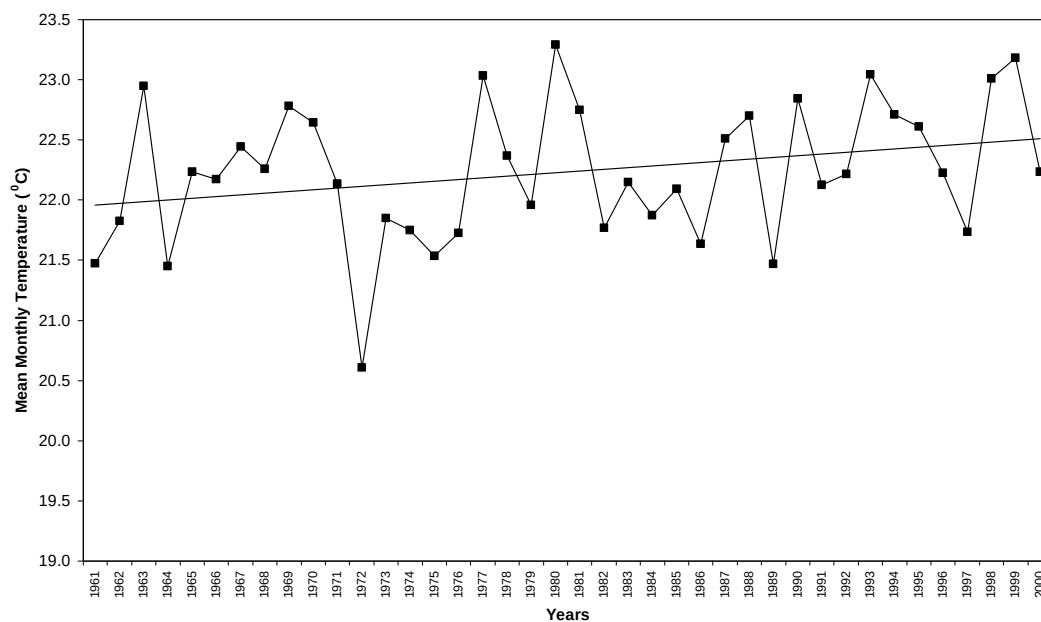
Graph-4.21: Jaccoabad
Annual Trend of Mean Monthly Temperature (1961-2000)



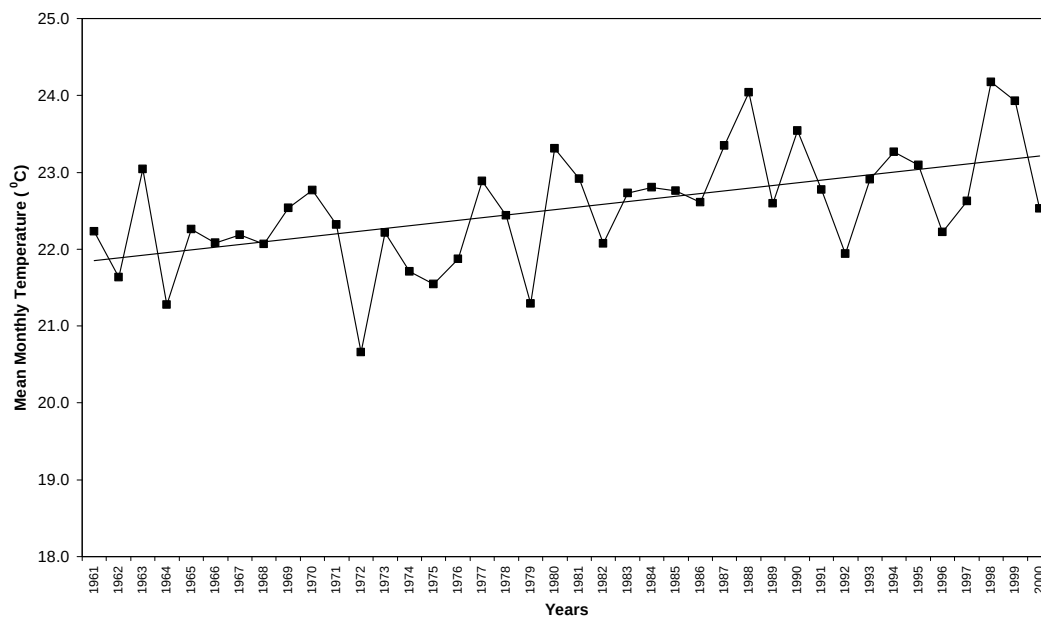
Graph-4.22: Karachi
Annual Trend of Mean Monthly Temperature (1961-2000)



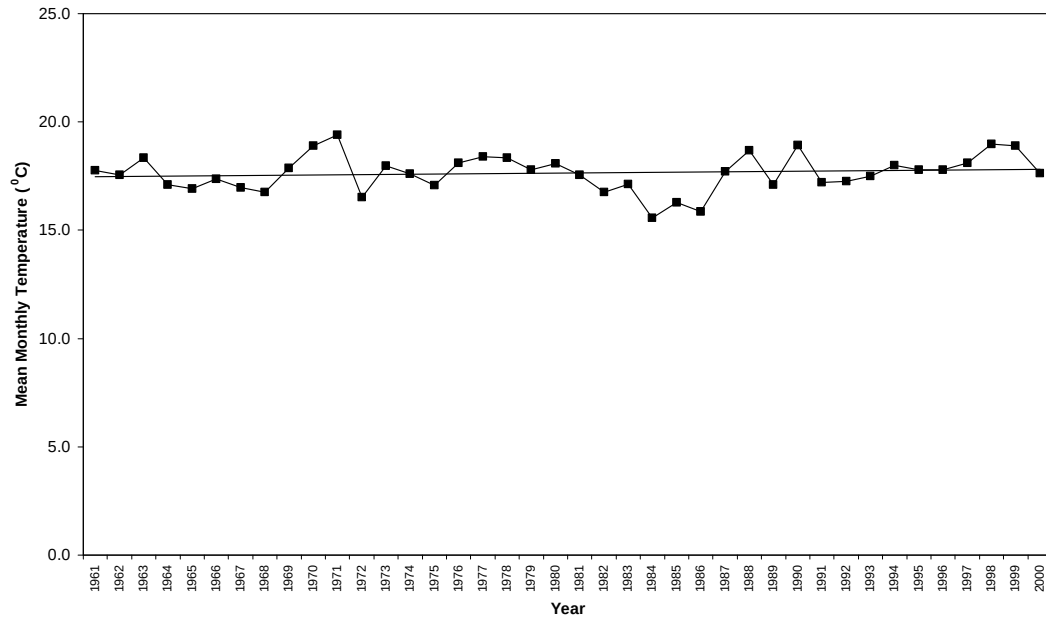
Graph-4.23: Panjgur
Annual Trend of Mean Monthly Temperature (1961-2000)



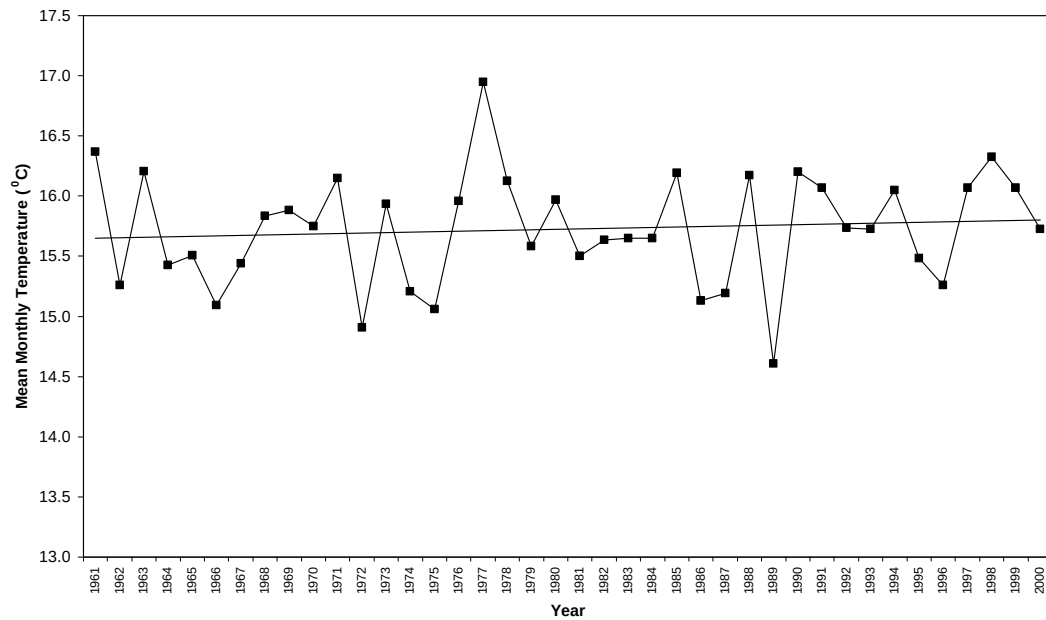
Graph-4.24: Dalbandin
Annual Trend of Mean Monthly Temperature (1961-2000)



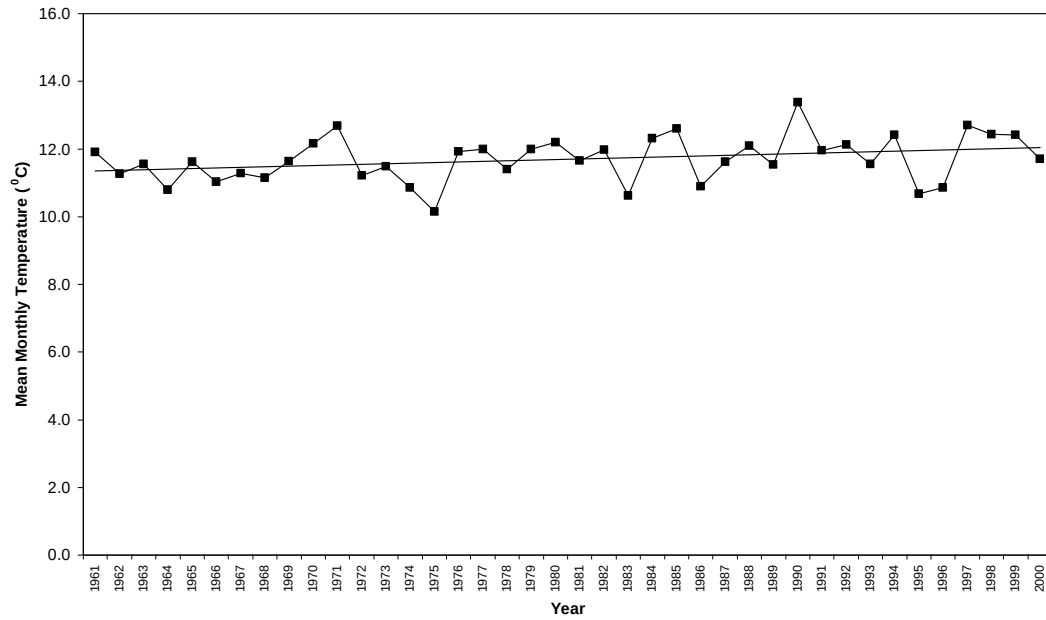
Graph-4.25: Drosh
Annual Trend of Mean Monthly Temperature (1961-2000)



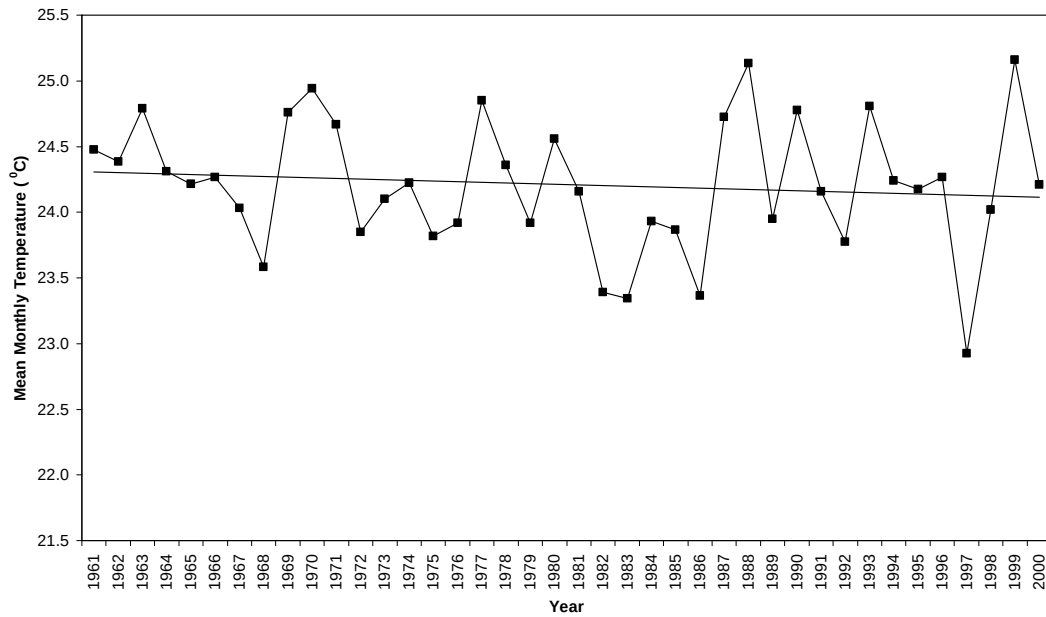
Graph-4.26: Gilgit
Annual Trend of Mean Monthly Temperature (1961-2000)



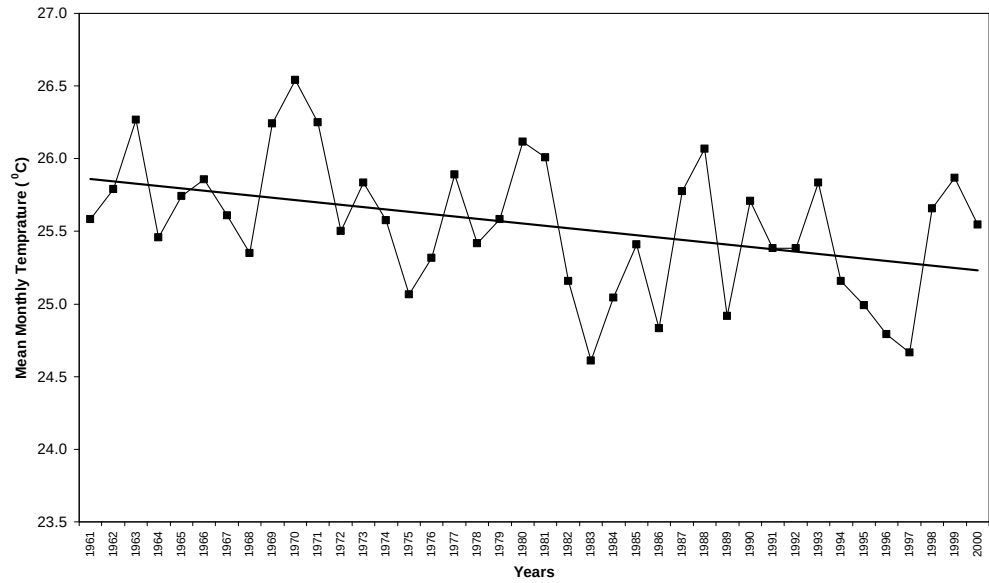
Graph-4.27: Skardu
Annual Trend of Mean Monthly Temperature (1961-2000)



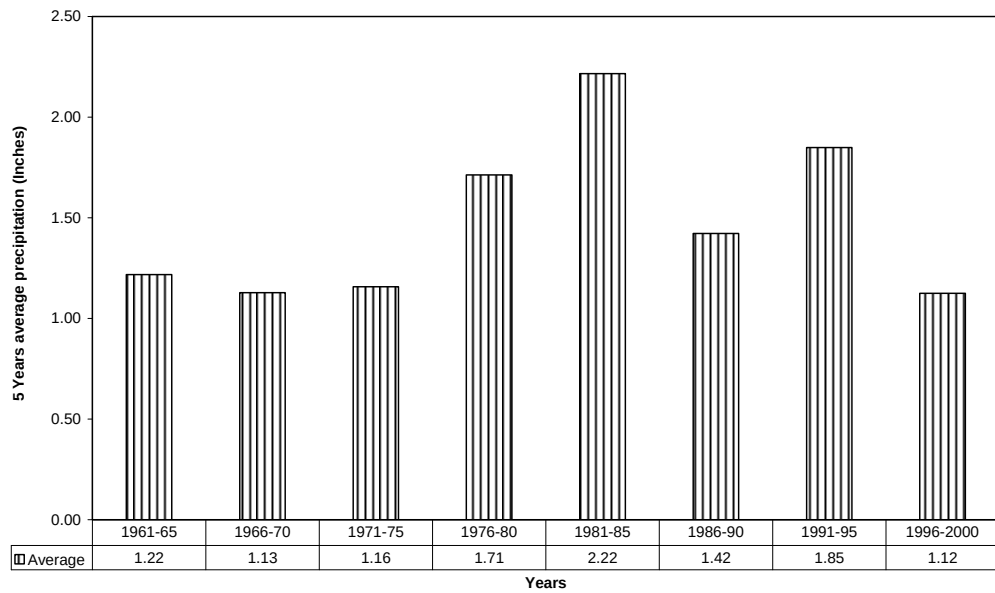
Graph-4.28: D I Khan
Annual Trend of Mean Monthly Temperature (1961-2000)



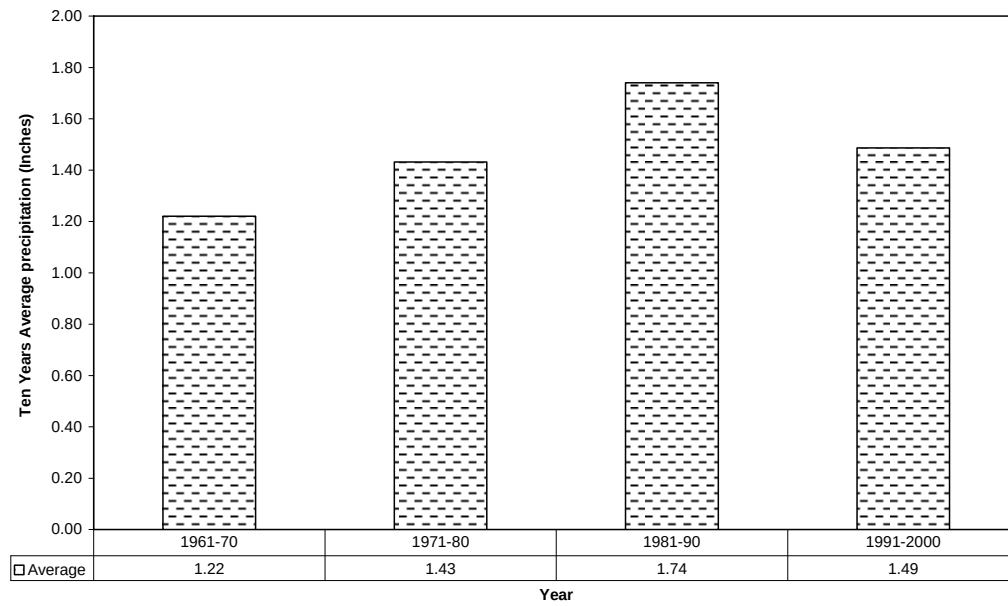
Graph-4.29: Bahawalpur
Annual Trend of Mean Monthly Temperature (1961-2000)



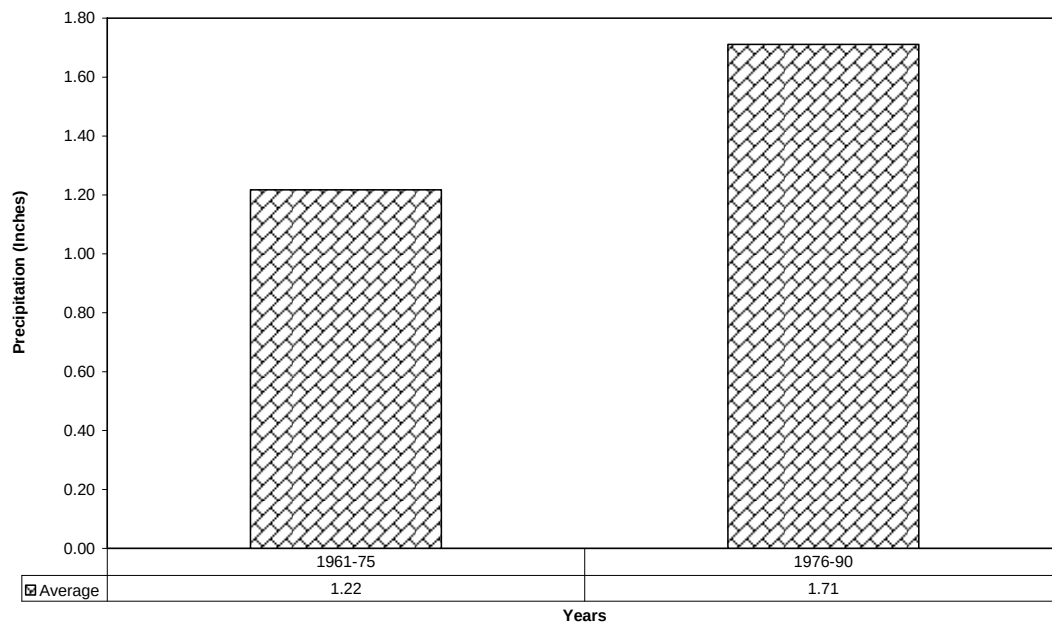
Graph-5.9: Arid Region
Annual Trend of Five Years Average Precipitation (1961-2000)



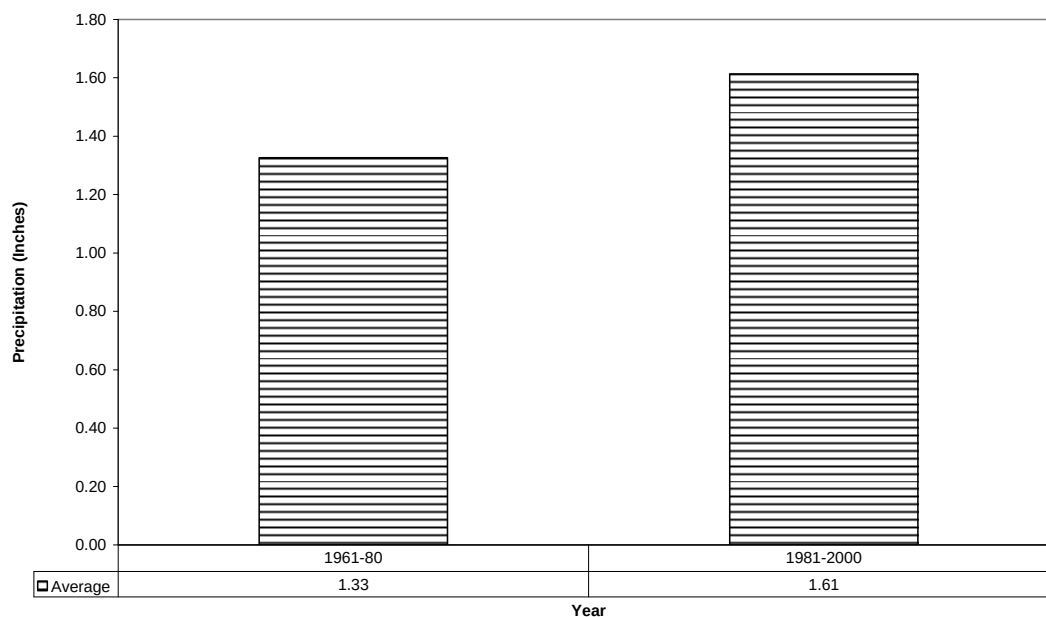
Graph-5.10: Arid Reigion
Annual Trend of Ten Years Average Precipitation (1961-2000)



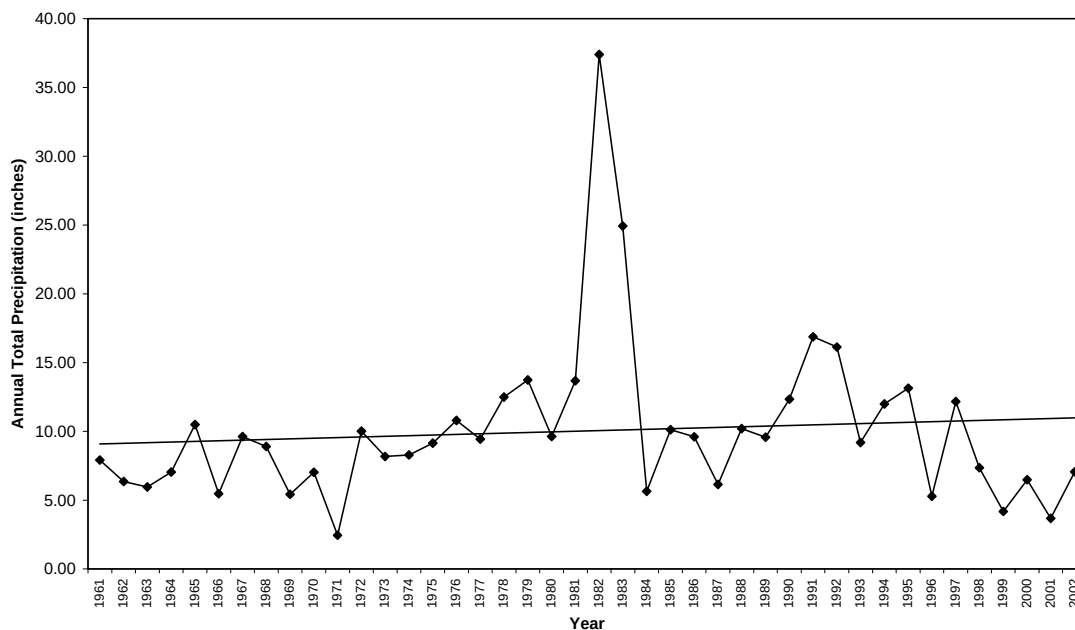
Graph-5.11: Arid Reigion
Annual Trend of Fifteen Years Average Precipitation (1961-2000)



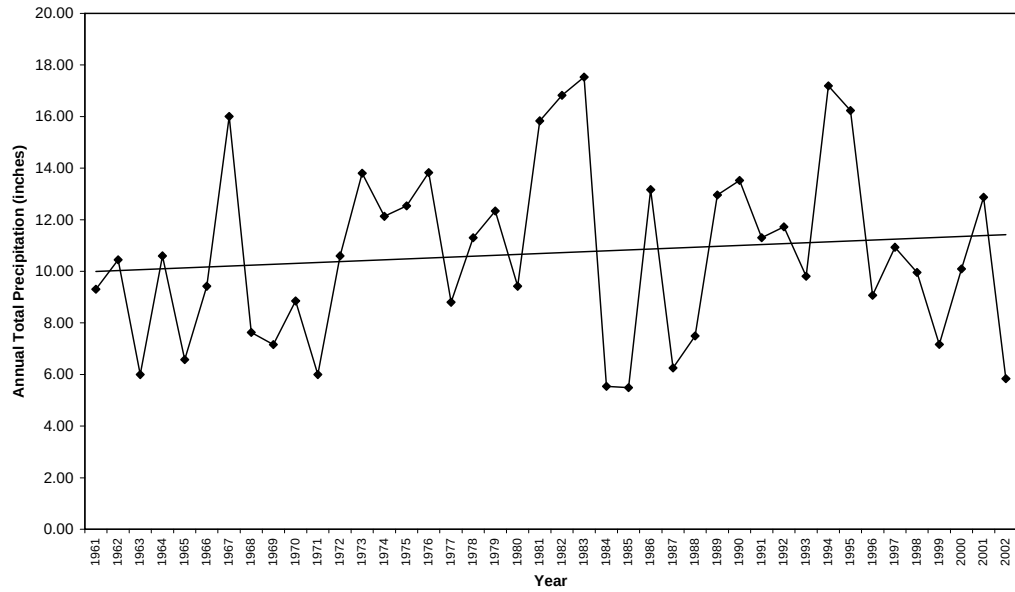
Graph-5.12: Arid Reigion
Annual Trend of twenty Years Average Precipitation (1961-2000)



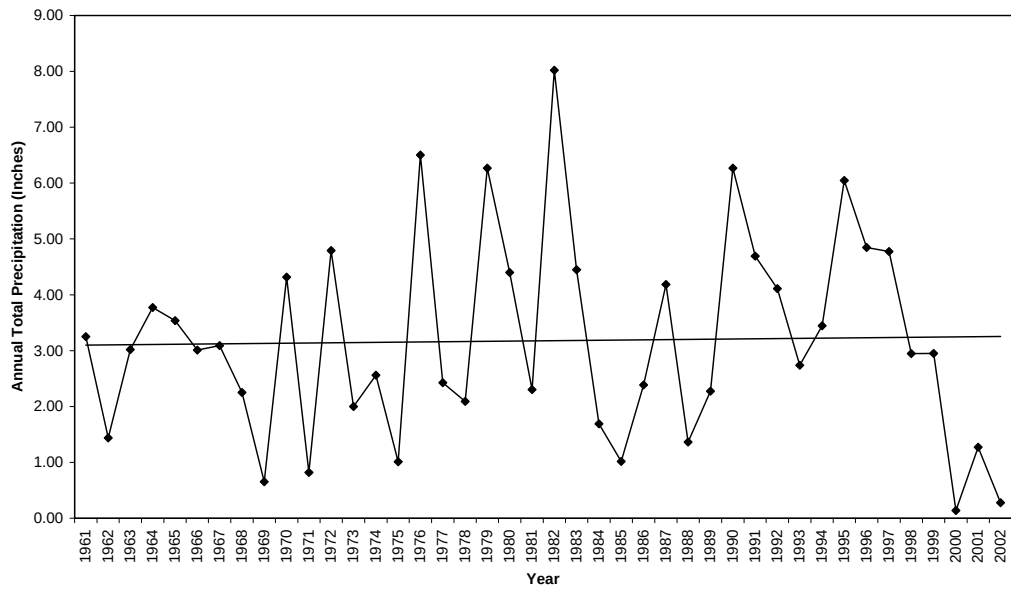
Graph-5.26: Quetta
Annual Trend of Precipitation (1961-2002)



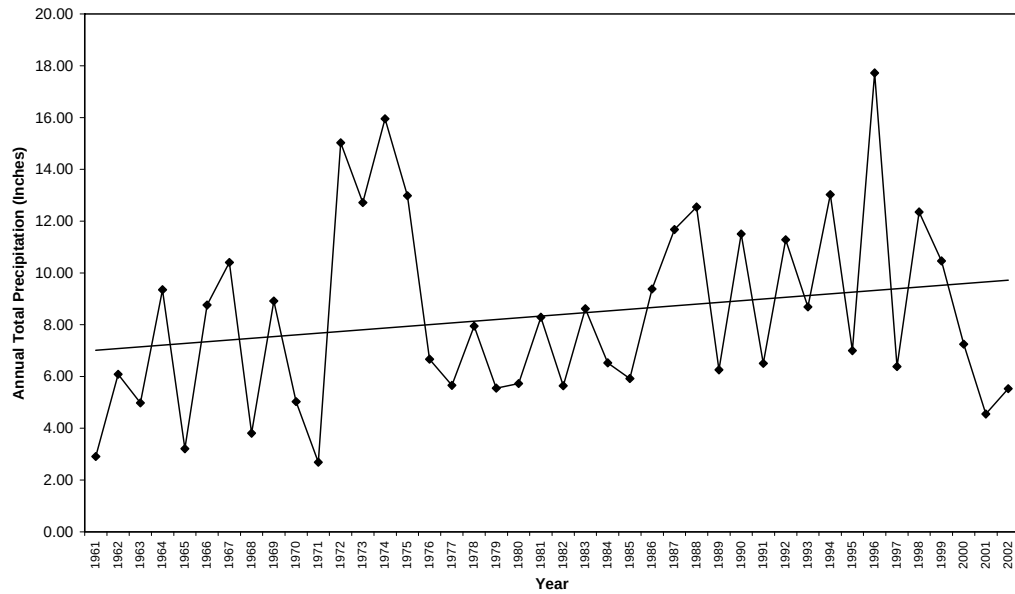
Graph-5.27: D I Khan
Annual Trend of Total Precipitation (1961-2002)



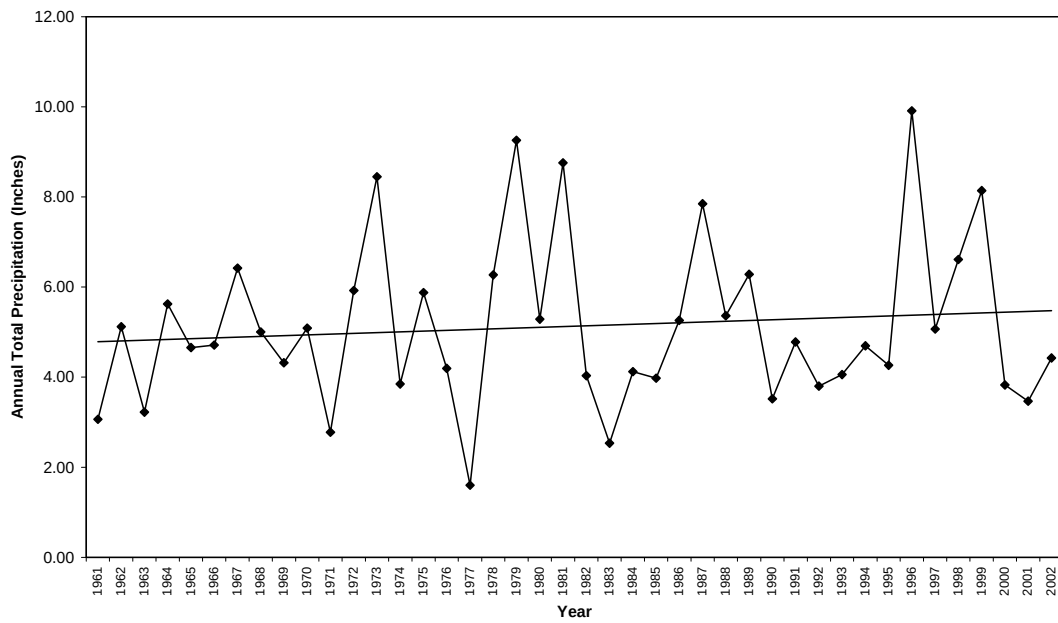
Graph-5.28: Dalbandin
Annual Trend of Precipitation (1961-2002)



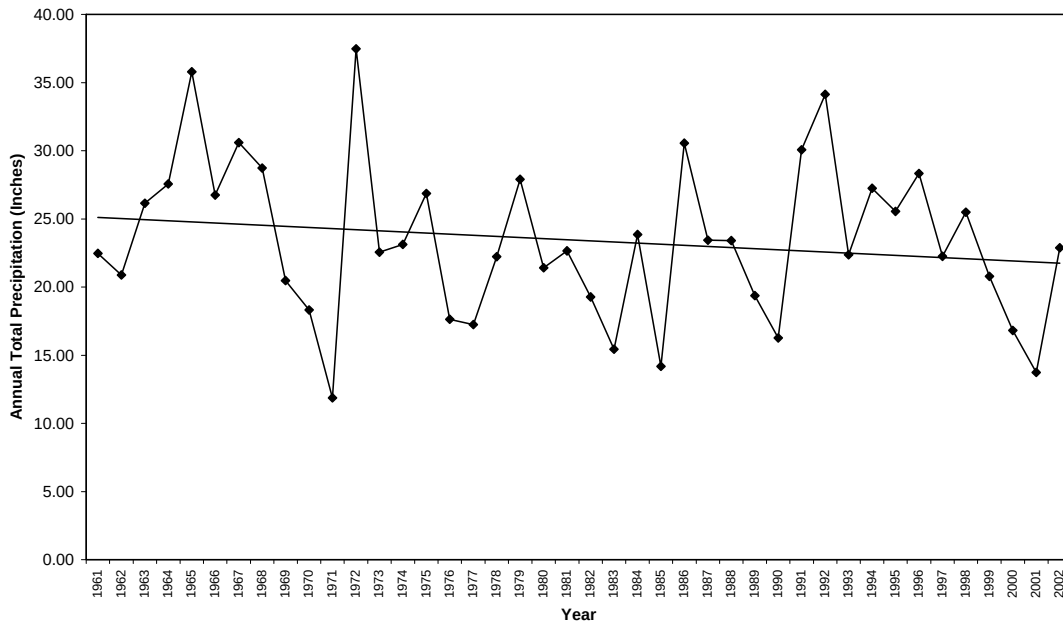
Graph-5.29: Skardu
Annual Trend of Precipitation (1961-2002)



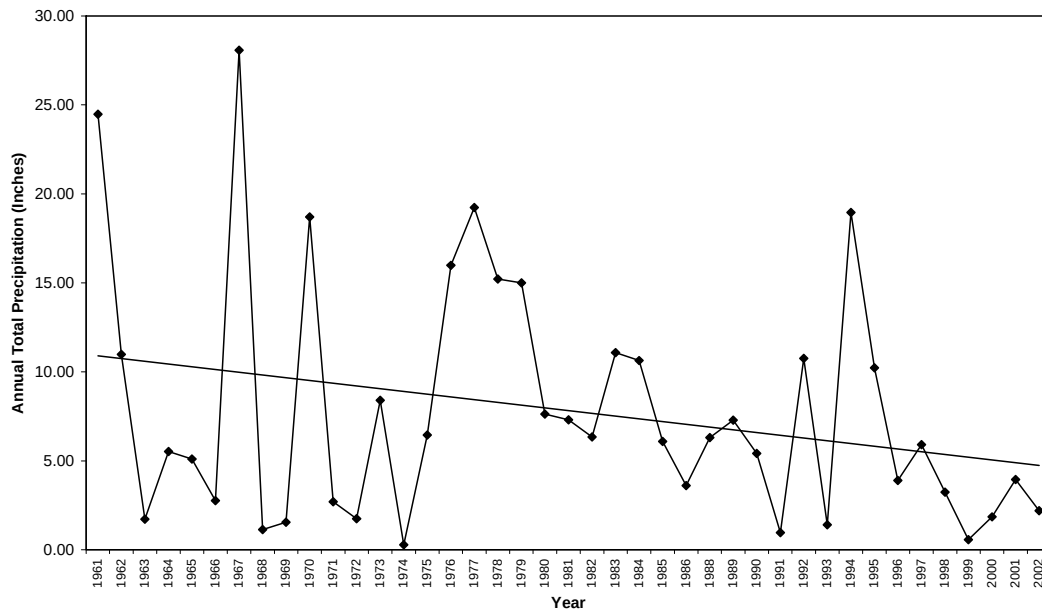
Graph-5.30: Gilgit
Annual Trend of Precipitation (1961-2002)



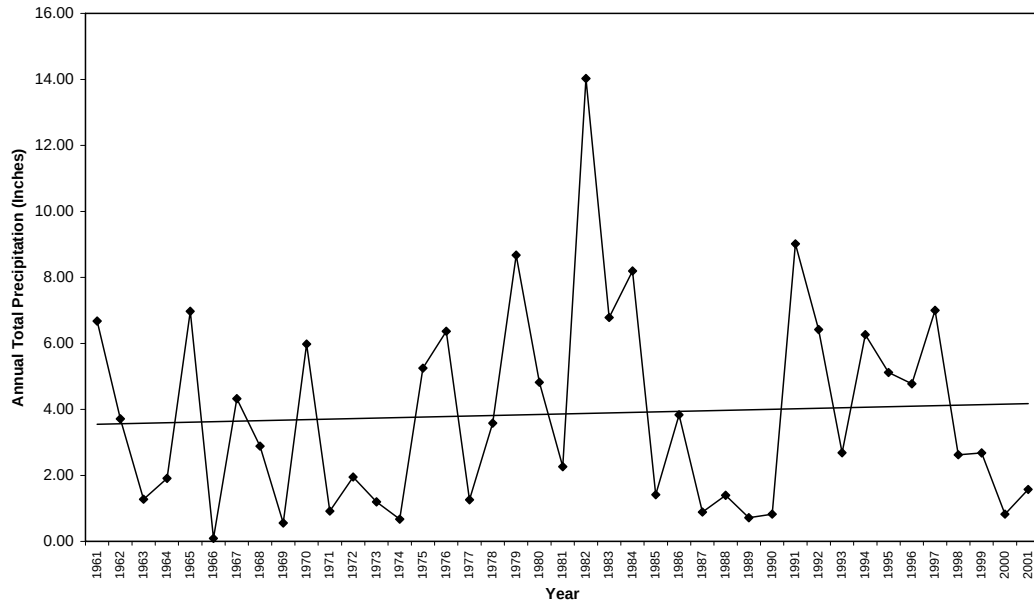
Graph-5.31: Drosh
Annual Trend of Precipitation (1961-2002)



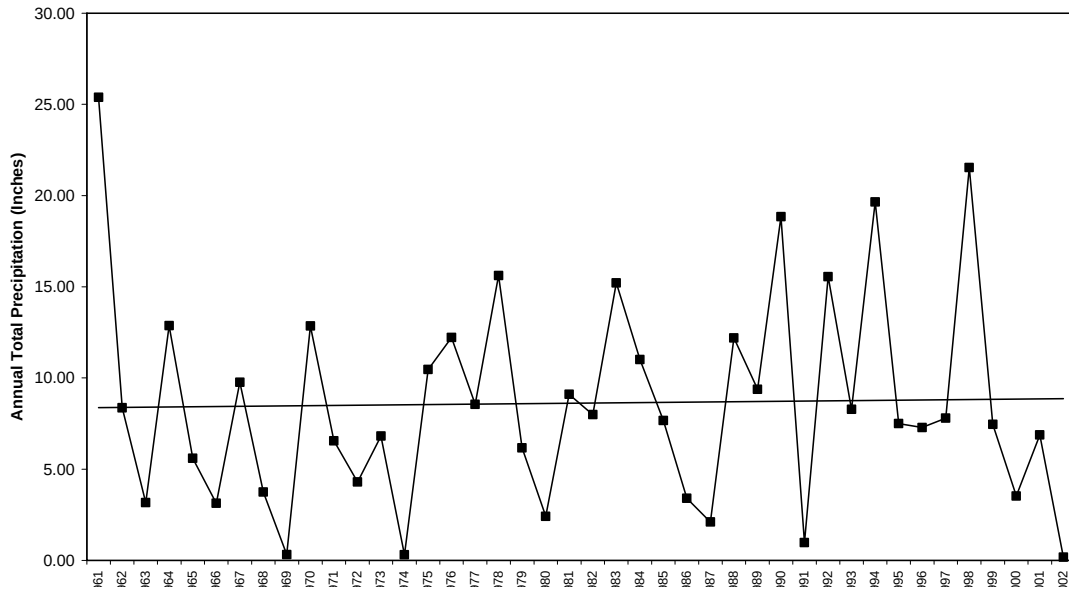
Graph-5.32: Karachi
Annual Trend of Precipitation (1961-2002)



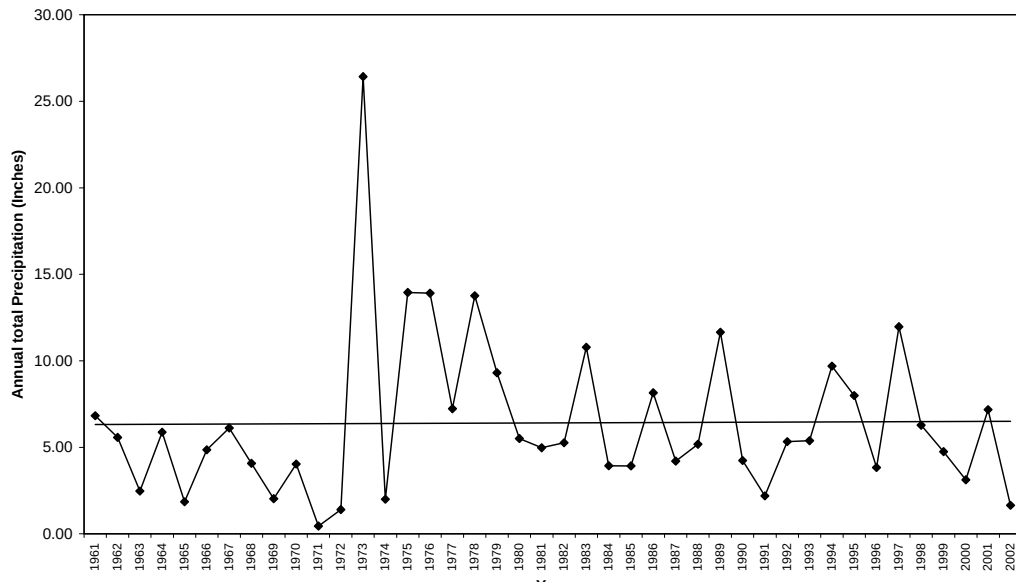
Graph-5.33: Pasni
Annual Trend of Precipitation (1961-2002)



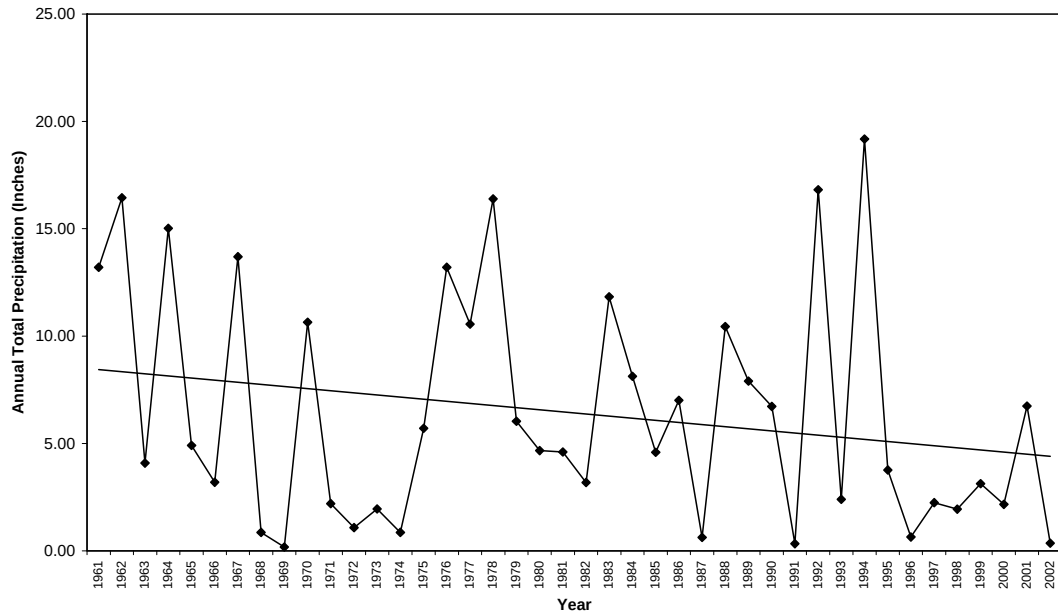
Graph-5.34: Chhor
Annual Trend of Precipitation (1961-2002)



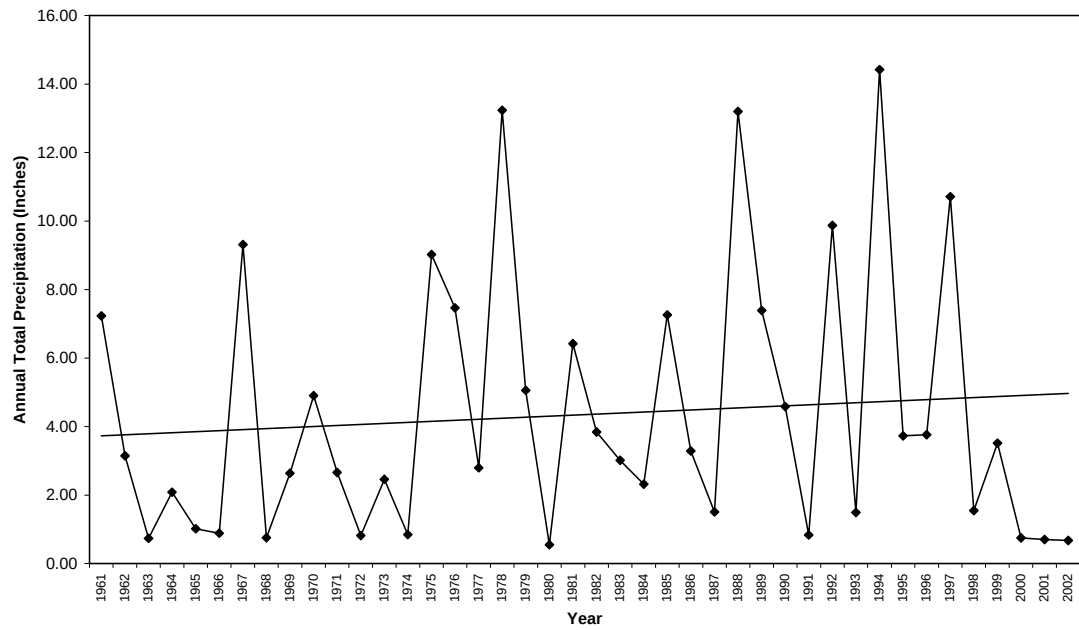
Graph-5.35: Bahawalpur
Annual Trend of Precipitation (1961-2002)



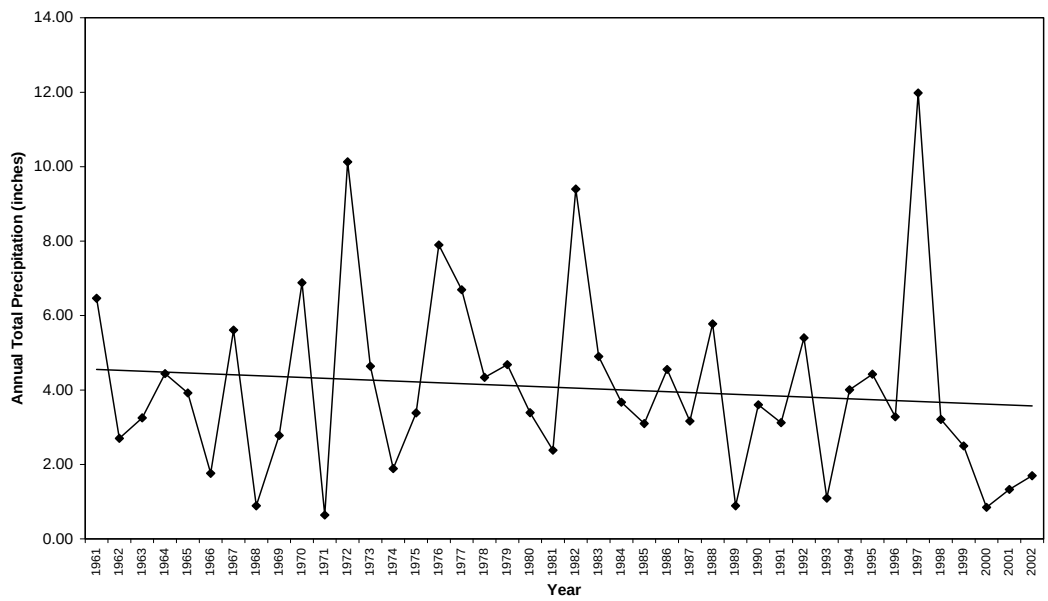
Graph-5.36: Hyderabad
Annual Trend of Precipitation (1961-2002)



Graph-5.37: Jaccobabad
Annual Trend of Precipitation (1961-2002)



Graph-5.38: Panjgur
Annual Trend of Precipitation (1961-2002)



Appendix-H: Glossary:

Abrupt climate change:

This essentially refers to both rapid and significant changes in at least one climatic element (wind, temperature, or precipitation).

Adaptation:

Adjustment or preparation of natural or human systems to a new or changing environment which moderates harm or exploits beneficial opportunities.

Acre:

The unit of measure most typically used to describe land area in Pakistan. An acre is equivalent to 43,560 square feet.

Acre-Inch:

A volume measurement typically associated with irrigation operations on cropland. An acre-inch is equivalent to 27,154 gallons.

Adaptation assessment:

The practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.

Adaptive capacity:

The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Anthropogenic:

Made by people or resulting from human activities. Usually used in the context of emissions that is produced as a result of human activities

Anthropogenic climate change:

Climate change with the presumption of human influence, usually warming.

Arid region:

A land region of low rainfall, where "low" is widely accepted to be <250 millimeters (10inches) precipitation per year.

Basin:

The drainage area of a stream, river, or lake.

Biodiversity:

The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems.

Climate:

The accumulation of daily and seasonal weather events over a long period of time. A description of aggregate weather conditions; the sum of all statistical weather information that helps describe a place or region.

Climate change:

Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer.

Climatic fluctuation:

A climatic inconstancy that consists of any form of systematic change, whether regular or irregular, except climatic trend and climatic discontinuity. It is characterized by at least two maxima (or minima) and one minimum (or maximum) including those at the end points of the record.

Climate model:

A series of calculations run on a computer that simulates how the atmosphere, oceans, land, living things, ice, and energy from the sun affect each other and the Earth's climate. Scientists use these models to study the Earth's climate and predict how it might respond to changing conditions, such as an increase in greenhouse gases in the atmosphere.

Climate variability:

Climate change, with no presumption of cause.

(Climate) Impact assessment:

The practice of identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems.

Cash Crop:

An agricultural crop grown to provide revenue from an off-farm source.

Crop year:

Generally refers to USDA-designated 12-month period for each crop that begins with that crop's typical month of harvest

Cropping Pattern:

The acreage distribution of different crops in any one year in a given farm area such as a county, water agency, or farm.

Desertification:

Land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities

Drought:

A period of abnormally dry weather sufficiently long enough to cause serious effects on agriculture and other activities in the affected area.

Data:

A collection of facts, numbers, or other pieces of information. Scientists use a variety of techniques to gather data about the Earth's climate. A single fact is called a datum (the singular form of data).

Degree days:

Computed from each day's mean temperature ($\text{max} + \text{min} / 2$). For each degree that a day's mean temperature is below or above a reference temperature is counted as one degree day.

Evapotranspiration:

The combined processes of evaporation from the Earth's surface and transpiration from vegetation.

Ecosystem:

A natural community of plants, animals, and other living organisms and the physical environment in which they live and interact.

Energy Efficiency:

Reducing the amount of energy used for a given service or level of activity in order to produce the same level of end - use service.

Emissions:

The release of a gas (such as carbon dioxide) or other substance into the air.

Erosion:

The wearing down of land by wind or water. Erosion can be made worse by certain types of farming and logging, road building, and clearing land for development.

Extreme weather event:

An extreme weather event is an event that is rare at a particular place and time of year.

Flood:

An overflowing of water onto land that is normally dry.

Forest:

A vegetation type dominated by trees.

Glacier:

A multi-year surplus accumulation of snowfall in excess of snowmelt on land and resulting in a mass of ice at least 0.1 km² in area that shows some evidence of movement in response to gravity.

Global climate:

The average climate around the world.

Global Warming:

The recent and ongoing global average increase in temperature near the Earth's surface.

Ground water:

Water that occurs below the surface of the Earth, where it occupies spaces in soil or layers of rock. When rain falls to the ground, some of it sinks into the ground and becomes ground water.

Greenhouse gases:

Gases that cause global warming and climate change. The major greenhouse gases (GHGs) are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

Gross domestic product (GDP):

The value of all final goods and services produced inside a country in a given time period.

Growing season:

The time period, usually measured in days, between the last freeze in the spring and the first frost in the fall.

Habitat:

The particular environment or place where an organism or species tend to live; a more locally circumscribed portion of the total environment.

Intergovernmental Panel on climate Change (IPCC):

The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change.

Isotherm:

A line connecting points of equal wind temperature.

Isohyet:

A line on a map connecting locations that receive the same amount of rainfall.

Irrigation:

Applying water (or wastewater) to land areas to supply the water (and sometimes nutrient) needs of plants.

Irrigation water management:

Limiting irrigation applications based on the water-holding capacity of the soil and the need of the crop.

January thaw:

A period of relatively mild weather around January 20 to 23 that occurs primarily in New England; an example of a singularity in the climatic record.

Land use and Land use change:

Land use *refers* to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). *Land use change* refers to a change in the use or management of land by humans, which may lead to a change in land cover.

Landslide:

The sliding of a large mass of rock material, soil, etc, down the side of a mountain or cliff.

Mitigation:

A human intervention to reduce the human impact on the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

Mean Annual Temperature:

The average temperature at any given location for the entire year.

Mean Daily Temperature:

The average temperature at any given location for 24 hours.

Mean Monthly Temperature:

The average temperature at any given location for the entire month.

Monsoon:

A monsoon is a tropical and subtropical seasonal reversal in both the surface winds and associated precipitation, caused by differential heating between a continental-scale land mass and the adjacent ocean.

Oilseed crops:

Primarily soybeans, sunflower seed, canola, rapeseed, safflower, flaxseed, mustard seed, peanuts and cottonseed, used for the production of cooking oils, protein meals for livestock, and industrial uses.

Permafrost:

Perennially (continually) frozen ground that occurs where the temperature remains below 0°C for several years.

Precipitation:

Any form of water particles-liquid or solid-that falls from the atmosphere and reaches the ground.

Physiographic:

Of, relating to, or employing a description of nature or natural phenomena.

Productivity:

A measure of technical efficiency, typically expressed as the added output for an additional unit of input or the average output per unit of input.

Pasture:

Land used primarily for the production of domesticated forage plants for livestock.

Reforestation:

Planting of forests on lands that have previously contained forests but that have been converted to some other use.

Reservoir:

A component of the climate system, other than the atmosphere, which has the capacity to store, accumulate or release a substance of concern, for example, carbon, a heat-trapping gas (greenhouse gas) or a precursor.

River discharge:

Water flow within a river channel, for example expressed in cubic meters per second (cubic feet per second). A synonym for stream flow.

Reclamation:

The process of rehabilitating disturbed lands, or converting unproductive lands to productive uses. The term is also used for the process of recycling or reusing water

Runoff, direct:

Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes. Runoff is the cause of rill erosion and a source of nonpoint pollution.

Sown:

Planted using a broadcast seeding machine that distributes seed upon the soil surface. The seed may then be incorporated into the soil to ensure adequate seed-soil contact for germination.

Scenarios:

A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships.

Sensitivity:

The degree to which a system is affected, either adversely or beneficially, by climate variability or change.

Sustainable development:

Development that meets the cultural, social, political and economic needs of the present generation without compromising the ability of future generations to meet their needs.

Sustainability:

In the sense of human sustainability on planet Earth, sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Scenario:

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world.

Temperature:

The degree of hotness or coldness of a substance as measured by a thermometer. It is also a measure of the average speed or kinetic energy of the atoms and molecules in a substance.

United Nations Framework Convention on Climate Change (UNFCCC):

The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. Gather and share information on greenhouse gas emissions, national policies and best practices

Vulnerability:

The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.

Variety:

A variety is a subdivision of a kind, and has different characteristics from another variety of the same kind.

Water stress:

A country is water-stressed if the available freshwater supply relative to water withdrawals acts as an important constraint on development.

Weather:

Atmospheric condition at any given time or place. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.