HYDRO METEOROLOGICAL HAZARD ASSESSMENT

OF SINDH PROVINCE

SINDH RESILIENCE PROJECT
SINDH IRRIGATION DEPARTMENT

ASIAN INSTITUTE OF TECHNOLOGY 1959
AIT Asian Institute of Technology

HYDRO METEOROLOGICAL HAZARD ASSESSMENT OF SINDH PROVINCE

AUGUST 2020

SUBMITTED BY:

ASIAN INSTITUTE OF TECHNOLOGY (AIT)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Sindh province and the Sindh Irrigation District are exposed to hydro-meteorological hazards such as drought and floods. Recent floods have occurred in Sindh in 2010, 2011, 2012, 2014 and 2015, and recent droughts have been experienced in 2014 and 2016.

The Sindh Irrigation Department (SID), Government of Sindh is in a process of institutional strengthening of the department under the 'Sindh Resilience Project soft component' funded by The World Bank. This should result in an improved preparedness and a more efficient handling of flood situations, reliable flood hazard and vulnerability assessments, and better preparedness and managing drought conditions. The 'Sindh Resilience Project soft component' thus aims to develop tools, concepts and methods to improve understanding of risks and eventually support rapid response through the flood disaster.

This current project analyses the hydrometeorological situation in the Sindh, and analysis the relation between hydrometeorological overall situation and hydrometeorological events leading to flood and drought situations.

The main objectives of this project are:

- To collect historical hydro-meteorological data for the province of Sindh;
- To analyze trends in historical hydro-meteorological data of the Sindh province;
- To characterize the hydro-meteorological hazards such as floods and droughts;
- To assess the socio-economic impacts of hydro-meteorological extreme events (Floods and droughts) in Sindh province; and
- To propose the action plan to deal with the hydro-meteorological hazards

The first section of the report (chapter 1) provides an overview of the overall hydrometeorological baseline situation and provides a vulnerability profile of the districts in the Sindh.

Chapter 2 describes the databases (temporal and spatial data) used in this study. In chapter 2 an overall chart of all relevant hydro-meteorological input parameters is given.

Chapter 3 gives the analysis of the drought. Chapter 3 distinguishes the meteorological drought (insufficient precipitation), the hydrological drought (insufficient water availability though precipitation and discharge), and the impact on agriculture and socioeconomics. In order to do this a few drought indices are developed (SPI and SPEI).

Chapter 4 gives the analysis of the flood situation. It gives the statistical analysis of discharge events and precipitation events leading to flooding, and it provides an overview of the impact of the flood events in terms of area flooded, people exposed and exposure assessment.

Chapter 5 gives the action points and recommendations. Recommendations include improver early warning systems and capacity enhancement at local and national level. This should include but not be limited to:

a) the adequacy of the meteorological and hydrological observing networks
b) the adequacy of the telecommunications systems to deliver timely hazard warnings including the degree of redundancy of those systems; the adequacy of their predictive capability including linkages to specialized regional centers
c) the adequacy of their access to current scientific developments with respect to early warning
d) the extent to which hazard warnings are already received by the target population in a timely manner and in a form which is recognized by them to be appropriate and useful
e) the degree to which their people are knowledgeable regarding meteorological and hydrological hazards, the availability and content of hazard warnings and appropriate preparedness and response actions;
f) the effectiveness of coordination between all parties involved in early warning for meteorological and hydrological hazards including droughts
g) the adequacy of disaster planning at local and national levels
h) the degree to which risk assessment is being used to support mitigation and response planning and to direct development away from high risk zones

i) the adequacy of emergency planning and management at local and national levels including the degree of involvement of local communities and people in the development, exercise and implementation of emergency plans
j) relationships with domestic broadcast and print media, and, where appropriate, with international broadcasters.

Chapter 5 concludes with recommendations for further research.

1. PROJECT BACKGROUND

1.1. INTRODUCTION

Hydro-meteorological natural hazards are considered one of the natural progressions or extreme phenomena of the hydrological or atmospheric nature, which may cause death or injury, property damage, socio-economic disruption and or geo-environmental degradation system (UNISDR 2002). We are dealing with two types of natural hazards, floods and droughts. Hazard assessment implies the determination of the magnitude and frequency and spatial delineation of the hazards.

The Sindh Irrigation Department (SID), Government of Sindh intends to undertake several activities for institutional strengthening of the department under the 'Sindh Resilience Project soft component' funded by The World Bank. The envisioned studies under soft component are to handle flood situations efficiently, meaningful preparedness before each flood season, reliable flood hazard and vulnerability assessments, and manage uninterrupted extreme drought conditions through the development of tools to improve understanding of risks and eventually support rapid response through the flood disaster.

Current hydro-meteorological hazards management in Sindh province is being carried out with limited information along with localized knowledge and experience of previous hazards.

The adequacy of real-time data can be accessible due to the advent of technology which can be efficiently used in overall hazard management. The assessment of the hydro-meteorological hazards needs detail data and information about the climatic and hydrogeological conditions. The integration process of the effects of these factors by using the remote sensing and GIS tools help to predict and estimate the hydro-meteorological hazards in an arid region. Thus, efficient hazard management can be achieved by conducting detailed development of hazard assessment methods, with real-time hydro-meteorological data of Sindh province.

1.2. OBJECTIVES

The main objectives of the project are:

- To collect historical hydro-meteorological data for the province of Sindh
- To analyze trends in historical hydro-meteorological data of the Sindh province
- To monitor and forecast the occurrence, intensity, and evolution of hydro meteorological extreme events (floods and droughts)
- To review and analyze hazard assessments for Sindh province regarding hydro- meteorological conditions
- To characterize the hydro-meteorological hazards such as floods and droughts
- To prepare the hydro-meteorological hazard maps of the Sindh province
- To prepare the hydro-meteorological hazards assessment report for Sindh province
- To assess the socio-economic impacts of hydro-meteorological extreme events (Floods and droughts) in Sindh province.
- To propose the action plan to deal with the hydro-meteorological hazards

1.3. DISASTER RISK PROFILE OF SINDH PROVINCE

1.3.1 SINDH PROVINCE AT A GLANCE

The Province of Sindh is located in the southeastern part of the country located around 25.8943° N latitude and 68.5247° E longitude. Its gross geographical area is 140,914 Sq. km, comprising 18% of the country. Sindh is bordered by Balochistan province to the west and Punjab province to the north. Sindh also borders the Indian states of Gujarat and Rajasthan to the east, and the Arabian Sea to the south. Sindh's landscape consists mostly of alluvial plains flanking the Indus River, the Thar Desert in the eastern portion of the province closest to the border with India, and the Kirther in the western part of Sindh.[1]

---

[1] *Rahimdad Khan Molai Shedai. (2013). "Janet ul Sindh"; 3rd edition, 1993; Sindhi Adbi Board, Jamshoro;*

1.3.2 CLIMATE

Sindh lies in the tropical to the sub-tropical region. It is hot in the summer and mild to warm in winter. Temperatures frequently rise above 46 °C between May and August, and the minimum average temperature of 2 °C occurs during December and January in the northern and higher elevated regions. The annual rainfall averages about seven inches (180 mm/year), falling mainly during July and August. The southwest monsoon wind begins in mid-February and continues until the end of September, whereas the cool northerly wind blows during the winter months from October to January.[2]

1.3.3 ECONOMY

Sindh has Pakistan's second-largest economy with a contribution to Pakistan's GDP of above 30%. Karachi is Pakistan's largest city and financial hub and hosts the headquarters of several national and multinational banks. Sindh is home to a large portion of Pakistan's industrial sector and contains two of Pakistan's commercial seaports, Port Bin Qasim and the Karachi Port. The remainder of Sindh has an agriculture-based economy.

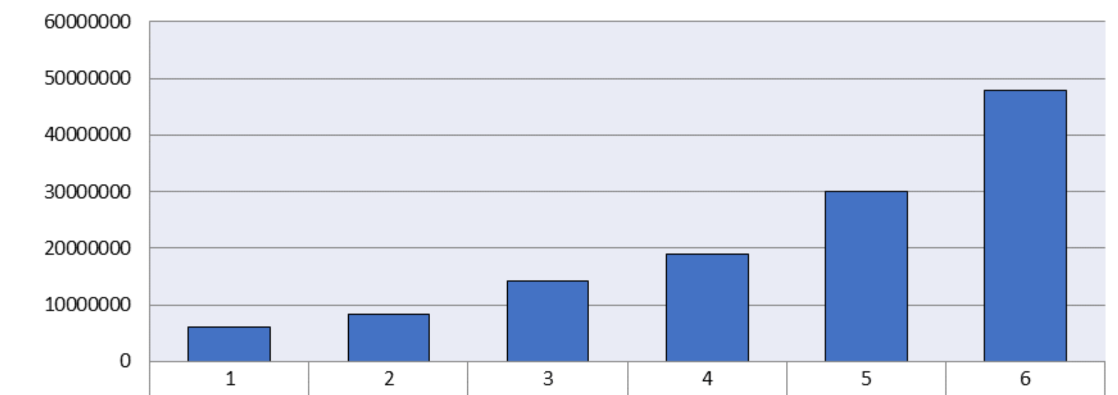
1.3.4 DEMOGRAPHICS

Sindh has the second highest Human Development Index (HDI) out of all of Pakistan's provinces at 0.628. The 2017 Census of Pakistan indicated a population of 47.9 million with a growth rate of 2.41% (Figure 1-1). Comparatively, with other provinces of Pakistan, Sindh has the highest urban population with 52%. Sindh also has Pakistan's highest percentage of Hindu residents.[3]

---

[2] *Rahimdad Khan Molai Shedai. (2013). "Janet ul Sindh"; 3rd edition, 1993; Sindhi Adbi Board, Jamshoro;*

[3] *Rahimdad Khan Molai Shedai. (2013). "Janet ul Sindh"; 3rd edition, 1993; Sindhi Adbi Board, Jamshoro;*



	1	2	3	4	5	6
Urban	29%	38%	40%	43%	49%	52%
Population	6,047,748	8,367,065	14,155,909	19,028,666	29,991,161	47,886,051
Year	1951	1961	1972	1981	1998	2017

Figure 1-1 Demography of Sindh Province

1.3.5 SOCIETY

The society is cosmopolitan, and the languages spoken besides Sindhi are Urdu, Punjabi, Pashto, Siraiki, Balochi, Brahui, Rajasthani, and Gujarati. The Balochi, Sindhi, and natives speak the Sindhi language as their mother tongue. Sindh's population is predominantly Muslim. The Province of Sindh is also home to nearly all of Pakistan's Hindus. Smaller groups of Christians, Parsis or Zoroastrians, Ahmadis, and a few members of the Jewish community can also be found in the province.[4]

1.3.6 GOVERNANCE

The Provincial Assembly of Sindh consists of 168 seats, of which 5% are reserved for non-Muslims and 17% for women. Karachi is the provincial capital of Sindh. The provincial government is led by Chief Minister who is directly elected by Sindh provincial Parliament Members; the Governor is nominated and appointed by the President of Pakistan.[5]

1.3.7 DIVISIONS AND DISTRICTS OF SINDH

Sindh is administratively divided into 6 divisions and 29 districts as shown in Table 1-1. The details are as follow.

[4] *Provincial Disaster Management Authority (2017). "Contingency Plan 2017 of Sindh". PDMA. P. 5*
[5] *Provincial Disaster Management Authority (2017). "Contingency Plan 2017 of Sindh".*

Table 1-1 Name of Administrative Divisions and Districts of Sindh Province

S.No.	District	Headquarters	Area (km²)[6]	Population (2017)[7]
Hyderabad Division				
1.	Hyderabad	Hyderabad	1,022	2,199,463
2.	Badin	Badin	1,797	1,804,516
3.	Dadu	Dadu	8,034	1,550,266
4.	Jamshoro	Jamshoro	11,250	993,142
5.	Matiari	Matiari	1,459	769,349
6.	Sujawal	Sujawal	7,335	781,967
7.	Tando Muhammad Khan	Tando Muhammad Khan	1,814	677,228
8.	Tando Allahyar	Tando Allahyar	1,573	836,887
9.	Thatta	Thatta	7,705	979,817
Mirpur Khas Division				
10.	Mirpur Khas	Mirpur Khas	3,343	1,505,876
11.	Tharparkar	Mithi	19,799	1,649,661
12.	Umerkot	Umerkot	5,503	1,073,146
Larkana Division				
13.	Larkana	Larkana	1,930	1,524,391
14.	Jacobabad	Jacobabad	2,797	1,006,297
15.	Kambar Shahdadkot	Qambar	5,676	1,341,042
16.	Kashmore	Kandhkot	2,682	1,089,169
17.	Shikarpur	Shikarpur	2,512	1,231,481
Sukkur Division				
18.	Sukkur	Sukkur	5,216	1,487,903
19.	Ghotki	Mirpur Mathelo	6,433	1,646,318
20.	Khairpur	Khairpur	15,910	2,404,334

[6] *Provincial Disaster Management Authority (2017). "Organizational capacity assessment and development of capacity enhancement plan (Part-B), 2017-18"*

[7] *Pakistan Bureau of Statistics, Government of Pakistan; Population census data of 2017, available at http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

S.No.	District	Headquarters	Area (km²)[6]	Population (2017)[7]
Shaheed Benazirabad Division				
21.	Shaheed Benazirabad	Nawabshah	4,618	1,612,847
22.	Naushahro Firoze	Naushahro Feroze	3,027	1,612,373
23.	Sanghar	Sanghar	10,259	2,057,057
Karachi Division				
24.	Karachi East	Karachi	165	2,907,467
25.	Karachi South	Karachi	84	1,791,751
26.	Karachi West	Karachi	630	3,914,757
27.	Korangi	Karachi	94.8	2,457,019
28.	Malir	Karachi	2,635	2,008,901
29.	Karachi Central	Karachi	61.5	2,971,626

Source: Organizational capacity assessment and development of capacity enhancement plan, PDMA Sindh, 2017-18

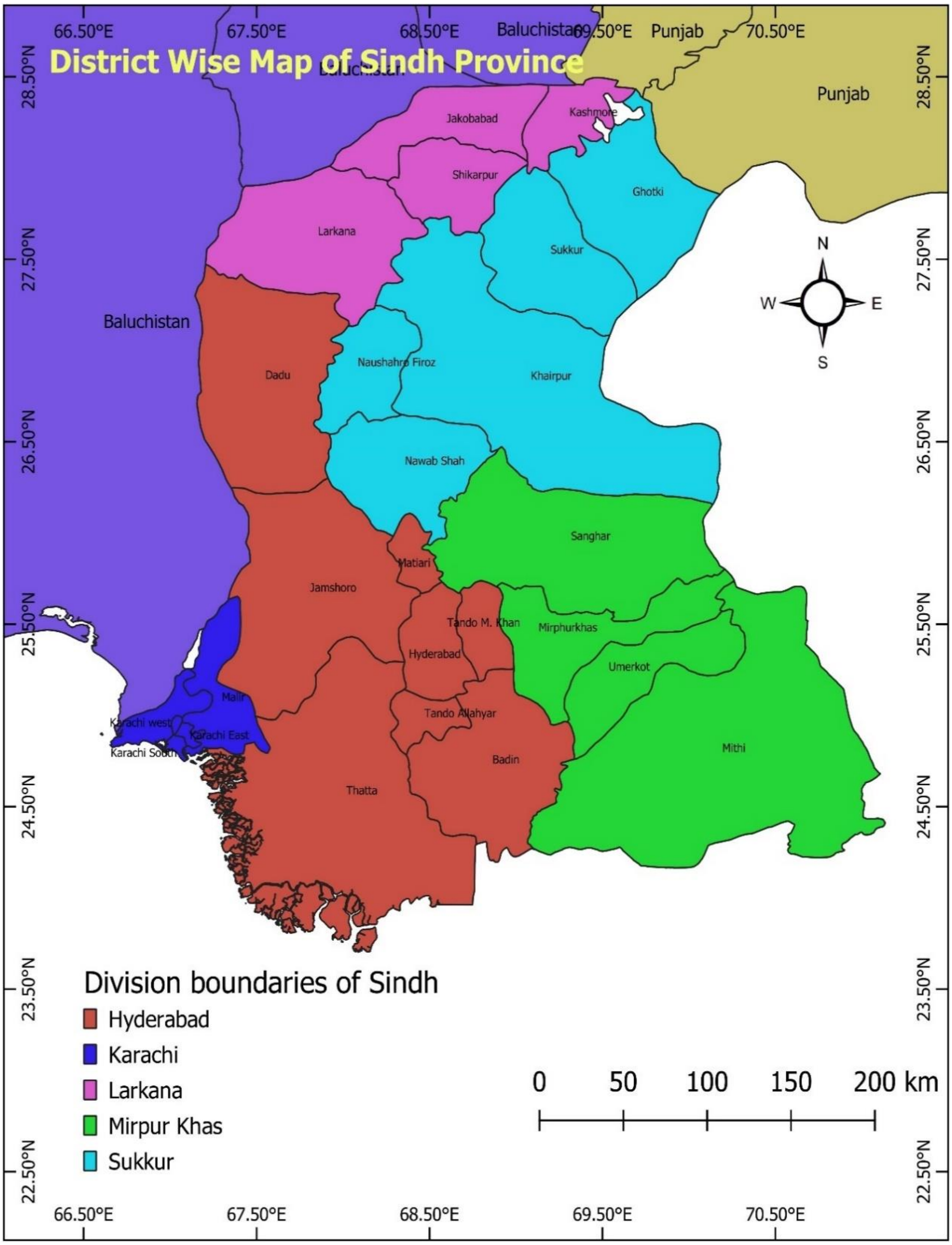


Figure 1-2 Maps showing Administrative Districts of Sindh Province

1.4. DISASTER RISK SITUATION OF SINDH PROVINCE

The province of Sindh has historically suffered from both natural and human-induced disasters. The high level of risk is mainly from floods/ heavy rains, and droughts, Table 1-2 indicates the District-wise severity index of risk in Sindh Province.

Table 1-2 Relative Severity of Various Vulnerabilities/Hazards per District in Sindh Province[8]

S.No.	Name of District	Droughts	Floods
1.	Karachi including all districts	4	3
2.	Thatta including Sujawal	4	4
3.	Badin	4	5
4.	Tharparkar	5	3
5.	Umerkot	5	3
6.	Mirpurkhas	4	3
7.	Tando Allahyar	3	4
8.	Tando Muhammad Khan	3	4
9.	Hyderabad	3	3
10.	Matiari	3	4
11.	Shaheed Benazirabad	4	4
12.	Naushahro Feroze	3	4
13.	Khairpur	4	4
14.	Sukkur	3	3
15.	Ghotki	3	4
16.	Shikarpur	2	3
17.	Kashmore	2	5
18.	Jacobabad	3	5
19.	Larkana	3	3
20.	Qambar- Shahdad kot	5	5
21.	Dadu	5	4
22.	Jamshoro	5	3
23.	Sanghar	4	4

5	4	3	2	1
Very High	High	Medium	Low	Very Low

Source: Ranking based on deliberation with staff from Relief Commissioner's Office and PDMA Sindh 2013

[8] *Provincial Disaster Management Authority (2013); "Multi-hazard contingency Plan 2013", pp 6-7*

1.4.1 FLOOD

Sindh province has two sources of flooding. The Riverine flood is more predictable and allows ample time to react, whereas the torrential rains and flash floods have very limited time to respond. Torrential rains and flash floods have lesser frequency and duration but very high intensity, therefore impact is severe. These floods normally occur during the monsoon months of July and August when its catchment areas in Balochistan receives heavy rains. The western boundary of Sindh is connected with Balochistan through Khirthar hills. Hill torrents originating from Balochistan enter in Sindh through Khirthar hills and inundate vast areas in the districts of Dadu and Shahdad Kot/Kambar.[9]

Sindh had suffered floods in 2010, 2011, 2012, 2014 and 2015. Sindh was heavily hit by the August 2011 floods and heavy rainfalls, where 462 people died, and 8,634,995 people were badly affected. Similarly, 280 people died during 2012 flooding and 27 people died during 2013 urban flooding in Karachi. Sindh was also affected by the September 2014 floods, making thousands of people homeless. Damages were mostly concentrated in District Ghotki, Kashmore and Khairpur. Further, riverine flooding was also experienced in 2015.[10]

1.4.2 DROUGHT

Geographically Sindh can be divided into the desert in eastern, mountains in western, coastal in southern and river plain in the middle. About 60% of the total land area is classified as arid, which receives less than 200 mm annual rainfall. Low rainfall and extreme variations in temperature characterize the climate that driven up to drought events. In the past, Sindh had severe drought events in 1871, 1881, 1899, 1931, 1942, 1999, 2014 and 2016.[11]

The people of Sindh are particularly affected in already water-scarce areas such as Tharparkar, Sanghar and surrounding areas where food security is an ongoing challenge. In 2014, 99 children and 67 adults died as a result of

---

[9] *LEAD Pakistan, "Factors Responsible for Flood Disaster in Sindh". Available at: http://www.lead.org.pk/cscc/attachments/articles/Factors_Flood_Sindh_NM.pdf*

[10] *Provincial Disaster Management Authority; "PDMA Sindh report – History of Flood Events", Available on main page of PDMA website http://www.pdma.gos.pk/new/aboutus/history.php*

[11] *Provincial Disaster Management Authority (2009). "Provincial Disaster Management Plan". PDMA Sindh. P.34*

water shortages, chronic malnutrition, and poor health services in the District Tharparkar. More than 190 children and 22,000 adults were hospitalized in District Tharparkar in 2016 due to drought-related, water-borne and viral diseases with families traveling an average of 17km to the nearest health facilities. Tharparkar has now confronted with four consecutive years of drought. Lower than average rainfall is frequently reported in talukas Chachro, Diplo, Khinser, Islamkot, and Mithi. According to the Joint UN Needs Assessment Report, 62% of people in Jamshoro and 100% of people in Tharparkar are affected by ongoing water shortages resulting in harvests reduction of 30-55% and livestock by 50%[12]. The worst drought experienced to date took place in 1998-2000, which severely stunted economic activities in Sindh.[13]

1.5. DISTRICT-WISE DISASTER RISK PROFILE OF SINDH PROVINCE

1.5.1 HYDERABAD DIVISION

Hyderabad division comprises of nine districts including Badin, Dadu, Jamshoro, Hyderabad, Matiari, Tando Allah Yar, Tando Muhammad Khan, Thatta, and Sujawal. According to the 2017 population census of Pakistan, the total population of Hyderabad division is comprising of 10,592,635 persons.[14]

1.5.1.1 DISTRICT BADIN

District Badin covers a total area of 1,797 km^2 and constitutes a population of 1,804,516 people. The district further has five Talukas (Badin, Matli, Shaheed Fazli Rahu, Talhar and Tando Bago) and 46 Union Councils[15]. District Badin has encountered a range of disasters including cyclones, floods, droughts, and earthquake during a different period of time.

---

[12] *PDMA Sindh (2018). Organizational Capacity Assessment and Development of Capacity Enhancement Plan.*
[13] *Provincial Disaster Management Authority (2009). "Provincial Disaster Management Plan". PDMA Sindh. P.34*
[14] *Pakistan Bureau of Statistics, Government of Pakistan (2017). Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*
[15] *BDRO (1998). "Badin Profile (1998)". Available at: http://bdro.org/wp-content/uploads/2013/04/Badin-Profile.pdf*

1.5.1.2 DISTRICT DADU

The District Dadu is situated at the right bank of River Indus. It covers an area of 8,034 km^2. Dadu comprises four Talukas (Dadu, Johi, Khairpur Nathan Shah and Mehr) and 52 Union Councils[16]. The district has a total population of 1,550,266 people. Dadu is vulnerable and prone to riverine floods and flash floods. Flash floods pose a great threat as the region lacks early warning mechanisms. It is among districts that had been affected badly during the 2010 and 2011 floods in the region in which 920,105 people were affected. During 2013 floods, about 27 villages of Katcha areas of Dadu along with Sehwan submerged in floodwater. In addition, harvest ready crops of cotton, rice, and onion got destroyed in an area of several hundreds of acres.[17]

1.5.1.3 DISTRICT JAMSHORO

Jamshoro is situated on the Western part of the Sindh and on the west bank of the River Indus. It covers an area of 11,250 km^2 and has a population of 993,142 people. It has four Talukas (Sehwan, Kotri, Thano Bula Khan and Manjhnd) and 28 Union Councils. The district encounters hazard of flooding as the Indus is the main source causing flooding in the adjacent areas. Jamshoro also got hit by 2010, 2011 and 2015 floods and heaving rainfall as many other districts. About 50% of the population were badly affected during floods 2010. These floods brought a great amount of loss to the crops and livestock accompanied by hundreds of acres of land damage.[18]

1.5.1.4 DISTRICT HYDERABAD

Hyderabad is situated in the southern part of Sindh. It has an area of 1,022 km^2 and comprising a population of 2,199,463 out of which 80% is urban population. It has four Talukas namely Hyderabad, Hyderabad city, Qasimabad, and Latifabad, and 53 Union Councils. Frequent monsoon floods are considered a common hazard in the district. The district was

---

[16] *District Profile. "Profile of District Dadu".*

[17] *PDMA Sindh. "Floods Contingency Plan (2012), Sindh Provincial Monsoon". Available at: https://doi.org/10.1017/CBO9781107415324.004*

[18] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Jamshoro". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Jamshoro-Sindh.pdf*

hit by 2011 floods and heavy rainfall and affected 20% of the population. The floods 2012 also caused damage with seven causalities in the district.[19]

1.5.1.5 DISTRICT MATIARI

District Matiari was established in 2005 having 769,349 people, spread over an area of 1,459 km^2. It has been administratively divided into 3 Talukas which are Matiari, Hala, and Saeedabad and comprised of 19 Union Councils. The district is prone to riverine floods due to River Indus which flows alongside the western border of the district. The district was hit by floods during 2010, 2011 and 2012. The flood 2012 affected around 2500 people while the flood 2011 affected 110,000 people and 45,600 people affected by the 2010 flood in Matiari.[20]

1.5.1.6 DISTRICT TANDO ALLAH YAR

District Tando Allah Yar is situated on an area of 1,573 km^2 having a population of 836,887 people. It has 3 Talukas (Tando Allahyar, Jhando Mari and Chamber) and 19 Union Councils. The district is vulnerable to heavy rainfall that gives birth to water-borne diseases and hence affecting this district badly. The heavy rainfall in 2011 affected 570,000 people and 66% of the cropped area. However, the severity of floods can be categorized as the medium risk for the district while droughts somehow also pose a threat to the region.[21]

1.5.1.7 DISTRICT TANDO MUHAMMAD KHAN

District Tando Muhammad Khan is spread on an area of 1,814 km^2 and has a population of 677,228 people[22]. There are 3 Talukas (Tando Muhammad Khan, Bulri Shah Karim and Tando Ghulam Hyder) and 17 Union Council in the district. The district is prone to riverine floods due to its geographical location. On the other hand, this district is also highly

---

[19] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Hyderabad". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Hyderabad-Sindh.pdf*
[20] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Matiari". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/DP%20Matiari%20Sindh.pdf*
[21] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Tando Allahyar". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-Tandoallahyar-Sindh.pdf*
[22] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

vulnerable to the risk of drought. The district was hit by floods in 2010, 2011 and 2015. The damages of 2011 floods were high as it affected 585,411 people 2,835 villages and destroyed all sources of livelihood.[23]

1.5.1.8 DISTRICT THATTA

District Thatta is spread over an area of 7,705 km^2 with a population of 979,817 people.[24] The district comprises of 4 Talukas (Ghorabari, Keti Bunder, Mirpur Sakro and Thatta) and 39 Union Councils. The district is situated on the right bank of River Indus that enhances its vulnerability to riverine floods. Due to its geographical location and nature, it is highly vulnerable to cyclones. On the other hand, droughts affected the district in the past. The heavy rainfall in 1973 brought severe impacts that affected the entire district. The floods 2010 and 2011 affected 895,400 people and 110,000 houses while PHET cyclone significantly caused damages in the district during 2010. In addition to this, the tsunami of December 2004 also hit the district and should be considered a major disaster which affected parts of Thatta.[25]

1.5.1.9 DISTRICT SUJAWAL

District Sujawal was established in 2013 with an area of 7,335 km^2 and has a population of 781,967 people. It has been administratively divided into 4 Talukas (Jaati, Bathoro, Shah Bandar and Sujawal) and 37 Union Councils. Sujawal is considered among the four most vulnerable districts of Sindh, affected by hydro-meteorological hazards that include cyclones, floods, and droughts. The district lies in close proximity with River Indus and hence, remains in threat situation of floods during monsoon.[26]

---

[23] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Tando Muhammad Khan". Available https://reliefweb.int/sites/reliefweb.int/files/resources/Pakistan_2.pdf*

[24] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[25] *Government of Sindh, District Thatta. "District Disaster Management Plan (2017-2027)". Available at: http://pdma.gos.pk/new/resources/Malteser/DDMPthatta.pdf*

[26] *Rural Support Programmes Network (RSPN) (2016). "Tahafuz: Building Resilience through Community Based Disaster Risk Management in Sindh Province of Pakistan". Available at: http://www.rspn.org/wp-content/uploads/2016/11/Highlights-of-Disaster-Preparedness-at-Community-Level-Final.pdf*

1.5.1.10 MIRPUR KHAS DIVISION

Mirpur Khas division has a population equal to 4,228,683. This division constitutes 8.8% of the province's population and has further been split into three districts namely Mirpur Khas, Tharparkar and Umerkot.[27]

1.5.1.11 DISTRICT MIRPUR KHAS

District Mirpur Khas covers an area of 3,343 km^2 and has a population of 1,505,876 people. Majority of the population is rural based. The district has been divided into 6 Talukas (Mirpur Khas, Sindhri, Digri, Hussain Bux Mari, Kot Ghulam Muhammad, and Jhuddo) and 41 Union Councils. Mirpur Khas district was badly affected by rains in 2011. The hazards include floods, cyclone, and droughts. Mirpur Khas got hit by flood during 2011, resulted in 61 deaths, 700,000 people affected, and 120,000 houses destroyed.[28]

1.5.1.12 DISTRICT THARPARKER

District Tharparker is spreading over an area of 19,799 km^2 with a population of 1,649,661 people.[29] It comprises 4 Talukas (Mithi, Dahli, Islamkot, Kaloi, Diplo, Chachro and Nagar Parker) and 48 Union Councils. Tharparker is exposed to a number of hazards including droughts, flash floods, desert storm, and earthquakes. Despite its deserted coverage, it is vulnerable to flash floods because of its geographical location as it lies adjacent to Badin which is a high flood-prone district due to LBOD. The drought 2014 affected the entire population of the district. During this calamity, 99 children and 67 adults reportedly died due to the scarcity situation in the district. During 2016 drought situation, more than 190 children died, and 22,000 people were hospitalized due to the related water-borne and viral diseases.[30] However, the earthquake also struck in the region in 2001 which took

[27] *Pakistan Bureau of Statistics. "Province Wise Provisional Results of Census – 2017". Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[28] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Mirpur Khas". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-District-Mirpurkhas-Sindh.pdf*

[29] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[30] *Reliefweb, "Pakistan: Drought - 2014-2017" Available at: https://reliefweb.int/disaster/dr-2014-000035-pak*

lives of 12 people, damaged 1989 houses beside a financial loss of Rs. 2.4 billion.[31]

1.5.1.13 DISTRICT UMERKOT

District Umerkot is situated at the edge of Thar Desert. It has two distinct geographical portions: one is irrigated area, bounded by Badin (north and west) and another part is desert, bounded by Tharparker (south and east). It has a total population of 1,073,146 and has a 5,503 km^2 of coverage area. It has 4 Taluka:Umerkot, Samaro, Kunri, and Pitharo and 27 Union Councils. The district is vulnerable to hazards including floods, heavy rainfall, earthquakes and droughts in which the later one is more frequent. The flood 2011 affected 80% of the population in the district. A total of 1,000,000 acres of the area was affected out of which 110,000 acres was cropped area[32].

1.5.1.14 LARKANA DIVISION

Larkana Division has been divided into five districts including Kashmore, Shikarpur, Jacobabad, Larkana and Kambar Shahadadkot. The division has a population of 6,192,380 people this hosts 12.93% of the Province's population.[33] Larka Division has the following districts.

1.5.1.15 DISTRICT KASHMORE

The district is situated in Northern Sindh and spread over an area of 2,682.46 km^2 with a population of 1,089,169 people.[34] The district has three Talukas (Kashmore, Kandhkot, and Tangwani) and 37 Union Councils. The district is prone to riverine floods as Indus River flows through the Eastern side of Kashmore district. The district was consecutively hit by 2010, 2011, 2012, 2013, 2014 and 2015 floods and is a prone area to flooding from Indus River. The severity of these floods was high in Kashmore as it affected 455,000 people and 93,000 houses during 2010. However, flood 2011 caused damages to a less extent but

---

[31] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Tharparker". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Tharparkar-Sindh.pdf*

[32] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Umerkot". Available at:*

[33] *Pakistan Bureau of Statistics. "Province Wise Provisional Results of Census – 2017". Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[34] *Pakistan Bureau of Statistics. "Province Wise Provisional Results of Census – 2017". Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

the intensity was high, while flood 2012 alone affected 850,000 people and destroyed 50,000 houses.[35]

1.5.1.16 DISTRICT SHIKARPUR

The geographical area of the district is 2,512 km^2, residing a population of 1,231,481 people.[36] It has four Talukas (Shikarpur, Garhi Yasin, Lakhi and Khan Pur) and 33 Union Councils. The district is prone to floods, cyclones, droughts, earthquake, windstorm, extreme temperature, etc. Due to extreme weather condition, the district usually suffers from heavy rains in monsoon season and hot temperature in the hot season. The district was hit by heavy rainfall in 2003, 2010 and 2011, riverine and flash flood in 2003, 2005, 2010 and 2011 and also an earthquake in 2001.[37]

1.5.1.17 DISTRICT JACOBABAD

District Jacobabad covers an area of 2,797 km^2 with a population of 1,006,297 people.[38] It has been divided into three Talukas (Jacobabad, Ghari Khairo, and Thul) and 40 Union Councils. The district also reflects the history of droughts. In addition, epidemics, causalities from accidents and environmental degradation are considered common hazards. The district Jacobabad was hit by droughts in 1999 and 2001 while floods hit the district during 2003, 2010, 2011 and 2012.[39]

1.5.1.18 DISTRICT LARKANA

District Larkana is situated in the northwest of Sindh Province with a population of 1,524,391 people and spread over an area of 1,930 km^2. The district has four Talukas whuch are Larkana, Rato Dero, Dokri and Bakrani and 47 Union Councils.[40] Larkana district is prone to riverine and flash floods due to its geographical location in proximity to River Indus

[35] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Kashmore". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Kashmore-Sindh.pdf*

[36] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[37] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Shikarpur". Available at: http://itacec.org/itadc/phase2/document/key_projects_documents_strategies/district_profiles/PESA_Shikarpur.pdf*

[38] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[39] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Jacobabad". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Jacobabad-Sindh.pdf*

[40] *Sindh Union Council and Community Economic Strengthening Support Programme (SUCCESS). "Brief District Profile Larkana".*

that makes it vulnerable to flood disaster. The district was hit by floods in the year 2010 and 2011. The households affected during flood 2010 were 250,000 in 2010 and 85,000 in 2011 flood.[41]

1.5.1.19 DISTRICT KAMBAR SHAHDADKOT

District Kambar Shahdadkot covers an area of 5,675.66 km^2 and exhibits a population of 1,341,042 people.[42] It has seven Talukas and 40 Union Councils. The district is prone to riverine and flash floods and was hit by 2010, 2011, 2012, 2013, 2014 and 2015 floods. The extent of damage was high during 2010 that affected 892,500 people in the district. Similarly, 45,000 people were affected while 250 houses were damaged during 2011. The flood 2012 affected a total of 250,000, besides 15 deaths and 31 injuries were reported. A total of 27,508 houses were damaged and 11,330 acres of crop affected.[43]

1.5.2 SUKKUR DIVISION

Sukkur division consists of three districts namely Sukkur, Ghotki and Khairpur. The division has a population of 5,538,555 that has been increased by 60.6% during the last Census.[44]

1.5.2.1 DISTRICT SUKKUR

District Sukkur is spread over an area of 5,216 km^2 and has a population of 1,487,903 according to the population census of 2017. The district comprises of five Talukas namely Sukkur, Rohrii, Pano Aqil, Salehpat, and New Sukkur and 46 Union Councils. The riverine floods pose a great threat to the district because of close vicinity to River Indus that flows in the north-western side of the district. In the Indus course, Sukkur is the narrowest part. Sukkur got hit by floods during 2010, 2011, 2012, 2013,

[41] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Larkana". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Larkana-Sindh.pdf*

[42] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[43] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Kambar Shahadatkot". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-KamberShahdadKot-Sindh.pdf*

[44] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

2014 and 2015. The intensity of the 2010 flood was comparatively high, resulting in 250,000 people affected and 3,000 houses damaged.[45]

1.5.2.2 DISTRICT GHOTKI

The district lies on the left bank of Indus, spread on an area of 6,432.59 km^2. The total population of the district is 1,646,318 persons.[46] The district is divided into five Talukas: Ghotki, Khan Garh, Mirpur Mathelo, Ubauro, and Daharki and 42 Union Councils. Ghotki has experienced flooding in 2010, 2011, 2012, 2013, 2014 and 2015 caused by the River Indus. It is also vulnerable to heavy rainfall in the region that resulted in flooding in the past. In 2010 flood, 170,000 persons in 380 villages/settlements of 12 union councils were affected and 5 casualties and 662 injuries were recorded. However, the 2011 flood end with 290,000-person affected and 1361 villages.[47]

1.5.2.3 DISTRICT KHAIRPUR

District Khairpur is located in north-eastern Sindh spread on an area of 15,910 km^2. It has a population of about 2,404,334.[48] The district constitutes eight Talukas (Khairpur, Gambat, Kingri, Sobodero, Kot Digi, Nara, Thari Mirwah and Faiz Gang) and 76 Union Councils. The district is prone to floods and droughts. Here, the heavy rain is the main cause of flooding. Khairpur was hit consecutively by 2010, 2011, 2012, 2013, 2014 and 2015 floods. These floods affected a total of 1,200,000 people and caused the deaths of 66 people. Droughts struck in the region during 2002 and in 2013-14. However, the later course brought damages and affected many districts.[49]

---

[45] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Sukkur". Available at: http://www.alhasan.com/system/files/skim-magazine/PESA-DP-Sukkur-Sindh.pdf*

[46] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[47] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Ghotki". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Ghotki-Sindh_0.pdf*

[48] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[49] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Khairpur". Available at:*

1.5.3 SHAHEED BENAZIRABAD DIVISION

Shaheed Benazirabad division has a total of three districts namely Shaheed Benazirabad, Naushahro Feroze and Sanghar. The division has a total population of 5,282,277 people.[50]

1.5.3.1 DISTRICT SHAHEED BENAZIRABAD

The district Shaheed was previously known as Nawabshah District. The total population is around 1,612,847 which cover an area of 4,618 km^2.[51] It has been administratively divided into four Talukas (Nawabshah, Sakrand, Kazi Ahmad and Daur) and 51 Union Councils. The district is prone to riverine floods as it is present on the left bank of Indus. The district was hit by 2010, 2011, 2012 and 2015 floods while the severity of 2011 floods was high. It affected 78,000 and 900,000 of the total population during 2010 and 2011 respectively.[52]

1.5.3.2 DISTRICT NAUSHAHRO FIROZE

The district covers a total area of 3,027 km^2 and has a population of about 1,612,373 people.[53] The district has five Talukas (Naushahro Feroze, Bhiria, Moro, Khandiaro, and Mehrabpur) and 51 Union Councils. The district is prone to riverine floods and its vulnerability to floods can be observed from the fact that it is situated on the left bank of River Indus. The district was hit by floods in 2010, 2011 and 2015.[54]

1.5.3.3 DISTRICT SANGHAR

District Sanghar is the largest district of Sindh and located in the center of the province. It has a population of 2,057,057 people with largest area coverage of 10,259 km^2.[55] It has been administratively divided into six Talukas (Sanghar, Sinjhoro, Khipro, Shahdadpur, Tando Adam, and Jam

---

[50] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[51] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[52] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Shaheed Benazirabad". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Shaheed%20Benazirabad.pdf*

[53] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[54] *Pakistan Emergency Situational Analysis (USAID, IMMAP). "A Profile of District Shaheed Naushahro Feroze". Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/PESA-DP-Naushahro%20Feroze-Sindh.pdf*

[55] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

Nawaz Ali) and 55 union councils. Flooding in Sanghar is not unusual phenomena instead the occurrence of floods is relatively frequent as the district in the absence of canal breaches. District Sanghar receive heavy rains during monsoon season (June-September) resulting in floods. Impacts of the flood are often local but can be devastating in case of breaches in FP bund, LBOD or river Indus combined with windy cyclones monsoon rains can be real havoc for the population.[56]

1.5.4 KARACHI DIVISION

Karachi division has been divided into six districts namely Karachi West, Karachi South, Karachi East, Karachi Central, Malir and Korangi. This division has the highest population i.e. 16,051,521 compared to all the divisions of Sindh[57] and covers an area of 3,530 km^2.

The districts are prone to both natural and human-induced disasters. Natural hazards include urban flooding, tsunami, earthquake, and cyclone, etc. The tsunami waves made flash floods that caused a huge impact on the city at periods date back to 1819, 1943 and 1945, 1946. Similarly, industrial hazards, fire, road accidents, disease outbreak, and conflict badly affected Karachi in the last two decades. The details of each district are as follows;

1.5.4.1 KARACHI CENTRAL

Karachi is based in the central part of Karachi with an estimated population of 2,971,626 people spreading over an area of 61.5 km^2.[58]

Karachi Central is prone to multiple natural and man-made hazards such as heavy rainfalls, and urban floods.

Karachi Central has a history in a number of disasters due to its mixed vulnerability. During 2011 and 2012, the area experienced high rainfall that caused destruction in many forms. Like September 2011 showers of rain sourced traffic jam, electrocution, sewerage overflow, contamination

---

[56] *Provincial Disaster Management Authority (2008). "Disaster Risk Management Plan; District Sanghar". Available at: http://www.ndma.gov.pk/plans/District%20DRM%20Plan%20Sanghar.pdf*

[57] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[58] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

of drinking water, power failure, uprooting of trees and billboards accidents in the city District.

1.5.4.2 KARACHI EAST

Karachi East is situated over an area of 165 km^2, while exhibiting total population of 2,907,467 people.[59] It is also under the risk of natural and man-made hazards such as heavy rainfalls, and urban floods.

Same disaster history is followed in East as in the Central part because overall Karachi is prone to the same hazards and disasters. However, heavy rainfalls of September 2011 caused a traffic jam, electrocution, sewerage overflow, contamination of drinking water, power failure, uprooting of trees and billboards accidents in the District.

1.5.4.3 KARACHI SOUTH

District Karachi South has an area of 84 km^2 with a population of 1,791,751 people.[60] Cyclones, heavy rainfalls, and urban floods, are prevailing hazards, faced in the region and exhibit a similar history in disasters with respect to the hazards.

1.5.4.4 KARACHI WEST

Karachi West covers an area of 630 km^2 and has a population of 3,914,757 people.[61] The district has a mixed population including Sindhi, Baloch, Punjabis, Pashtuns, and Muhajirs.

Karachi West also followed the same trend in hazards and disasters. Cyclones, heavy rainfalls, and urban floods, are commonly found hazards in the district, following similar disaster history that correspond to 2011/2012 rains.

---

[59] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[60] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[61] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

1.5.4.5 KORANGI

District Korangi has a population of 2,457,019 spreading over an idea of just 94.8 km^2.[62] It was formerly a part of East district but later got an individual identity in 2013. Sindhi people are in majority however, Baloch, Pashtun, Muhajir, Punjabi and other ethnic groups can also be found.

Furthermore, climate change has emerged a rainfall trend, particularly monsoon rains and leads to urban flooding. 2011 and 2012 rains are supporting examples of the underlying hazards and risks. However, the geographical location of the district makes it prone to earthquake and the level of a vulnerability is high but distinctly has not shown a record yet.

1.5.4.6 MALIR

District Malir has a coverage area of 2,635 km^2 and consists of a population of 2,008,901 people.[63] Malir is prone to many natural and man-made hazards such as cyclones, heavy rainfalls, urban floods, and droughts.

Heavy rains during 2011 and 2012 brought disturbance in the form of traffic jam, sewerage overflow, contamination, power breakdown, uprooting of trees and billboards and other accidents are common examples that depict the vulnerability of the district to this disaster.[64]

1.6. TECHNICAL APPROACH AND METHODOLOGY

For successful and smooth execution of the project activities, the AIT has performed the following approach and methodology.

1.6.1 FLOOD HAZARD ASSESSMENT

Sindh province historical extreme events of lower Indus basin shows that up to the year 1942, the damage and devastation through breaches or erosion was almost a regular feature. The historical record of a breach is at Jamshoro front Bund near Hyderabad in the year 1984 From then on, the tale of

---

[62] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[63] *Pakistan Bureau of Statistics, 2017. Available at: http://www.pbs.gov.pk/sites/default/files/PAKISTAN%20TEHSIL%20WISE%20FOR%20WEB%20CENSUS_2017.pdf*

[64] *Provincial Disaster Management Authority, Sindh (2017). “Organizational Capacity Assessment and Development of Capacity Enhancement Plan”.*

destruction was repeated almost every year at one or other point of the river course. In the current century when Tori and Surjani breaches occurred near Sukkur & Sujawal in the year 2010 supper flood of Lower Indus Basin were shown along with the highest recorded flood Extreme values for the respective year.

This study uses Optical satellite data and draws on the spectral reflectances within the Green and NIR (Near InfraRed) channels to calculate the NDWI (Normalized Difference Water Index). The NDWI facilitates the differentiation between water and non-water inundated areas. In the method, a threshold is derived from the NDWI to classify the image and determine the flood extent. We have identified inundated areas based on the increase in the water index value between the pre- and post-flood satellite images. Values of the Normalized Difference Water Index (NDWI) and Modified NDWI (MNDWI) will be higher in the post-flood image for flooded areas compared to the pre-flood image. Based on a threshold value, pixels corresponding to the flooded areas can be separated from non-flooded areas.

The hydrologic data series for Sukkur Barrage upstream for the period before 1940 does not represent the true flood extreme. Similarly, the data for the Gudu, Sukkur and Kotri Barrages for the period 1941 to 1974 also do not represent the real natural flood conditions as during this period a number of barrages and dams were constructed and the adjustments made for flood flows lost in breaches were based on estimators only. From 1973 onwards things appear to happen in a natural way so that 28-year period from 1973-2010 may be assumed to represent the currently existing flood regimes in the Lower Indus Basin. Extreme flood analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence using extreme maximum annual distribution of lower Indus Basin from 1956 to 2015 for the return period 200 years.

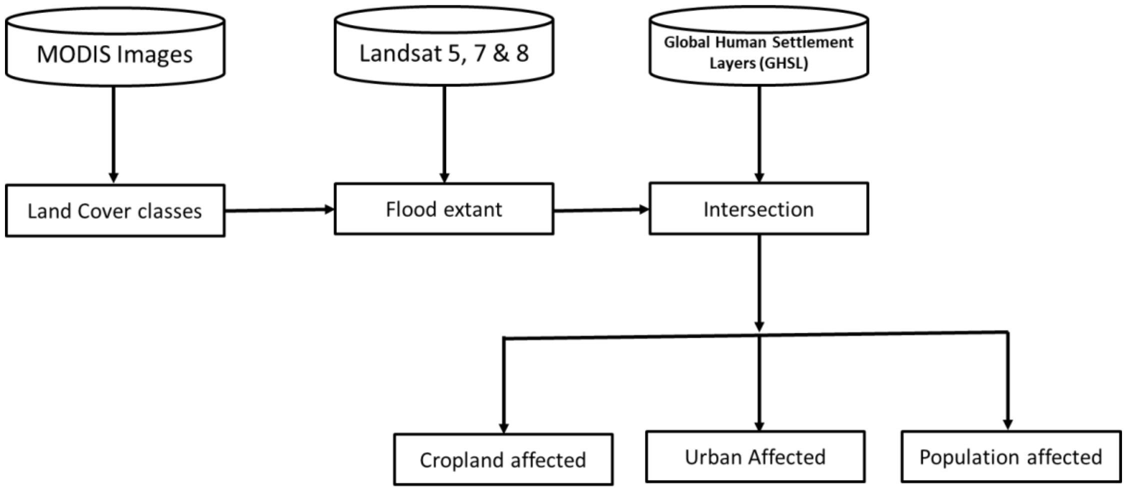


Figure 1-3 Methodology for Flood Damage Assessment

Historical super flood 2010 broke all the previous records. Flood records of Indus reveals that a flood discharge exceeding one million cusecs shown in Table 1-3Table 1-1.

Table 1-3 Extreme Super Floods of Lower Indus Basin

Barrages	Completion Year	Design Discharge cusecs	Passed Peak Discharge (D/S) million cusecs			
			1976	1986	1992	2010
Guddu	1962	1,000,000	1.176	1.172	1.069	1.148
Sukkur	1932	1,500,000	1.161	1.123	1.022	1.109
Kotri	1955	875,000	0.765	0.471	0.674	0.939

Before 1973, floods at Sukkur exceeding 0.900 million cusecs occurred in the year 1914 and 1958. A flood exceeding 0.900 million cusecs at Sukkur occurred only once before in living memory after 1914 in 1973. Extreme flows recorded at Sukkur exceeded 1.200 million cusecs on 15th August 1976, which broke all previous records on score of peak and duration.

The scale of devastation of Pakistan’s monsoon flood 2010, 1.131 million cusecs on 10th August 2010 at Sukkur Barrage surpass the devastation from the 2004 India Ocean tsunami, the 2008 north Pakistan earthquake, and 2010 Haiti earthquake combined. In July 2010, flooding caused by heavy monsoon rains began across several regions of Pakistan. The floods have affected about one-fifth of this country of more than 170 million. Tens of thousands of villages have been flooded, more than 1500 people have been killed, and millions have been left homeless.

Therefore, it is felt urgent and essential to manage, design and reduce the disaster risk in floods scenarios to carry out a comparative Extreme flood analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence using extreme maximum annual distribution of lower Indus Basin from 1956 to 2015 for the return period 200 years.

Flood frequency is the concept of the probable frequency of occurrence of a given flood. For the design of engineering works, for example, it is not enough to say that the maximum observed flood was, say, X cusecs, it is also necessary to say what is the frequency of occurrence of this flood.

If the X Cusecs flood referred to above is a size that occurs on average once in every N year, then for instance any bridge designed to cope with this would be under designed by most sensible standards, and we could expect that it might not last very long. Normally the design problem is an economic one, involving the capital and ongoing costs of a conservatively large structure versus the greater risk of loss of a smaller and cheaper one.

As well as engineering works like bridges, dams, etc. flood frequency information is commonly applied to controlling land use and settlement on flood-prone areas and has many other applications.

There are several ways of describing flood frequency, all using statistical probability.

Assigning return periods to floods was traditionally used but is an unhelpful term when trying to explain its meaning to the public and others. An example of a return period is when a flood has a 1 % probability of occurring each year (i.e. 1 chance in 100) and is thus described as a 100-year flood event. This term suggests the common but mistaken notion that there should be an interval of 100 years between such events. In fact, the probability of having two 100-year floods within 10 years is almost 10 %.

The annual exceedance probability (AEP) is also used. This is simply the probability that a flood size will occur in any given year. As for the example above, the 100-year flood will have an AEP of 1 % (or 1 chance in 100). Explaining the probability to the public in this way is usually better.

The probable maximum flood (PMF) concept is sometimes used for engineering applications. Again, this is like the above two methods, and often uses the 100-year / 1 % probability, as many designs are based on this. However, PMF also implies a lower probability than 1 %, and values as low as 0.1 % will be used for some applications. Trying to derive a PMF is usually very risky unless there is a very long record.

For the purposes of this study we will use return period, but also use annual exceedance probability, as this is the reciprocal of return period and the two terms are thus simple to relate.

In this study a four different types of Extreme value distribution models will discussed,

- Gumbel Extreme Value Type-I
- Pearson Type-III
- Log Pearson Type-III
- Log Normal

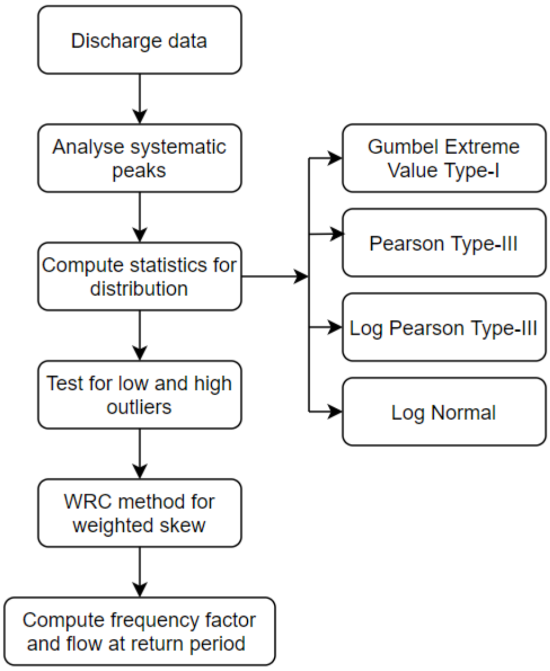


Figure 1-4 Flow Diagram of the Flood Frequency Analysis Methodology

Computational process involved in following steps,

- Rearrange the extreme flood values in ascending order from high to low flood values.
- Rank (m) them all the flood values from maximum to minimum.
- Compute the Recurrence Interval (T) using Weibull Equation, T= (n+1) / m.
- Compute Probability P= (1/T) x 100.
- Computation for Statistical Parameters of the mean value, Standard Deviation, and Coefficient of Skew (Csy)
- Computation for Extreme value Distribution Models
- Calculate the Extreme value of occurrence for different return periods from 20 to 200 years.
- Plot the Graph b/w x_T v/s T where x_T = Probable Discharge for the Return Period T.

This task will focus on the development of a flood model for flood forecast in the Lower Indus basin using satellite remote sensing data and hydro-meteorological parameters for the study area.

Flood hazard mapping will include determining the extent and intensity of floods for various return periods for assessing the active flood-prone areas over the project area; flood modeling to identify hot spots for flood hazards using remote sensing techniques.

1.6.2 DROUGHT HAZARD ASSESSMENT

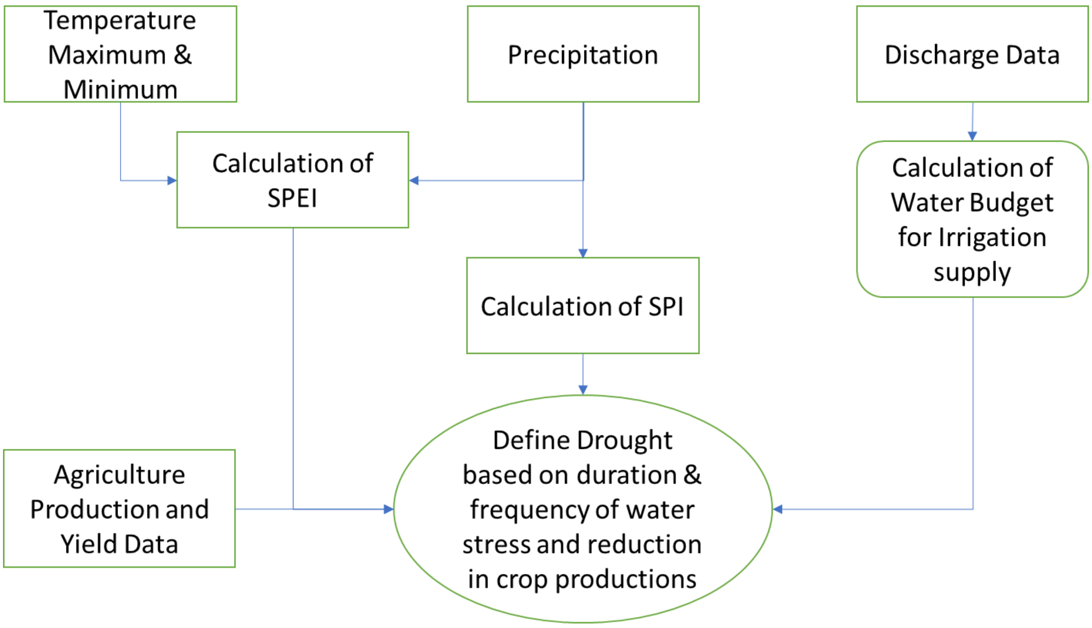


Figure 1-5 Overall Methodology of Drought Assessment

There are four major classes of types of droughts;

1.6.2.1 METEOROLOGICAL DROUGHT

Meteorological drought is defined by the degree of dryness compared to a normal or average amount and the dry period duration. Meteorological drought concepts must be region-specific, as the atmospheric conditions resulting in precipitation deficits are extremely region-specific. The variety of meteorological definitions in different countries illustrates why it is not possible to apply a definition of drought developed in one part of the world to another. The indices SPI (Standardized Precipitation Index), and SPEI (Standardized Precipitation Evapotranspiration Index) are commonly used to identify drought. These drought indices SPI and SPEI are calculated based only on meteorological variable such as precipitation and Temperature. While SPI only takes into account precipitation data, SPEI is drought index also takes into account temperature data for the calculation of potential evapotranspiration. They both basically fit probability distribution calculated as the difference between rainfall and potential evapotranspiration in order to obtain a climatic water balance which is then used to obtain positive and negative of SPI and SPEI values through three probability distribution functions. SPEI is a very useful drought index because it also takes into account temperature, so the areas with higher temperatures better represent the drought figure by adding temperature as drought calculation parameter along with precipitation. Like in SPI calculation, SPEI can also be calculated over various time scales such as shorter timescales of 1-, 3-, 6-month scales and also for longer timescales of 9, 12, 18, 24, 36, 48 month and even more. For short term drought assessment SPI and SPEI 3, and 6 are generally used, and for long term SPI and SPEI of 9 and 12 are used.

1.6.2.2 HYDROLOGICAL DROUGHT

Hydrological drought relates to a persistently low runoff and water volume in streams and reservoirs that last months or years. Hydrological drought is a naturally occurring phenomenon, but human activities may exacerbate it. The severity and frequency of hydrological droughts may be affected by changes in land use and land degradation. Barrage storage and flow in the Indus river has been take in account to classify the hydrological drought.

1.6.2.3 AGRICULTURAL DROUGHT

The demand for plant water depends on prevailing weather conditions, the particular plant's biological characteristics, its growth stage, and the soil's physical and biological properties. A clear definition of agricultural drought must take into account crop susceptibility to water shortage and moisture deficit during various stages of crop development. Deficient topsoil moisture during planting can impede germination, resulting in low plant populations per hectare and reduced yield. This type of drought occurs due to water scarcity and that lead to reduce in crop production. In our study we will identify the key water stress event base on meteorological drought and hydrological drought and for the event we had analysis the relation in reduction of production and cropping area for the drought duration.

1.6.2.4 SOCIOECONOMIC DROUGHT

Drought socioeconomic concepts combine the supply and demand of certain economic products with meteorological, hydrological and agricultural drought elements. If the need for water for economic activities greatly exceeds the availability, socioeconomic drought is likely to be increased to greater extent.

1.6.2.5 SOCIO-ECONOMIC IMPACTS

The historic data of impacts associated with various intensity/frequency floods and droughts will be collected from the government departments. The affected areas will be visited for ground trothing of the collected data. The damages will be segregated in crops, population and infrastructures and a damage frequency curve will be prepared. Furthermore, scenarios will be formulated showing the impacts/damage potential of various intensity/frequency floods and droughts in the Sindh province.

1.7. DATA COLLECTION AND TREND ANALYSIS

In the Sindh province three following agencies are monitoring the hydro-meteorological data:

- Pakistan Meteorological Department (PMD)
- Surface Water Hydrology Project (SWHP) of WAPDA
- Sindh Irrigation Department (SID)

In the first step, climatic stations and river gauging stations will be identified in whole province, using the available information of previous projects and liaisons with the above-mentioned departments. The data of identified hydrometric network will be collected and arranged in the standard formats as per the Client’s requirement.

The trends in the data will be analyzed for the consistency and homogeneity of the data and to sort out the dry and wet spells, to define extent of climatic anomalies and to define frequency and intensity of droughts based on existing hydro- meteorological regime. Prior to trend analysis, the authenticity of data was checked for consistency and homogeneity. Various statistical and numerical tests will be carried out i.e. F-test, T-test, and double mass curve analyses. The consistent data will be recommended for planning pertains to the hazards associated with floods and droughts, whereas the data gaps will also be identified, and data gaps may be filled with the correlation and using satellite data sets (TRMM & RFE).

1.7.1 DATA OBTAINED FROM PAKISTAN METEOROLOGICAL DEPARTMENT

The Pakistan Meteorological Department, at the time of its establishment in 1947, inherited only 15 Meteorological Observatories (8 in East Pakistan and 7 in West Pakistan) from the Central Meteorological Organization then operating In the Subcontinent The Department with Its continuous efforts has expanded the network of meteorological observatories, developing methods of observation, improving telecommunication facilities and improved forecasting technique. Apart from meteorology, the department is also extending services in the fields of Hydrology, Earthquake Seismology and Geomagnetism operates under World Meteorological Organization (WMO) umbrella as 198 member states of the world and act as National Meteorological and Hydrological Service of Pakistan has divided the globe into 8 meteorological regions and Pakistan lies in Region #2 known as Regional Association (R A-O which includes Asia and Pacific; Director-General of PMD is vice president of R A -n and Permanent Representative of Pakistan. The major achievements of the Department are the introduction of modern flood prediction system, computerized weather forecasting system, earthquake, and nuclear explosion detection system, incorporating radar, satellite, information technology, flight safety, In the seismic design of dams, buildings and other development and disaster relief scheme The Department has also played a vital role in research work and its scientists have made valuable contribution More than 350 scientific papers have been written and published in both national and international scientific Major emphasis in the research has been laid on the field of climate change, Glaciology, renewable energy, arid zone research, ozone measurements, drought monitoring, Climate Modeling, Monsoon onset, solar energy, wind power potential, satellite meteorology and allied Many of the Research Organizations such as Arid Zone Research Institute (AZRI), Space and Upper Atmospheric Research Corporation (SLIP ARCO), and Pakistan Atomic Energy Commission (PA EC) staffed their functioning with the initial assistance of the

Pakistan Meteorological Department Meteorological services are extended on regular basis to Civil Aviation Authority (CAA), Federal Flood Commission (FFC), Pakistan Agriculture Research Council (PARC), National Disaster Management Authority NDMA), Climate Change Division, and Ministry of Religious Affairs.

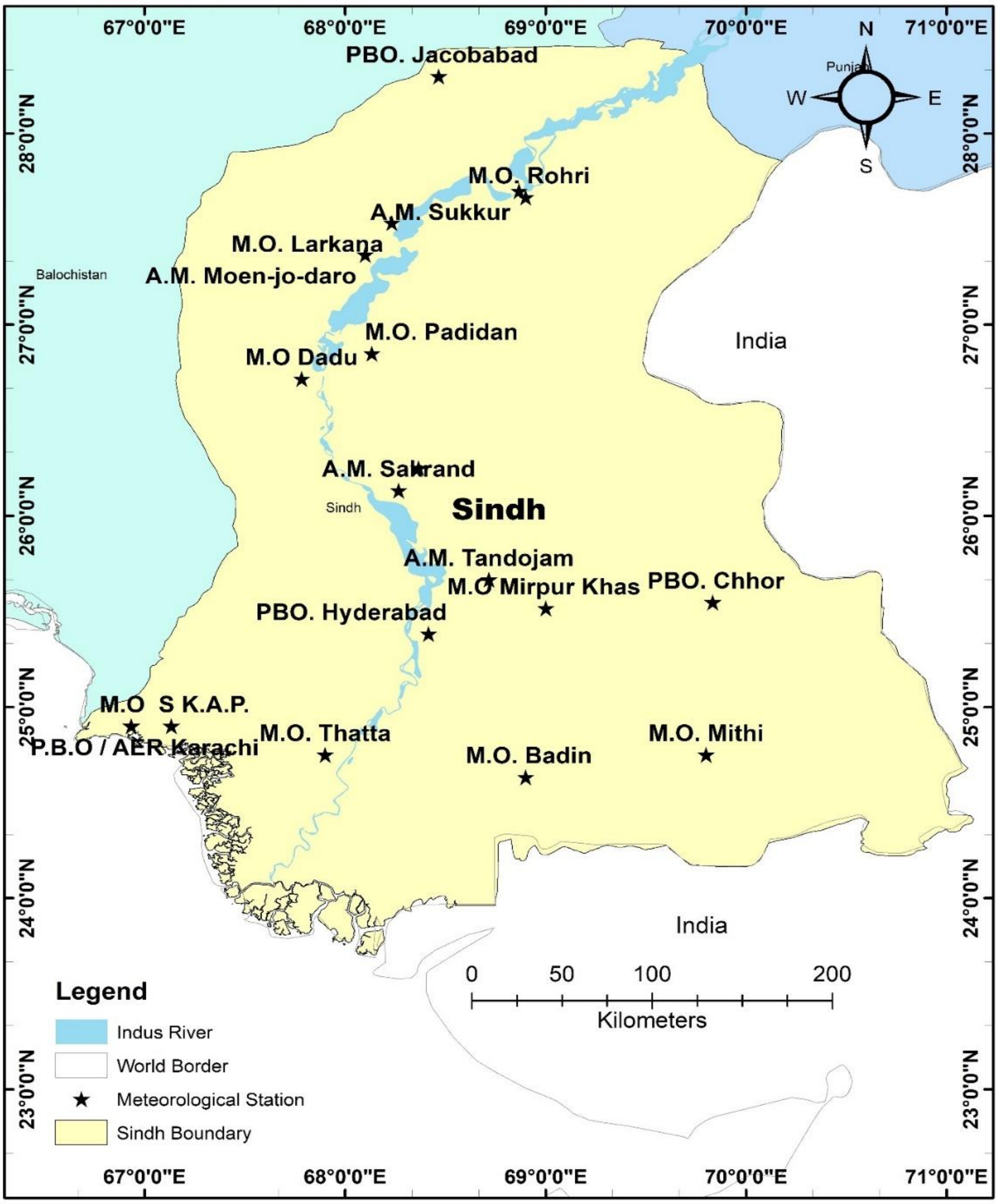


Figure 1-6 Location of PMD Stations in Sindh Province

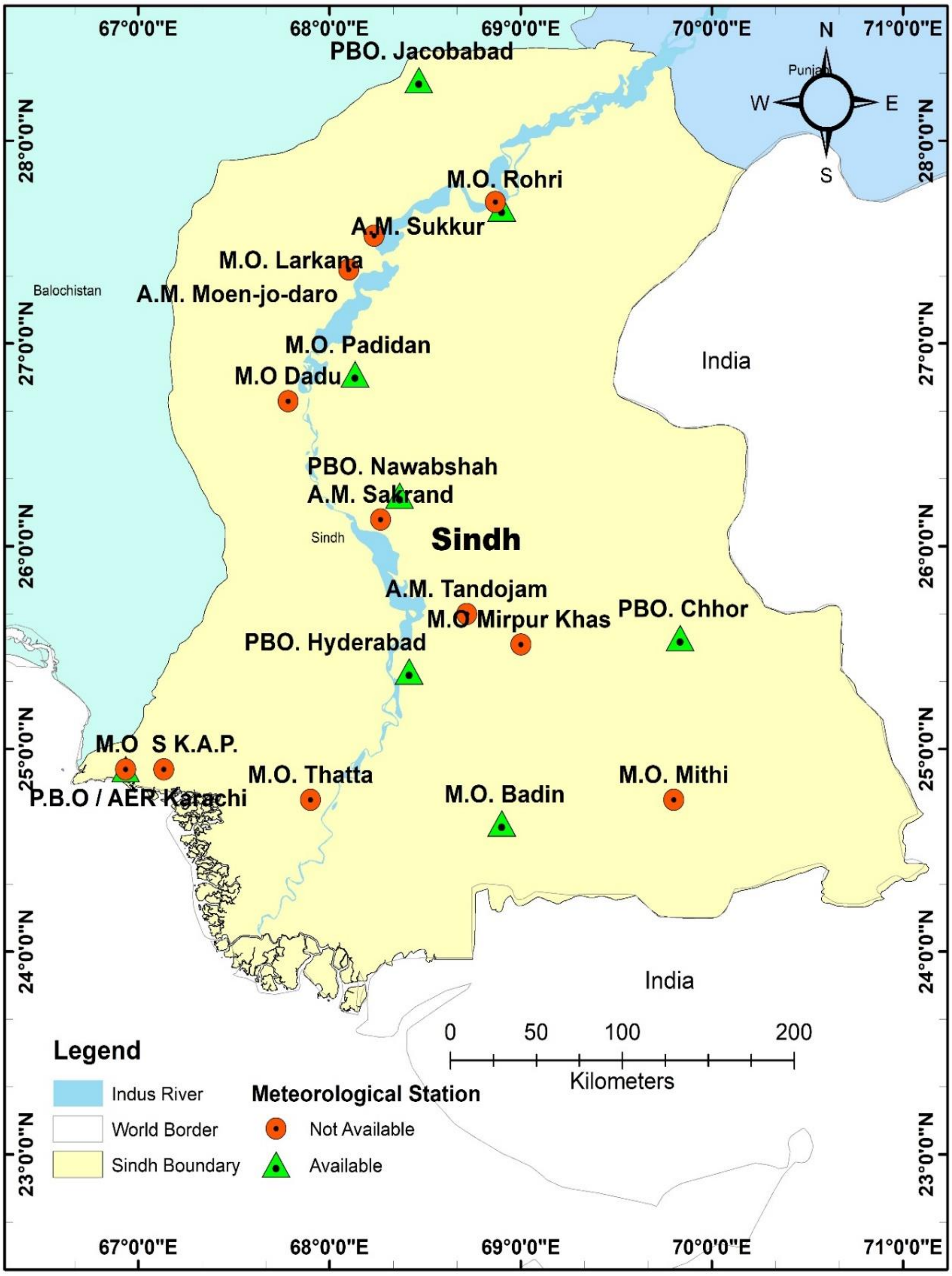


Figure 1-7 Map of Data Collected for PMD Stations

Table 1-4 List of PMD Meteorological Data Collected

S. No.	Index No.	Name of Station	Tmax	Tmin	Rainfall
1	41685	PBO. Chhor	1988-2017	1988-2017	1988-2017
2	41764	PBO. Hyderabad	1988-2017	1988-2017	1988-2017
3	41715	PBO. Jacobabad	1988-2017	1988-2018	1988-2017
4	41749	Nawabshah	1988-2017	1988-2018	1988-2017
5	41785	M.O. Badin	1988-2017	1988-2018	1988-2017
6	41746	M.O. Padidan	1988-2017	1988-2018	1988-2017
7	41725	M.O. Rohri	1988-2017	1988-2018	1988-2017
8	--	AER Karachi	1988-2017	1988-2018	1988-2017

1.7.2 DATA OBTAINED THROUGH APHRODITE

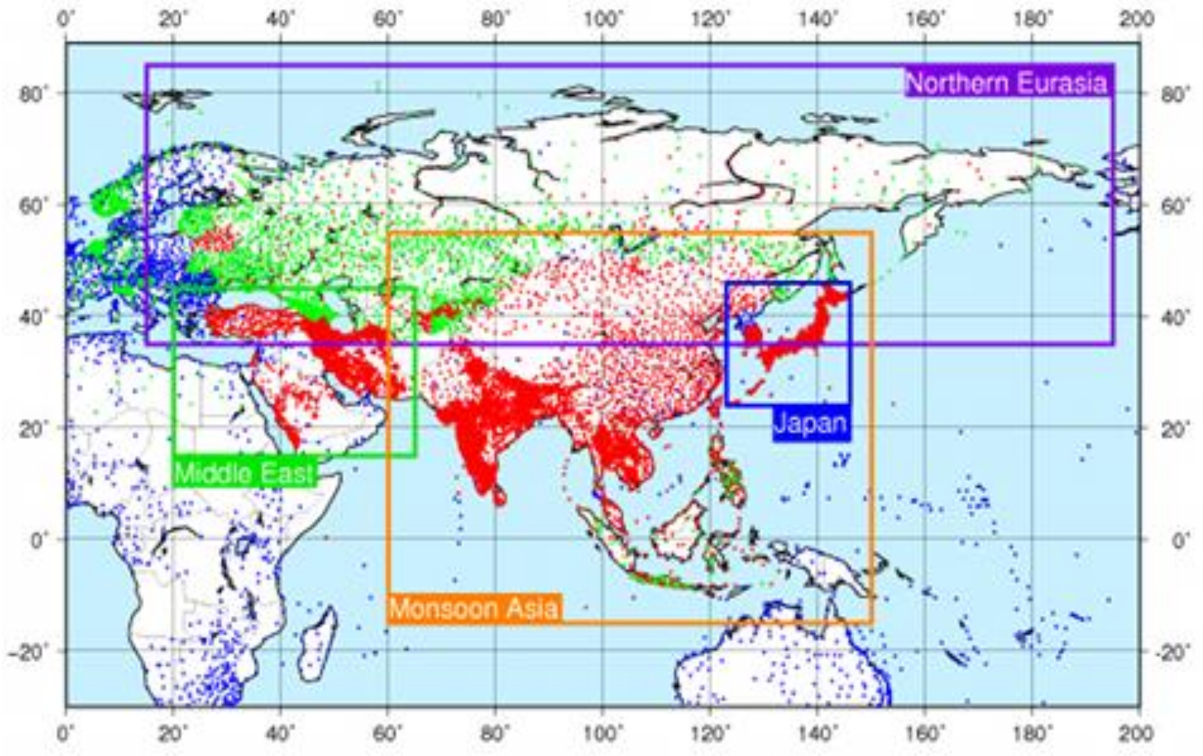


Figure 1-8 APHRODITE Stations.

Source: http://www.chikyu.ac.jp/precip/product

APHRODITE's (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation) daily gridded precipitation is the only long-term (1951 onward) continental-scale daily product that contains a dense network of daily rain-gauge data for Asia including the Himalayas, South and

Southeast Asia and mountainous areas in the Middle East. The number of valid stations was between 5000 and 12,000, representing 2.3 to 4.5 times the data available through the Global Telecommunication System network, which was used for most daily grid precipitation products. The products are available on a regional basis. We have downloaded all available datasets and extract all data of precipitation for Sindh province. Which is shown in figure 1.9.

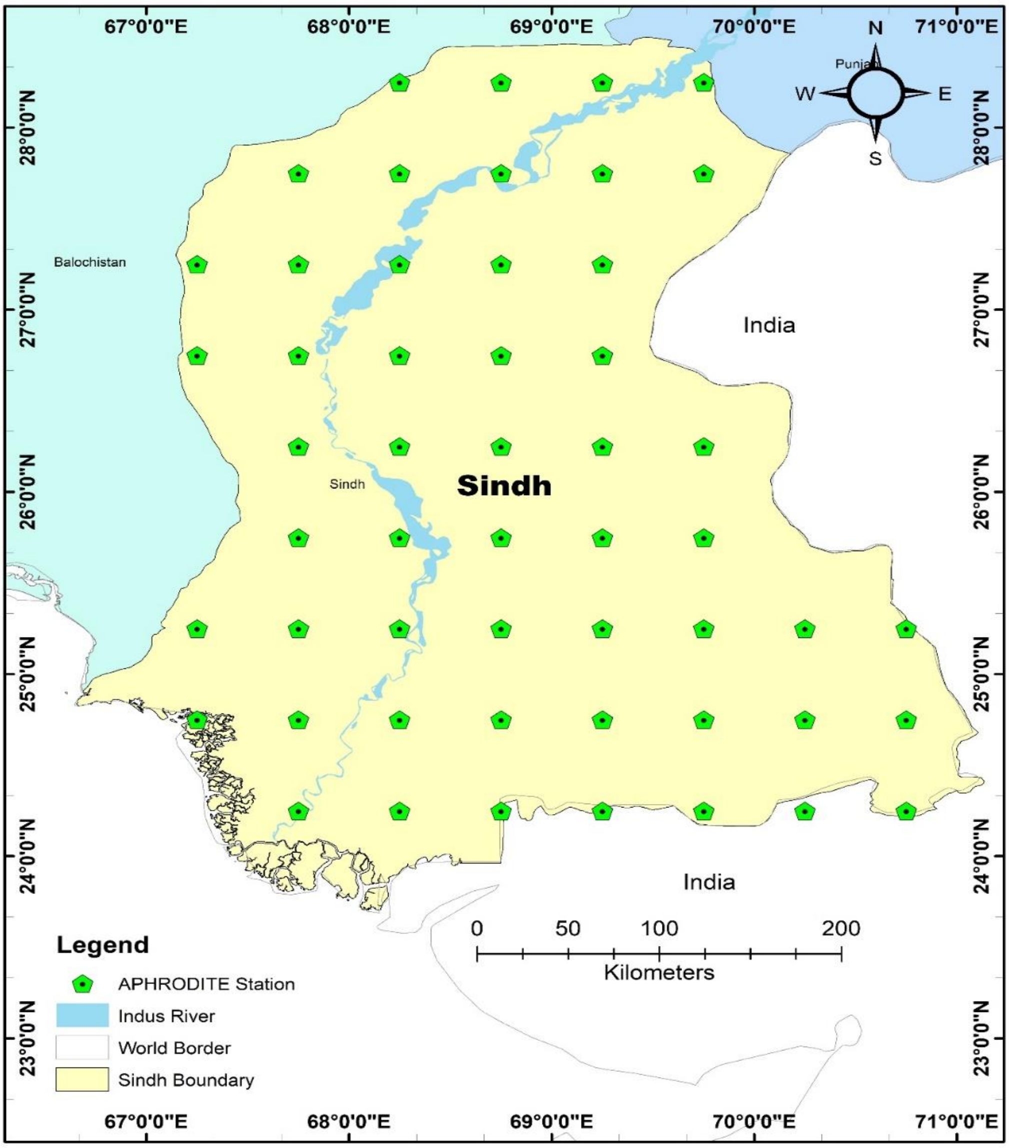


Figure 1-9 Location of APHRODITE Stations in Sindh

1.7.3 OBTAINED HYDROLOGICAL DATA

Irrigation System Network Irrigation is critical for agriculture in Sindh, as the contribution of rain towards crop water requirements is negligible. Canal water diverted from the Indus is the primary source of irrigation water, followed by groundwater pumping. River water is diverted at three barrages – Guddu (commissioned 1962), Sukkur (1932) and Kotri (1955). It is then conveyed in 14 main canals to service a total design area of about 5.1 million hectares (Mha). The actual irrigated area varies depending on the amount of available water, with an average of 3.8 Mha. The diversion capacity of the canals off-taking from Guddu Barrage is 45,000 ft3/s; from Sukkur Barrage, it is 58,000 ft3/s; and from Kotri Barrage, it 35,000 ft3/s. The total design diversion is therefore138,000 ft3/s. But, the actual diversions and flows in the canals are reportedly at least 30-40% higher, which has become necessary because of the increased cropping intensity and the cultivation of high water-consuming crops such as rice and sugarcane. Also, the canal conveyance losses have increased in the earth canals.

Almost 50% of the design service area, amounting to 2.4 Mha, does not have land drainage facilities. This is a serious constraint to crop production since much of the agricultural land is flat with low natural drainage. The flat topography combined with high water losses at farm and excessive canal seepage have resulted in extreme water logging and salinity. Close to 30% of irrigated land is now salt affected, and salinity poses a serious threat to the sustainability of irrigated agriculture in Sindh (FAO, 2003; Habib, 2011).

Controlling water logging and salinity will substantially increase crop yields and crop production and as such should receive investment priority in the irrigation sector. Prior to all, the problems of high irrigation duties and unscheduled supplies should be resolved, as it makes no sense to invest in drainage if its main purpose is to remove excess water from high irrigation duties.

There are three barrages in Sindh province, who feed the whole province along with groundwater abstraction to fulfill the agricultural, industrial, domestics, etc. demands in the province. Various details of the irrigation network of Sindh province is discussed as under.

1.7.3.1 GUDDU BARRAGE

It is the uppermost barrage in Sindh which was constructed in 1962 and commands an area of 0.88 million hectares through two canals on the right bank (Desert Pat Feeder and Begari Sindh Feeder) and one on the left bank (Ghotki Feeder). The diversion capacity of the canals off-taking from Guddu Barrage is 1,281 m3/s (45, 232 cubic feet per sec [cusecs]). The present discharges carried by the system are 24% higher than designed. The Desert Pat Feeder also carries the share of the Pat Feeder canal in Balochistan province. Areas cultivated through Guddu barrage mainly are Kashmore, Shikarpur, Jacobabad, Sukkur, Khairpur, etc.

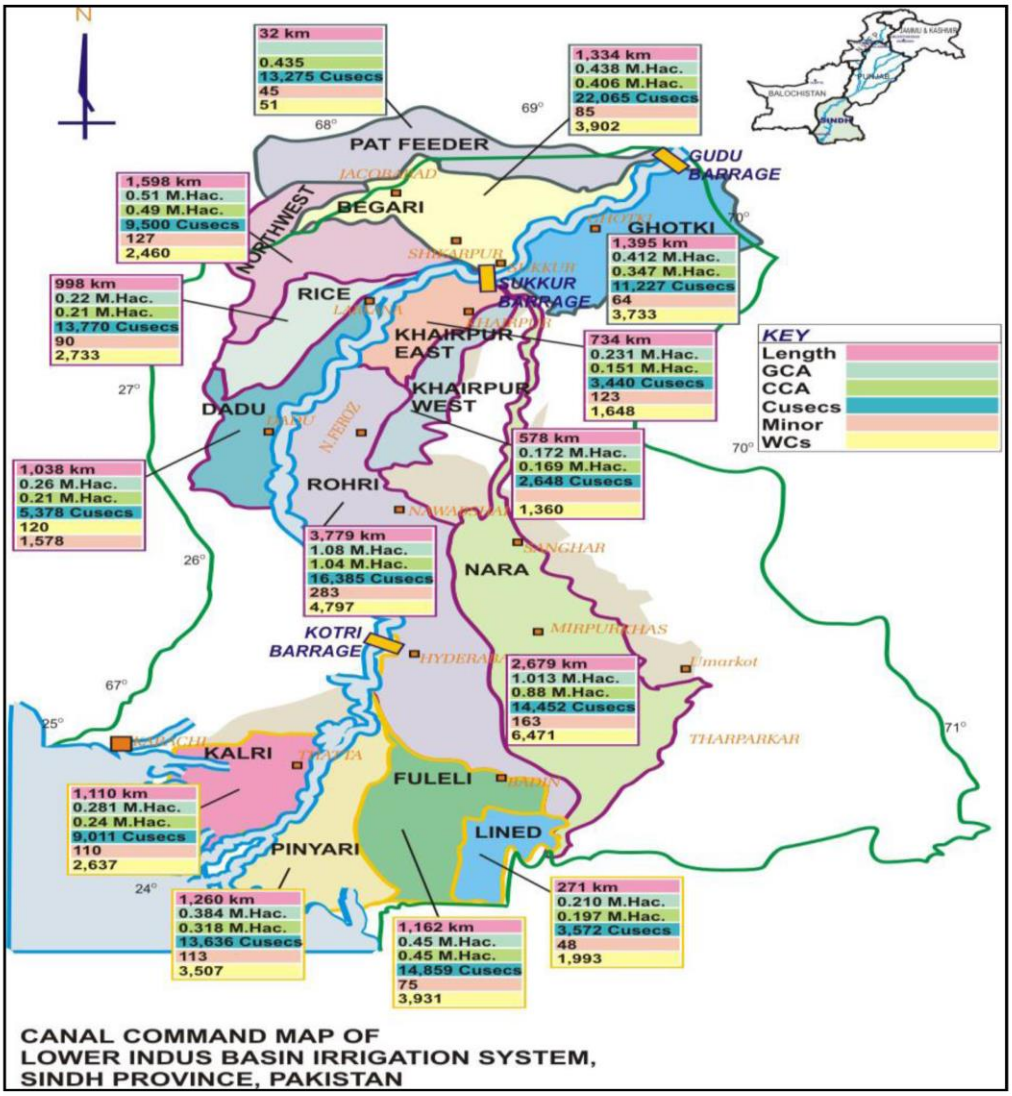


Figure 1-10 Irrigation Network in Sindh (Source Sindh Irrigation Department)

1.7.3.2 SUKKUR BARRAGE

It was constructed in 1932 and commands one of the largest irrigation networks in the world. The combined diversion capacity of this barrage is 1,642 m3/s (57,978 cusecs). It commands an area of about 3 million hectares through North Western, Rice and Dadu Canals on the right bank and Nara, Rohri, Khairpur Feeder East and Khairpur Feeder West on the left bank. This is the oldest barrage of the Sindh province, and having the largest command area as compared to the other barrages in the province.

Currently, the Sukkur Barrage system is operating at 22% higher discharge than designed.

1.7.3.3 KOTRI BARRAGE

It was constructed in 1955 commands an area of 1.17 million hectares and withdraws 991.5 m3/s (35,000 cusecs) of water into its canals. It is the last barrage constructed on the river Indus. Kotri Barrage irrigates through Fuleli, Pinyari and Akram Wah on the left bank and connects to Kalri Lake through Kalri Baghar Feeder for providing drinking water for Karachi. Areas irrigated through the Kotri barrage are Badin, Thatta, Tando Mohammad Khan, Sujawal, Hyderabad, Jamshoro, etc.

1.7.3.4 COLLECTED DISCHARGE DATA FOR THE BARRAGES

We have collected 18 discharge station in the mainstream of Indus river and diversion from barrages for irrigation and water supply in Sindh province. There are three main barrages with a daily observation of inflow into and outflow from the barrage. We also collected canal diversion data from the majority from 2010 to 2019 (Table 1-5).

Table 1-5 Flow Data Collected for Barrages

Index No.	Barrage	Name of Station	Year	Time series	Location
1	Kotri Barrage	Kotri Barrage	2011-2019	Daily	Upstream-Downstream
2	Kotri Barrage	K. B	2011-2019	Daily	K. B
3	Kotri Barrage	Akram W	2011-2019	Daily	Akram W
4	Kotri Barrage	Pinyari	2011-2019	Daily	Pinyari
5	Kotri Barrage	N Fuleli	2011-2019	Daily	N Fuleli
6	Guddu Barrage	Guddu Barrage	1985-2019	Daily	Guddu Barrage
7	Guddu Barrage	Rainee	2019	Daily	Rainee
8	Guddu Barrage	Beghari	1985-2019	Daily	Beghari
9	Guddu Barrage	Desert	1985-2019	Daily	Desert
10	Guddu Barrage	Ghotki	1985-2019	Daily	Ghotki
11	Sukkur Barrage	Sukkur Barrage	2010-2019	Daily	Upstream-Downstream
12	Sukkur Right Canals	NW	2010-2019	Daily	NW
13	Sukkur Right Canals	Rice	2010-2019	Daily	Rice
14	Sukkur Right Canals	Dadu	2010-2019	Daily	Dadu
15	Sukkur Left Canals	Nara	2010-2019	Daily	Nara
16	Sukkur Left Canals	KhpurE	2010-2019	Daily	KhpurE
17	Sukkur Left Canals	Rohri	2010-2019	Daily	Rohri
18	Sukkur Left Canals	KhpurW	2010-2019	Daily	KhpurW

1.7.4 OBTAINED TOPOGRAPHICAL DATA AND ELEVATION DATA

The topography and elevation are extracted from the various tiles of SRTM (Shuttle Radar Topographic Model) data of NASA (see Figure 1-11). The horizontal resolution is this dataset on 30 meters.

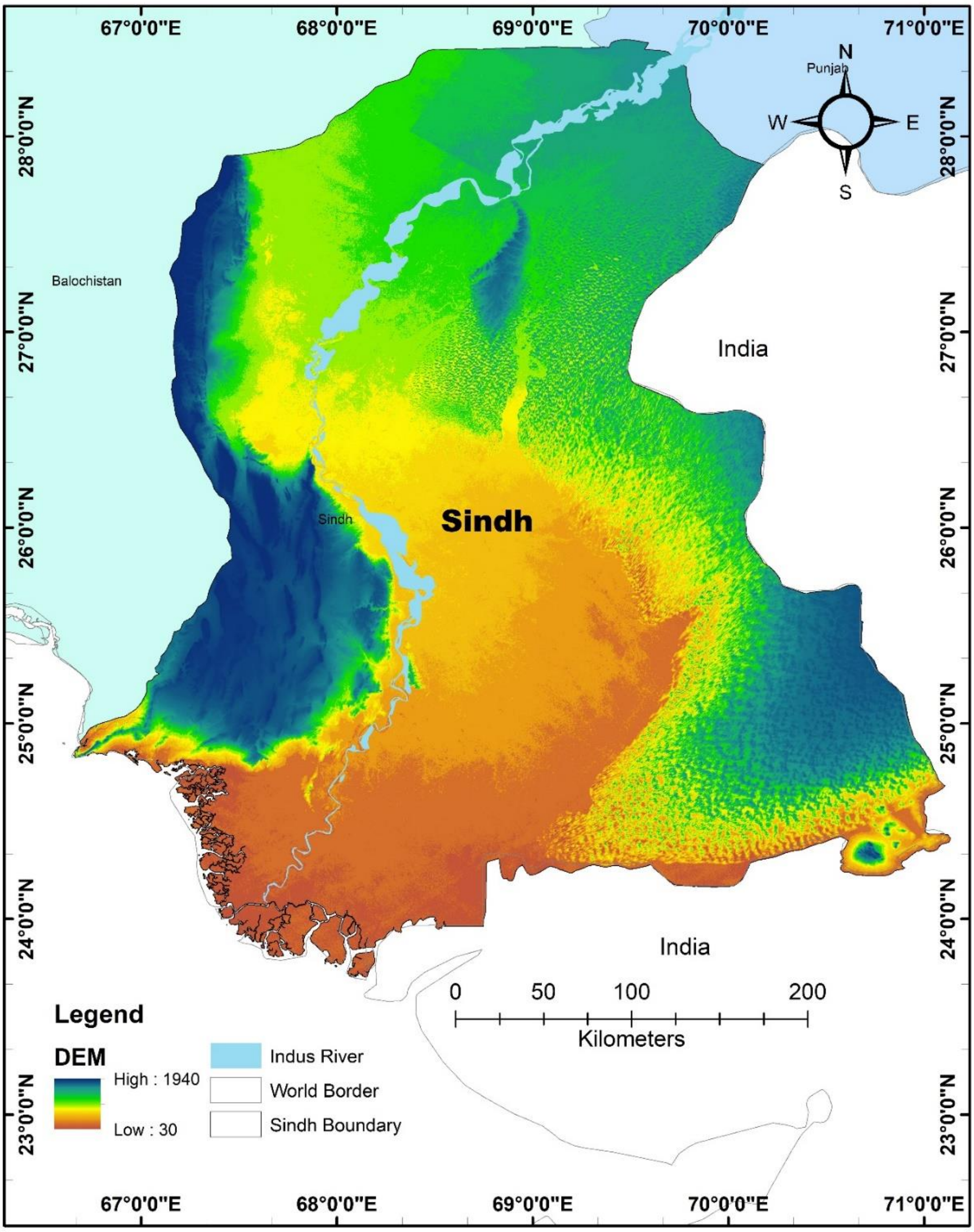


Figure 1-11 Elevation Maps of the Sindh Province

1.7.5 OBTAINED AGRICULTURAL DATA AND SOIL DATA

Data on soil texture, depth of soil layers, water content at saturation, hydraulic conductivity, permanent wilting point, soil field capacity is also needed. These data were obtained from the Pakistan Department of Soil Survey, FAO global datasets, etc. For some features data was unavailable, for that purpose global source as well soilgrids.org was used to get information data about the study area, and. Soil layer data was obtained through global datasets and the local study area information. Figure 1-12 shows the special distribution of soil. Soil data along with its various parameters and soil layers with depth etc.

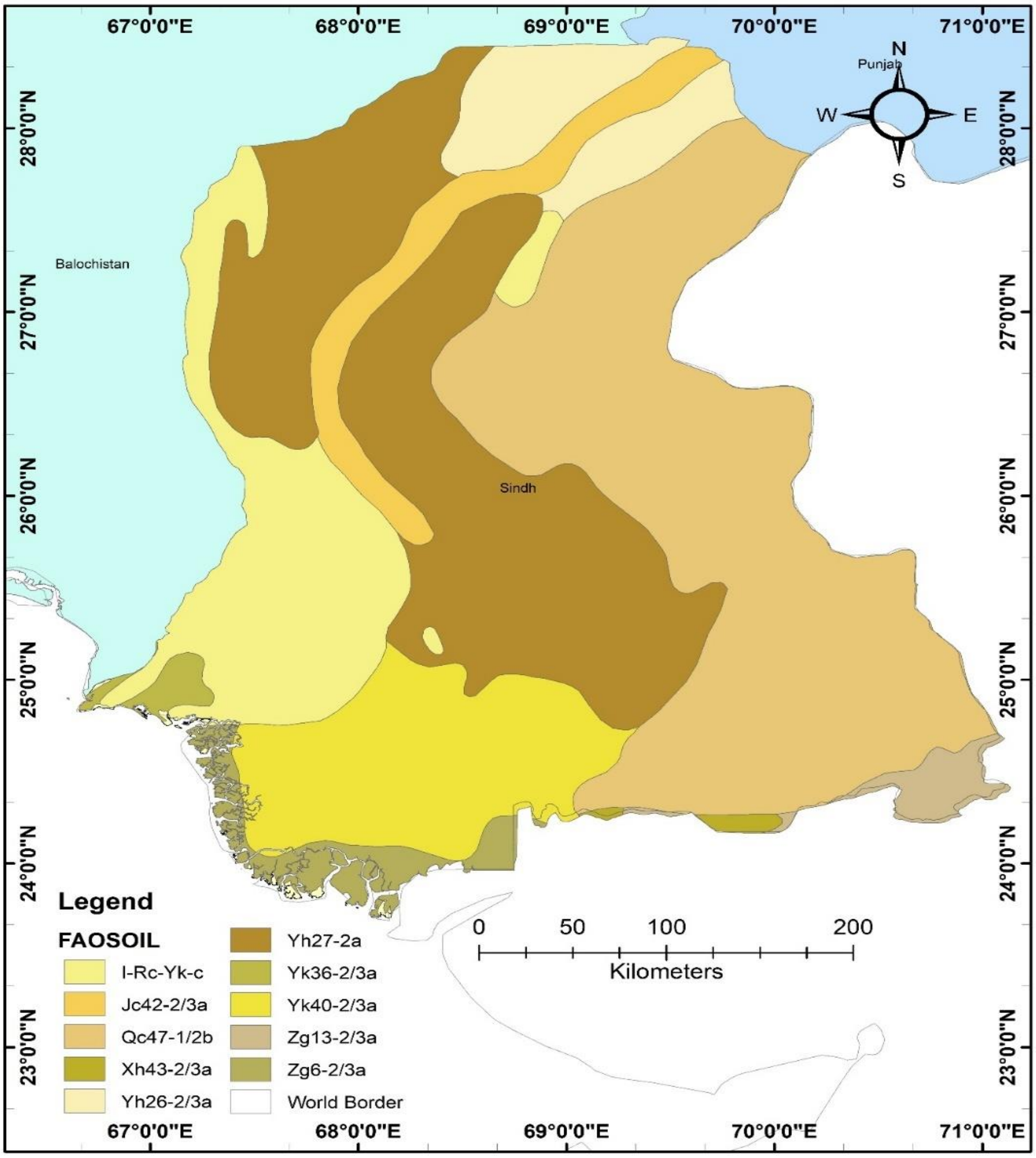


Figure 1-12 Soil Map of Sindh (Source: FAO)

2. SPATIO-TEMPORAL VARIATION

The hydrometeorological situation in the Sindh province can be described with the local meteorological situation, combined with the hydrological situation of the Indus River coming from upstream (inflow at Taunsa and Panjnand) and flowing through the Sindh. Combined, these situations describe the hydrometeorological situation of the Sindh province, and are responsible for the flooding and the drought situation in the Sindh.

This chapter gives an overview of the average situation of both meteorological and hydrological situation of the Sindh province. This average should be considered as a baseline condition. The next chapters will describe the specific hydrological and meteorological events leading to the drought and flood challenges.

2.1. LAND COVER DYNAMICS

The CCI-LC project (https://www.esa-landcover-cci.org/) delivers global land cover maps at 300m spatial resolution. These maps are used to analyse the land use for years 2010, 2015, the major finding from this analysis show Cropland increased from 33% to 42%. Furthermore tree cover and shurb cover are also increasing in this area (Figure 2-1, Figure 2-2 and Figure 2-3). But reduction in Mosaic natural vegetation, Shrubland and Baran Land is clearly seen.

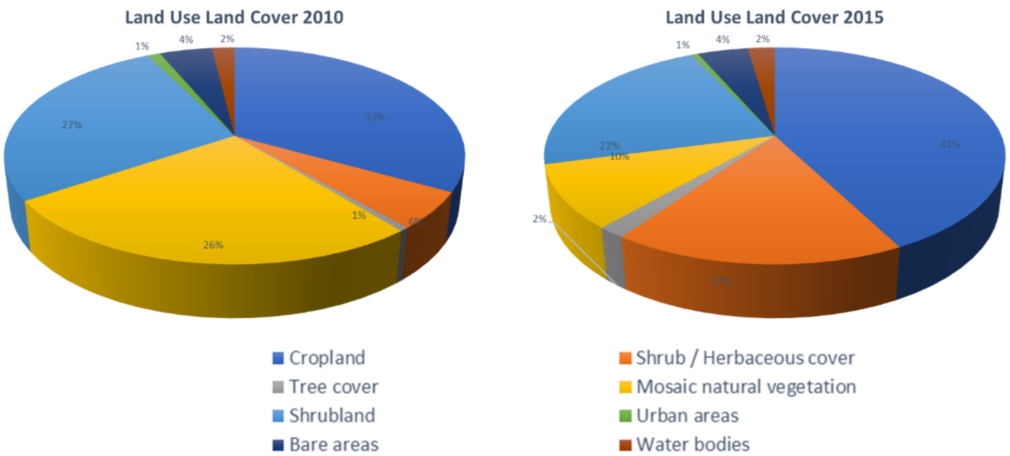


Figure 2-1 Land Cover of 2010 and 2015 of Sindh Province

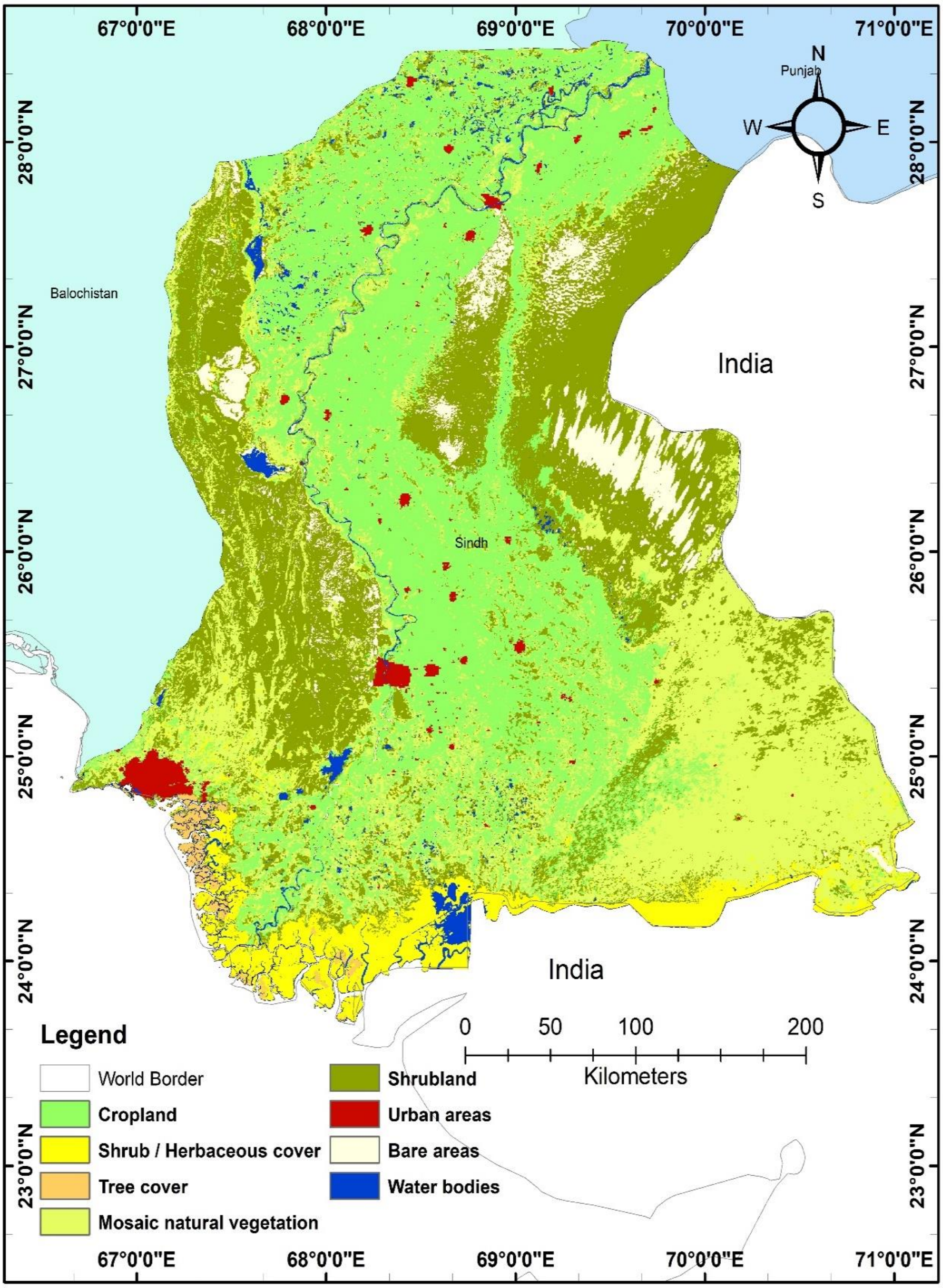


Figure 2-2 Land Cover Map of 2010

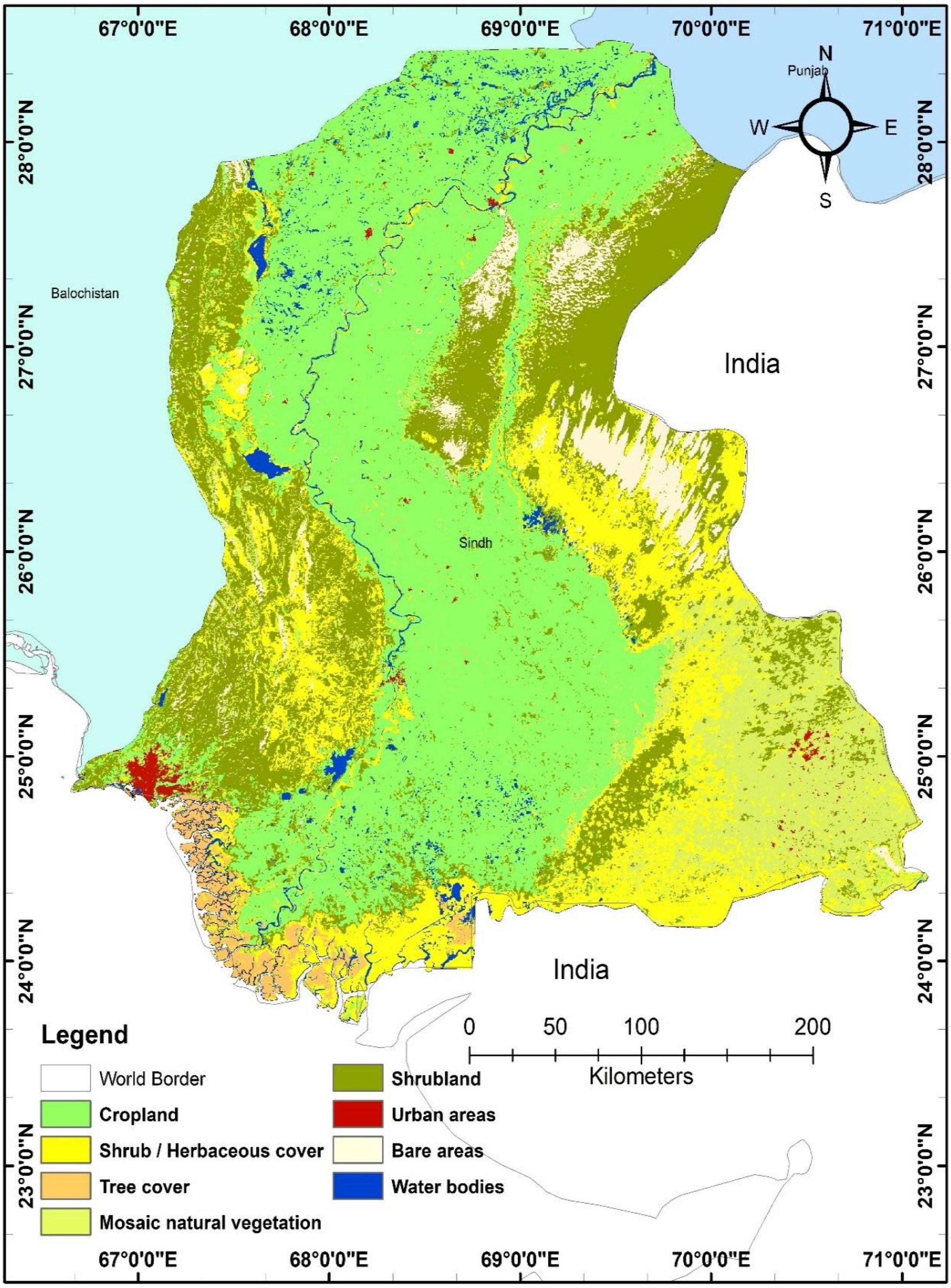


Figure 2-3 Land Cover Map of 2015

2.2. METEOROLOGICAL BASELINE SITUATION

The meteorological situation in the Sindh can be constructed from the long-term precipitation and temperature datasets for the Sindh. These datasets are available as the observed data obtained from Pakistan Meteorological Department (PMD), European Centre for Medium-Range Weather Forecasts (ECMWF) and the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) datasets for precipitation and the PMD observed data for temperature. The total yearly precipitation is given in Figure 2-4. An overview of the precipitation data as obtained form PMD is given in Figure 2-6. An overview of daily maximum and minimum temperature data is given in Figure 2-7.

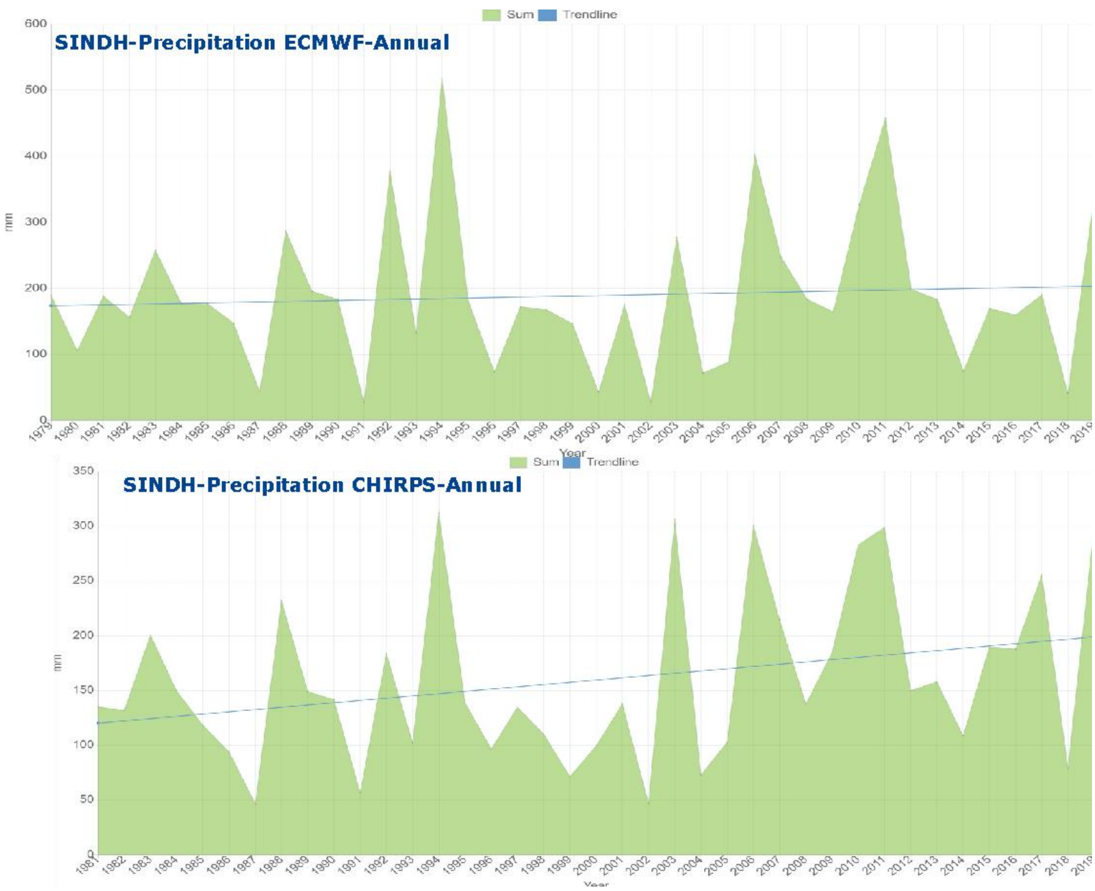


Figure 2-4 Yearly Total Precipitation

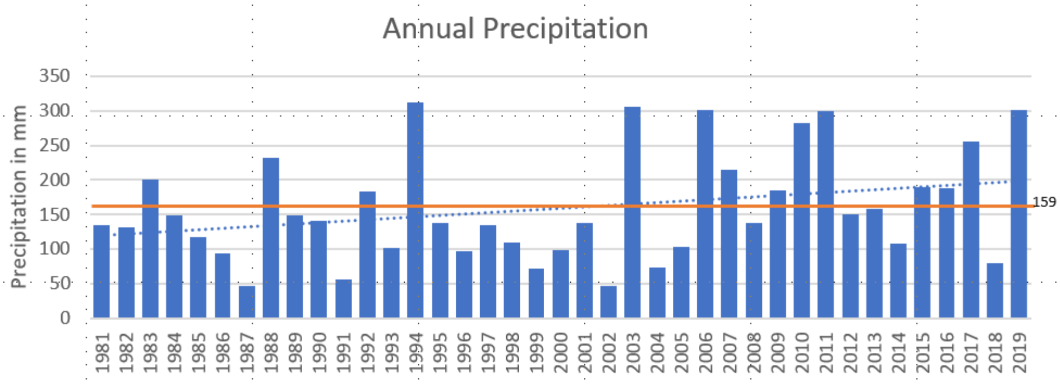


Figure 2-5 Annual Precipitation

For the baseline period 1981-2020, total annual rainfall and average monthly rainfall was calculated for all the stations in the province. It can be observed that the average annual precipitation of the Sindh is 159 mm and the trend of total annual precipitation is showing rising trend of 2 mm per year. The months of May and June are generally named as a pre-monsoon period, the duration from October to November as a post-monsoon period. the maximum precipitation occurs in the monsoon season that is July to September and contributes to about 72 to 84 % of the total precipitation. As shown in Figure 2-6.

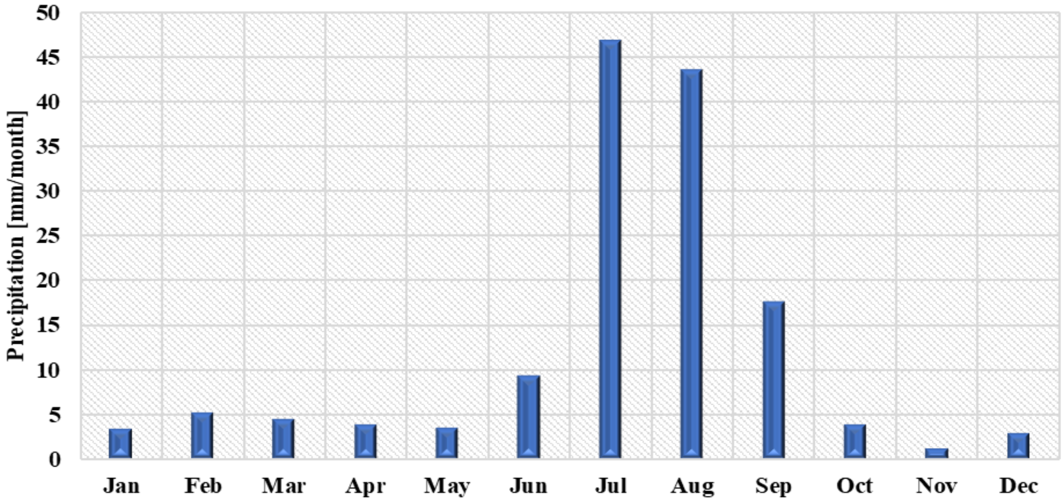


Figure 2-6 Average Monthly Precipitation (1981-2018)

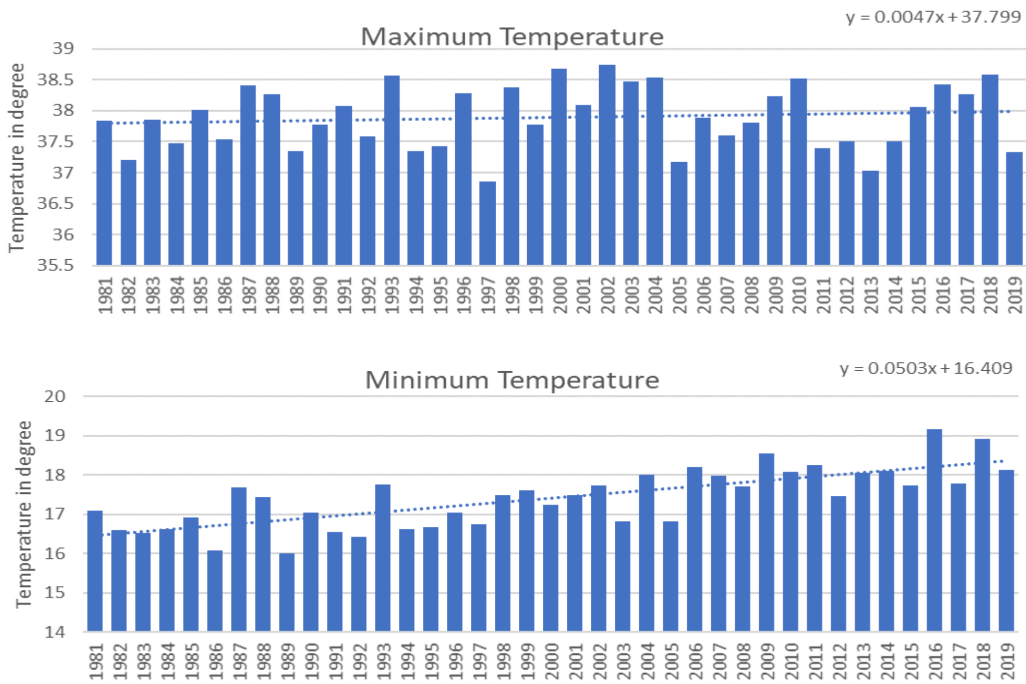


Figure 2-7 Average Annual Tmax and Tmin in the Sindh

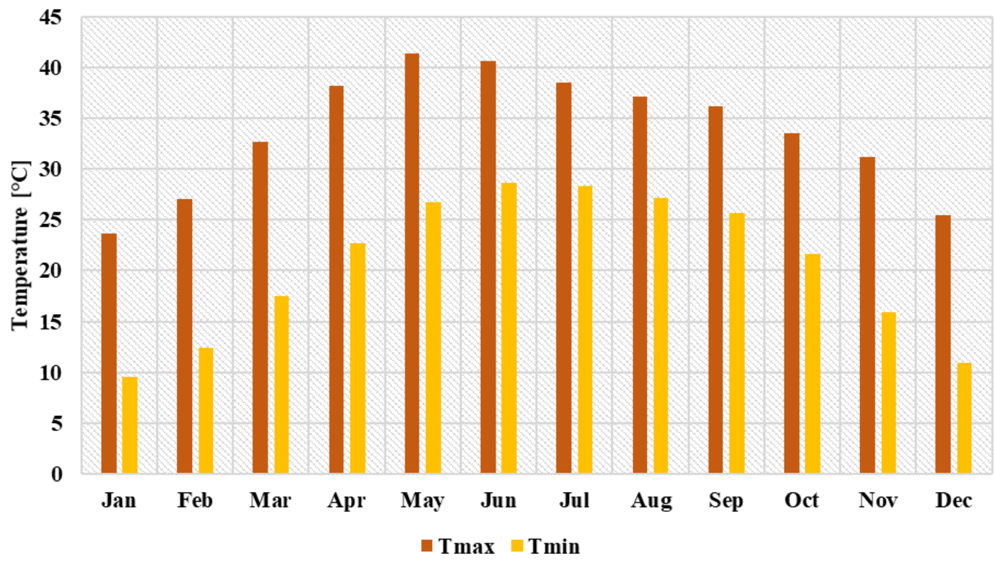


Figure 2-8 Mean Monthly Tmin and Tmax in the Sindh (1981-2019)

Mean monthly maximum temperature Tmax, minimum temperature Tmin in the study area was calculated from the 30 years past data, i-e in Sindh province. Jacobabad, Shaheed Benazirabad, Umerkot and Tharparkar districts have been observed to be the hottest districts in the whole study area. Temperature is minimum in the months of December and January, while maximum in the months of July-September. Representation of average monthly maximum and minimum temperature is given in Figure 2-8.

2.3. SPATIAL DISTRIBUTION OF PRECIPITATION AND TEMPERATURE

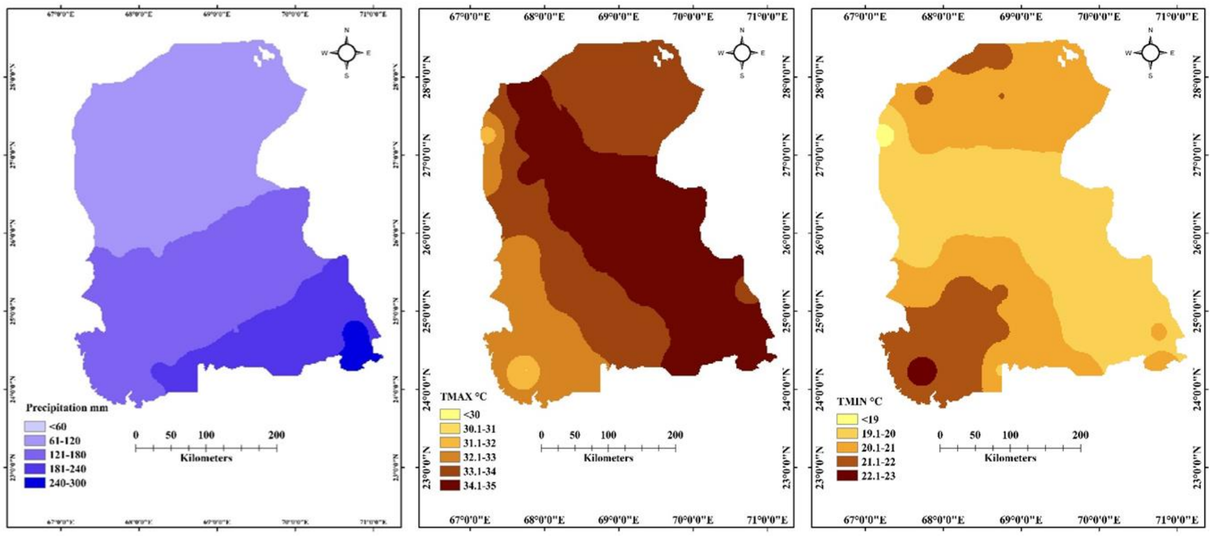
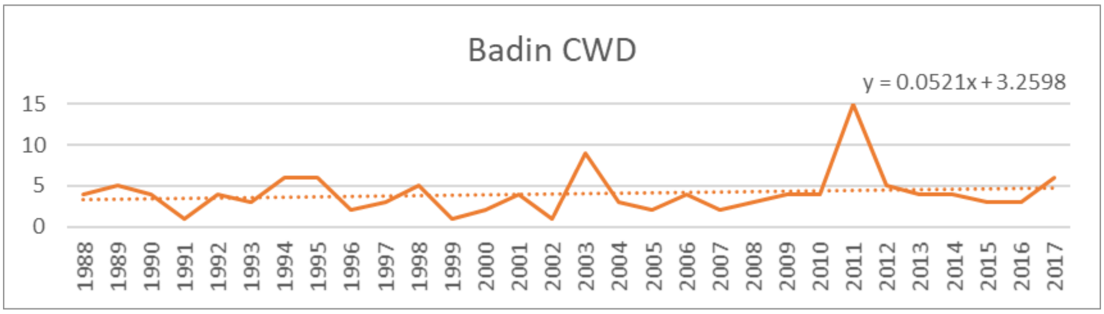
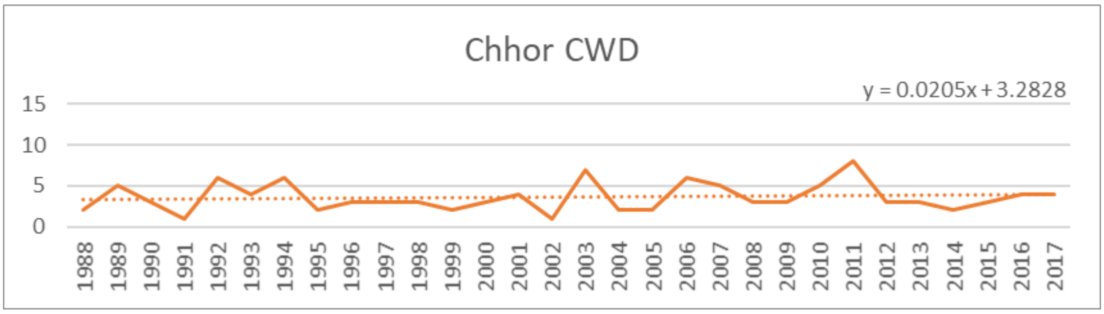


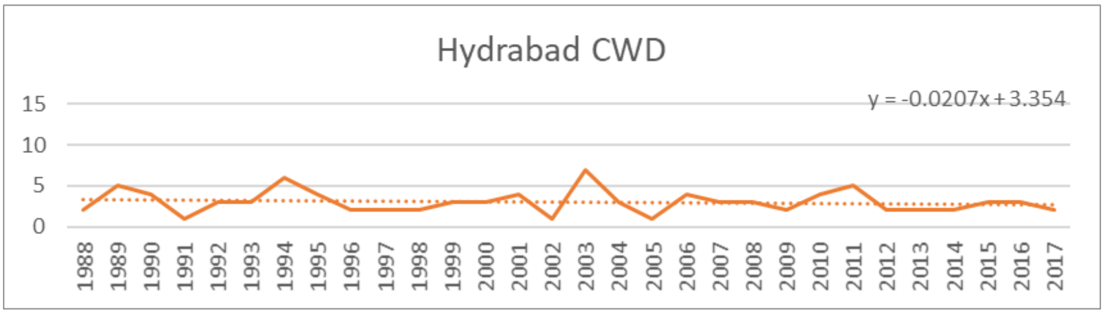
Figure 2-9 Spatial Distribution of Mean Annual Precipitation and Temperature

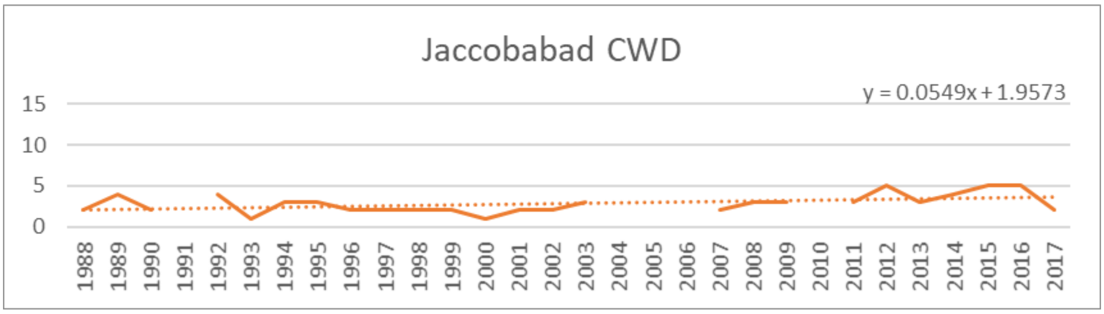
It is obvious from the spatial maps (Figure 2-9) that northern areas are having minimum average annual precipitation whereas southern areas are having peak average annual maximum temperature causing more evaporation thus more drought. Average precipitation in southern east districts is found to be more as compared to northern areas, because there is abnormal precipitation means in some years it is twice or even thrice of an average year, whereas sometimes there is no precipitation for almost several years such as Tharparkar and Umerkot districts where past trends of drought have been observed quite more.

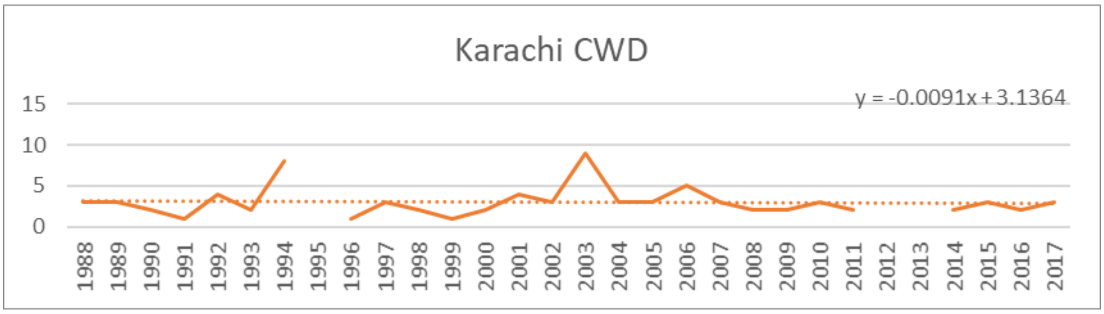
Consecutive Wet Days (CWD) represents the maximum number of consecutive days with Rainfall>=1mm, and overall trend of CWD is increasing with a slope estimate of 0.032 that means that no of rainy days is increasing in all station accept Hyderabad and Karachi with decreasing slope of 0.009 as show in Figure 2-10.


Badin CWD
y = 0.0521x + 3.2598
15
10
5
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Chhor CWD
y = 0.0205x + 3.2828
15
10
5
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Hydrabad CWD
y = -0.0207x + 3.354
15
10
5
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Jaccobabad CWD
y = 0.0549x + 1.9573
15
10
5
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Karachi CWD
y = -0.0091x + 3.1364
15
10
5
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

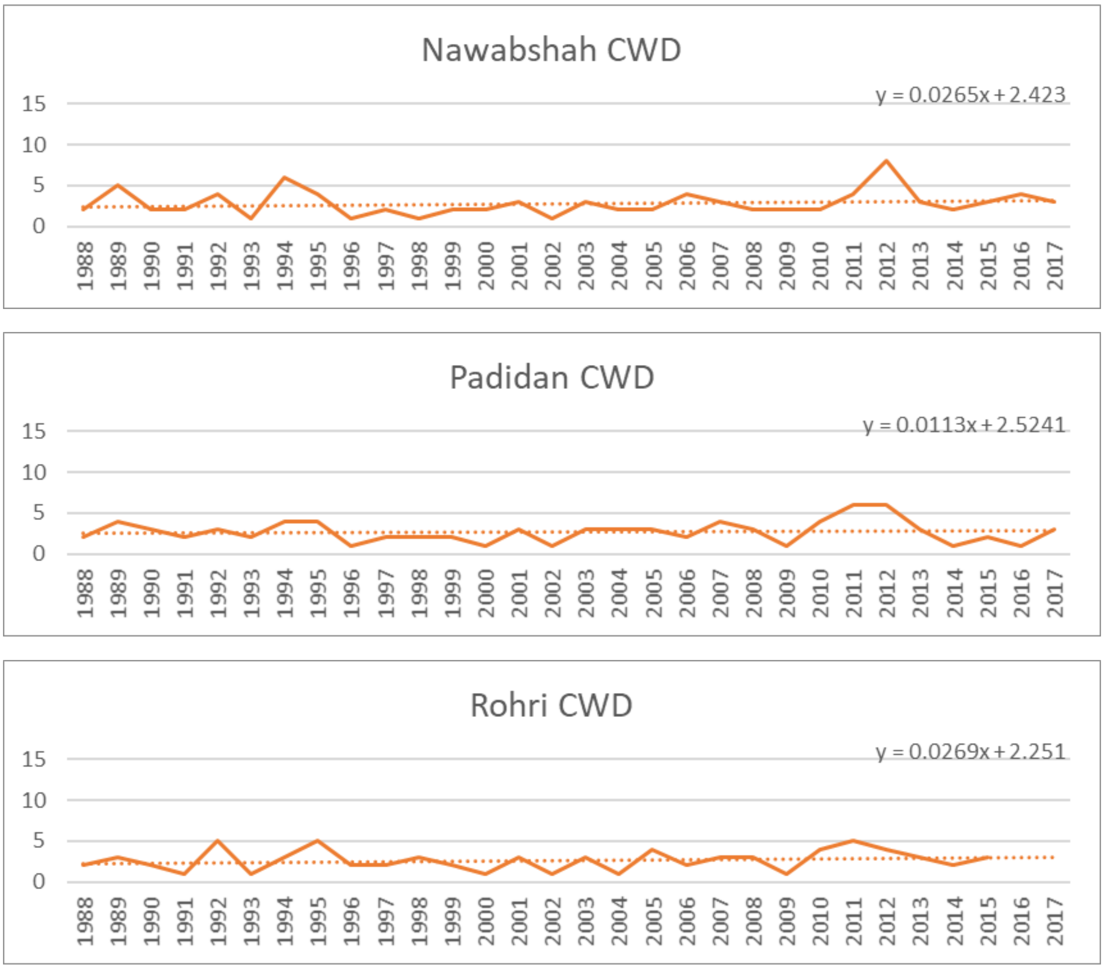
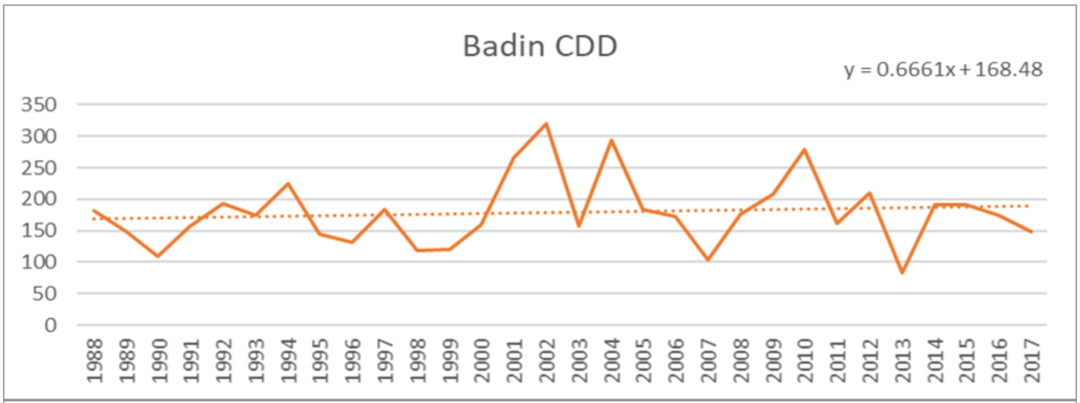
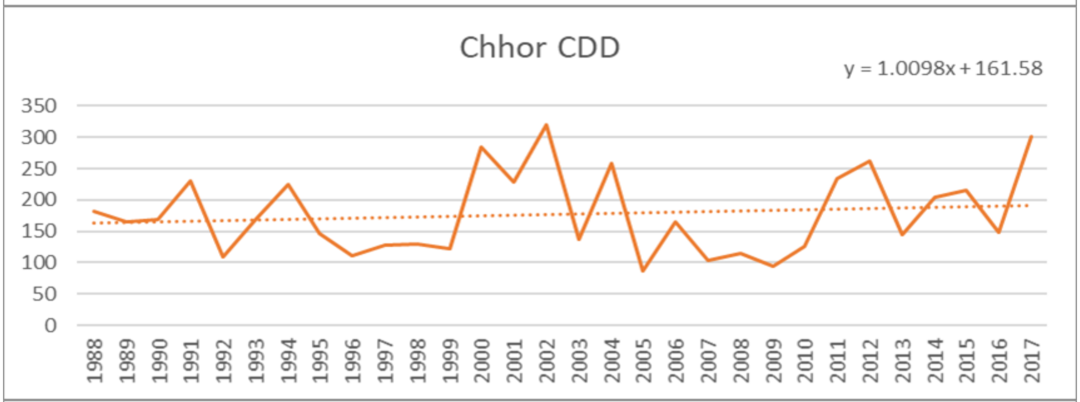
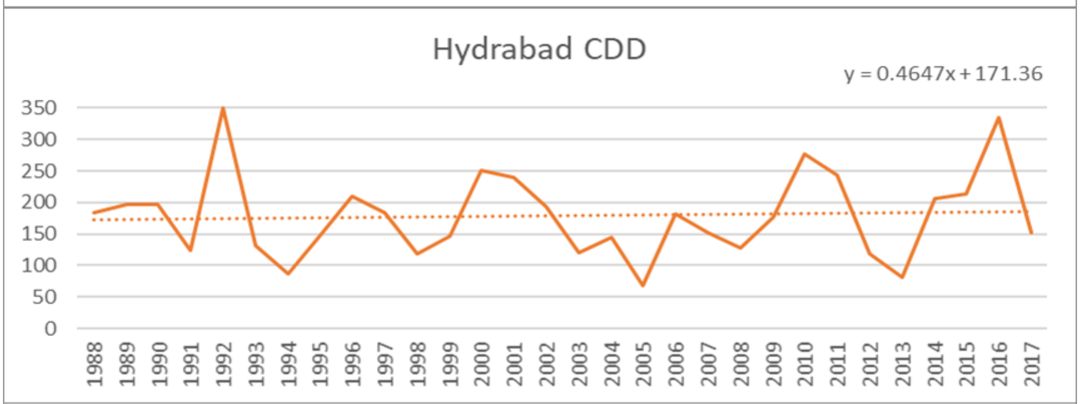


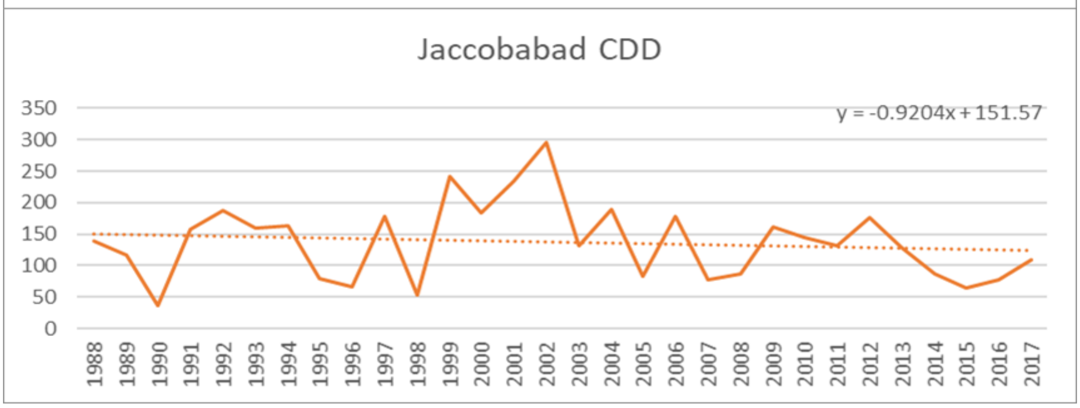
Figure 2-10 Trend of Consecutive Wet Days (CWD) in the Sindh province

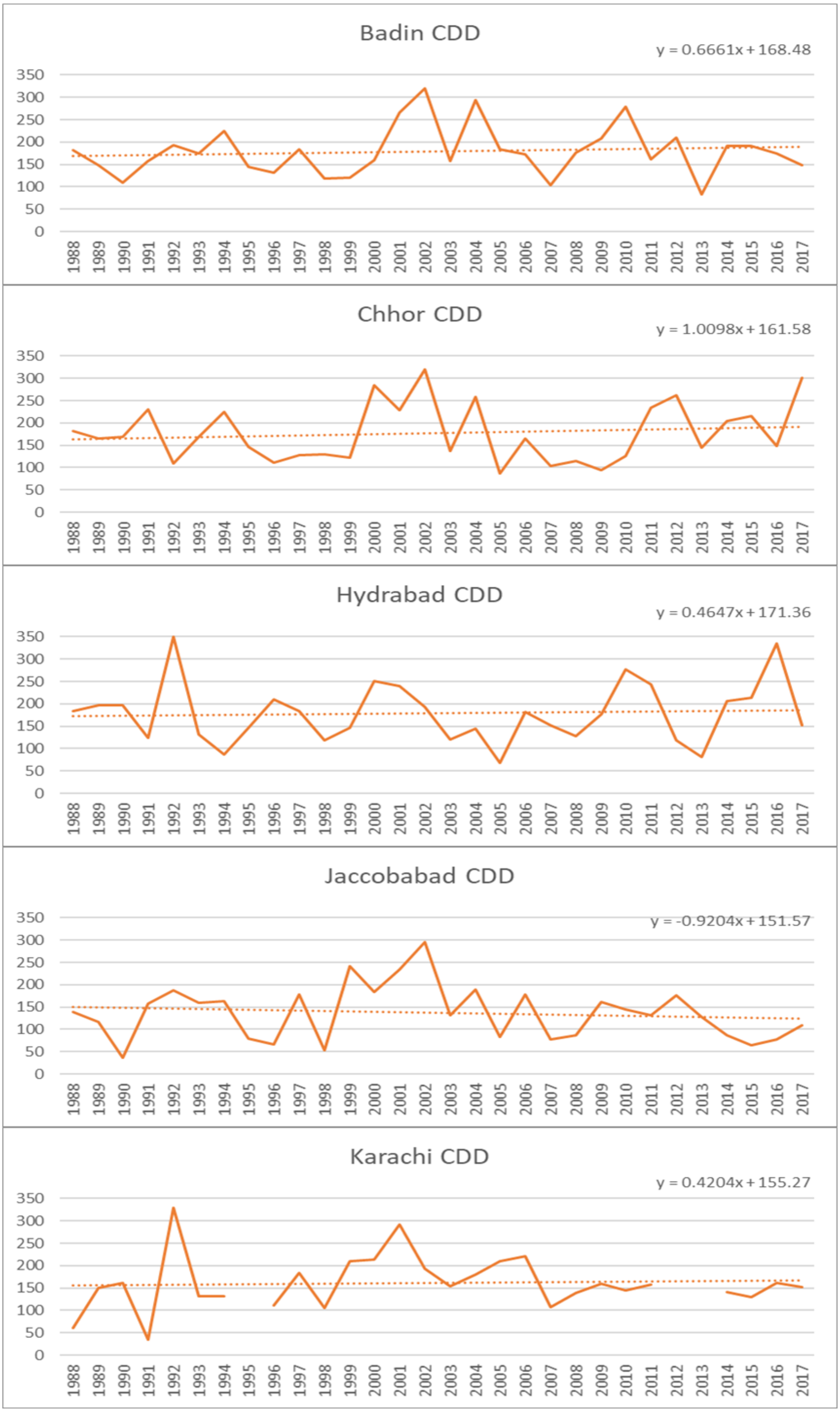
Consecutive Dry Days (CDD) means that maximum number of consecutive days with rainfall less than 1mm per day. As shown in Figure 2-11, in Sindh number of dry days are rise in many stations, however some stations have slight downward trend in dry days overall number of dry days are increasing that can also be cause more droughts in that region.


Badin CDD
y = 0.6661x + 168.48
350
300
250
200
150
100
50
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Chhor CDD
y = 1.0098x + 161.58
350
300
250
200
150
100
50
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Hydrabad CDD
y = 0.4647x + 171.36
350
300
250
200
150
100
50
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Jaccobabad CDD
y = -0.9204x + 151.57
350
300
250
200
150
100
50
0
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


Badin CDD
y = 0.6661x + 168.48
Chhor CDD
y = 1.0098x + 161.58
Hydrabad CDD
y = 0.4647x + 171.36
Jaccobabad CDD
y = -0.9204x + 151.57
Karachi CDD
y = 0.4204x + 155.27
0 50 100 150 200 250 300 350
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

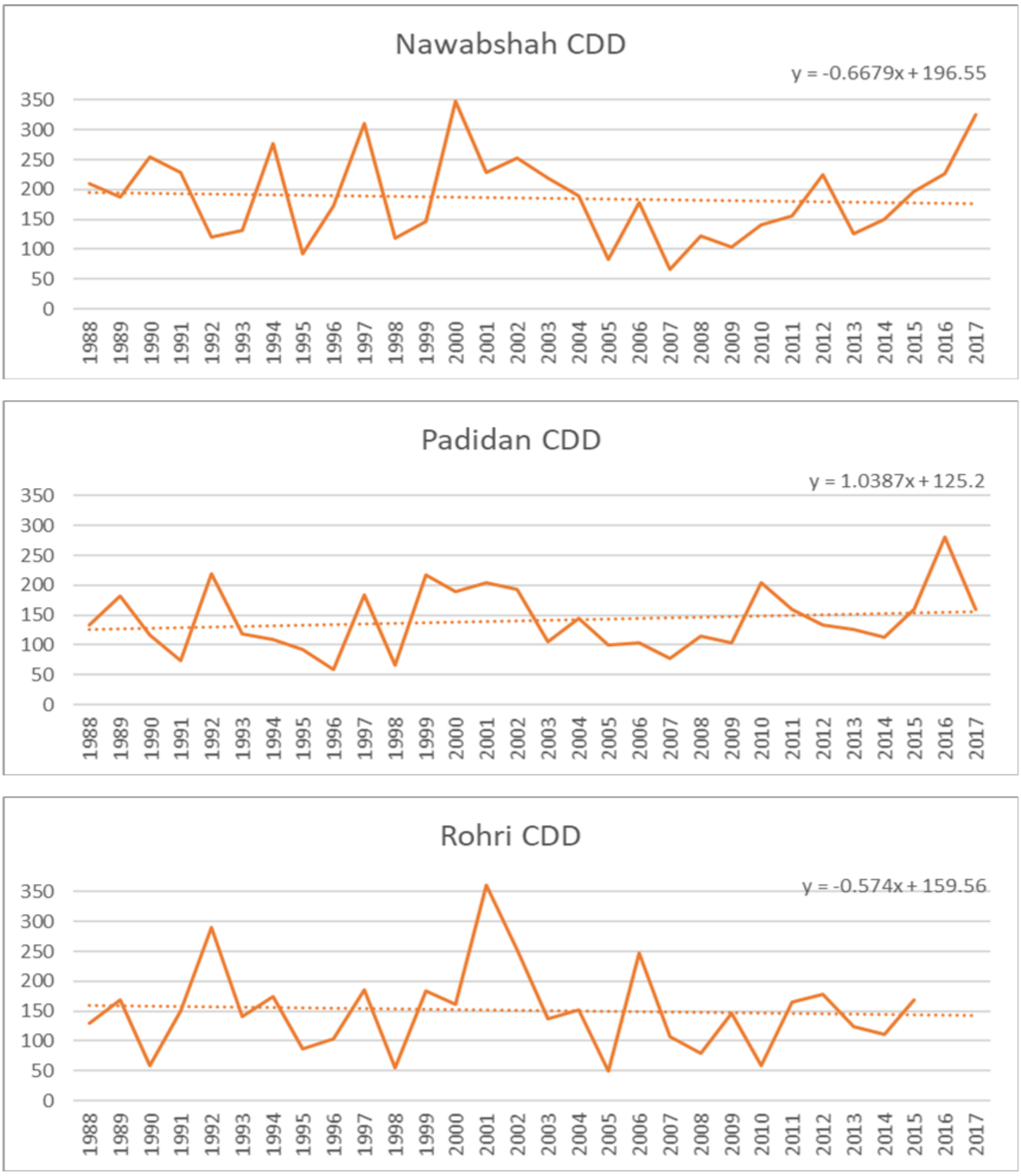


Figure 2-11 Trend of Consecutive Dry Days (CDD) in the Sindh province

It is obvious from the spatial maps that northern areas are having minimum average annual precipitation whereas southern areas are having peak average annual maximum temperature causing more evaporation and hence more drought. Average precipitation in southern east districts is found to be more as compared to northern areas, because there is abnormal precipitation means in some years it is twice or even thrice of an average year, whereas sometimes there is no precipitation for almost several years such as Tharparkar and Umerkot districts where past trends of drought have been observed quite more.

2.4. HYDROLOGICAL BASELINE SITUATION

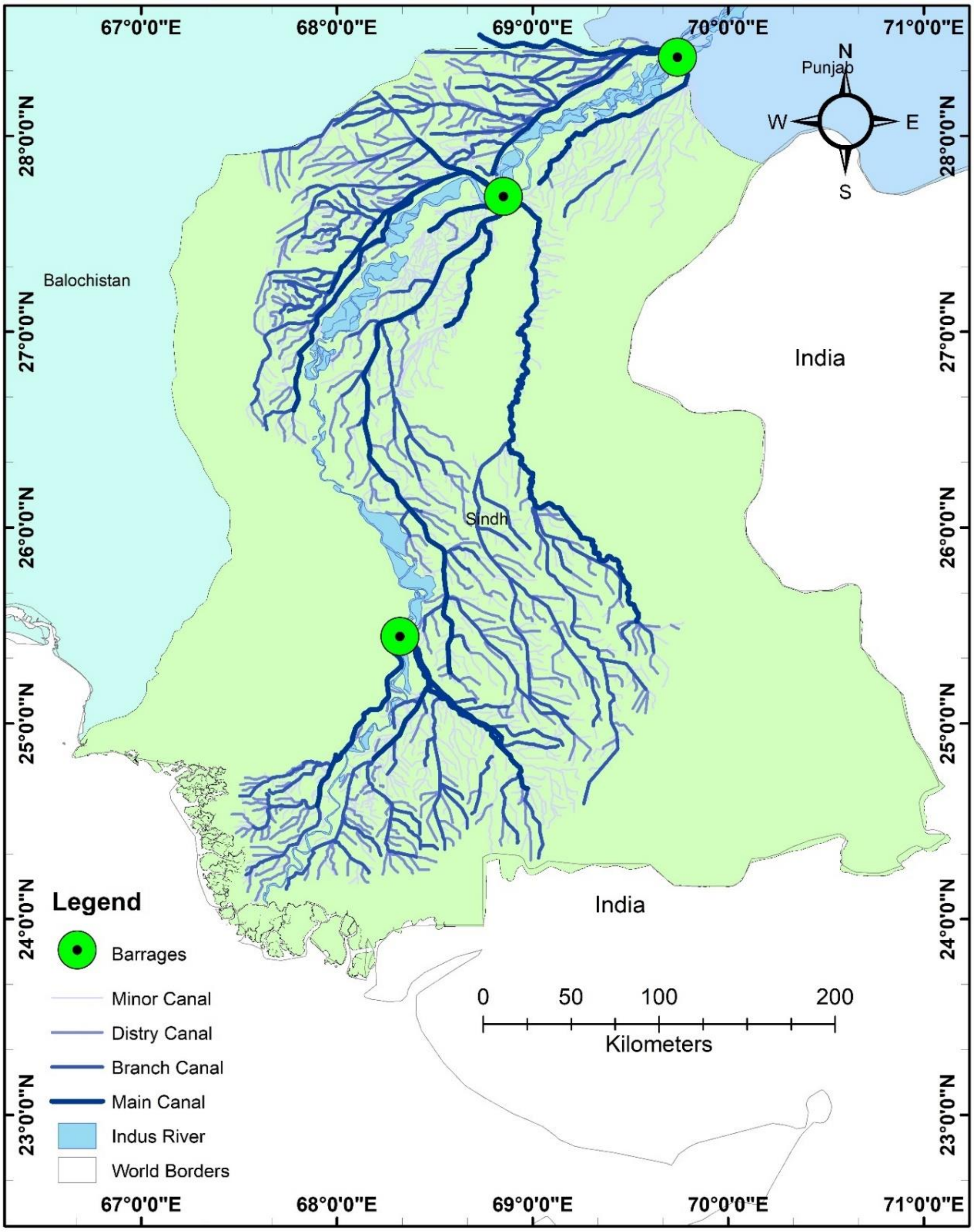


Figure 2-12 Overview of Barrages in the Sindh

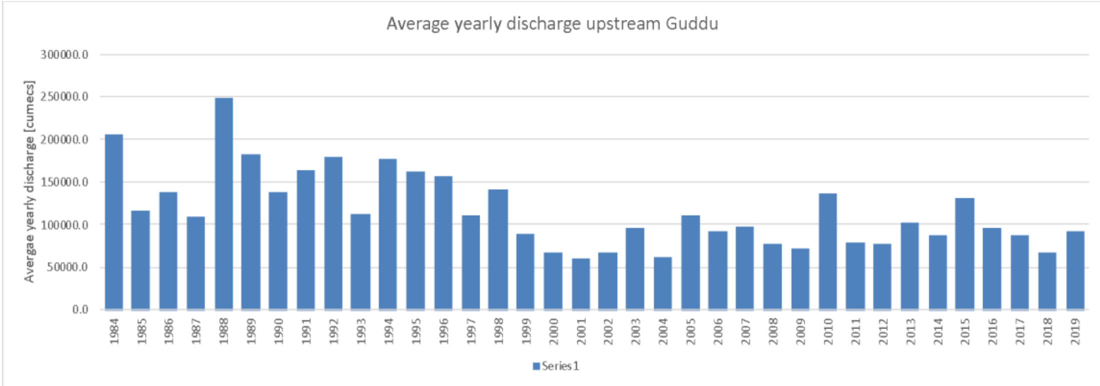


Figure 2-13 Average Yearly Discharge Upstream Guddu Barrage

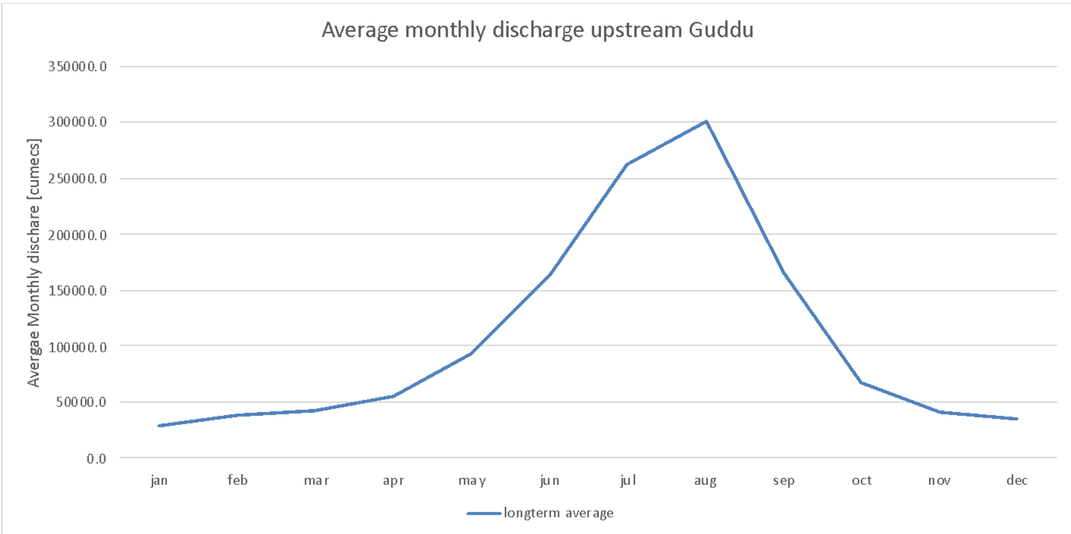


Figure 2-14 Average Monthly Discharge Upstream Guddu Barrage System

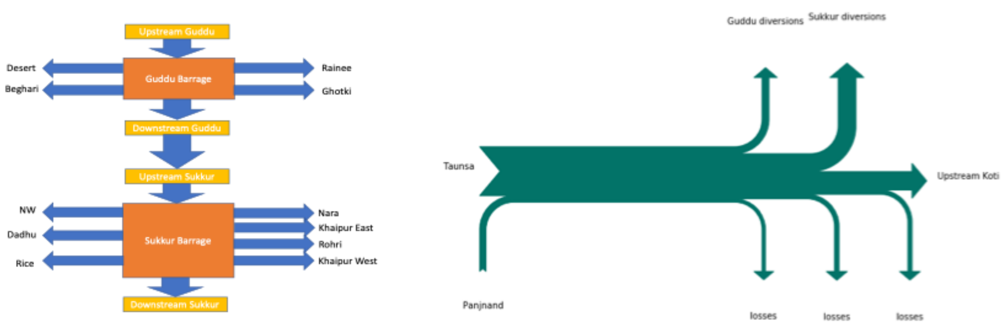


Figure 2-15 Overview of Flow Distribution in The Sindh Main Irrigation

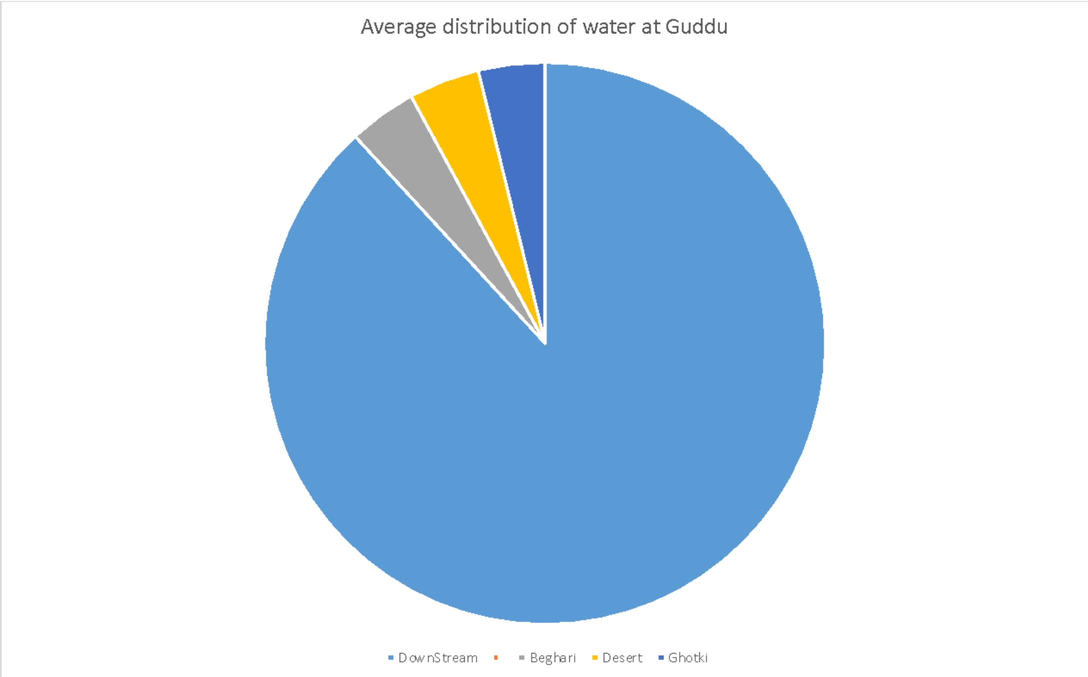


Figure 2-16 Average Water Distribution at Guddu Barrage

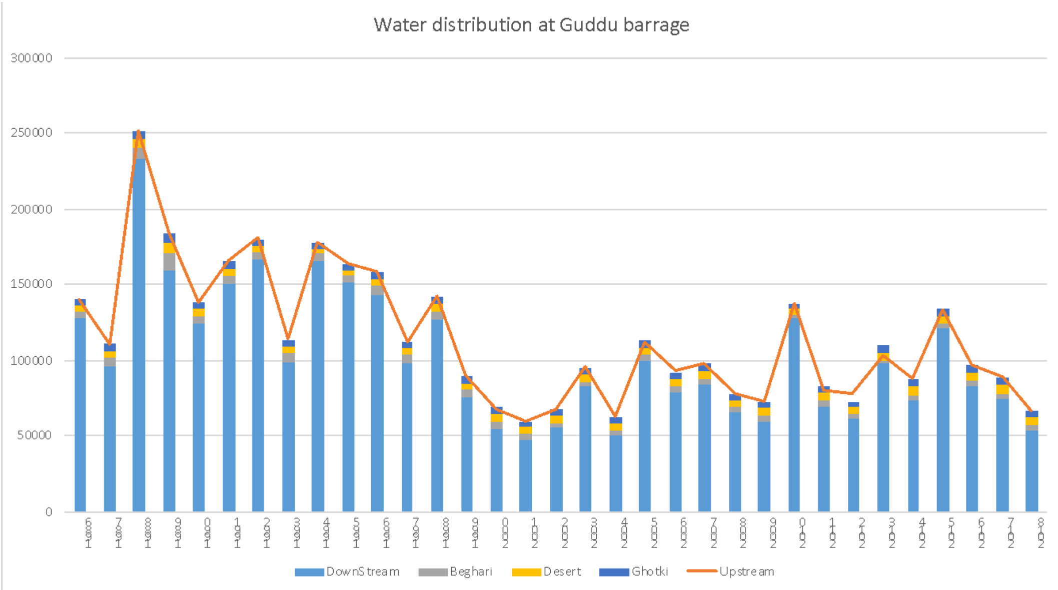
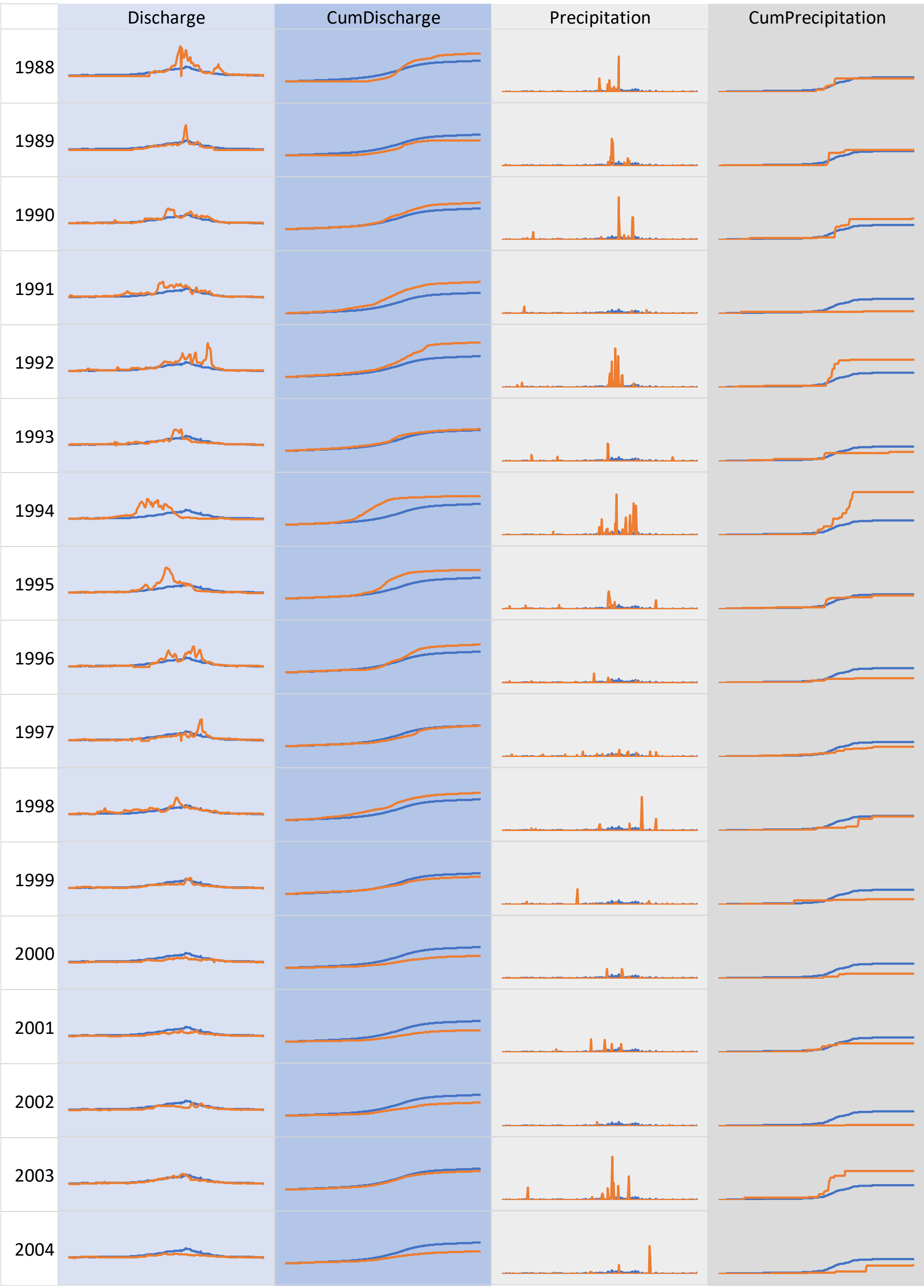


Figure 2-17 Yearly Water Distribution at Guddu Barrage

2.5. HISTORICAL HYDRO-METEOROLOGICAL SITUATION

Hydrometeorological information is important for planning, operation, and management of water resources and for flood protection. Hydrometeorological observations include precipitation and discharge data. Time series plots of mean and cumulative precipitation and discharge are developed. These time series plots are helpful in understating profile of major extreme events in the region. These plots are derived from mean of precipitation derived from four major rain gauge station located in Nawabshah, Hyderabad, Chhor and Badin. Discharge plots are derived from Guddu station. These plots clearly depict that six major floods have occurred since 2000 in the Sindh region—in 2006, 2007, 2010, 2011, 2012, 2013, and 2017. It has been observed that 2010 flood event was due to increased flow and erratic precipitation. In general, the 2010 flooding was caused by the cumulative effects of heavy rainfall in July, saturation of soil, and steady rain in August. Whereas the cause of 2012 flood is lies in local increase in flow. Time series plots shows Sindh had severe drought events in 1999, 2005, 2014 and 2016. It is observed that longest drought event was between year 1996 to 2003.


Discharge
CumDischarge
Precipitation
CumPrecipitation
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

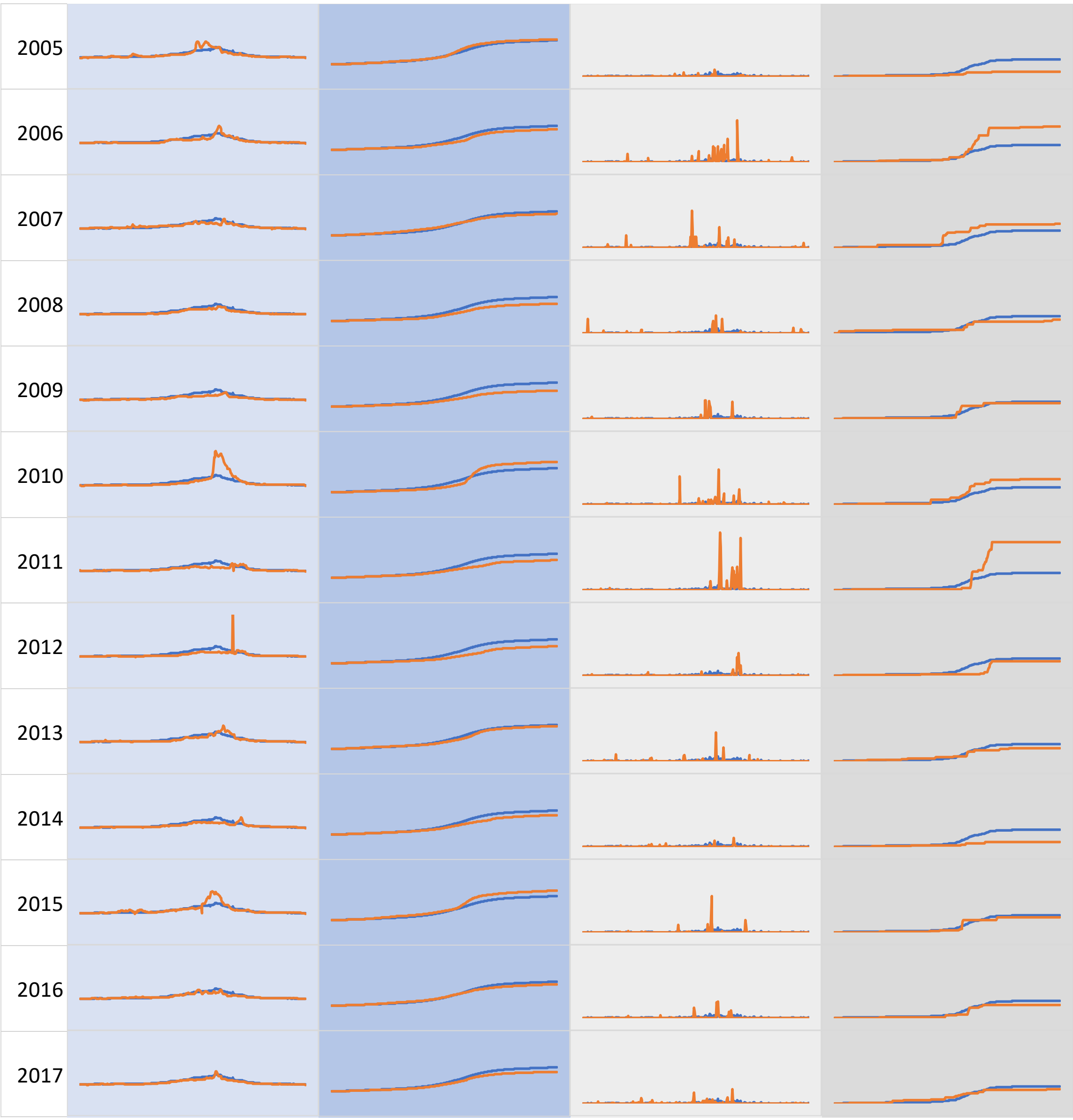


Figure 2-18 Year Wise Precipitation and Discharge Over Sindh

3. DROUGHT RISK CHARACTERIZATION

3.1. BACKGROUND

Geographically Sindh can be divided into the desert in eastern, mountains in western, coastal in southern and river plain in the middle. About 60% of the total land area is classified as arid, which receives less than 200 mm annual rainfall. Low rainfall and extreme variations in temperature characterize the climate that driven up to drought events. In the past, Sindh had severe drought events in 1871, 1881, 1899, 1931, 1942, 1999, 2014 and 2016.[65]

The people of Sindh are particularly affected in already water-scarce areas such as Tharparkar, Sanghar and surrounding areas where food security is an ongoing challenge. In 2014, 99 children and 67 adults died as a result of water shortages, chronic malnutrition, and poor health services in the District Tharparkar. More than 190 children and 22,000 adults were hospitalized in District Tharparkar in 2016 due to drought-related, water-borne and viral diseases with families traveling an average of $17km^2$ to the nearest health facilities. Tharparkar has now confronted with four consecutive years of drought. Lower than average rainfall is frequently reported in talukas Chachro, Diplo, Khinser, Islamkot, and Mithi. According to the Joint UN Needs Assessment Report, 62% of people in Jamshoro and 100% of people in Tharparkar are affected by ongoing water shortages resulting in harvests reducing by 34-53% and livestock by 48%[66]. The worst drought experienced to date took place in 1998-2000, which severely stunted economic activities in Sindh.[67]

Sindh has an arid climate and is mostly prone to prolong droughts with an occasional extreme precipitation events that leads to flooding. Historically, Sindh has experienced the worst prolong droughts extending over a couple of years (1968–69, 1971–74, 1985–87, and 1999–2002).

To monitor drought there are different types of indices based on the meteorology variable such as precipitation, evaporation, and temperature are

[65] *Provincial Disaster Management Authority (2009). "Provincial Disaster Management Plan". PDMA Sindh. P.34*
[66] *PDMA Sindh (2018). Organizational Capacity Assessment and Development of Capacity Enhancement Plan.*
[67] *Provincial Disaster Management Authority (2009). "Provincial Disaster Management Plan". PDMA Sindh. P.34*

used to calculate drought Indices such as Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI).

Sequence of meteorological situations that lead to the drought event.

3.2. LOCAL METEOROLOGICAL SITUATION

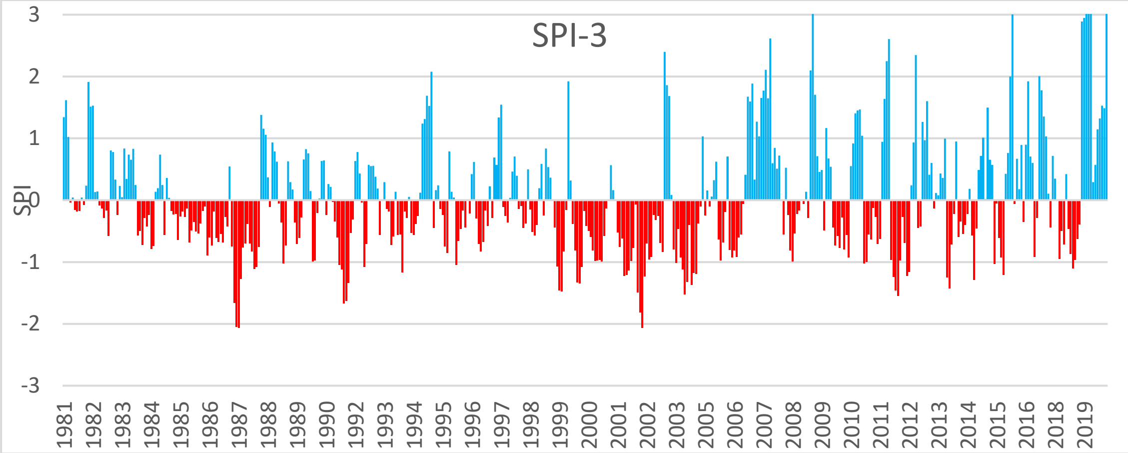
Using long-term monthly precipitation data (McKee et al. 1993), the SPI is one of the most common meteorological drought indices for identifying and tracking drought. This index needs as input only monthly data on precipitation and can track drought on multiple time scales such as 1,3,6,9,12,24 and 48-month times laces and even higher than that scales. Initially, the available long-term rainfall data are fitted to a distribution of gamma probability and then transformed into a normal distribution so that the mean SPI is zero (see Bayissa et al. 2015 for more details). When there are positive values of SPI, that means there is excessive or normal rainfall in the area. But when there are negative values of SPI, that means there has been less rainfall than the average rainfall in an area. SPI values more than 2 indicate that the precipitation in the specified time period is more than the average precipitation and the period with values 2 are thus identified as wet periods, while when there is a -2 value of SPI, it indicates that the precipitation in the specified period is much less than the average and causes extreme drought conditions in that period (McKee et al. 1993). A drought duration can be well defined from the SPI values obtained, for example, starting of a drought period is defined when negative SPI values continue, and the drought period is said to be finished when negative SPI values are shifted to positive b=values, thus indication of normal or wet years (Mishra et al. 2009).

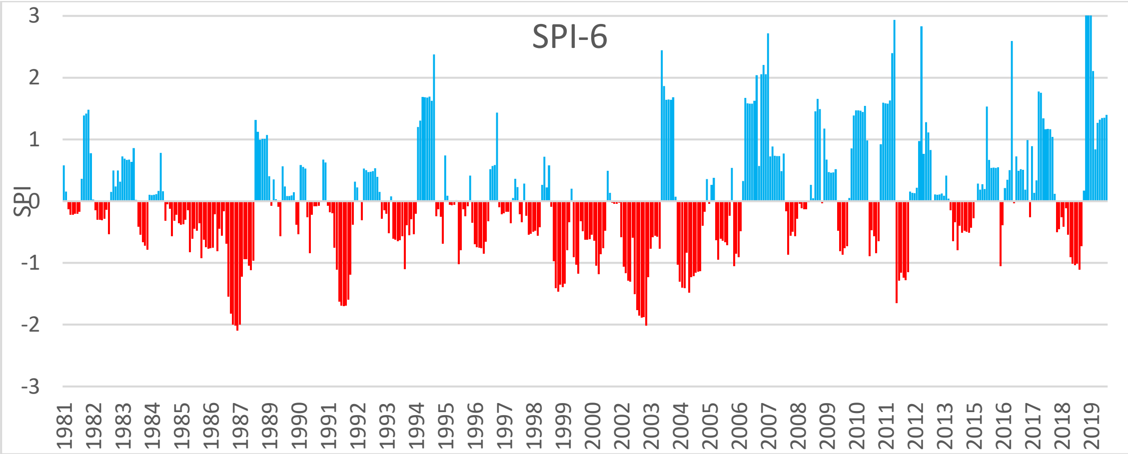
Sindh, Pakistan in order to furnish drought mitigation planners and other users with information that will be helpful to review current drought in historical perspective. Table 3-1 shows the average SPI value for all stations in Sindh. The time series of the average 3-month SPI for all stations in Sindh shows that short term mild droughts are common throughout the period of record and the 6-month give a little indication of intense drought whereas 12 & 24.

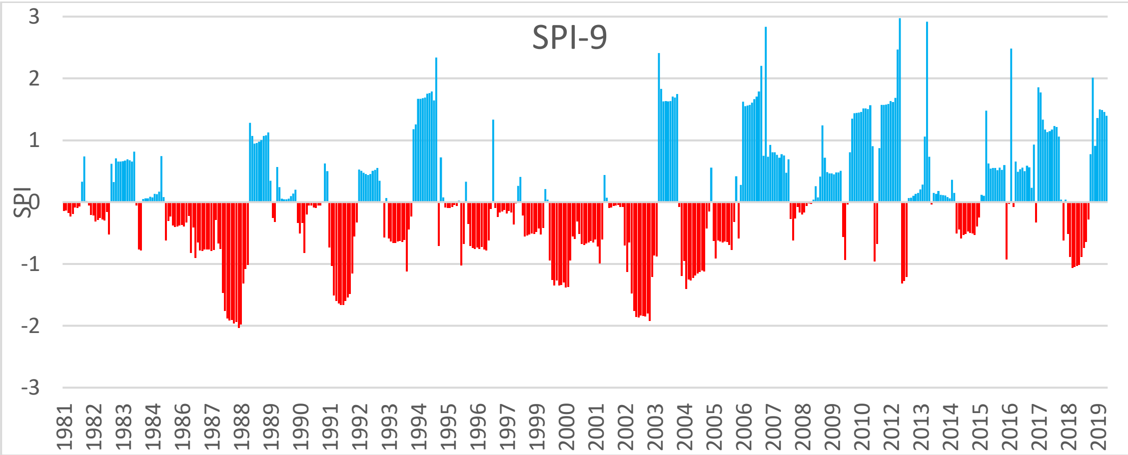
Table 3-1 Drought Intensity Versus SPI

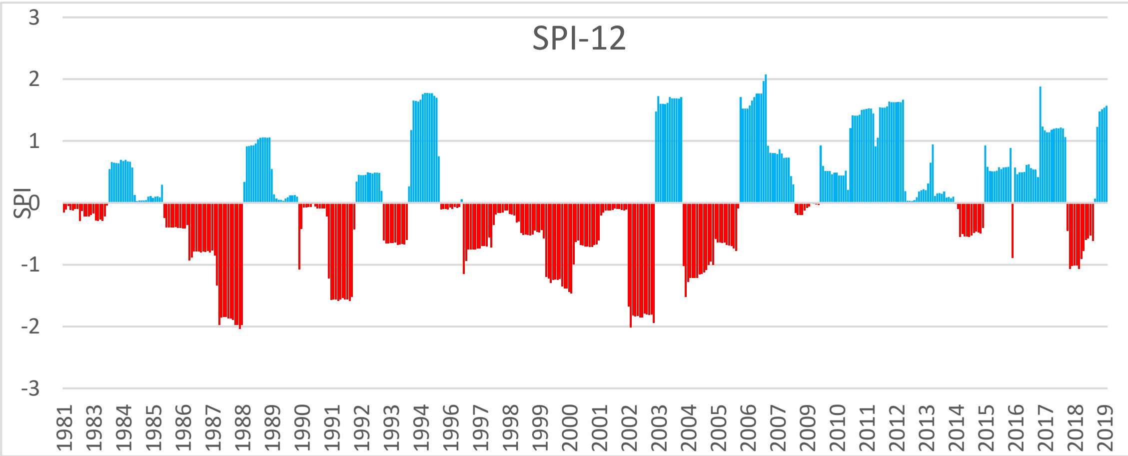
SPI	Intensity	Percentage of time w.r.t. SPI
-0.00 to 0.99	Mild	34.1%
-1.00 to -1.49	Moderate	9.2%
-1.50 to -1.99	Severe	4.4%
-2 .00 or less	Extreme	2.3%

The three-month SPI was calculated to compare the precipitation of a specific 3-month period with the precipitation of same three-month period for all the years encompassed in the historic record. For example, a three-month SPI at the end of September compared the July–August-September rainfall total in that year with the July–August-September precipitation totals of all the years encompassed in the historic record for a given location. The station wise detailed study indicates that moderate to severe drought is commonly observed at different time scale. In 3-months' time scale moderate droughts have been observed 47 time and severe and extreme drought observed 9 time in the Sindh Province and longest duration of 3-month drought event occur is 26. In 6-months' time scale moderate droughts have been observed 60 time and severe and extreme drought observed 18 time in the Sindh Province and longest duration of 6-month drought event occur is 40 (1985-1988), 25 (1998-2001). In 12-months' time scale moderate droughts have been observed 67 time and severe and extreme drought observed 34 time in the Sindh province and longest duration of 12-month drought event occur is 84(1995-2003). In 24 months', time scale moderate drought have been observed 47 (1985- 1989), and longest drought event of 83(1996-2003) the detail of all SPI is shown in Figure 3-1.


SPI-3
SPI
3
2
1
0
-1
-2
-3
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2018 2019


SPI-6
SPI
3
2
1
0
-1
-2
-3
1981 1982 1983 1984 1985 1986 1987 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2015 2016 2017 2018 2019


SPI-9
SPI
3
2
1
0
-1
-2
-3
1981 1982 1983 1984 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2012 2013 2014 2015 2016 2017 2018 2019


SPI-12
SPI
3
2
1
0
-1
-2
-3
1981 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

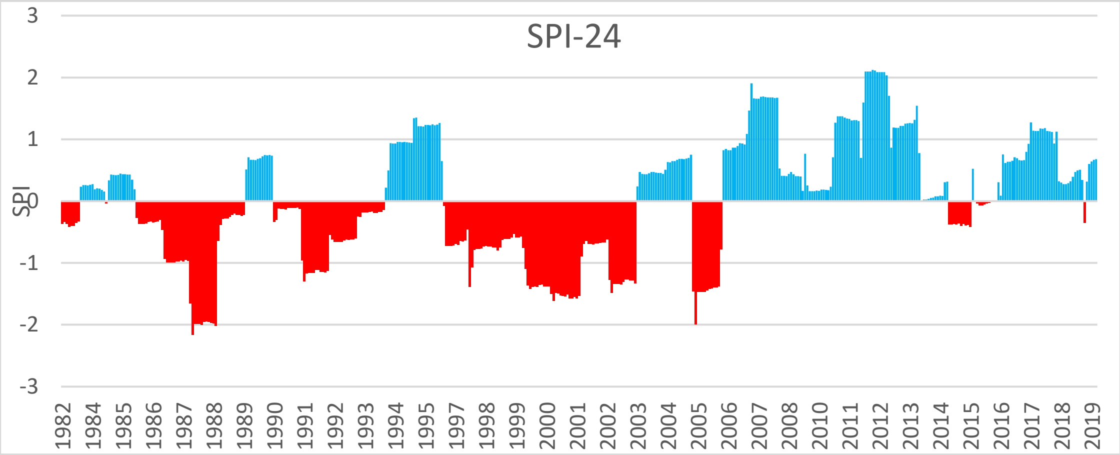


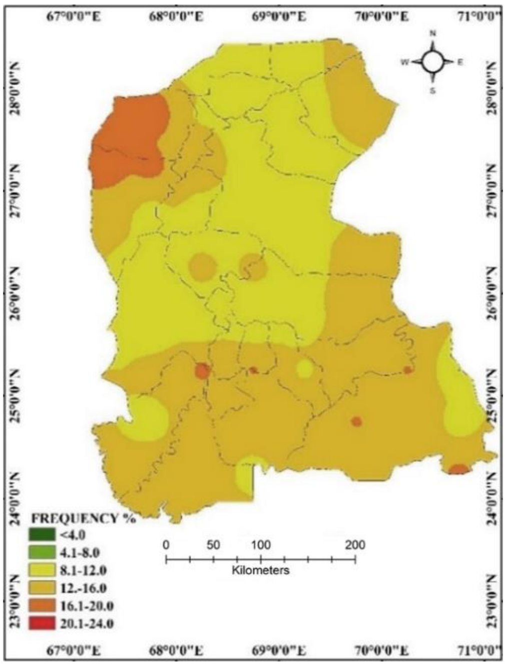
Figure 3-1 SPI-3 to SPI-24 for the Study Area

This drought index is the same as the SPI, but as compared to the SPI, which takes into account only prepetition data, this drought index also takes into account temperature data for the calculation of potential evapotranspiration. It is based on probability distribution calculated as the difference between rainfall and potential evapotranspiration in order to obtain a climatic water balance which is then used to obtain positive and negative SPEI values through three probability distribution functions. This is a very useful drought index because it also takes into account temperature, so the areas with higher temperatures better represent the drought figure by adding temperature as drought calculation parameter along with precipitation. Like in SPI calculation, SPEI can also be calculated over various time scales such as shorter timescales of 1, 3, 6-month scales and also for longer timescales of 9, 12, 18, 24, 36, 48 and even more. SPEI values are obtained through climatic water balance obtained through difference of precipitation and potential evapotranspiration, calibrated using a log logistic distribution of three parameters (Vicente Serrano et al. 2010). Vicente Serrano et al. 2010 introduced the SPEI index for the calculation of drought with the addition of temperature, this index was used in the present study to calculate drought index.

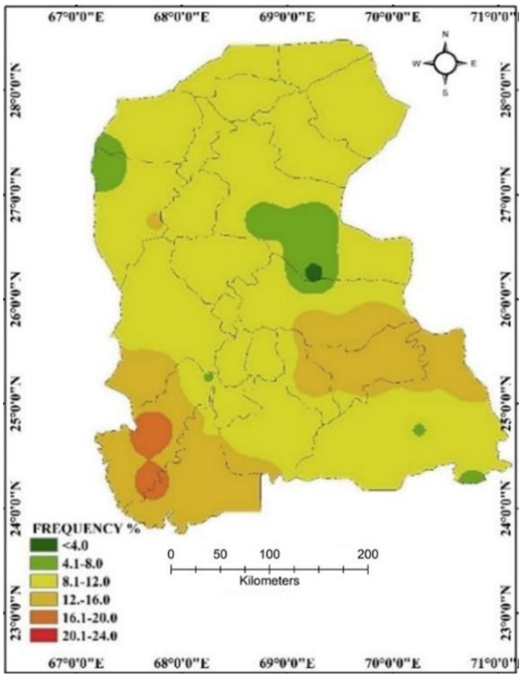
1998-2002 Sindh province precipitation versus ‘normal’ long-term average Sindh precipitation

It is very clear from Figure 3-2, for SPEI 1, almost all the 23 districts in the study area have faced severe to extreme mild drought in the past, where as it is also obvious that the mild drought frequency in the northern part of the province is more than the southern part. Whereas moderate drought has been almost same in the whole province with same frequency except in some districts in south such as Tharparkar and Umerkot where drought frequency is observed more as compared to the other parts of the province. A very light occurrence of severe drought has been observed in SPEI 1 in the past limiting to almost 4 to 5 districts. Severe drought frequency in abundance can be observed in the south east and north part of the Sindh Province. For this scale of time, no extreme drought has been observed in the whole study area. Overall Drought has occurred more in south and south east including most severely affected districts of Tharparkar, Umerkot and Badin (Adnan et al., 2015).

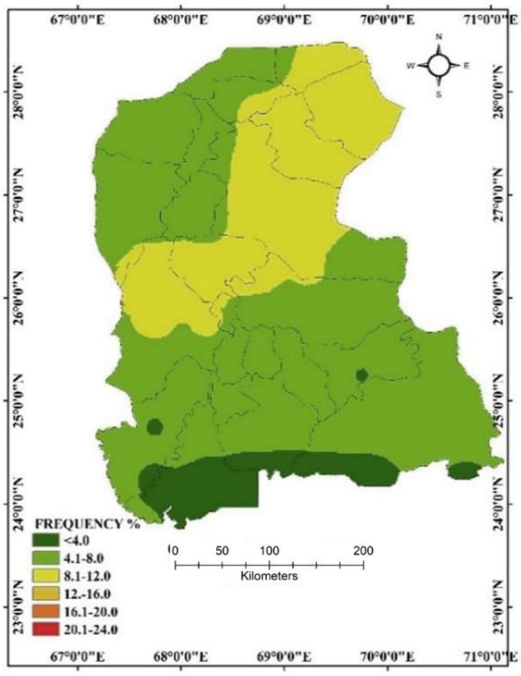
The figure 3.2 for SPEI 3 timescale shows drought frequencies for mild, moderate, severe and extreme droughts in the study area. Like SPEI 1, mild drought for this category has also occurred almost same in the whole province ranging more in southern parts of the province. Moderate drought is seen to be same almost all the districts in the province whereas it is little bit more in the south west districts such Tharparkar, Mirpurkhas and Umerkot where average drought frequency is more as per previous studies conducted in Sindh province. Whereas severe drought is more as compared to that of frequencies of SPEI 1 in the northern districts such Qamber Shahdadkot, Larkana, Sukkur and Kashmore. Like SPEI 1, no extreme drought is frequent in the whole province, as it is below 5 %.



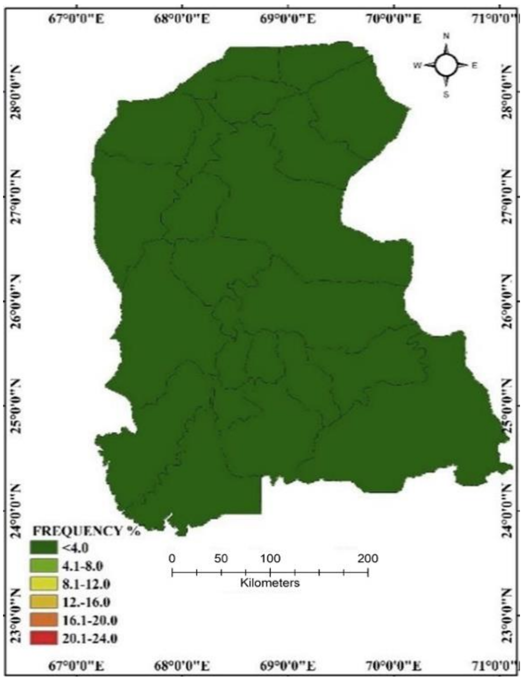
SPEI 12 MILD



SPEI 12 MODERATE



SPEI 12 SEVERE



SPEI 12 EXTREME

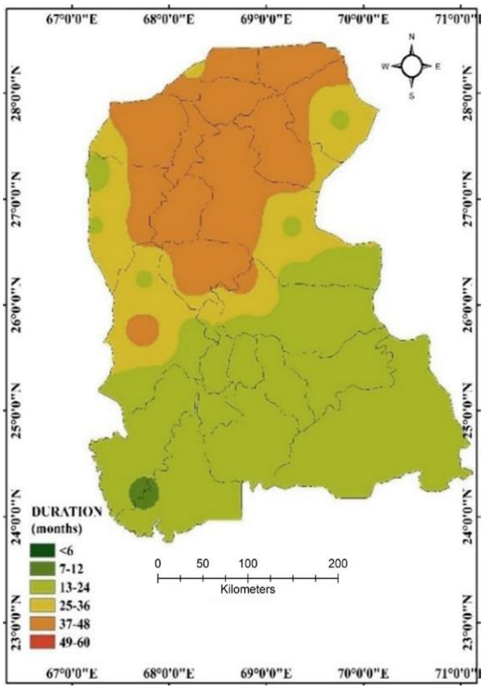
Figure 3-2 Spatial Distribution of Frequency of Drought Over Sindh

It can be observed from the above figure for SPEI 6 timescale, mild drought is maximum in the south west districts named Mirpurkhas, Umerkot, Tando Allahyar and Tando Mohammad Khan, whereas it is lowering in the central districts and again increasing in the northern districts in which Qamber

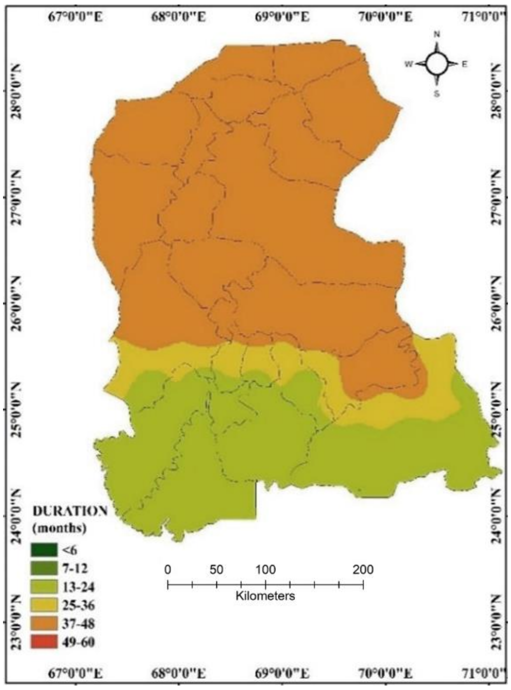
Shahdadkot and Larkana being the most affected in the Sindh Province, where as in the rest districts it more in north as compared to south. Whereas moderate drought frequency is almost same in the study area. Also, it is visible that severe drought is more in north than that of the southern part of the province which seems to be quite normal for this category and timescale, in north Kashmore and Sukkur districts seem to be severely affected by severe category of drought. Whereas Extreme drought frequencies seem to be very low in the whole study area and is ranging below 4%.

As we move from smaller time scales to larger one, i.e. 1, 3, 6 to 9, it can be observed that mild drought has occurred almost severe in the whole province making south west districts such as Badin and Sujawal being the more affected, whereas south west districts also come under quite affected category under this drought. Whereas drought frequency for moderate drought in all the districts in Sindh province seem to high even compared to that of SPEI 1, 3, and 6, among these, Badin, Dadu and Sujawal districts seem to be more affected due to moderate drought category for this timescale. Also, it is very much interesting to note here in the figure, that the drought frequency is quite high in northern and central areas of the province for severe category, it is also observed that the drought of this class is almost nil in the south west part of the province. While noticing the recurrence of extreme drought, it is very clear that it is near normal in the whole province.

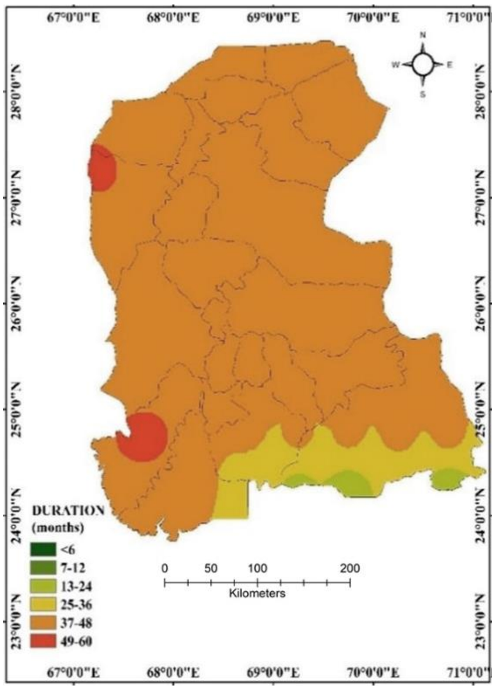
Fig 3.2 represents the SPEI 12-time scale for mild, moderate, severe and extreme categories drought for the study area. Mild drought seems to be more frequent in southern districts in the study area making Badin, Sujawal and Thatta, Umerkot and Tharparkar to face the drought impacts more severely, whereas it is almost normal in central province and again increasing in northern districts making them more vulnerable to the drought for this category of drought. Unlike SPEI 1, 3, 6- and 9-months timescales, it is clearly observed that the moderate drought category is more frequent in southern districts in the study area. Whereas as we notice the severe category for SPEI 12-time scale, we come to know that it is almost same in whole province except Dadu and Shaheed Benazir Abad districts where drought seems to be more frequent, also some districts in the north west part of the province seem to have thus category of drought having in abundance. Near normal extreme drought for this time scale is observed in the whole province.



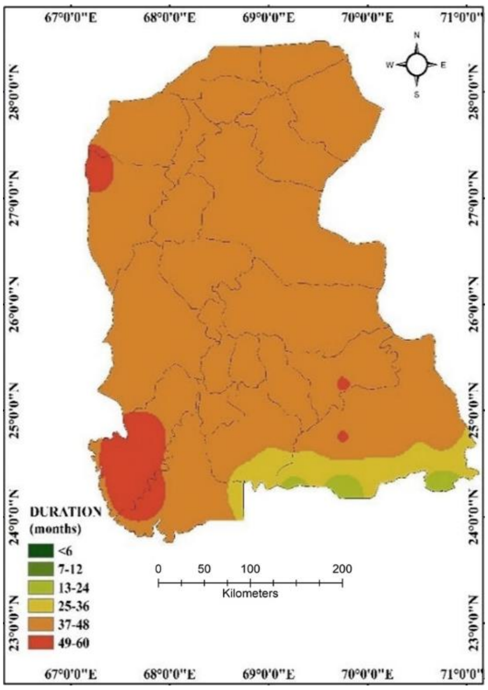
SPEI 3



SPEI 6



SPEI 9



SPEI 12

Figure 3-3 Drought Duration Maps for SPEI 3,6,9 And 12 in The Study Area

From Figure 3-3 it is clear that the drought duration for SPEI 3 seems to be longer and frequent drought durations in the northern districts in the study area where as for this timescale center and south districts seem to be quite having lower drought durations, but a dramatical change in increase in drought duration can be observed towards the central and southern districts such as Tando Allahyar, Mirpurkhas and Umerkot districts in the south west, but it is very much clear to see that there is a high drought durations observed in the south west districts such as Badin, Sujawal and Thatta districts lying in the south part of the Sindh Province. Same can be stated for SPEI 12-month timescale that drought duration is more towards south as compared to north and central districts in the study area, Districts Umerkot and Tharparkar seem to have longer drought durations same as like Sujawal and Badin.

3.3. UPSTREAM HYDROLOGICAL SITUATION

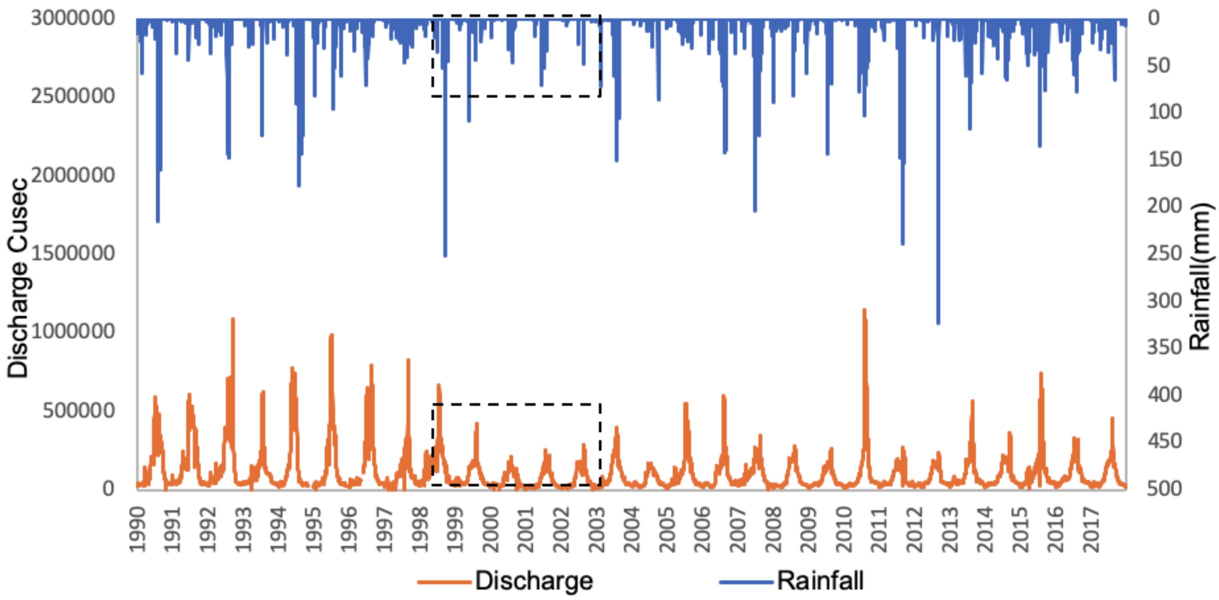
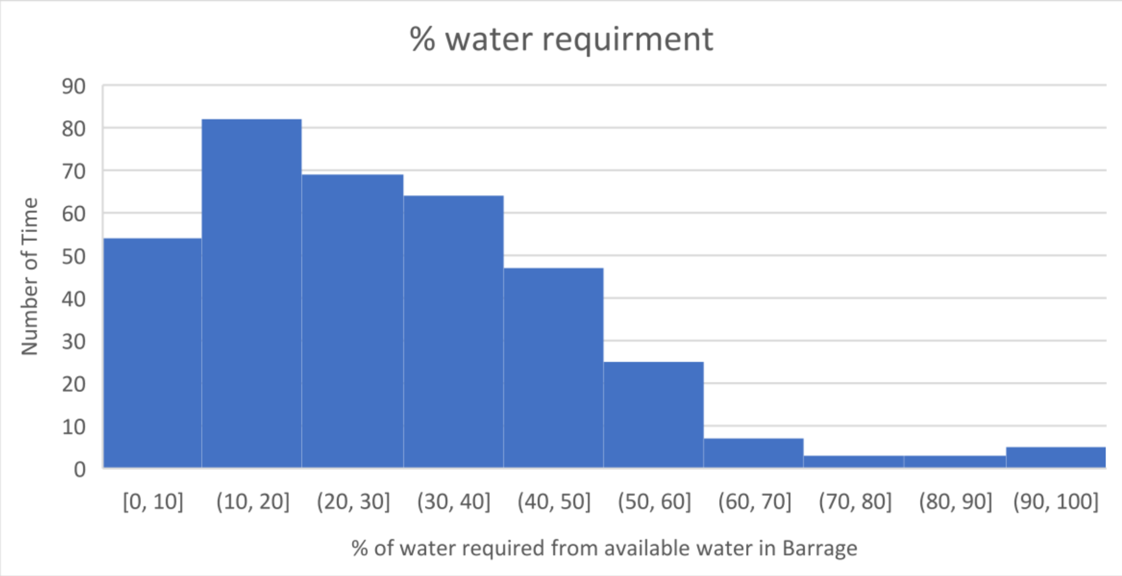


Figure 3-4 Discharge Rainfall Relationship Curve

From Figure 3-4 we can clearly see that rainfall and discharge in the entry point of Sindh is low as compare to other year so low discharge in 1998-2002 discharge into the system versus 'normal' long-term average system inflow



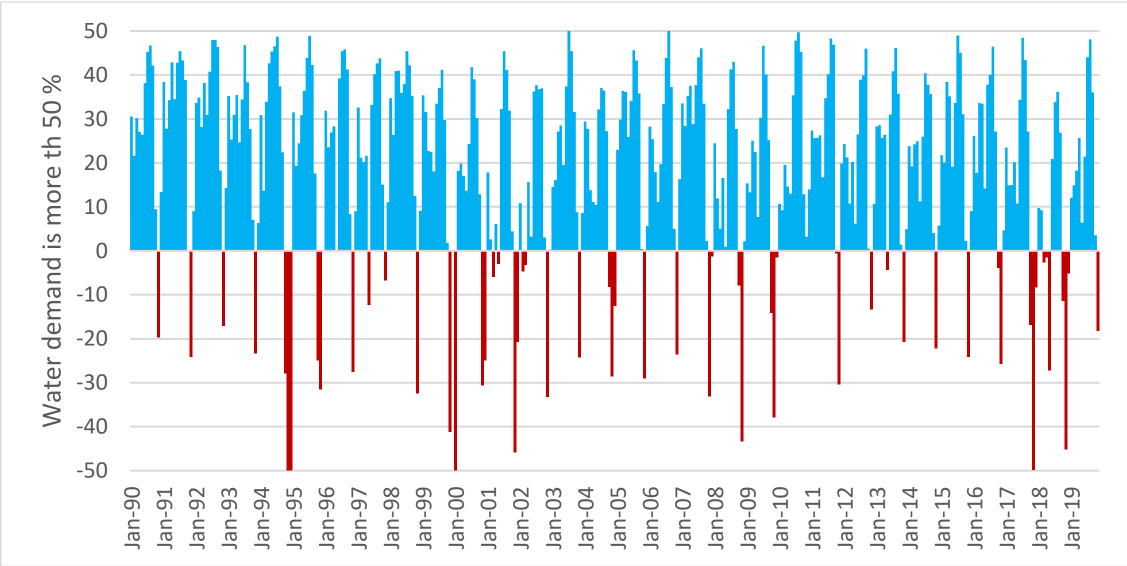


Figure 3-5 Average Water Demand from Guddu Barrage is Around 1300 Million Cubic Meter Per Month

According to the National Water Sector Profile till year 2005, approximately 2.5 million ha is actually irrigated area that have water supplied by wells, tube wells, canal wells and canal tube wells etc. and 5.4 million ha area had been equipped for irrigation with 5% with area equipped for groundwater irrigation and 95 % with area equipped for surface water irrigation in Sindh province.

May, October, November and December are the most stressful season for irrigation water demand from Indus river, this is due to multi crop overlap demand in month of October and November.

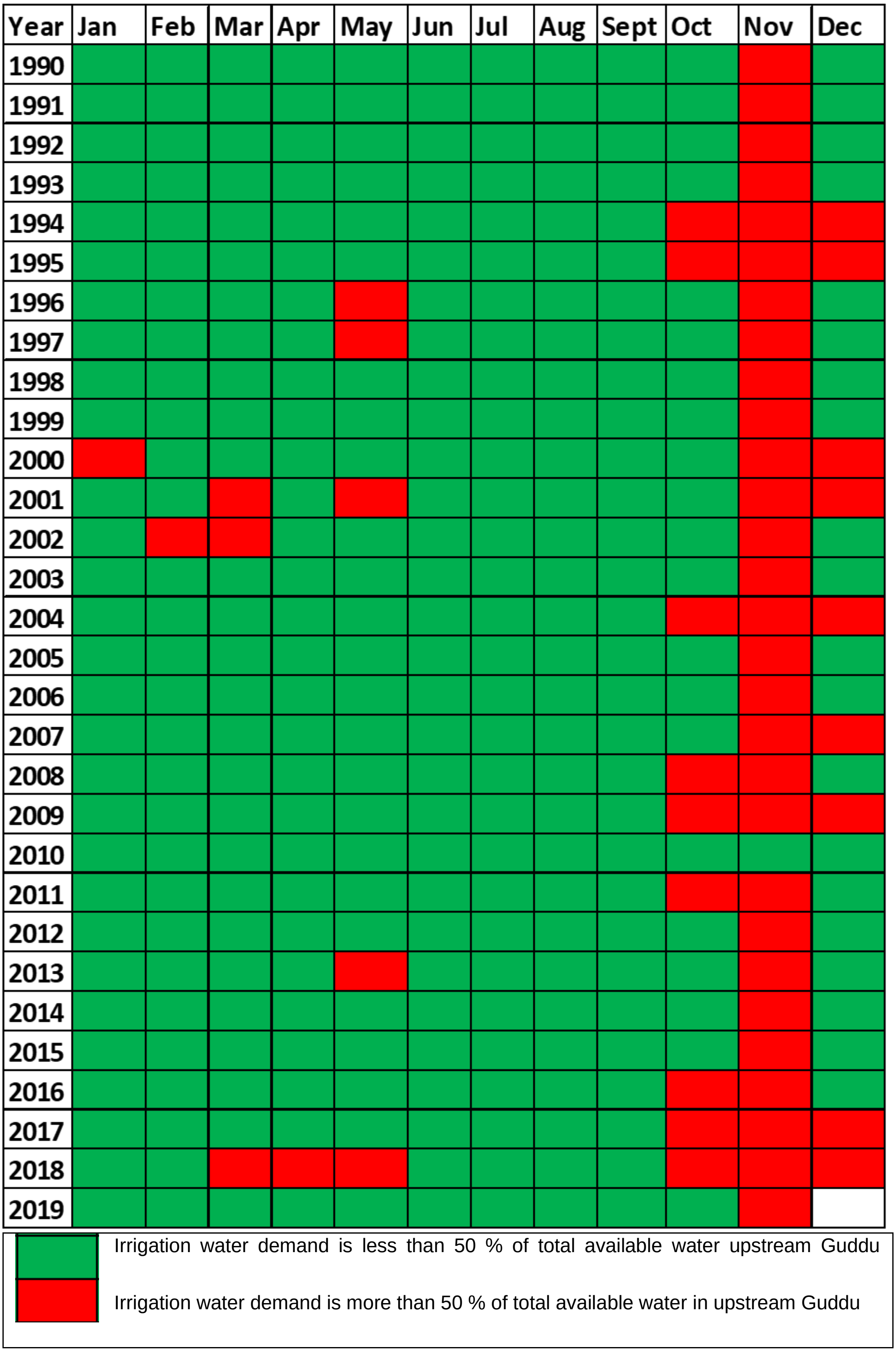
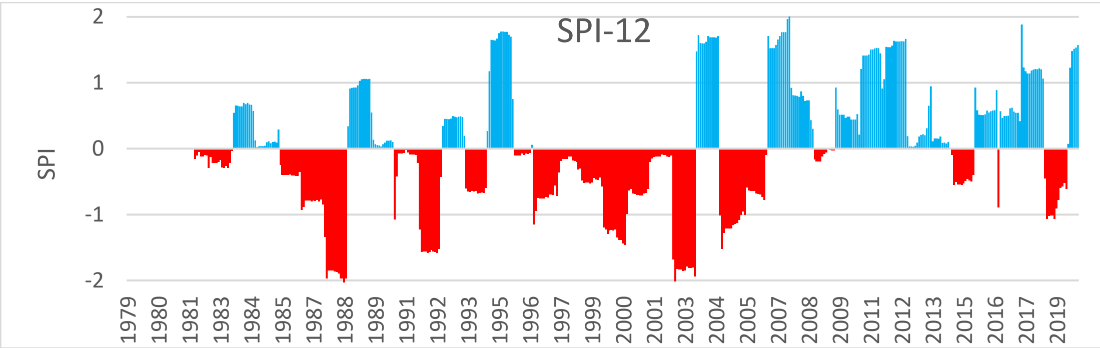
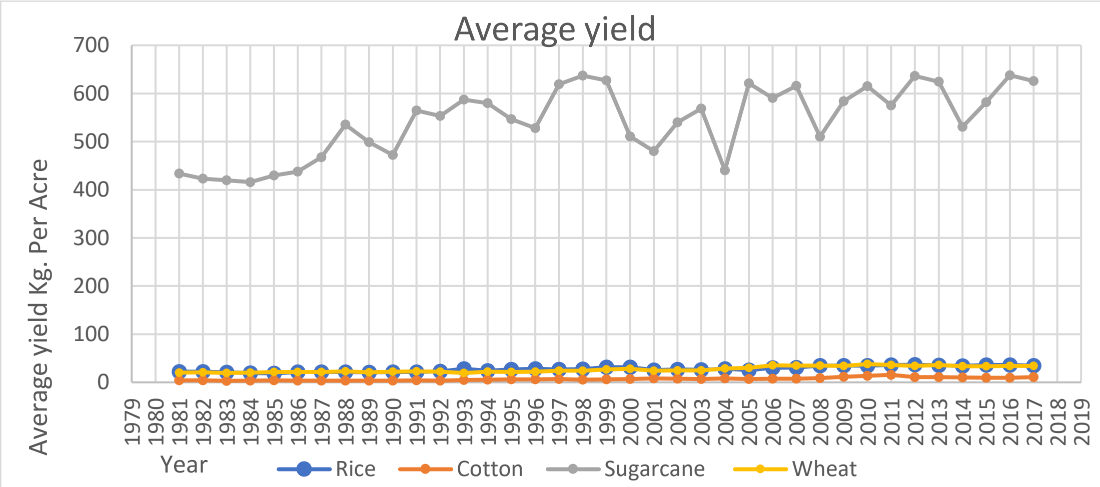
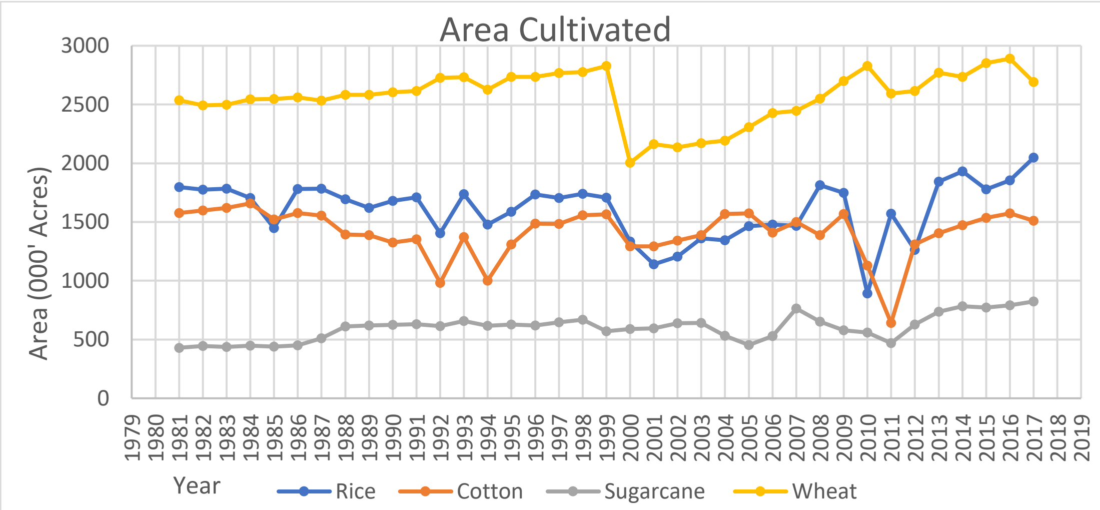


Figure 3-6 Monthly Availability of Demanded Irrigation Water Demand in Sindh Irrigation District

3.4. AGRICULTURE AREA, PRODUCTIVITY, AND YIELD SITUATION







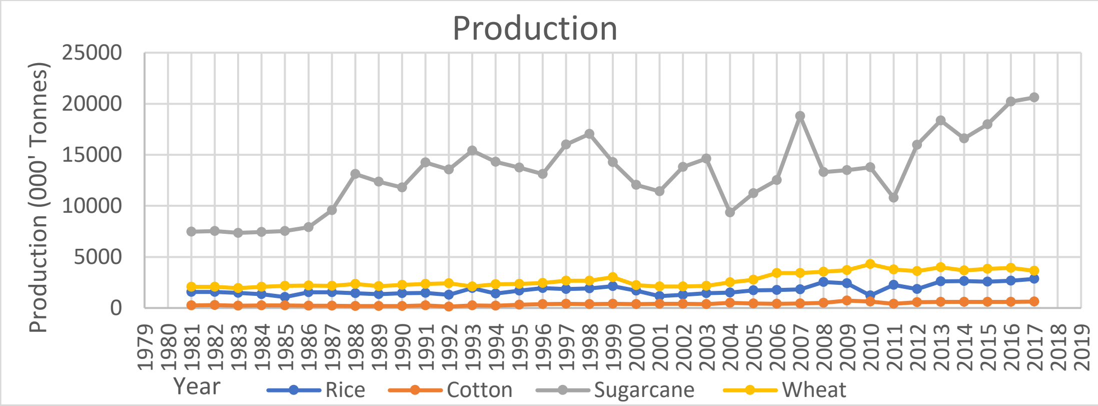


Figure 3-7 Trend of Area, Productivity, And Yield of Wheat in Sindh Province.

Figure 3-6 Show the statistic of area, productivity, and yield of wheat, sugarcane, cotton, and rice in Sindh Province. And, Table 3-2. Area and production of major crops in Sindh during severe drought period the reduced water supply in the Indus basin canal system has caused major reductions in area and production of major crops. The combination of drought and reduced irrigation water supply had a negative effect on crop production. Reductions in area during 2000–2001 and 2001–2002, in comparison with 1998–1999, have ranged from 5 to 35% and those in production from 19 to 40%. Reductions are particularly high in rice, Wheat and sugarcane.

Table 3-2 Area and Production of Major Crops in Sindh.

Crop	1998-1999		1999-2000 % change over 1998-1999		2000-2001		% change over 1998-1999		2001-2002		% change over 1998-1999	
	Area	Pro	Area	Pro	Area	Pro	Area	Pro	Area	Pro	Area	Pro
Wheat	2777	2675	2	12	2003	2227	-28	-17	2163	2101	-22	-21
Sugarcane	669	17051	-12	-29	595	11416	-11	-33	639	13798	-5	-19
Cotton	1557	363	1	11	1294	364	-17	0	1294	416	-17	14
Rice	1740	1930	-2	10	1335	1682	-23	-13	1139	1159	-35	-40

Area in 000' Acres and Production in 000' Tonnes

3.5. SOCIOECONOMIC IMPACT OF DROUGHT

Historically, Sindh's contribution to Pakistan's GDP has been between 30% to 33%. Its share in the service sector has ranged from 21% to 27.8% and in the agriculture sector from 22% to 28%. Major crop of the Sindh district are wheat, sugarcane, cotton, and rice. From meteorological, hydrological and agriculture drought and longest duration of 12-month drought event occur is 84 is in year 1995 to 2003 based on meteorology in same duration we can clear see the drop in agriculture productivity in major crops by 11 to 54%. As 30% of GDP depends on Sindh province that to approx. 25% obtain from agriculture sector the reduction in productivity due to drought has caused severe reduction in growth of percentage growth of Pakistan annual percentage growth rate of GDP per capita based on constant local currency in year 1997 to 2003 is clearly show in Fig 3.7. have negative percentage change in GDP is case due to extreme drought in that duration. Furthermore, in Fig 3.8 we can observed that trend of growth in GDP in not constant rising trend it starts decreasing from year when severe or extreme drought event occurs.

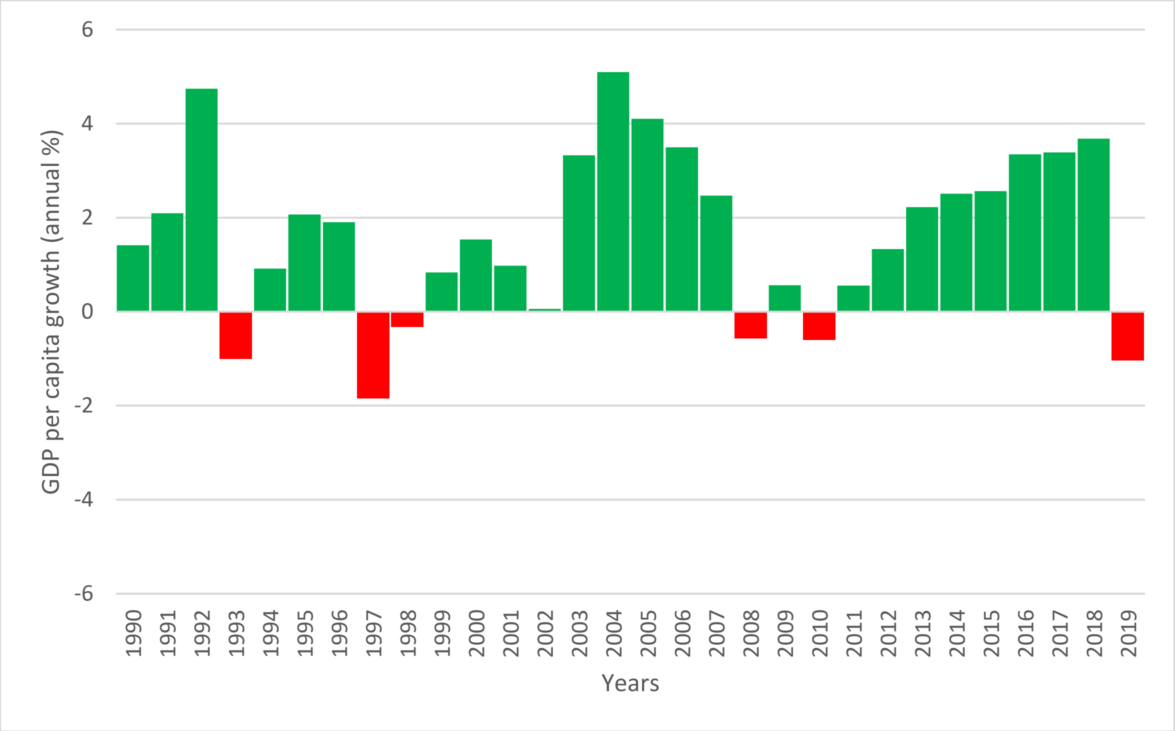


Figure 3-8 Annual Change in Percentage Growth Rate of GDP per Capita Based on Constant Local Currency in Pak.

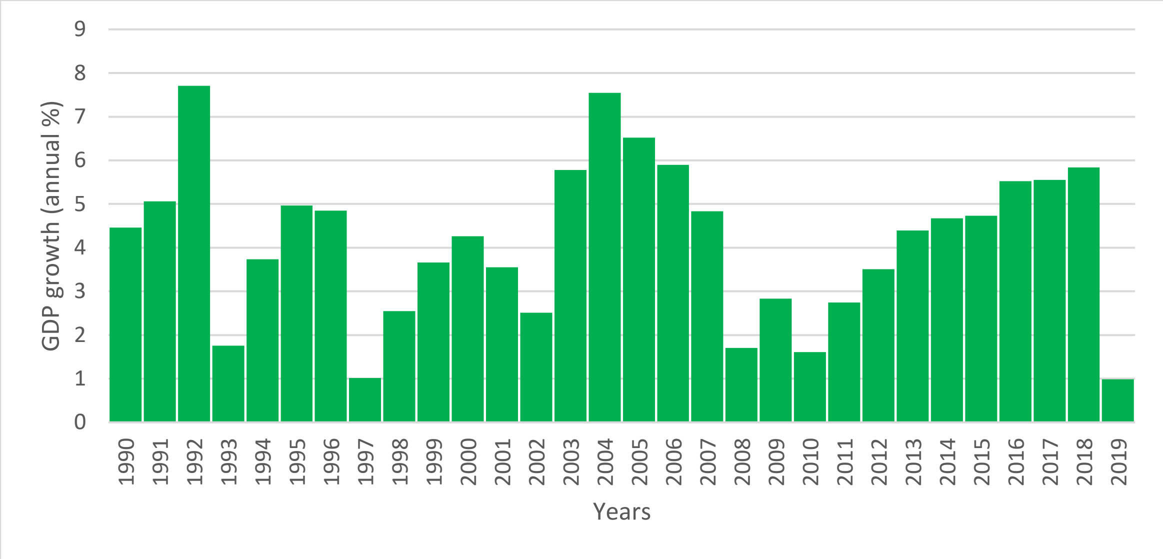


Figure 3-9 Annual Percentage Growth Rate of GDP Per Capita Based on Constant Local Currency in Pak.

4. FLOOD RISK CHARACTERIZATION

4.1. BACKGROUND

During flood emergencies, assessment of the extent of flooding, flood impact and resultant needs of the affected communities is essential for flood relief coordination. Depending on the severity of a flood and the level of preparedness in the affected area, this assessment has to be carried out under extraordinary circumstances, involving a variety of chaotic conditions, contingencies and time pressures. Due to chaotic circumstances and mounting public pressure, immediate estimates are usually drawn arbitrarily. These immediate assessments later provide the basis for reconstruction planning and decisions on flood management policy reform. Nevertheless, certain basic principles can be observed to avoid too unrealistic estimates and resulting repercussions.

The importance of assessing potential flood impact becomes evident when policy makers try to strike an optimal balance between the development needs of a particular area and the level of flood risk society is willing to accept. In this context, flood impact become a vital element in assessing the net benefits society can derive from using flood plains. This involves balancing overall benefits, such as access to land that is relatively easy to exploit for economic activities in various sectors, space for settlement, fertile alluvial soils for agriculture, and readily available navigation links, against the expected flood impact. Both positive and negative factors are assessed for the same timeframe.

Estimation of potential damage needs to be assessed governmental and non-governmental agencies for effective mitigation of direct impacts of hydro-metrological disasters to aid decision making for resource allotment for mitigation. Physical examination of each damage structure is human resource intensive and sometimes operationally not feasible within the time frame available. Traditional approaches for damage assessment are based on field visits to gather information using surveys, discussions, and photographs for preliminary evaluation. However, to acquire comprehensive information, considerable time and human resources are required depending on the extant and severity of the losses and damage in the area affected. Therefore, there is need to develop improved robust approaches for preliminary flood damage assessment which are less time and labor intensive.

In the Indus Basin, the major source of flooding is monsoonal rains, followed by the size, shape, and land-use of the catchments, and by the conveyance capacity of the corresponding streams.

From 1950 to 2011, 22 major floods in Pakistan's Indus River Basin killed a total of 11,481 people, affected 148,683 villages, and caused a cumulative direct economic loss of about $19.045 billion. Indirect losses that were not quantified included health hazards, land and water quality degradation, temporary disruption of transport, and the slowing down of economic growth. Following is the list of major floods in Indus Basin including damages;

Table 4-1 Flood Damage in the Indus Basin, 1950–2011

Year	Direct losses ($ million)	Lost Lives	Affected Villages	Flooded Area (km^2)
1950	227	2,910	10,000	17,920
1955	176	679	6,945	20,480
1956	148	160	11,609	74,406
1957	140	83	4,498	16,003
1959	109	88	3,902	10,424
1973	2,388	474	9,719	41,472
1975	318	126	8,628	34,931
1976	1,621	425	18,390	81,920
1977	157	848	2,185	4,657
1978	1,036	393	9,199	30,597
1981	139	82	2,071	4,191
1983	63	39	643	1,882
1984	35	42	251	1,093
1988	399	508	100	6,144
1992	1,400	1,008	13,208	38,758

Year	Direct losses ($ million)	Lost Lives	Affected Villages	Flooded Area (km²)
1994	392	431	1,622	5,568
1995	175	591	6,852	16,686
1998	Na	47	161	na
2001	Na	201	na	na
2003	Na	230	na	na
2010	10,056	1,600	na	38,600
2011	66	516	38,700	9,098

Sources: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2006. Flood Protection Plan, 2006. Islamabad; M.S. Sardar, M. A. Tahir, and M. I. Zafar. 2008. Poverty in Riverine Areas: Vulnerabilities, Social Gaps and Flood Damages. Pakistan Journal of Life and Social Sciences. 6 (1). pp. 25–31.

Table 4-2 Flood Damage by Sector and Region, 2010 ($ million)

Flood Damage by Sector			Flood Damage by Region		
Sector	**Damage**	**%**	**Region**	**Damage**	**%**
Agriculture and livestock	5,045	50.2	Balochistan	620	6.2
Education	311	3.1	FATA	74	0.7
Energy	309	3.1	Gilgit- Baltistan	49	0.5
Environment	12	0.1	Khyber Pakhtunkhwa	1,172	11.7
Finance sector	674	6.7	National	1,095	10.9
Governance	70	0.7	Northeast Pakistan	86	0.9
Health	50	0.5	Punjab	2,580	25.7
Housing	1,588	15.8	**Sindh**	**4,380**	**43.6**
Irrigation and flood protection	278	2.8			
Private sector and industries	282	2.8			
Transport and communications	1,328	13.2			

Flood Damage by Sector			Flood Damage by Region		
Sector	**Damage**	**%**	**Region**	**Damage**	**%**
Water supply and sanitation	109	1.1			
Total	**10,056**				

FATA = Federally Administered Tribal Areas.

Note: Percentages may not total 100% because of rounding.

Source: ADB, Government of Pakistan, and the World Bank. 2010. Pakistan Flood 2010. Preliminary Damage and Needs Assessment Report. Islamabad, Pakistan.

4.2. HISTORICAL FLOOD EVENTS

As per EM-DAT (global database on natural and technological disasters), Sindh province has received 30 hydro-metrological disasters in last 20 years, out of which 25 events was associated with flood and tropical cyclones and rest associated with extreme temperature. Flooding events in 2010 and 2011 made significant impact on livelihood and economy of province.

Table 4-3 Major Flooding Events and their Impact

Year	Disaster Type	Disaster Subtype	Total Deaths	No Injured	No Affected	No Homeless	Total Affected	Total Damages ('000 US$)
2003	Storm		51	57		2500	2557	
2003	Flood	Riverine flood	230	456	1265767		1266223	
2003	Flood	Riverine flood						
2005	Flood	Riverine flood	42	20	58000		58020	
2005	Flood	Riverine flood	39		460073		460073	
2006	Flood	Riverine flood	74	50		5000	5050	
2006	Flood	Riverine flood						
2007	Storm	Tropical cyclone (Yemyin)	242		1650000		1650000	1620000
2007	Flood	Riverine flood	228	186			186	
2007	Flood	Flash flood	44	20			20	327118

Year	Disaster Type	Disaster Subtype	Total Deaths	No Injured	No Affected	No Homeless	Total Affected	Total Damages ('000 US$)
2009	Flood	Riverine flood	52	70			70	
2010	Storm	Tropical cyclone (Phet)	23		4000		4000	80000
2010	Flood	Flash flood	1985	2946	20356550		20359496	9500000
2011	Flood	Riverine flood	509	755	5400000		5400755	2500000
2012	Flood	Riverine flood	480	2902	5046462		5049364	2500000
2013	Flood	Riverine flood	234	855	1496870		1497725	1500000
2015	Flood		238	232	1572191		1572423	
2016	Flood	Flash flood	32			2900	2900	
2016	Flood		10					
2016	Flood		22	60	2900		2960	
2017	Flood	Flash flood	167	167	2200		2367	110000
2019	Flood	Flash flood	64	71	800		871	
2019	Flood		26	4			4	
2019	Flood		16					

4.3. TIME SERIES ANALYSIS

Sindh has an arid climate and mostly prone to prolong droughts with an occasional extreme precipitation events that leads to flooding. Historically, Sindh has experienced the worst prolong droughts extending over a couple of years (1968–69, 1971–74, 1985–87, and 1999–2002). The major source of precipitation is summer monsoon (June – September) in Sindh as shown in monthly average precipitation derived from ECMWF and CHIRPS.

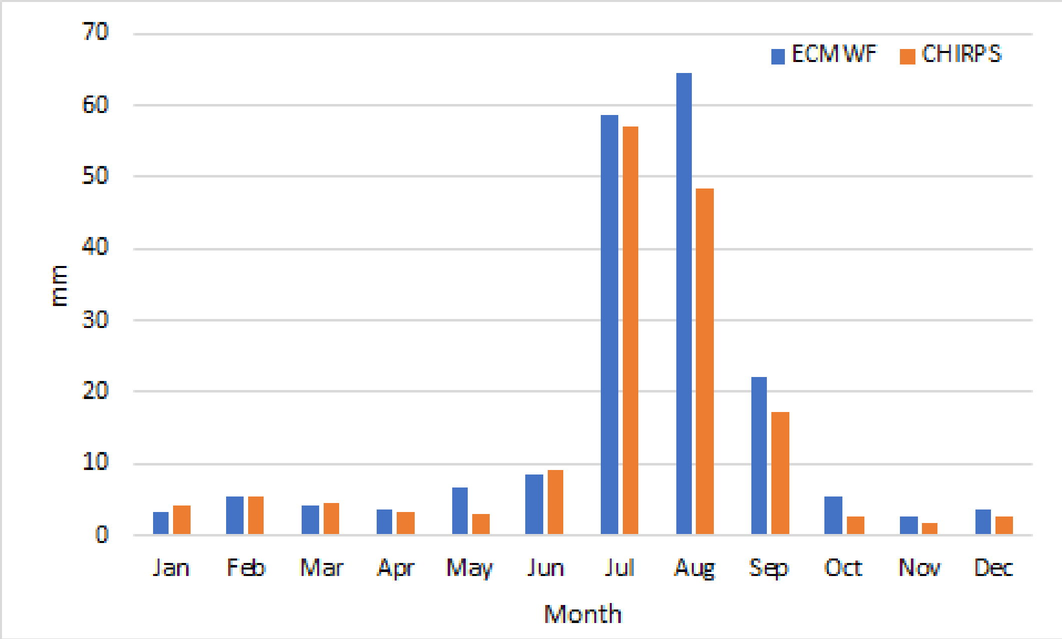


Figure 4-1 Monthly Average Precipitation (1981-2019), ECMWF and CHIRPS

The months of May and June are generally named as a pre-monsoon period, and the duration from October to November as a post-monsoon period. Interannual time series plot of average merged satellite-gauge precipitation (mm/ month) estimates derived from GPM is shown in figure. Extreme precipitation events have complex and non-uniform spatial patterns during monsoon in Sindh. It was found that mean monthly rainfall was uniform for winter (DJF: December, January and February) season and summer season (MAM: March, April and May) whereas precipitation in other two seasons (JJA: June, July and August/ SON: September, October and November) found to be non-uniform and complex.

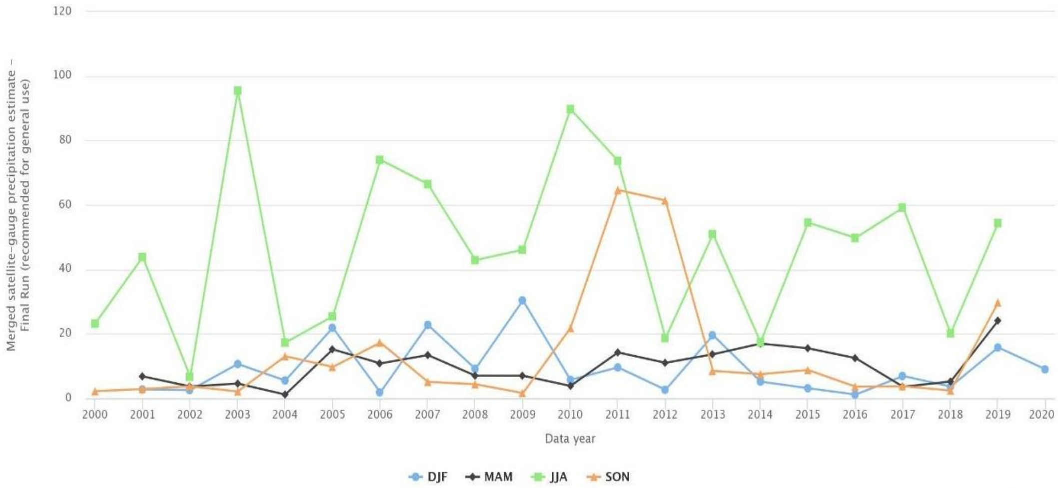


Figure 4-2 Seasonal Precipitation (mm/month) from GPM (IMERG) for Sindh, Pakistan

Seasonal precipitation (mm/ month) from GPM (IMERG) of Sindh, Pakistan (Figure 4-2) shows the mean monthly climatic characteristics of the region from 1981-2019. Annual precipitation plots derived from ECMWF and CHIRPS shows increasing trend of precipitation. These plots depict occurrence of extreme precipitation events in year 2003, 2010, 2011 and 2019. It is still complex and unclear to identify future extreme precipitation event due to non-uniform and complex pattern.

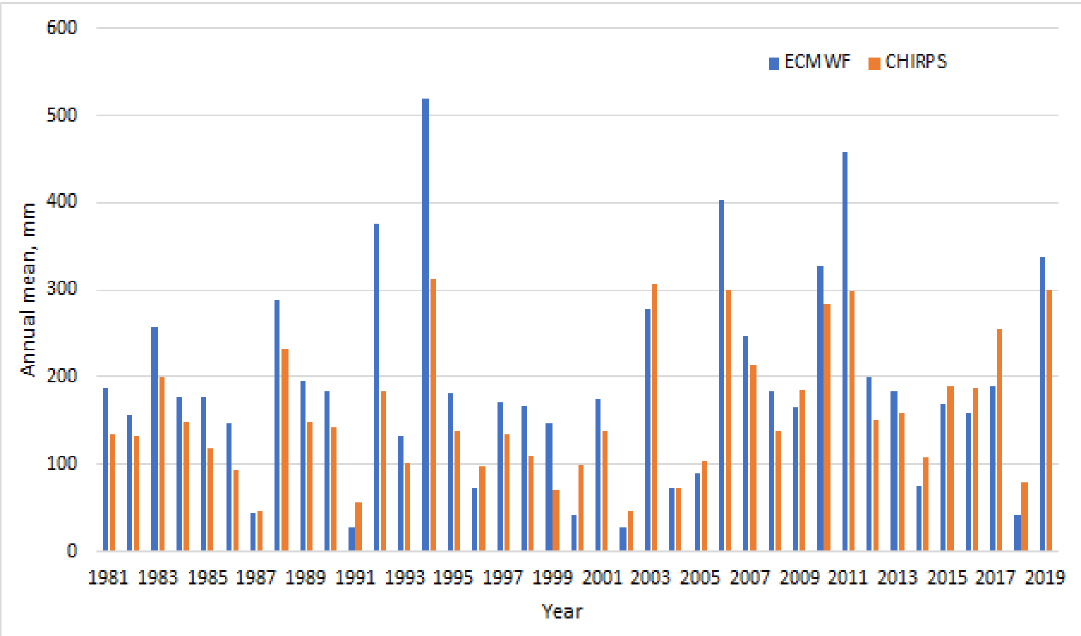


Figure 4-3 Annual Precipitation from ECMWF and CHIRPS Data of Sindh, Pakistan

Sindh receives precipitation mostly during summer monsoon from June to September, which fulfills the need of water for irrigation. But, Sindh is becoming wetter and experience more intense precipitation events (>100 mm/day) than before during monsoon, which causes urban flooding almost every year (Zahid and Rasul, 2011).

4.4. PRECIPITATION ANOMALY

The hydro-meteorological data used for the analysis included rainfall (July–August) and flood discharges at barrages. Since March 2014, the Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrievals for GPM (IMERG) has provided satellite precipitation estimates across the globe. Using gridded surface precipitation data derived from local rain gauges as a reference, this study evaluated the performance of IMERG in depicting the spatial-temporal characteristics of precipitation variations over Sindh at multiple (including annual, seasonal, intra-seasonal, diurnal and semidiurnal) timescales. The analysis focused on the period of 2000-2019. Figure 4-4 shows the temporal evolution of the 20-year (200 to 2019) mean monthly precipitation area-averaged over Sindh (hereafter Sindh precipitation) and estimated by the seasonal IMERG data of June. July August (JJA).

Throughout the entire study, the seasonal precipitation anomalies of June, July, and August (JJA) were obtained by removing the seasonal (JJA) mean value of 20 year from the seasonal (JJA) precipitation of every year. The red color in plot shows precipitation below mean, whitish color shows precipitation equivalent or near to mean and blueish color shows precipitation above mean. Following observations are made from spatial distribution of precipitation anomalies of Sindh: IMERG is able to qualitatively depict many features of the changes in Sindh rainfall. Excess precipitation has been observed in 2006, 2007, 2009, 2010, 2011, 2013 and 2017. In year 2003, excess precipitation was distributed more on coastal and downstream areas rather than upstream areas. This flood was due to combined effect of high discharge at Guddu barrage and excess precipitation. In year 2006, excess precipitation was limited to central and North-southern part of Sindh. This flood was also due to combined effect of discharge and excess precipitation.

The 2010 flood in Indus started in July and continued till early September following heavy rainfall in the upper catchment. Analysis of the rainfall data published by Pakistan Metrological Department suggests that the rainfall at many stations in NWFP, Punjab, and Sindh regions during the month of July and August of 2010 was much higher than the monthly averages at these locations. As a result of such extreme rainfall, the Indus carried very high discharge during this period and flow at several barrages along the Indus, namely Taunsa, Guddu, Sukkur, and Kotri barrages, not just exceeded the discharges at danger levels (typically bankfull levels) but also came very close to ‘designed capacity’ (defined as the maximum discharge that is likely to pass through the barrage for a given probability of occurrence) for the barrages.

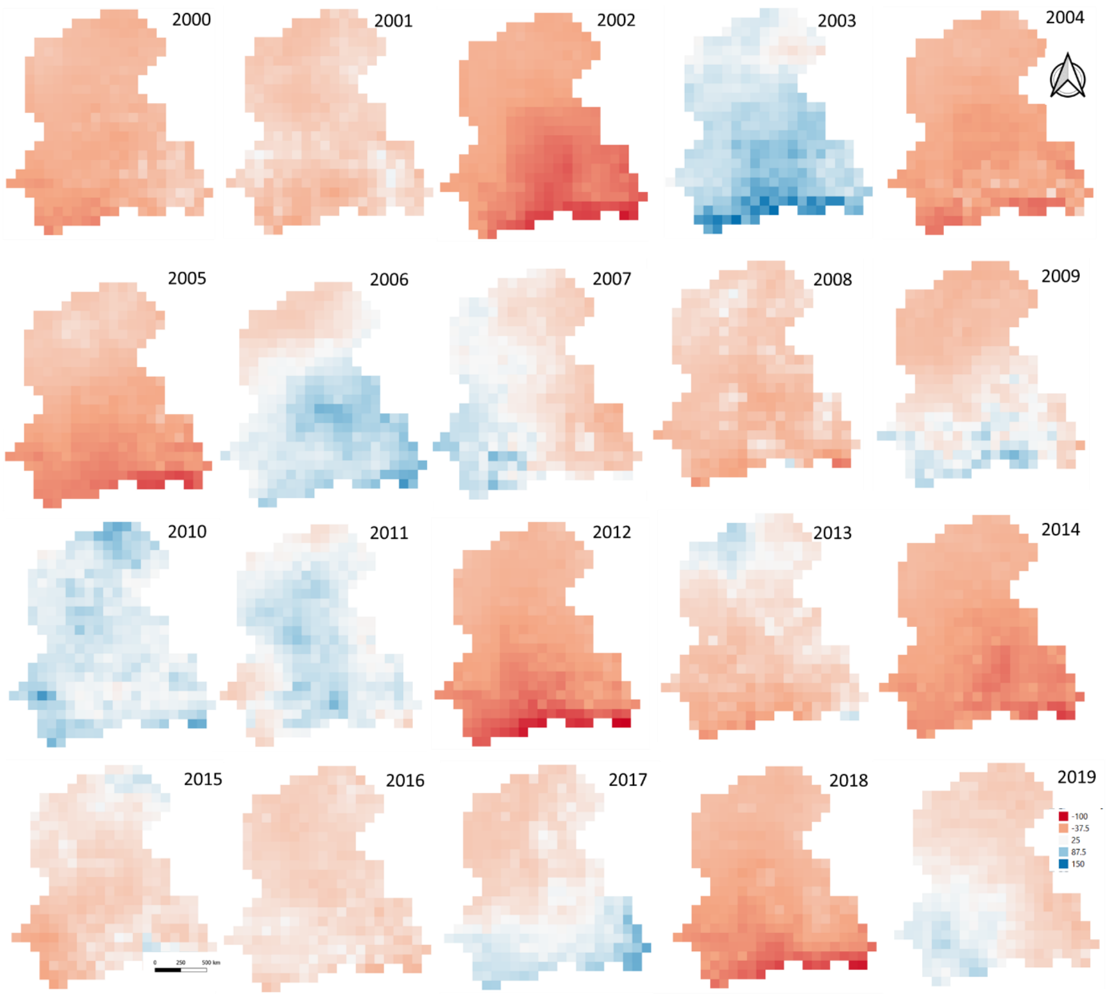


Figure 4-4 Precipitation Anomalies of June, July and August of Sindh, Pakistan

In the month of July, Pakistan received below-normal monsoon rains. However, in August and September, the country received above-normal monsoon rains. A strong weather pattern entered Sindh and adjacent areas from the Indian states of Rajasthan and Gujarat in August. The strong weather gained strength and resulted in heavy downpours. The four weeks of continuous rain had created an unprecedented flood situation in Sindh.

In 2017, flash flood was observed. In a 24-hour period between 31 August 2017 to 01 September 2017 Karachi recorded 83 mm of rain. This excess precipitation was majorly distributed on coastal areas of Sindh.

In 2019 flood, Pakistan Meteorological Department (PMD) data showed that Karachi recorded 129.40mm of rain in 24 hours to 11 August and 51mm the next day. Elsewhere in the province, Badin recorded 93.4mm in 24 hours to 11 August and Thatta 142mm during the same period.

4.5. FLOOD OCCURRENCE

Major floods in the Sindh province happened in 1994, 2003, 2006, 2010, 2011, 2013 and 2017. In some cases, due to a lack of cloud-free images in these years, leading to under-estimation of flood inundated area. Later years have sufficient image coverage. This is mainly due to improvement in technology, and the availability of Sentinel satellite images.

Interpretation of satellite images available for the Sindh Region results in maps showing timing, frequency and occurrence of flooding. Based on globally available datasets (https://data.jrc.ec.europa.eu/collection/id-0054) the map of frequency of inundation is given in Figure 4-5.

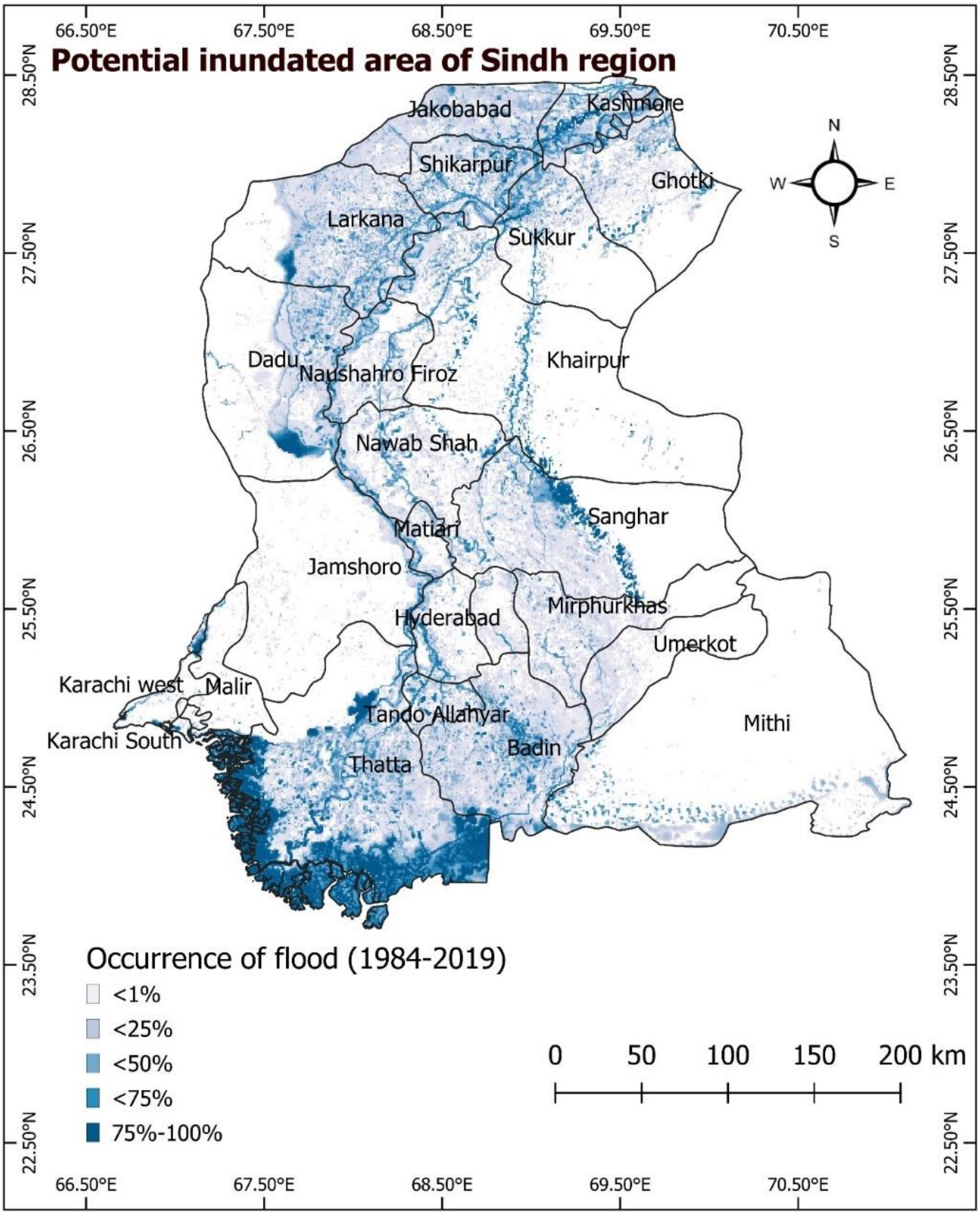


Figure 4-5 Potential Inundated area Sindh Region

The JRC Monthly Water History (V1) was used in this study. The dataset contains monthly layers of the location and temporal distribution of surface water from 1984 to 2015. The data contains information on (0) no data, (1) not water and (2) water. The flood frequency for any given period is calculated by dividing the number of water observation by total number of observation where no data is not taken into account. All available Landsat data in the JRC tool as historical occurrence contain valuable information on the probability of occurrence. Pixels with high water occurrence values are marked as permanent water. Based on the aggregated annual JRC data, the flood occurrence map of Sindh was generated. The flood recurrent map indicates that the areas located near to Indus River and coastal areas in southern portions of Sindh were the most affected by flood events in the past 16 years.

4.6. RAINFALL INTENSITY

Floods are often caused by intense rainfall events. Areas experiencing the highest amounts of rainfall are more susceptible to flooding. Daily rainfall data available on Google Earth Engine (GEE) was analyzed within the GEE cloud computing platform to derive the average of maximum annual rainfall per year from 1984 to 2019. It is found that south and south-eastern potion of Sindh receive more instance rainfall.

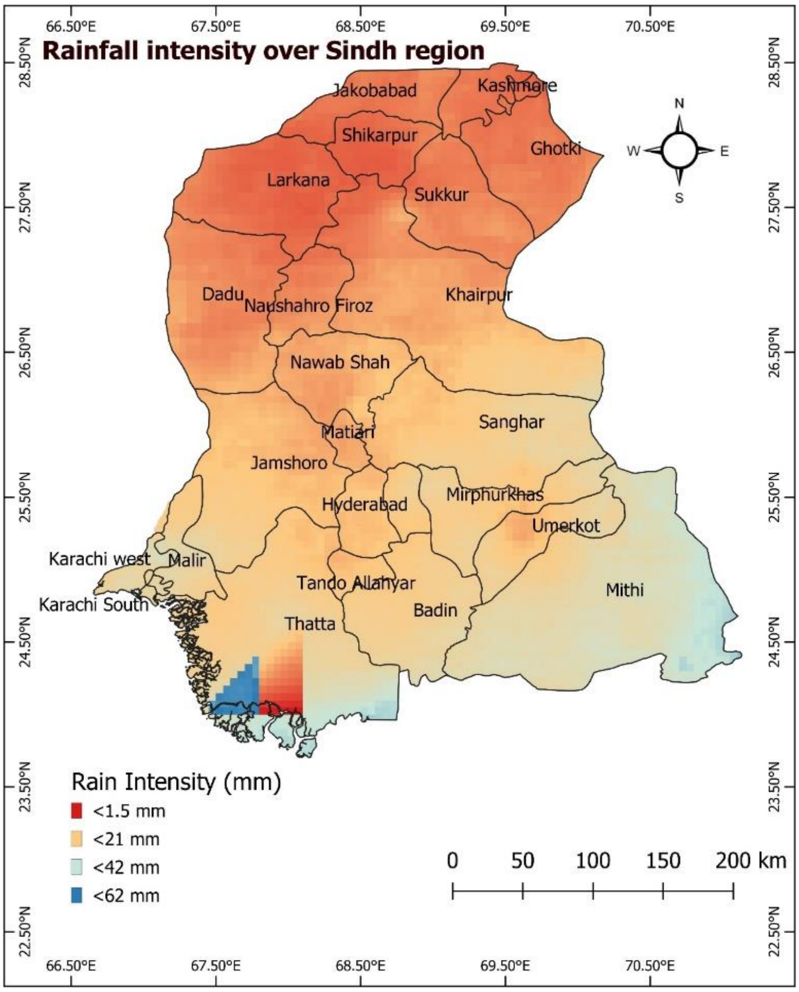


Figure 4-6 Spatial Distribution of Rainfall Intensity (mm)

4.7. RAINFALL DURATION

Floods are often caused by intense rainfall events. Areas experiencing long periods of rainfall are more susceptible to flooding Daily rainfall data available on GEE was analyzed within the GEE cloud computing platform to derive an average of the longest period of consecutive days of rainfall per year from 1984 to 2019. It is found that south-eastern potion of Sindh receives average of 5 days of consecutive rainfall.

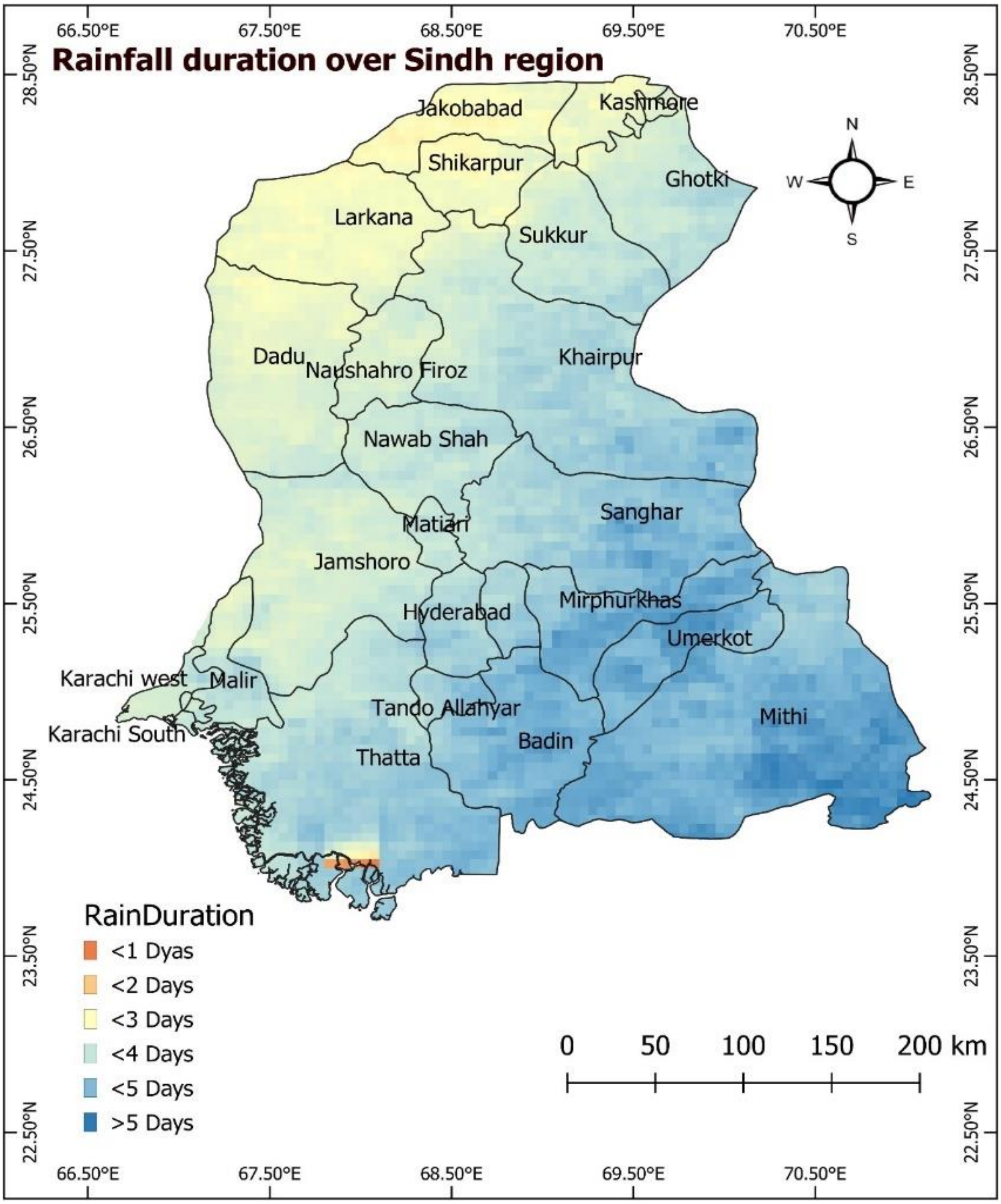


Figure 4-7 Spatial Distribution of Rainfall Durations (Days)

4.8. DISCHARGE DATA ANALYSIS

Historical maximum and minimum discharge data of the Guddu barrage stations from 1984 to 2019 were analyzed to understand the temporal variation of maximum and minimum flow. Analyses of historical discharge data from 1985 to 2019 showed that the volume of water rises after April and reaches its peak in August as shown in . Discharge of the the Guddu barrage stations over the last 35 years has been decreasing. Boxplot diagram shows plot of mean annual discharge (upstream) for Guddu barrage station from 1984 to 2019. It shows that August month receives maximum discharge (Figure 4-9).

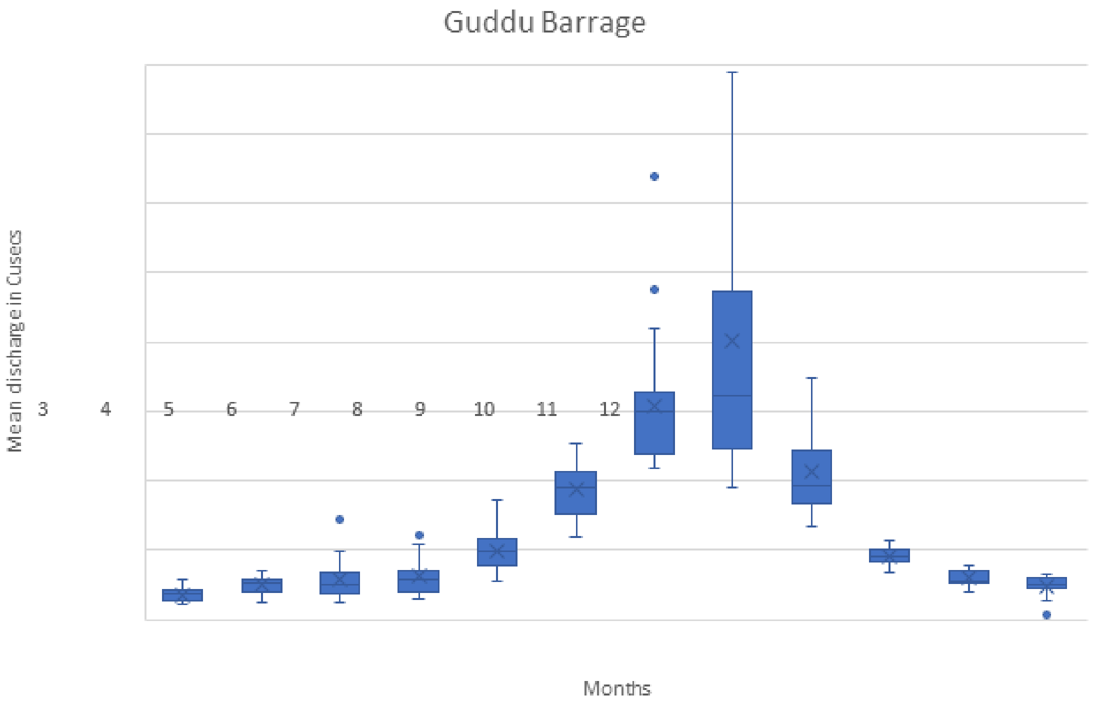
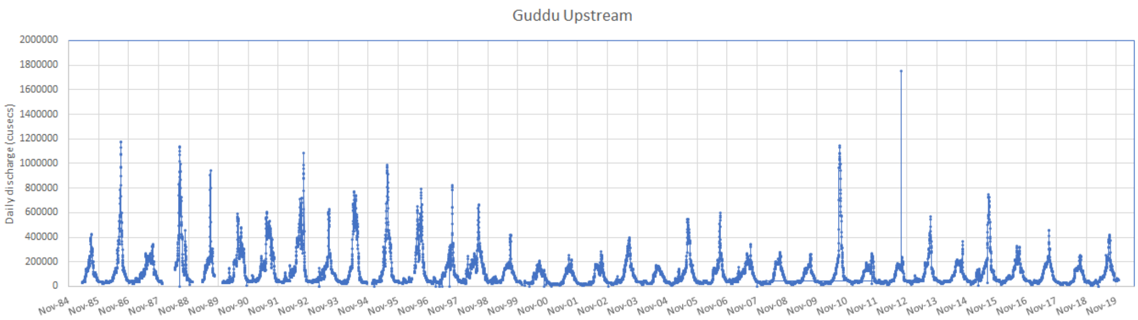


Figure 4-8 Mean Discharge at Guddu Barrage



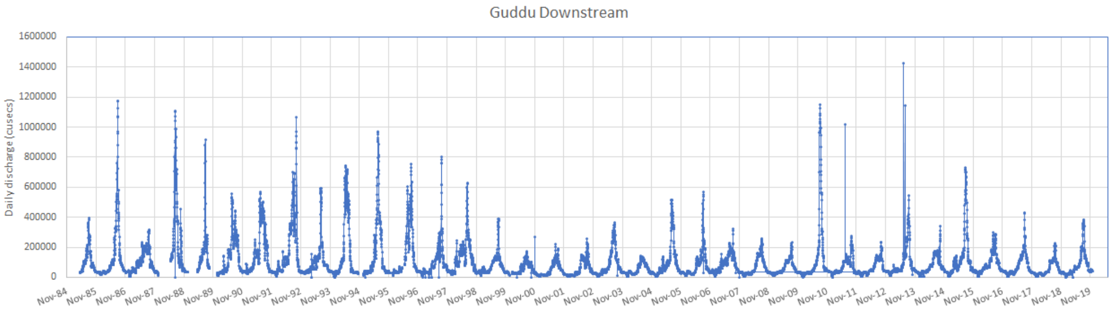


Figure 4-9 Upstream and Downstream Flow at Guddu Barrage

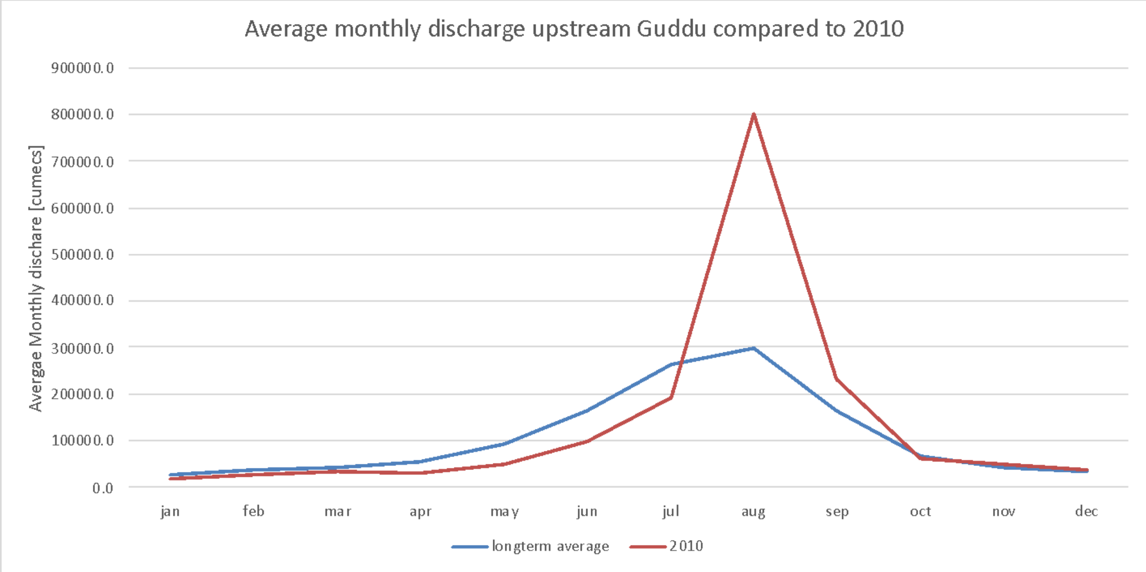


Figure 4-10 Overview of 2010 Discharge Versus Average Year (Upstream Guddu Barrage)

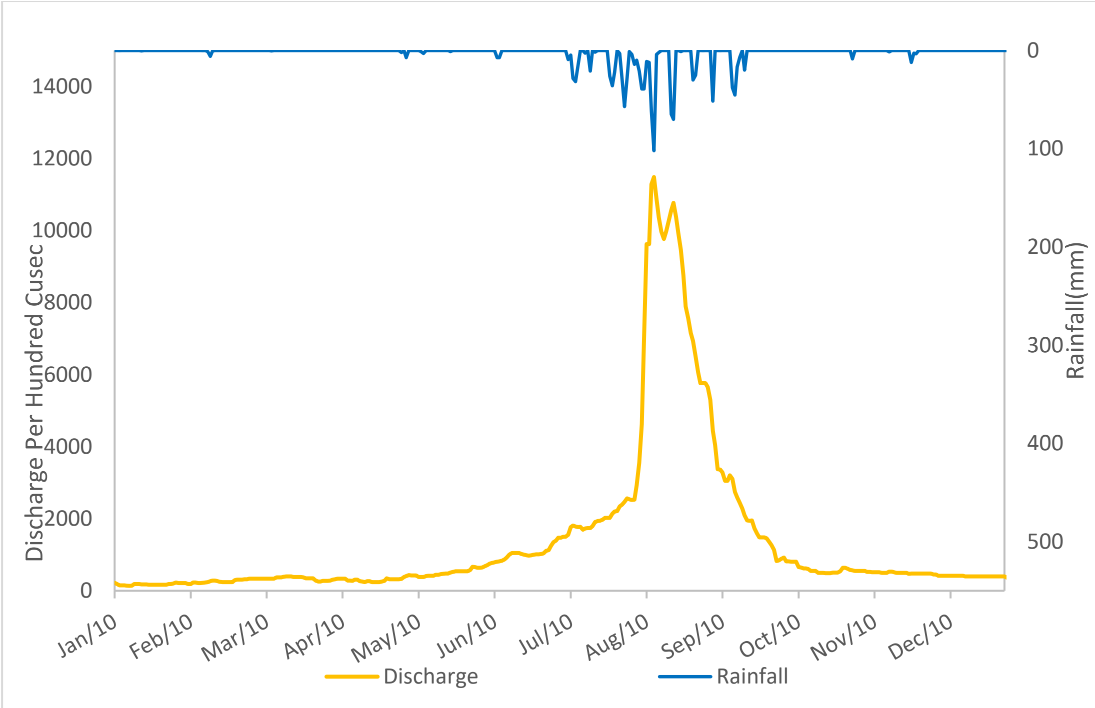


Figure 4-11 Rainfall Discharge Relationship in Year 2010

4.9. FLOOD FREQUENCY ANALYSIS

Accurate and reliable estimation of extreme events[68], i.e. meteorological and hydrological, is useful for the flood risk, optimum design and management of water related activities. Changes in the climate cycle and the need of water with growing population index resulted in a demand of more accurate estimates of rainfall for the regions having scarcity of freshwater resources. Pakistan is a country having fairly large population, agriculture based economy and high vulnerability index to natural disasters, i.e. extreme floods and rainfall.

Sindh is the second largest province of Pakistan on the basis of its contribution to agricultural progress of the country (Government of Sindh, 2014). Due to the scarcity of rainfall in this region, the need for rainfall frequency analysis becomes intensively integral part of decision making in agriculture water management. Furthermore, as a need of time it is vital to introduce popular techniques for the estimation of rainfall quantiles not only at gauged sites but also at ungauged sites (the sites with no observed data) of the region.

[68] Fletcher, Tim D., Herve Andrieu, and Perrine Hamel. "Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art." Advances in water resources 51 (2013): 261-279.

The flood frequency (return period) analysis was carried out to predict the occurrence of discharge of Guddu barrages through analysis of hydrologic statistics.

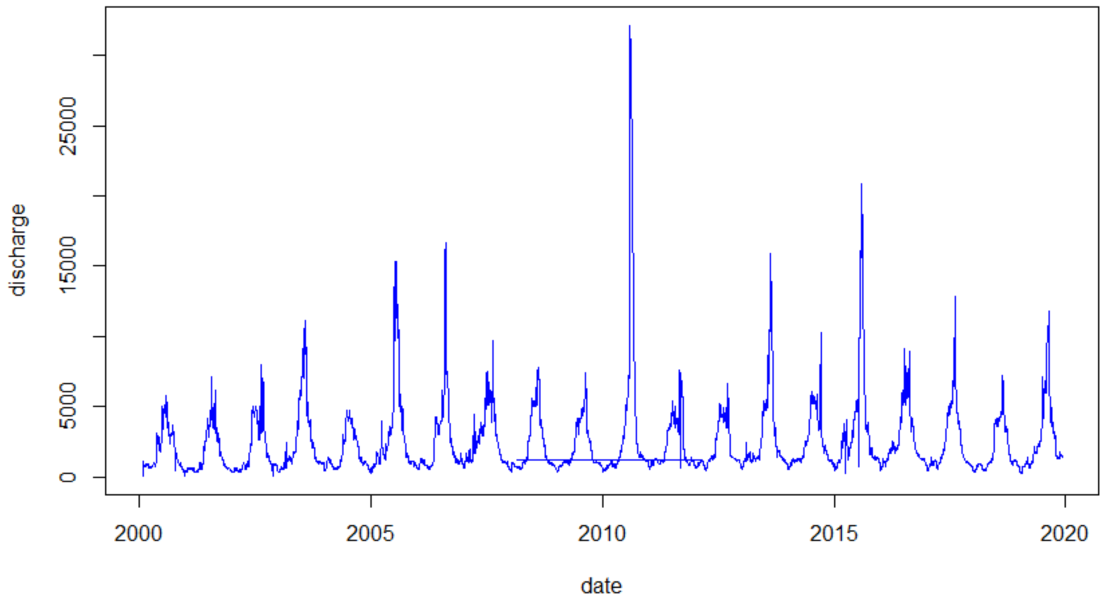


Figure 4-12 Monthly Variation of Flood Peaks Flow (cumecs) at Guddu Barrage.

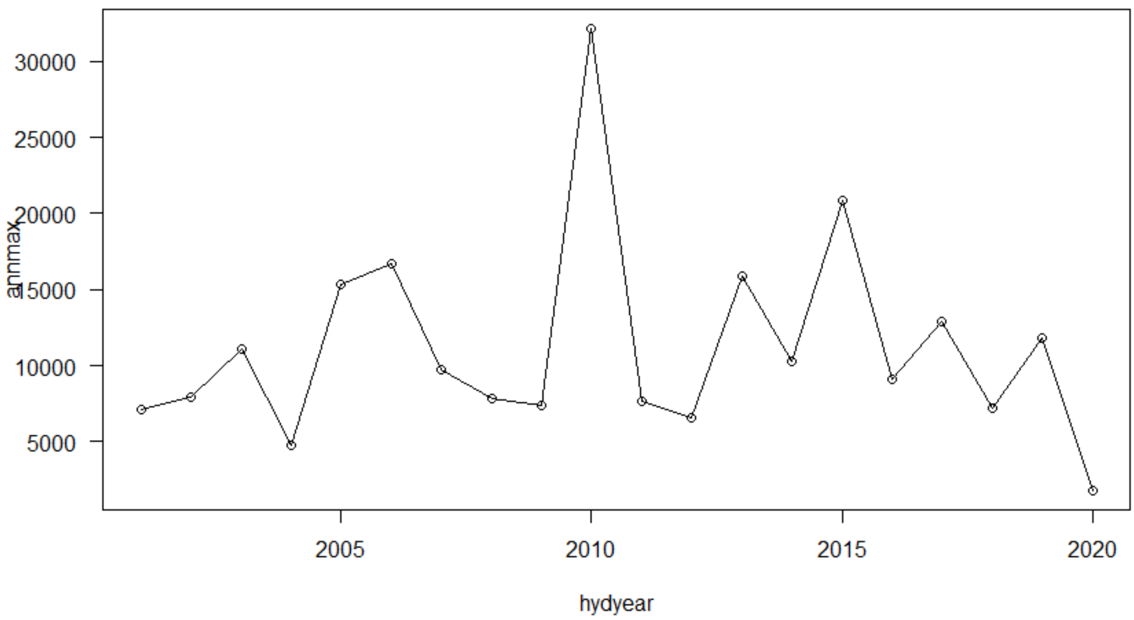
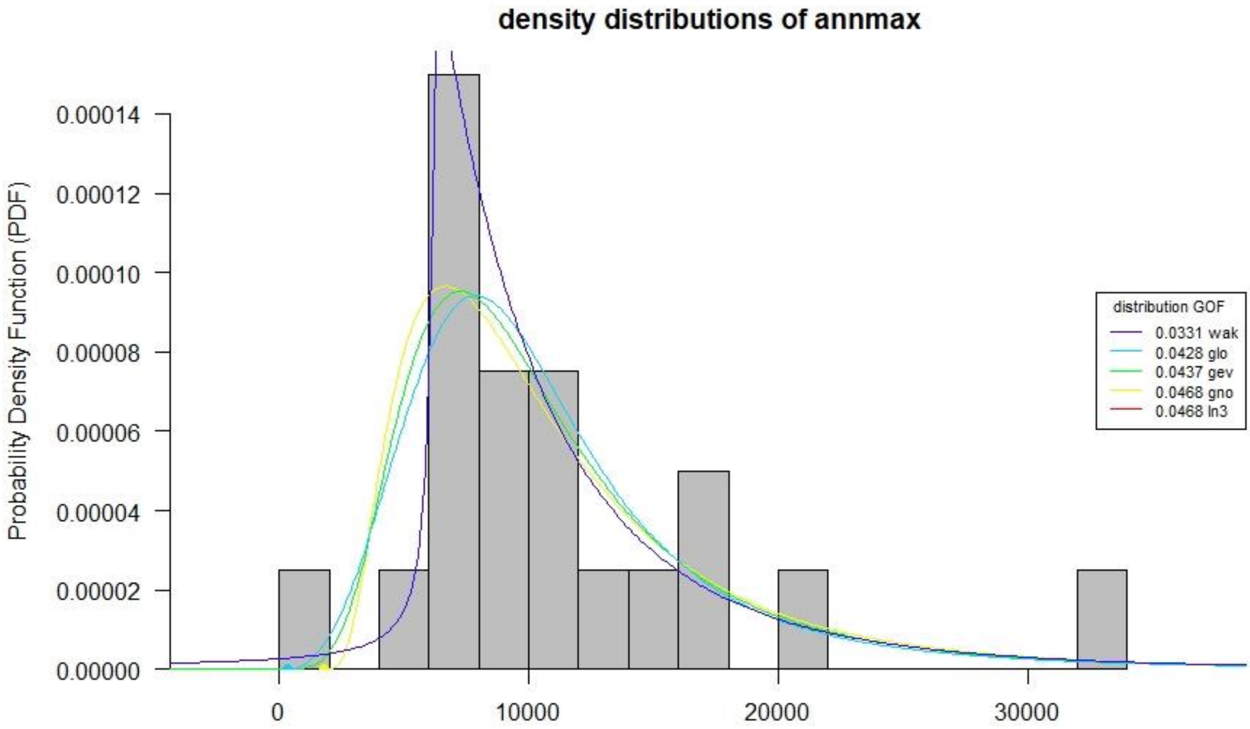


Figure 4-13 Annual Variation of Flood Peaks Flow (cumecs) at Guddu Barrage.

The major variation in the historic discharge at Guddu barrage from 2000 to 2020 was seen in 2010. The maximum flow is 33165 m3 /s on 9th August 2010 was observed at Guddu barrage. The erratic supper flood occurred at Guddu barrage with discharge 33165 m3 /s in 2010 while the design discharge of Guddu barrage is 31150m3 /s. It was observed that it is difficult to pass erratic supper floods which occurred due to climate change and became cause of occurrence of breaches and overtopping the embankments at upstream of barrage. Therefore, huge area of Sindh came under destruction of structural and non-structural developed which cause billions of US$ loss in country.

Based on the probability density graphs, we can assume that the Generalized Pareto and Wakeby distributions are most likely to fit the best, while the Lognormal distribution fits poorly. Regional flood frequency analysis has been carried out for estimating peak discharge at regional level over the Sindh province, along with at-site flood frequency analysis. A number of L-moments-based frequency distributions (i.e., generalized logistic (GLO), generalized extreme value (GEV), generalized Pareto (GPA), generalized normal (GNO), Generalised Normal (LN3), and 5-parameter Wakeby (WAK) distribution) have been used in order to find a suitable distribution for quan-tile estimates. it was found that the WAK, GNO, and GEV could provide the most accurate extreme rainfall estimates. However, the GEV could be recommended as the most suitable distribution due to its theoretical basis for representing extreme-value process and its relatively simple parameter estimation.



Probability density graphs

Results shows that return period of flood Guddu barrage, one in hundred years' event might occur 39662 m3 /s has been estimated for one in fifty years' event the discharge rate could be 32663 cm3 /s. For one in twenty years' event the flood discharges could be 19263 m3 /s and one in ten years' event the discharge could be 14572 m3 /s by using Wakeby (WAK) distribution method and the design discharge of Guddu barrage is 31150 m3 /s.

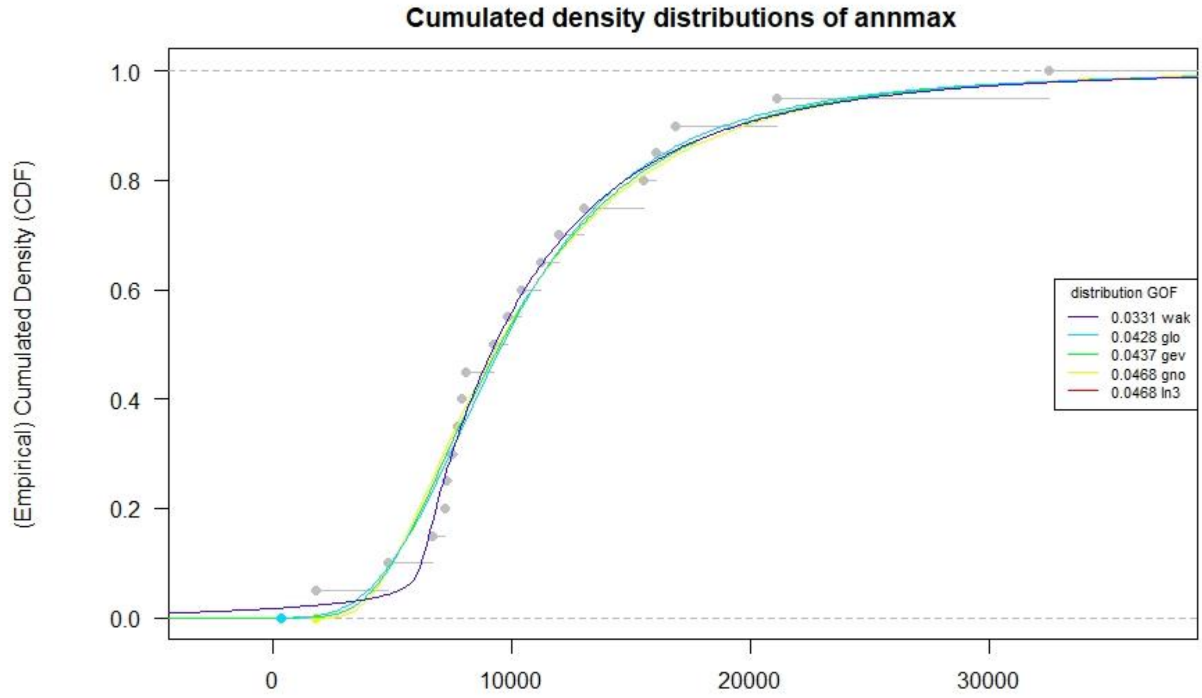


Figure 4-14 Flood Frequency Curves of Wak, GLO, GEV, GNO and ln3 for Guddu Barrage

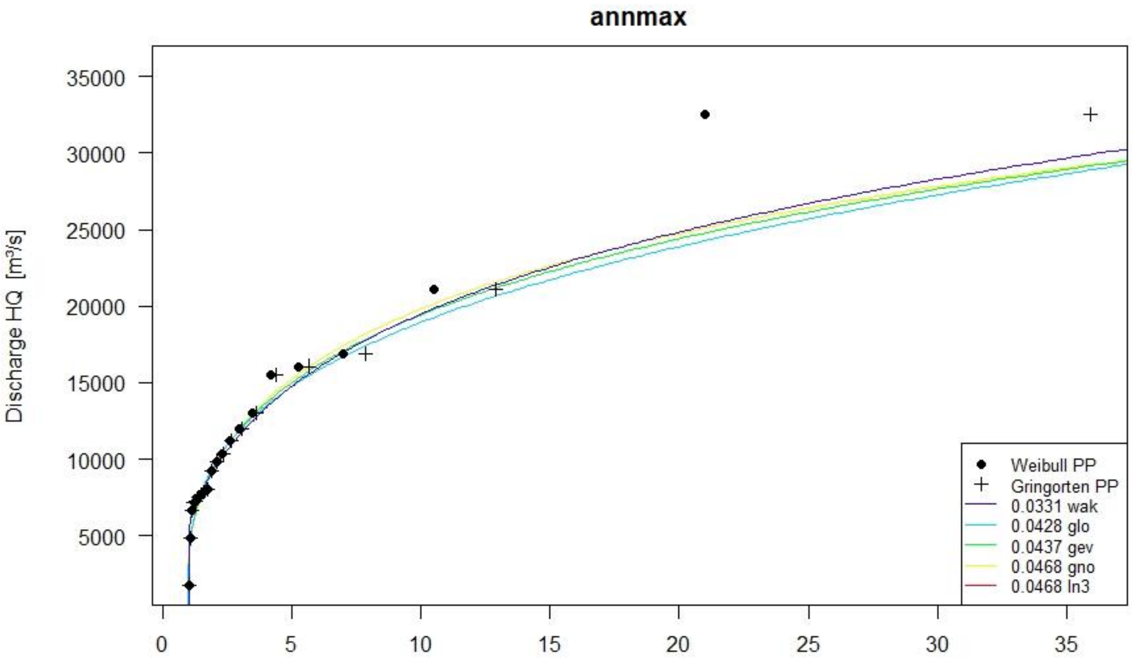


Figure 4-15 Logarithmic Plot with Many Fitted Distribution Functions

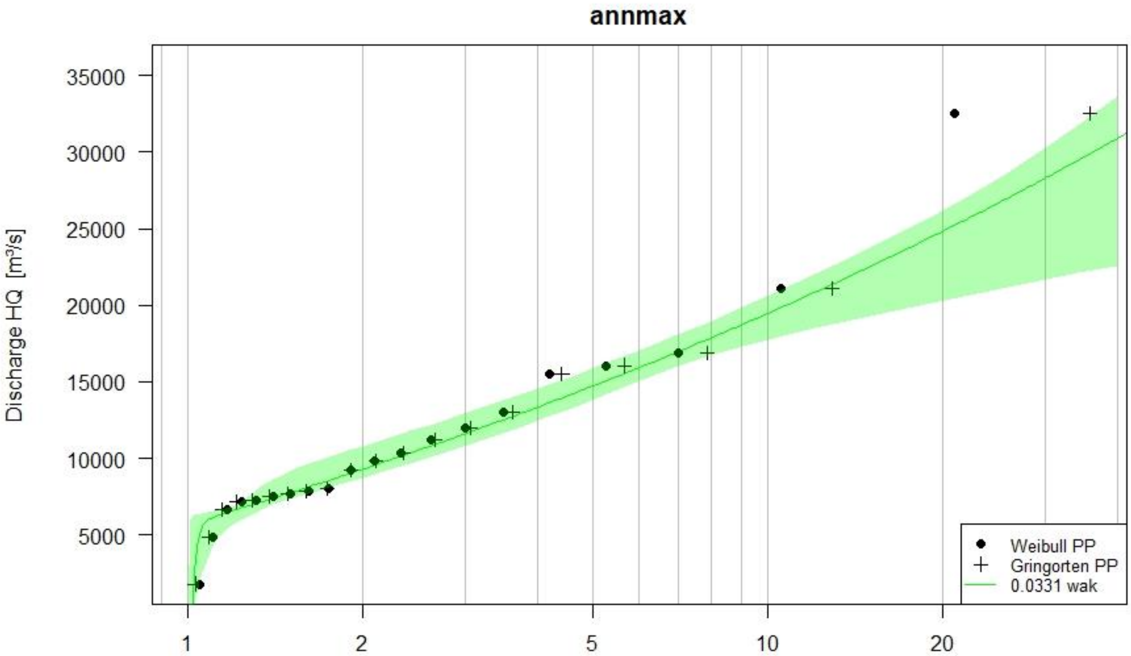


Figure 4-16 Peak Discharge Analyses at Various Return Period

Table 4-4 Estimated Discharge at Various Return Period

Method	RP.5	RP.10	RP.50	RP.100
wak	14737	19481	33003	40111
glo	14723	18933	32120	40033
gev	14984	19420	32111	38988
gno	15221	19805	31915	37900
ln3	15221	19805	31915	37900
lap	13726	16879	24200	27354
pe3	15654	20361	31162	35783
wei	15683	20391	31101	35646
exp	15579	20409	31623	36453
gpa	15746	20485	30993	35315
gam	16096	19951	28039	31311
gum	15970	19742	28044	31553
rice	16222	19404	25292	27441
ray	16465	19805	25985	28241
nor	16530	19246	24015	25698
revgum	16626	18426	21090	21910

Flood frequency analyses are used to predict design floods along a river. The technique includes using observed yearly peak flow discharge data to calculate statistical information. Rated curve (or stage-discharge curve) displays the relationship between the stage (water level) and the displacement of the point on the flow path. The flood frequency curve is a graph showing the relationship between the flood magnitude and the repeated interval of the specified location. Different formulas (e.g. Gumble Formula, Hazen Formula, Blom Formula etc.) were applied and different curves were obtained as shown in Figure 4-17. Based on literature. Best fitted formula was found to be Gumbel formula. We find the peak values of flow after 2 years, 5 years, 10 years, 15 years and 100 years return period.

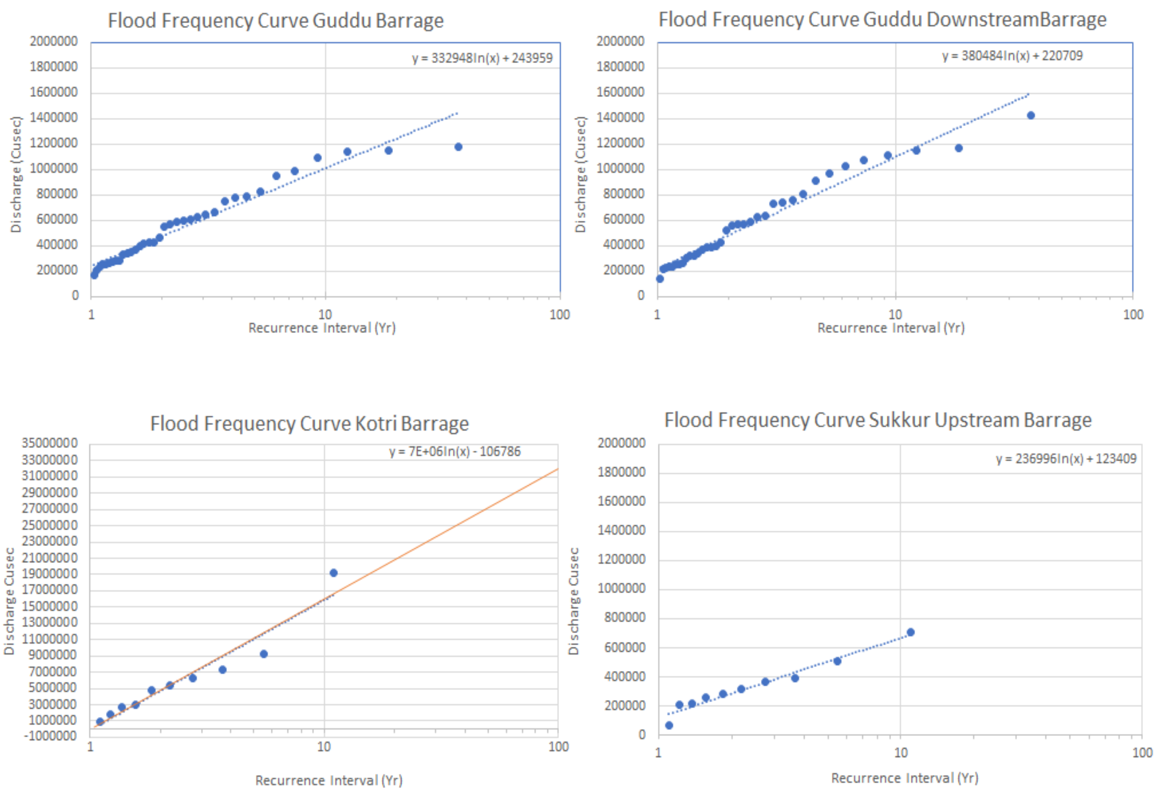
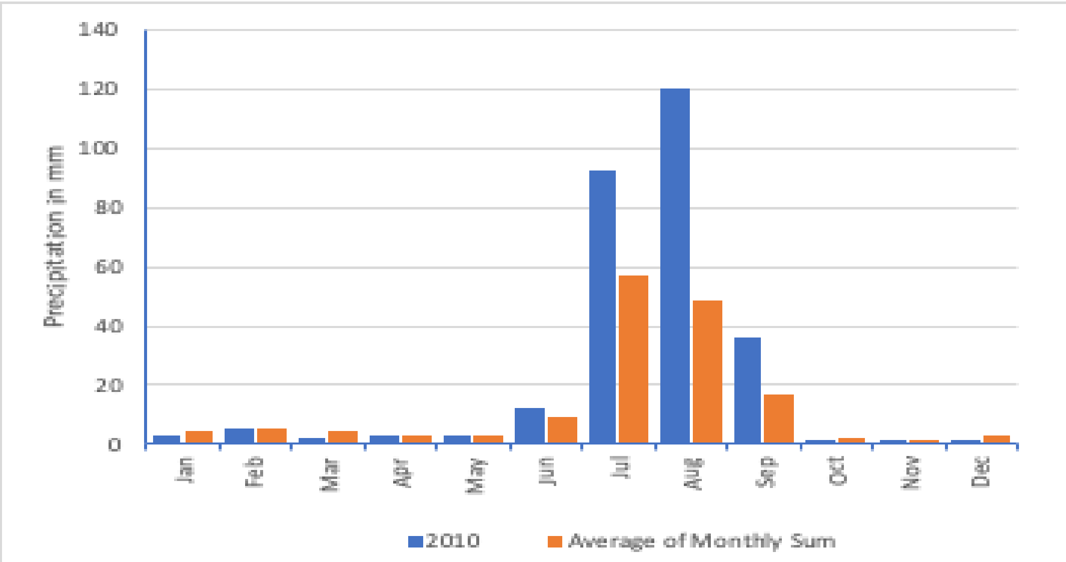


Figure 4-17 Flood Frequency Curves for The Barrages

In general, four mechanisms are at work to cause floods in the Sindh. Combinations of various degrees of intensity of these mechanisms will yield a flood situation in the Sindh region: Upstream discharge (discharge at Taunsa, and Panjnad Barrage), entering the Sindh Irrigation District as upstream discharge at Guddu barrage. Local precipitation in the Sindh region, resulting in local inundation or congested drainage. The function, capacity, management and operation of the Indus irrigation and drainage channels, eventually resulting in overloading the channels in the Sindh Irrigation System. Stability and overtopping levels of embankments. Instability or overtopping results in inundation of protected and low-lying areas.

4.10. FLOODS OF AUGUST - NOVEMBER 2010

In 2010, heavy and spatially uneven rainfall during the monsoon period resulted in flooding in various parts of Sindh. The hydro-meteorological data used for the analysis included rainfall and flood discharges at barrages. The 2010 flood in Indus started in July and continued till early September following heavy rainfall in the upper catchment. Analysis of the rainfall data published by Pakistan Metrological Department[69] suggests that the rainfall at many stations in NWFP, Punjab, and Sindh regions during the month of July and August of 2010 was much higher than the monthly averages at these locations (Figure 4-18). Total of more than 100 mm of rainfall was recorded in August 2010 in Sindh that was approximately 2.5 times higher than the monthly average.



[69] Gaurav, Kumar, Rajiv Sinha, and P. K. Panda. "The Indus flood of 2010 in Pakistan: a perspective analysis using remote sensing data." Natural hazards 59.3 (2011): 1815.

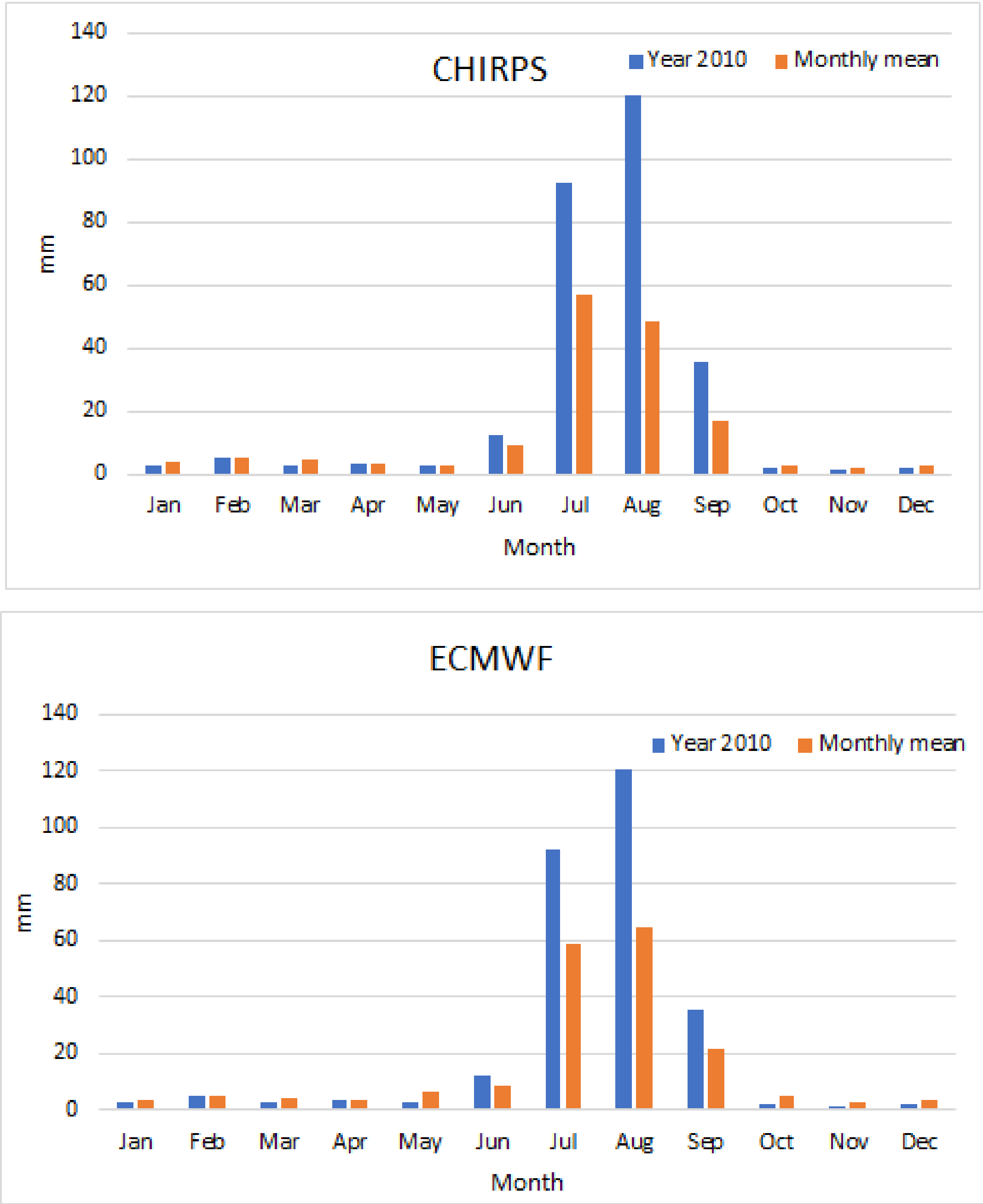


Figure 4-18 Precipitation in 2010 Versus Average Precipitation

As a result of such extreme rainfall, the Indus river carried very high discharge during this period and flow at several barrages along the Indus, namely Guddu, Sukkur, and Kotri barrages, not just exceeded the discharges at danger levels but also came very close to 'designed capacity' (defined as the maximum discharge that is likely to pass through the barrage for a given probability of occurrence) for the barrages. Although it did not cross the designed capacity of 1213571 cusecs. So, from Figure 4-19. it can be inferred that 2010 flood in Sindh was not due to excessive discharge whereas it was due to excess precipitation only.

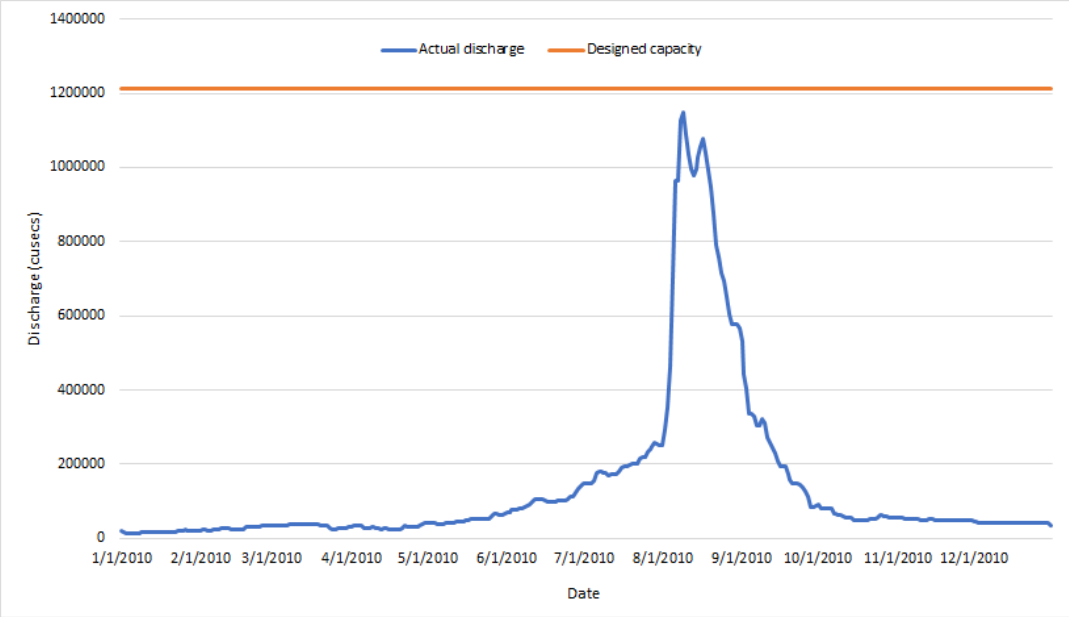


Figure 4-19 Overview of 2010 Discharge Versus Average Year (Upstream Guddu Barrage)

4.10 FLOOD HAZARD MAPPING

Flood hazard assessment and mapping is used to identify areas at risk of flooding, and consequently to improve flood risk management and disaster preparedness. Flood hazard assessments and maps typically look at the expected extent and depth of flooding in a given location, based on various scenarios (e.g. 100-year events, 50-year events, etc.). Measures to improve preparedness can include changes in land-use planning, implementation of specific flood-proofing measures, creation of emergency response plans, etc. Flood hazard assessments can be further expanded to assess specific risks, which take into consideration the socioeconomic characteristics (e.g. industrial activities, population density, land use) of the exposed areas. Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily read, rapidly accessible charts and maps which facilitate the identification of areas at risk of flooding and also helps prioritise mitigation and response efforts (Bapulu & Sinha, 2005)[70]. Flood hazard maps are

[70] Bapulu, G.V. and Sinha, R. (2005) GIS in Flood Hazard Mapping: a case study of Kosi River Basin, India. Noida: GIS Development. Environment Agency (2010)

designed to increase awareness of the likelihood of flooding among the public, local authorities and other organizations. They also encourage people living and working in flood-prone areas to find out more about the local flood risk and to take appropriate action.

This study uses Optical satellite data and draws on the spectral reflectance's within the Green and NIR channels to calculate the NDWI (Normalized Difference Water Index)[71]. The NDWI facilitates the differentiation between water and non-water inundated areas. In the method, a threshold is derived from the NDWI to binarize the image and determine the flood extent. We have identified inundated areas based on the increase in the water index value between the pre- and post-flood satellite images. Values of the Normalized Difference Water Index (NDWI) and Modified NDWI (MNDWI) will be higher in the post-flood image for flooded areas compared to the pre-flood image. Based on a threshold value, pixels corresponding to the flooded areas can be separated from non-flooded areas.

4.11 FLOOD EXPOSURE ASSESSMENT

The exposure assessment[72] for floods provides vital information about the elements and assets, which are located in the areas at risk of flood inundation or the flood hazard prone areas. The information generated from the assessment are important and useful to and decision-makers as basis for plans and interventions on preparedness, early warning, response recovery, and mitigation. In Sindh, floods primarily affect agriculture followed by population, and physical infrastructure such as buildings.

[71] Fisher, Adrian, Neil Flood, and Tim Danaher. "Comparing Landsat water index methods for automated water classification in eastern Australia." Remote Sensing of Environment 175 (2016): 167-182.

[72] Koks, Elco E., et al. "Combining hazard, exposure and social vulnerability to provide lessons for flood risk management." Environmental science & policy 47 (2015): 42-52.

Table 4-5 Data Used for Socio-Economic Impact Assessment

Primary Affected Sectors	Exposer mapping	Data source
Agriculture	Cropland	MCD12Q1.006 MODIS Land Cover Type
Housing	Urban	
Education		
Health		
Population	Population Density	GHSL: Global Human Settlement Layers

4.11.1 Cropland and Urban mapping

The MCD12Q1 V6[73] product provides global land cover types at yearly intervals (2001-2016) derived from six different classification schemes. It is derived using supervised classifications of MODIS Terra and Aqua reflectance data. The supervised classifications then undergo additional post-processing that incorporate prior knowledge and ancillary information to further refine specific classes.

4.11.2 Population mapping

The Global Human Settlement Layers (GHSL)[74] relies on the design and implementation of new spatial data mining technologies allowing to automatically process and extract analytics and knowledge from large amount of heterogeneous data including: global, fine-scale satellite image data streams, census data, and crowd sources or volunteered geographic information sources. This dataset depicts the distribution and density of population, expressed as the number of people per cell, for reference epochs: 1975, 1990, 2000, 2015.

[73] https://lpdaac.usgs.gov/products/mcd12q1v006/
[74] https://ghsl.jrc.ec.europa.eu/datasets.php

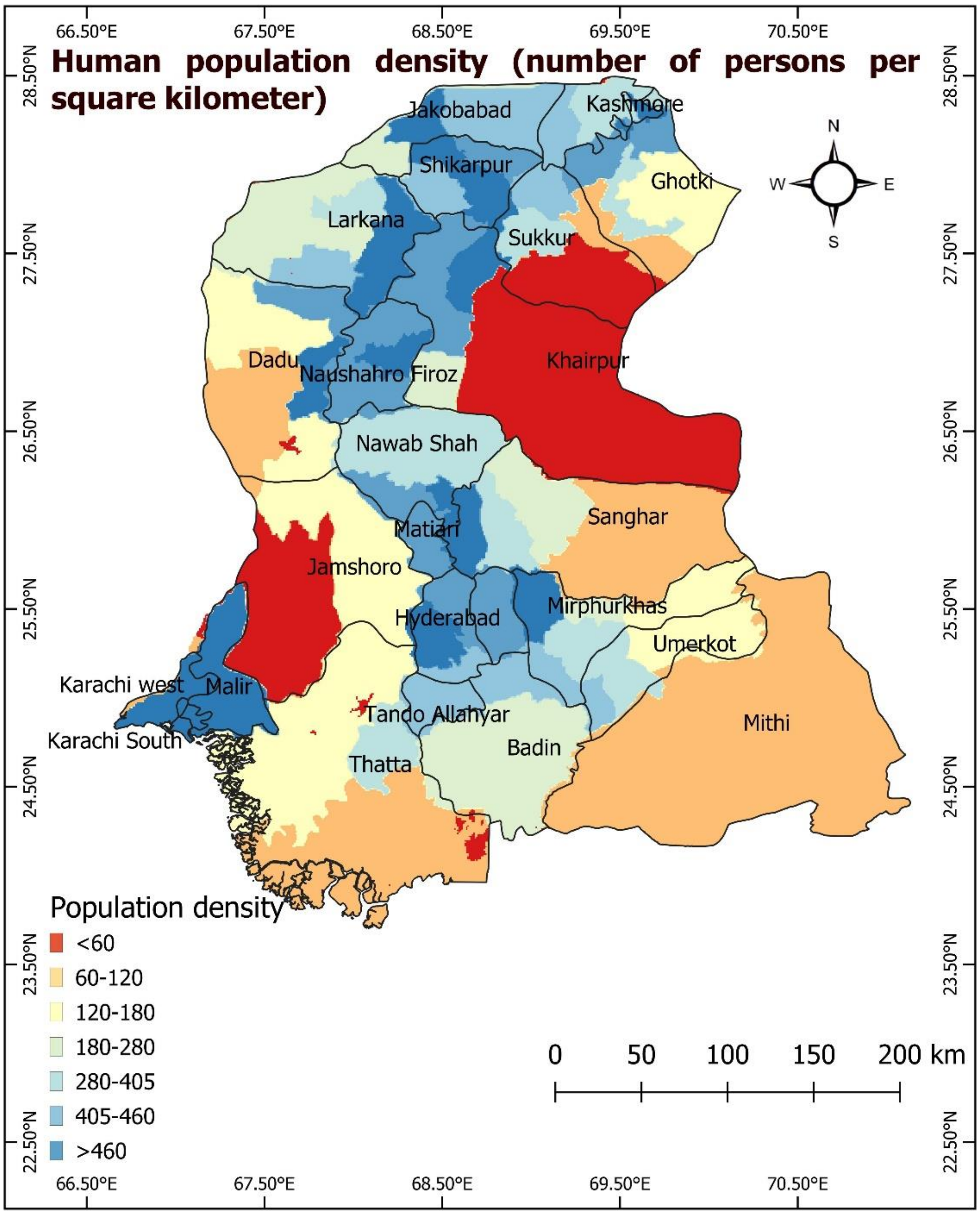


Table 4-6 Population Density Map of Sindh, Pakistan

4.12 SOCIO ECONOMIC IMPACT BY FLOOD

Inundation maps generated for each year was overlaid on the land cover map, in order to analyses potential impact of flood over various land cover classes of Sindh province. Table shows the total area of flooding increase for each evaluated flood event. The 2010 event showed the largest flood extent (about 6354 km^2) and the 2006 event had the smallest extent (about 1555 km^2). The 2012 flood event showed the least amount of flooding in vegetation (about 7% of the total flooding). Floods in Pakistan in 2010 inundated a wide swath of territory, affecting 18 million people and killing approximately 2,000. The impact was particularly severe in Sindh, where rainfall was ten times higher than normal. As per reports, Flooding killed 411 people and around 2.8m were in immediate need of assistance in Sindh. More than two-thirds were concentrated in the three districts included in this study, Sukkur, Shikarpur and Jacobabad. The floods reached their peak in August 2010, shortly after households had harvested their wheat or had taken out loans to finance rice cultivation. 2010 flood was most devastating flood which inundated 41% cropland, 2015 km2 of urba area and 0.9 million people in Sindh province.

Table 4-7 Area (sq.km) of Land Cover Classes Inundated During Flood

Year	Flood Extant	Cropland affected	Urban Affected	Population affected
Unit	Km^2	Km^2	Km^2	Number of people
2017	2466	692	139	470345
2013	4495	1588	7	171697
2011	3944	2028	49	358871
2010	6354	2642	215	898240
2007	1935	1313	7	59163
2006	1555	826	7	94937

Table 4-8 Percentage of Land Cover Classes Inundated During Flood

Year	Flood Extant	Cropland affected	Urban Affected	Population affected
Unit	Km^2	%	%	%
2017	2466	28.06%	5.64%	0.98%
2013	4495	35.33%	0.16%	0.36%
2011	3944	51.42%	1.24%	0.75%
2010	6354	41.58%	3.38%	1.88%
2007	1935	67.86%	0.36%	0.12%
2006	1555	53.12%	0.45%	0.20%

In the year 2010 flood is heavy in the history of Sindh province. Flood inundation map of the river for the year 2010 is shown in . The damage caused by 2010 flood is heavier than flooding events. The interpretation of MODIS land use map product for year 2010 represents that the study area was 2.50% of the water body, 0.72% of the urban area, 27.19% of agricultural and vegetation land, 24% of open shrubland and 28.46% barren land of 140914 sqkm area. In 2010, The data shows the extreme rainfall and increased flow of water in August 2010, the inundation extant was observed to be 6354 km2, which is about 4.51% of total study area. Results shows the massive changes in temporary surface water extant during the flood which affected all other land uses. The 2010 flooding inundated 3.38 % (2015 km2) of urban and built up areas and 41.58 % (2642 km2) agricultural and vegetation land. The results indicate that, due to the overflow of water most vegetation and agricultural land were flooded which washed out most of the agricultural crops and causes negative impacts on rural people as well as economy, ultimately affecting 898240 people of Sindh province of Pakistan.

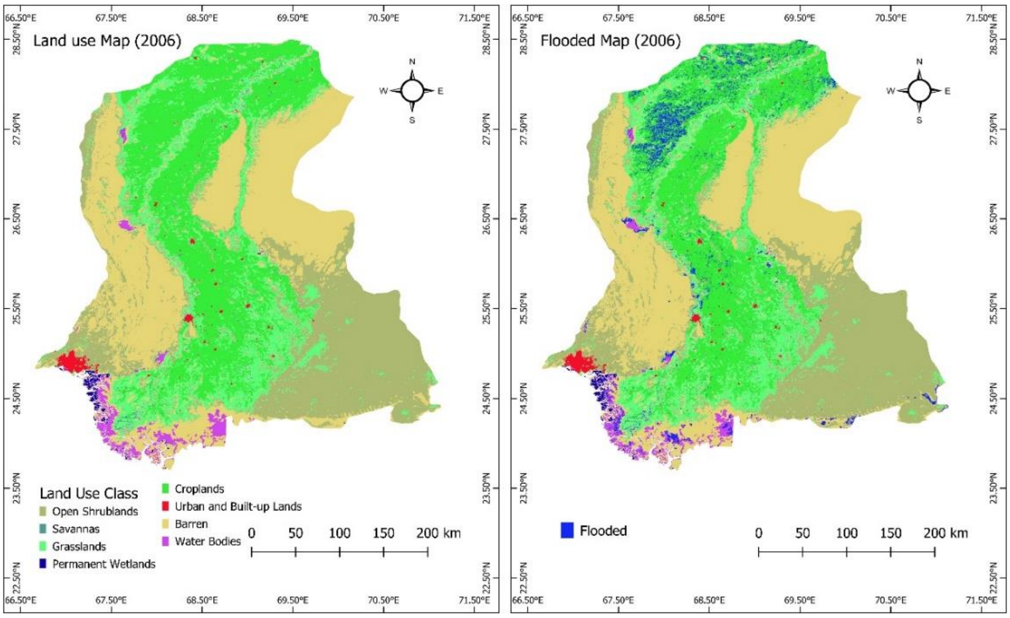


Figure 4-20 Land Use Map Before Occurring Flood and Flood Extant Map (2006)

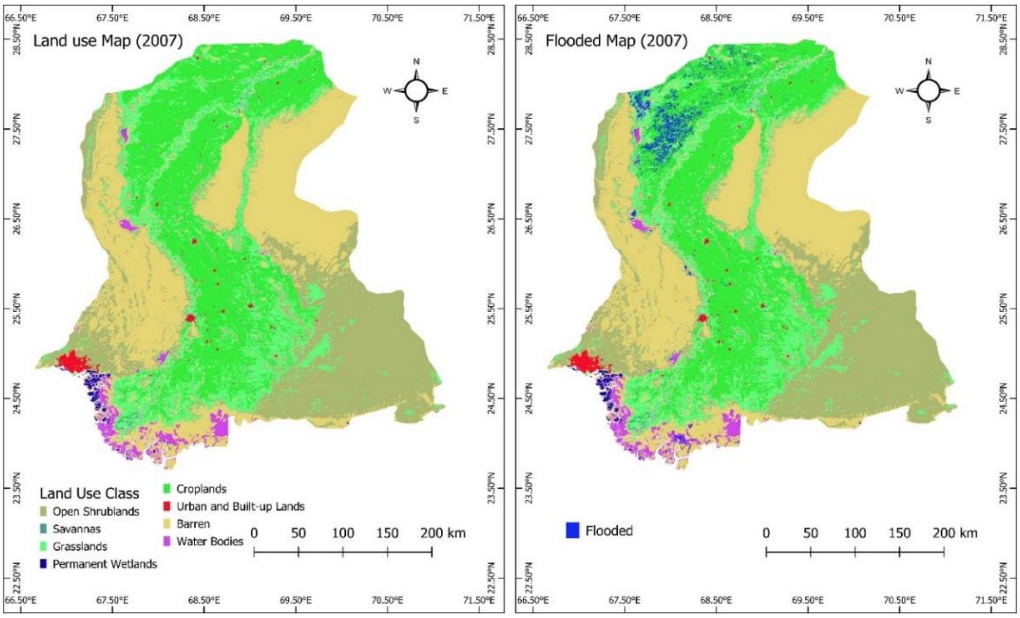


Figure 4-21 Land Use Map Before Occurring Flood and Flood Extant Map (2007)

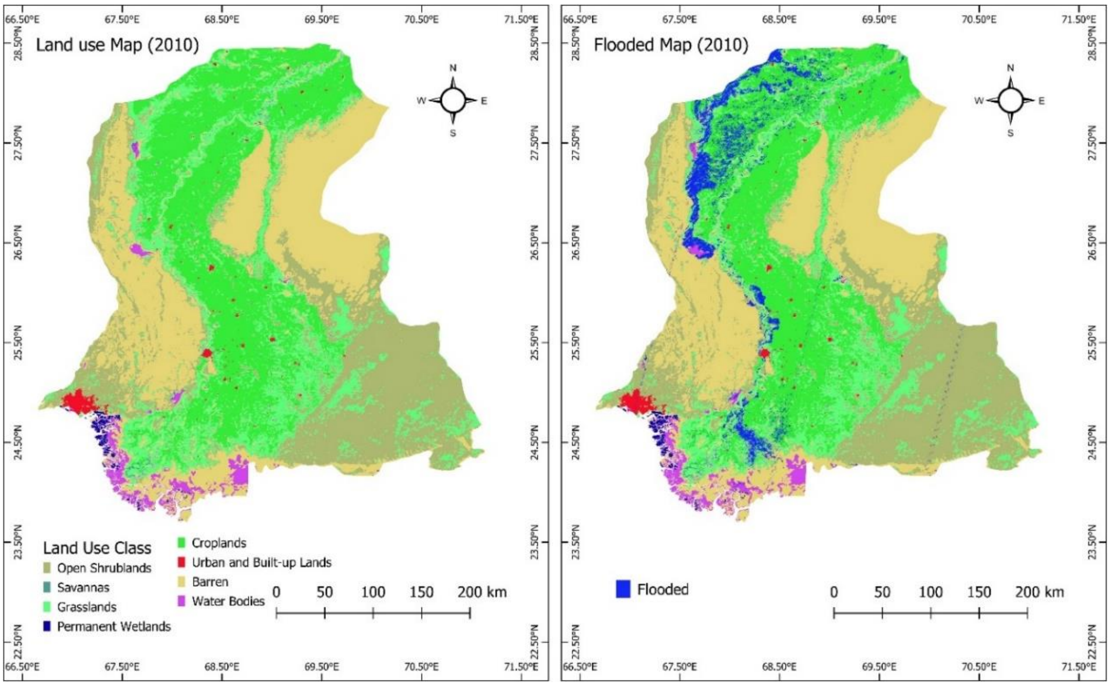


Figure 4-22 Land Use Map Before Occurring Flood and Flood Extant Map (2010)

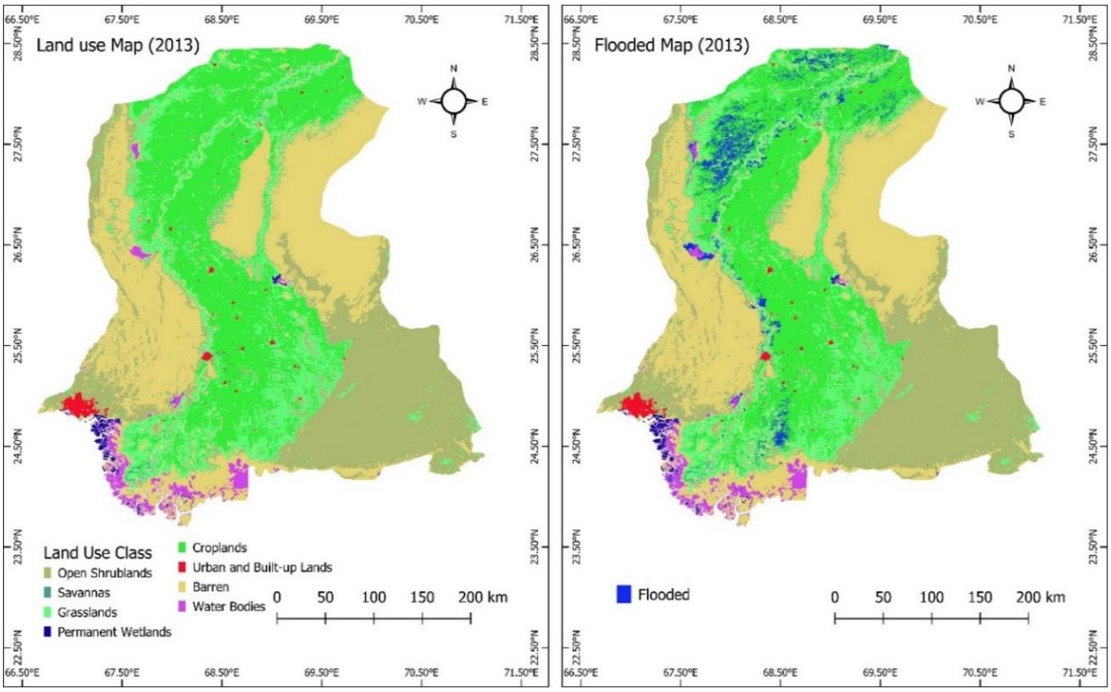


Figure 4-23 Land Use Map Before Occurring Flood and Flood Extant Map (2013)

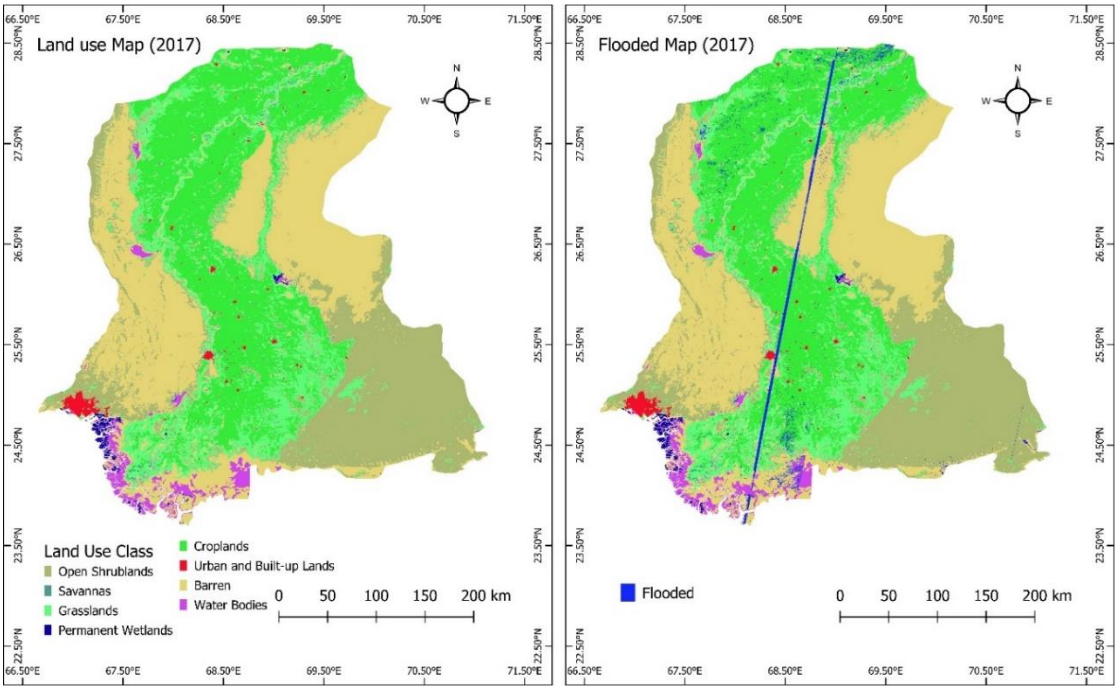


Figure 4-24 Land Use Map Before Occurring Flood and Flood Extant Map (2017)

After 2010 flooding event, Sindh province was being affected by another flood events in 2011, 2012 and 2013. 2011 flood was second most flooding event which impacted life and economy of Sindh. The extant of 2011 flood was 3944 km2, which affected 2028 km2 of cropland and 49km2 of urban and built-up areas. 2012 and 2013 flood had moderate impact over agricultural land and minor impact of urban and built up areas. Severity of 2006 flood in Sindh was less as compared to other flood events. Figure 4-20 shows the flood inundation map of the Sindh province for the year 2006. Table 4-7 lists different land use and land cover classes affected by flood. It is observed that out of 1555 km2 total flood affected area, nearly 826 km2 of land got affected is agricultural lands which 53% of the total damage. Similarly, an extent of 7 km2 of urban land is affected by the flood which was 0.45% of the total damage. 2017 flood event mostly affected urban areas of Sindh province. Ultimately affecting about half a million of population in Sindh province.

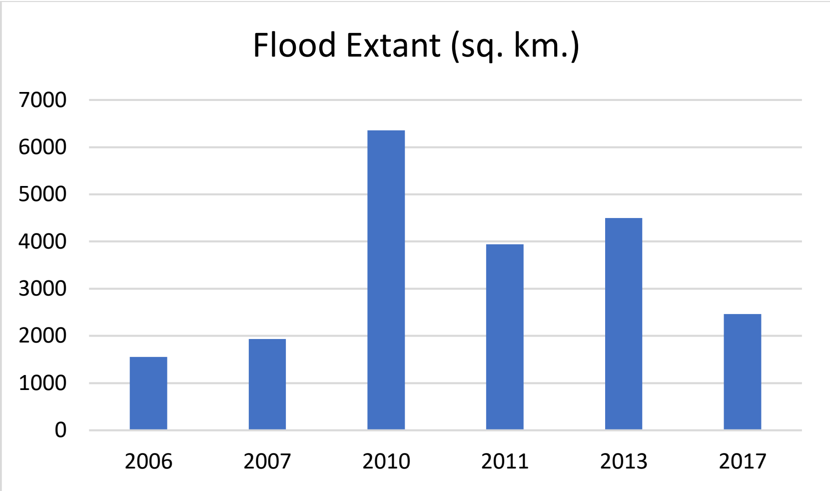


Figure 4-25 Area (sq.km) Under Water During Flood

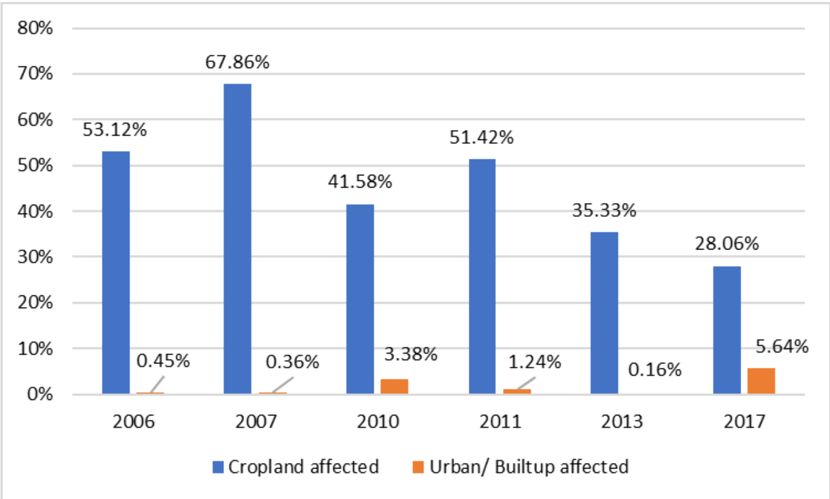


Figure 4-26 Percentage of Built-up and Agricultural and Vegetation Land Damage

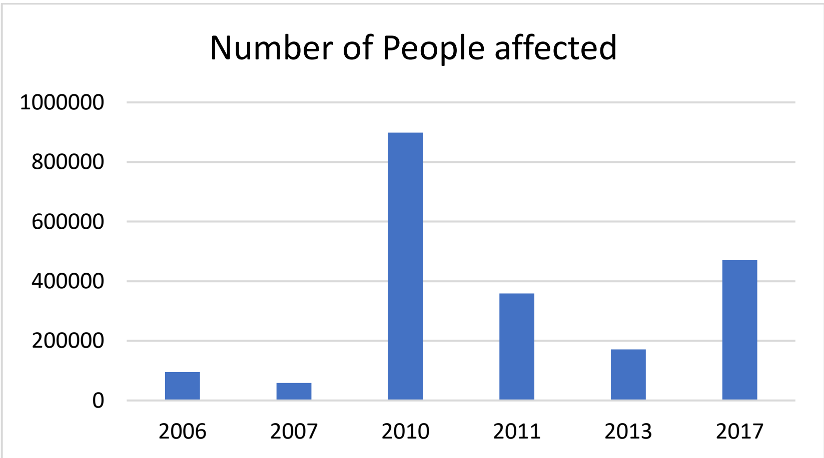


Figure 4-27 Number of People Affected During Flood Occurring Months

5. ACTION POINTS AND RECOMMENDATIONS

Metrological and hydrological hazards are of growing concern for the mankind as the rate of natural disasters is increasing dramatically as a consequence of population growth and increased vulnerability. Natural hazards cannot be avoided, but timely, accurate prediction of hydro-climate extremes helps civilizations to organize to mitigate disasters and to reduce losses in infrastructure and productive activities. Early warning systems and forecasts provide lead time, which together with public awareness, education and preparedness, can allow people to act quickly in response to hazard information, thereby increasing human safety and reducing the human and economic losses from natural disasters.

Early warning systems coupled with response, mitigation, awareness and preparedness are needed in many developing countries like Pakistan. Due to the current and projected impact of weather induced natural hazards, the effective functioning of hydrometeorological systems is critical for disaster risk mitigation, preparedness and response. Governments and regional organizations should engage in providing comprehensive hydrometeorological services to boost the efficiency of disaster risk management systems through the knowledge and experience they are acquiring.

Building Capacities at The Local and National Level,

i) Sindh government, Pakistan Meteorological Department, WAPDA (Hydrological Services) and Sindh Irrigation Department (Drought Monitoring) should put more effort for the vulnerable regions to undertake urgent reviews of their early warning capacities. These reviews should examine:

A. the adequacy of the meteorological and hydrological observing networks
B. the adequacy of the telecommunications systems to deliver timely hazard warnings including the degree of redundancy of those systems; the adequacy of their predictive capability including linkages to specialized regional centers
C. the adequacy of their access to current scientific developments with respect to early warning

D. the extent to which hazard warnings are already received by the target population in a timely manner and in a form which is recognized by them to be appropriate and useful

E. the degree to which their people are knowledgeable regarding meteorological and hydrological hazards, the availability and content of hazard warnings and appropriate preparedness and response actions;

F. the effectiveness of coordination between all parties involved in early warning for meteorological and hydrological hazards including droughts

G. the adequacy of disaster planning at local and national levels

H. the degree to which risk assessment is being used to support mitigation and response planning and to direct development away from high risk zones

I. the adequacy of emergency planning and management at local and national levels including the degree of involvement of local communities and people in the development, exercise and implementation of emergency plans

J. relationships with domestic broadcast and print media, and, where appropriate, with international broadcasters.

ii) Results of such reviews should be used as a basis for the development of national and provincial Strategic Plans to remedy identified weaknesses in local and national early warning programmes. PMD, SID, WAPDA and Drought Monitoring authorities should place a high priority on implementing these plans and on designating sufficient funds to maintain the improved early warning capacity. WMO, UNESCO's IHP and other international agencies and donor countries should continue to provide advice, assistance, training and other forms of support in the development and implementation of these plans through mechanisms such as UNDP, WMO VCP, STEND, HOMS and bilateral technical assistance programmes.

iii) Pakistan vulnerable to drought should continue to place a high priority on the development and maintenance of Drought Monitoring and Prediction Systems, Drought Monitoring Centres and related activities. This would include the increased dissemination of regional drought indices, sustained public education campaigns, the enhancement of telecommunications facilities and other elements of early warning infrastructure.

iv) Donor countries and international agencies should continue to assist governments to develop the national capacities. This may be accomplished by means of training and human resources development programmes, the provision of technological assistance, by encouraging research about local conditions, by facilitating greater access to research results developed elsewhere and by implementing early warning demonstration projects. It is equally important for there to be increased opportunities for recognized scientific and technical experience to become more involved in the determination of policy and decision-making processes that shape hazard monitoring and disaster prevention activities.

Research about local conditions should include the following items:

Table 5-1 Natural Hazard Theme Challenges, Goals, Science Priorities and Actions

No	Theme Challenge	High- level priorities	Key Science Goals (applications)	Key Science priorities (processes)	Actions Studies Under
Reducing societal exposure to natural hazards by better forecasting, integrated risk assessment & scientific advice.					
Hydro-meteorological Hazards					
1	Flooding	To increase understanding and prediction of coupled hydro-meteorological processes and how these will alter with climate change. (Main partners include: WAPDA, SID, & PMD plus others from Sindh government)	To improve flood forecasting through enhanced weather prediction and catchment characterization.	1) Catchment hydrological interactions and vulnerability; 2) Groundwater flooding; 3) Pluvial flooding.	Changing Water Cycle; Flooding from intense rainfall
2	Droughts,		To assist decision-making through better prediction o, droughts, and their impacts	1) Development of blocking highs; 2) Catchment response to drought; 3) impacts.	Changing Water Cycle; Sindh Droughts
Uncertainty, risk and scientific advice					
3	Integrated risk assessment & scientific advice	To reduce human and economic losses through enhanced analysis of probability, uncertainty & risk	To improve decision making through provision of clearer natural hazard science	1) New approaches and methodologies for integrated risk assessment;	Analysis, propagation and communication of probability, uncertainty

No	Theme Challenge	High- level priorities	Key Science Goals (applications)	Key Science priorities (processes)	Actions Studies Under
		and improved scientific communication.	advice and better engagement with users.	2) New cross-sectoral science tools.	and risk; Increasing resilience.
4	Uncertainty in forecasting & risk assessment		To increase uptake of natural hazard science by decision makers & expand its utilization and enhance communication between scientists.	1) New tools and protocols for improved usage of natural hazard-based probability, uncertainty and risk in natural hazard assessments.	Analysis, propagation and communication of probability, uncertainty & risk; Quantifying uncertainty. Increasing resilience

ANNEXURES

Annexure I: District wise mean monthly precipitation in mm/ month (1970-2019)

District	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Badin	1.692	3.498	2.717	2.535	2.208	12.712	82.622	74.885	33.804	3.427	2.000	1.813
Dadu	4.010	8.979	8.811	4.238	7.138	6.565	43.989	44.424	15.838	1.307	2.309	5.291
Hyderabad	2.163	4.923	3.142	4.022	3.760	7.567	55.934	56.625	14.521	1.662	2.000	2.445
Jamshoro	4.231	9.129	6.654	5.559	6.365	15.425	75.645	68.763	15.435	1.473	2.570	4.298
Matiari	2.000	4.022	3.016	3.040	2.905	9.149	54.618	47.315	12.546	1.000	2.000	3.000
Tando Allahyar	2.656	5.006	4.000	4.015	2.909	9.076	58.957	60.855	17.959	2.018	2.000	2.000
Tando M. Khan	2.000	4.189	3.000	3.469	3.742	8.309	74.219	54.275	14.793	1.649	2.000	2.581
Thatta	3.921	7.116	3.768	2.452	2.397	16.761	100.852	56.439	20.292	1.331	2.074	2.528
Karachi Central	7.984	14.525	7.066	3.852	1.984	13.590	73.311	29.590	7.705	0.902	2.000	5.295
Karachi East	7.582	13.531	6.294	3.345	1.876	12.582	68.904	26.339	6.559	0.475	2.000	5.000
Karachi South	8.000	13.956	6.015	3.007	1.102	10.015	58.401	19.964	4.781	0.022	2.000	5.000
Karachi west	7.887	14.607	7.263	4.065	2.272	13.522	71.393	29.398	8.095	0.792	2.000	5.628
Malir	6.801	13.781	7.883	5.329	4.643	19.067	95.077	53.512	13.212	1.311	2.237	4.981
Jakobabad	4.768	7.709	6.820	2.131	3.370	3.372	19.108	24.026	8.400	1.000	1.694	4.361
Kashmore	5.457	6.770	8.086	2.386	3.383	3.137	23.028	28.061	8.988	1.000	1.000	2.920
Larkana	4.160	8.933	7.220	3.657	4.426	4.131	29.935	28.626	11.681	1.341	2.064	5.793
Shikarpur	4.492	7.937	5.881	2.488	2.786	4.385	21.342	24.517	7.885	1.000	1.339	4.158
Mirphurkhas	1.908	3.863	2.801	2.547	4.503	12.577	87.266	66.236	22.415	3.799	2.042	1.504
Mithi	1.880	2.830	1.713	1.661	6.225	13.813	111.780	83.626	43.947	6.058	2.402	1.024
Sanghar	1.393	3.789	2.131	2.535	2.738	12.896	74.151	56.830	16.385	2.433	1.800	1.688
Umerkot	2.000	3.773	2.570	2.000	5.795	13.132	90.421	70.148	31.121	5.544	2.395	1.000
Ghotki	3.655	4.898	5.512	2.145	1.826	3.985	31.739	33.625	8.873	1.000	0.816	1.450
Khairpur	1.971	4.744	2.106	2.214	1.179	10.833	51.873	40.625	8.384	1.345	1.025	1.814
Naushahro Firoz	2.108	5.589	5.179	2.337	2.420	5.670	42.090	33.925	12.227	1.000	1.659	3.552
Nawab Shah	1.996	3.876	3.628	2.723	2.019	9.186	49.872	42.757	11.233	1.000	1.727	2.955
Sukkur	3.312	6.084	3.291	2.010	1.281	7.881	35.982	29.589	5.764	1.000	0.610	1.846

Annexure II: District wise mean seasonal precipitation in mm/ month (December, January, February)[75]

District	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001
Badin	3.70	0.16	2.13	0.41	0.29	0.29	3.80	0.36	2.01	0.48	8.64	5.98	6.69	0.89	1.86	0.83	7.98	0.43	0.22
Dadu	24.79	4.06	5.00	0.60	2.20	4.11	20.64	2.62	8.34	7.33	35.01	5.75	18.85	1.51	23.17	2.13	7.46	1.16	0.60
Hyderabad	9.47	0.46	1.88	0.35	0.33	0.14	4.70	0.93	1.46	0.67	12.36	9.11	9.12	0.33	2.47	1.11	13.42	1.27	0.13
Jamshoro	12.72	1.62	4.78	0.77	0.88	0.72	8.42	1.14	4.18	1.55	14.74	9.84	15.21	1.86	7.03	1.87	10.75	1.08	0.33
Matiari	14.60	0.92	3.15	0.51	0.56	0.51	7.84	1.00	3.78	1.34	19.23	11.66	10.44	0.80	4.96	1.14	9.70	1.30	0.24
Tando Allahyar	5.03	0.22	1.78	0.42	0.25	0.09	4.15	0.65	1.55	0.49	10.16	7.39	8.63	0.55	2.38	0.90	10.53	0.42	0.07
Tando M. Khan	9.15	0.30	1.45	0.18	0.21	0.13	5.10	0.74	1.14	0.78	12.33	8.14	7.88	0.14	2.09	1.29	12.71	1.44	0.03
Thatta	6.34	1.12	5.03	1.12	1.60	1.34	7.24	0.55	2.91	0.99	8.28	7.19	15.55	2.73	7.05	2.36	9.14	1.03	0.56
Karachi Central	10.04	2.68	12.13	0.74	2.31	0.52	9.67	1.31	2.15	2.24	11.76	9.03	34.94	2.91	12.50	4.86	10.87	0.75	0.41
Karachi East	9.77	2.53	12.25	0.74	3.07	0.51	10.22	1.00	2.29	2.06	10.98	8.05	34.80	3.06	14.10	4.79	9.97	0.76	0.43
Karachi South	9.33	1.83	13.50	0.92	4.31	0.51	9.93	1.24	2.64	1.95	11.66	7.67	36.14	3.15	15.21	5.21	9.65	0.75	0.45
Karachi west	10.30	3.14	11.32	0.90	3.99	0.80	9.08	0.98	2.69	3.39	16.22	11.13	36.05	3.32	12.02	4.33	13.41	0.69	0.36
Malir	10.62	2.07	8.18	0.78	1.73	0.85	9.89	0.90	3.28	1.98	10.37	9.27	27.73	3.24	10.72	2.99	12.93	0.82	0.36
Jakobabad	24.39	7.05	8.37	0.29	3.24	6.30	35.43	2.99	17.54	5.71	64.71	7.54	21.97	0.63	35.53	5.97	6.72	1.67	1.42
Kashmore	26.98	5.08	6.34	0.19	3.43	3.69	31.65	2.62	12.91	3.85	53.64	8.15	22.26	0.73	29.64	10.62	8.06	1.21	1.31
Larkana	26.19	6.86	8.12	0.60	3.60	6.69	30.50	2.67	11.99	9.73	55.28	6.47	21.34	1.57	32.59	3.82	6.88	2.23	1.44
Shikarpur	24.12	7.50	5.17	0.16	2.90	3.09	25.12	1.85	10.94	7.77	55.30	5.00	19.11	0.38	23.48	4.09	4.29	1.19	0.95
Mirphurkhas	5.91	0.18	2.24	0.15	0.27	0.05	6.98	0.36	0.90	1.05	9.40	5.50	7.29	0.14	1.96	1.06	9.88	0.50	0.03
Mithi	1.78	0.27	1.52	0.18	0.59	0.25	4.48	0.12	1.23	0.66	3.73	2.65	8.13	0.75	0.87	0.64	5.96	0.12	0.05
Sanghar	9.16	0.58	1.88	0.20	0.33	0.12	9.31	0.35	1.99	1.03	15.62	6.15	8.95	0.16	2.98	1.01	6.83	0.51	0.06
Umerkot	3.64	0.11	3.77	0.12	0.42	0.04	5.77	0.22	0.98	0.98	6.13	3.90	6.95	0.30	1.46	0.68	8.52	0.07	0.04
Ghotki	19.06	2.94	3.07	0.07	2.47	1.59	18.61	0.60	8.59	2.63	40.28	5.16	18.61	0.40	15.60	2.56	5.50	0.58	0.82
Khairpur	15.75	2.22	2.11	0.26	1.19	0.45	11.71	0.31	4.49	1.81	27.47	4.07	13.07	0.32	7.58	1.03	4.05	0.37	0.15
Naushahro Firoz	24.58	3.70	3.36	0.69	1.72	1.66	18.99	1.37	6.95	3.16	39.38	4.86	17.18	0.90	17.20	1.51	4.77	0.99	0.26
Nawab Shah	16.93	1.87	2.81	0.54	0.43	0.36	12.03	0.68	5.38	1.42	28.43	6.03	12.62	0.66	5.98	0.72	4.76	0.98	0.12
Sukkur	21.16	2.38	2.67	0.20	2.88	1.08	14.87	0.57	6.57	2.91	39.87	3.76	16.95	0.33	13.81	1.95	3.94	0.42	0.43

[75] G. Huffman, D. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, P. Xie, 2014: Integrated Multi-satellitE Retrievals for GPM (IMERG), version 4.4. NASA's Precipitation Processing Center, accessed 31 March 2015, ftp://arthurhou.pps.eosdis.nasa.gov/gpmdata/

Annexure III: District wise mean seasonal precipitation in mm/ month (March, April, May)[76]

District	2001	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
Badin	57.42	2.32	0.28	0.41	2.46	1.94	2.28	4.22	3.00	1.50	0.10	0.53	2.03	4.08	5.49	1.46	0.94	0.39	0.43
Dadu	24.76	27.06	6.26	2.99	10.80	8.54	21.09	12.61	12.38	16.01	2.39	6.56	6.06	15.45	6.74	17.12	0.84	6.01	3.07
Hyderab	50.22	5.36	0.56	0.56	2.37	1.65	7.24	8.35	3.63	1.71	0.22	2.22	4.65	12.48	11.37	4.65	1.03	1.04	0.51
Jamshor	45.03	9.84	1.38	1.23	4.39	2.52	9.62	8.57	3.42	3.38	0.70	2.48	3.15	14.64	7.37	6.25	0.67	1.79	0.69
Matiari	46.19	10.73	1.16	0.99	5.16	2.96	12.73	7.06	3.85	5.28	0.32	3.60	4.03	14.28	9.65	5.91	0.87	2.14	0.98
Tando A	48.83	3.27	0.24	0.27	1.50	1.62	3.76	5.27	3.05	0.74	0.16	0.96	2.41	6.37	7.34	2.58	0.85	0.48	0.77
Tando M	58.26	4.62	0.52	0.48	2.37	1.66	6.36	8.17	3.21	1.02	0.19	1.17	5.28	10.50	10.21	3.77	0.99	0.34	0.60
Thatta	51.29	5.42	0.97	0.79	2.74	5.06	2.58	6.13	2.18	1.88	0.40	0.98	1.71	8.38	5.01	1.79	1.30	0.57	0.85
Karachi	48.52	5.03	0.76	0.88	1.84	3.75	4.05	8.56	2.60	1.27	0.82	1.26	1.32	29.67	2.84	3.36	0.25	1.58	0.12
Karachi	44.21	5.42	0.63	0.83	1.65	4.16	4.00	9.30	1.95	1.14	0.67	1.17	1.20	22.29	2.89	2.84	0.26	1.34	0.17
Karachi	49.24	6.80	0.62	0.87	2.20	3.74	3.65	8.68	1.74	1.14	0.62	1.15	1.07	21.14	2.47	2.67	0.22	1.31	0.24
Karachi	46.16	5.44	0.87	1.03	2.29	2.18	5.23	10.82	3.15	1.47	0.91	1.76	1.60	37.02	2.66	3.99	0.23	1.75	0.12
Malir	55.97	5.49	0.78	0.79	1.85	4.27	6.59	10.46	1.96	1.25	0.80	1.39	1.84	19.81	4.29	3.89	0.41	1.50	0.24
Jakobab	18.11	40.04	2.81	3.44	9.11	25.43	11.97	11.43	7.19	16.45	3.71	8.54	6.82	15.86	8.44	12.15	0.30	2.04	3.26
Kashmo	27.82	29.62	2.58	3.32	8.83	27.44	14.21	11.56	4.96	11.34	3.19	10.38	7.55	12.06	12.92	15.26	0.62	2.18	3.55
Larkana	18.46	36.38	5.30	2.83	14.45	16.34	18.17	13.33	16.67	27.47	4.23	7.60	7.05	14.69	8.80	19.10	0.80	4.27	4.40
Shikarpu	16.89	31.53	2.36	2.56	7.67	20.73	8.02	7.11	5.43	15.39	2.94	6.58	6.13	11.88	6.60	10.49	0.38	1.11	3.51
Mirphur	58.56	3.79	0.21	0.66	2.31	3.89	5.25	4.77	1.67	0.46	0.13	1.10	6.05	6.79	7.80	2.62	0.63	0.21	0.46
Mithi	82.25	3.86	0.17	0.40	1.92	3.92	5.29	4.42	1.29	0.32	0.05	0.97	5.18	2.82	4.85	2.56	0.69	0.16	0.24
Sanghar	50.65	6.34	0.59	1.59	3.66	5.17	8.18	5.33	2.40	1.48	0.21	1.78	5.06	8.68	7.17	4.64	0.61	0.22	1.20
Umerko	67.82	3.35	0.19	0.43	2.36	3.45	5.08	5.34	1.57	0.28	0.07	0.79	5.33	4.04	6.55	2.10	0.52	0.24	0.29
Ghotki	33.82	16.99	2.41	4.64	6.33	23.44	11.96	10.21	5.66	5.77	1.71	7.65	5.04	7.76	9.66	11.45	0.37	1.08	4.47
Khairpur	34.12	13.11	1.11	2.90	4.70	9.37	9.42	4.45	3.55	2.85	0.48	3.25	4.76	8.28	5.25	8.06	0.15	0.33	2.58
Naushah	19.93	21.64	2.02	1.89	8.16	8.15	12.69	7.41	9.28	9.53	1.22	4.66	5.14	14.31	4.49	11.26	0.29	2.01	2.85
Nawab S	31.23	16.04	1.12	1.12	6.57	4.60	14.28	4.14	4.31	4.67	0.57	2.98	3.55	13.18	4.74	8.03	0.41	0.94	2.16
Sukkur	34.46	16.35	2.16	2.97	4.78	18.16	8.18	6.67	4.47	5.56	1.01	5.70	6.13	6.87	6.99	10.86	0.15	0.49	3.05

[76] G. Huffman, D. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, P. Xie, 2014: Integrated Multi-satellitE Retrievals for GPM (IMERG), version 4.4. NASA's Precipitation Processing Center, accessed 31 March 2015, ftp://arthurhou.pps.eosdis.nasa.gov/gpmdata/

Annexure IV: District wise mean seasonal precipitation in mm/ month (June, July and August)[77]

District	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
Badin	104.90	25.10	108.52	86.11	79.48	29.33	53.73	16.99	133.94	111.36	115.01	64.69	104.64	122.78	27.93	43.33	182.74	15.19
Dadu	42.00	8.07	23.10	31.36	40.84	6.20	36.75	6.95	74.90	70.94	14.58	29.23	58.65	46.38	18.33	6.71	77.37	1.65
Hyderab	83.36	14.95	68.22	64.44	48.29	14.59	49.31	7.22	109.93	97.04	63.88	46.43	78.49	120.93	15.33	16.97	140.37	4.24
Jamshor	70.89	5.63	46.60	48.47	32.17	7.62	30.22	5.22	70.12	88.18	45.03	30.02	82.27	78.65	10.67	8.21	98.74	5.76
Matiari	70.46	10.76	50.96	45.18	39.44	9.69	31.22	6.34	113.29	92.85	49.66	40.31	68.40	109.61	15.17	8.60	114.03	1.96
Tando A	91.79	17.06	89.47	72.89	56.26	19.60	42.55	10.70	126.00	92.02	88.30	47.95	93.95	105.36	17.99	29.48	144.65	9.98
Tando M	85.71	24.96	74.97	59.00	50.72	16.71	55.03	12.15	116.96	95.23	66.76	35.22	77.22	123.85	17.90	20.52	146.00	3.38
Thatta	108.09	18.33	109.32	74.01	49.85	24.61	39.50	9.69	92.22	119.09	101.49	44.47	113.71	110.55	20.79	25.37	154.15	17.56
Karachi	91.05	4.13	87.94	62.42	20.18	9.21	39.22	2.79	42.43	112.62	84.11	27.66	140.79	77.63	5.64	9.99	86.36	10.99
Karachi	87.08	6.36	88.74	64.06	19.95	9.18	39.12	3.40	44.14	111.65	90.29	27.65	138.76	87.72	6.31	10.52	89.58	11.25
Karachi	89.28	5.57	88.43	57.95	19.23	9.93	37.97	2.72	42.03	102.77	105.20	25.78	132.12	84.39	5.73	9.71	89.65	11.79
Karachi	84.45	6.70	88.12	64.76	21.18	12.41	43.06	2.46	43.27	110.28	80.21	25.28	132.00	75.96	5.32	8.74	84.90	10.37
Malir	86.08	5.77	73.39	60.36	22.18	8.98	34.52	7.78	53.04	123.84	68.71	32.00	102.85	80.81	7.65	12.58	96.31	11.99
Jakobab	28.00	10.78	24.89	27.12	49.76	8.97	67.87	7.53	46.15	110.83	7.74	26.91	46.20	27.37	23.55	6.43	71.06	2.08
Kashmo	26.65	14.41	32.65	34.03	72.56	9.81	43.94	14.49	51.92	107.73	10.25	24.32	39.58	37.58	27.55	12.07	62.37	2.02
Larkana	31.02	10.79	22.76	24.70	39.70	7.03	66.72	6.82	58.28	64.63	11.76	35.59	53.12	26.87	24.78	8.29	65.11	1.73
Shikarpu	25.36	9.46	21.37	25.33	50.25	6.93	67.00	4.20	55.78	82.40	8.19	37.28	36.19	26.18	22.57	7.13	68.08	1.92
Mirphur	74.50	32.87	83.40	65.53	61.79	14.76	59.67	21.06	107.87	103.47	87.31	38.68	65.55	137.92	26.22	24.41	148.76	4.65
Mithi	80.99	37.86	138.50	83.25	97.97	34.27	75.38	32.97	120.05	125.57	109.93	69.48	78.15	151.02	34.10	44.20	161.18	22.28
Sanghar	61.16	28.13	70.77	54.03	51.31	11.73	56.55	18.47	99.49	94.34	65.71	36.08	58.02	131.15	21.93	15.84	127.86	2.80
Umerko	68.06	35.36	93.92	66.43	75.97	17.37	62.42	21.84	111.10	99.10	94.89	47.59	59.05	134.00	26.55	34.16	145.51	8.32
Ghotki	27.59	19.95	46.23	38.28	62.96	9.22	46.98	14.66	67.03	80.96	17.37	35.03	30.45	53.24	22.35	9.27	55.76	2.38
Khairpur	39.92	16.05	47.17	37.08	42.82	6.39	51.52	10.91	82.92	80.85	32.61	33.06	48.83	75.83	20.47	8.34	90.74	1.50
Naushah	38.39	7.58	25.23	28.09	41.95	4.10	47.05	4.09	86.13	84.34	15.53	30.22	53.71	54.93	20.55	5.20	74.47	0.84
Nawab	56.36	9.63	38.85	40.47	44.54	6.83	39.53	6.21	107.35	99.51	32.18	28.86	67.59	87.23	18.85	5.75	101.15	1.05
Sukkur	28.28	13.22	40.68	34.64	47.91	6.95	50.92	7.46	73.18	77.69	16.18	25.83	36.08	45.52	23.77	7.43	56.30	1.93

[77] G. Huffman, D. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, P. Xie, 2014: Integrated Multi-satellitE Retrievals for GPM (IMERG), version 4.4. NASA's Precipitation Processing Center, accessed 31 March 2015, ftp://arthurhou.pps.eosdis.nasa.gov/gpmdata/

Annexure V: District wise mean seasonal precipitation in mm/ month (September, October and November) from GPM[78]

District	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
Badin	41.46	4.01	6.02	5.28	12.09	18.17	20.24	71.87	145.63	42.29	3.52	8.92	8.73	41.57	12.84	39.66	3.49	4.02
Dadu	28.33	1.86	1.97	3.78	2.86	1.26	2.30	53.85	63.46	17.51	1.33	1.07	1.01	8.26	3.65	4.72	0.73	2.55
Hyderab	19.34	2.33	1.91	0.97	4.79	5.32	8.45	43.88	118.59	24.64	1.68	1.53	1.75	42.23	4.29	32.29	0.80	1.50
Jamshor	17.41	0.98	2.92	1.20	1.32	2.43	4.53	39.04	72.18	22.72	0.98	0.85	0.96	22.36	5.38	16.54	0.35	1.30
Matiari	21.62	0.76	0.96	0.57	2.03	2.51	4.50	59.95	139.66	30.84	0.95	0.51	0.67	26.91	2.25	21.22	0.16	1.01
Tando A	30.06	2.59	4.30	2.52	6.15	9.42	11.75	47.57	126.80	30.07	3.25	3.68	3.28	51.06	7.75	37.63	2.54	3.06
Tando M	21.05	1.92	1.25	0.84	10.48	7.60	8.62	51.27	137.30	24.66	1.21	1.32	2.38	44.50	6.43	32.53	0.47	1.14
Thatta	37.40	5.37	8.04	5.63	8.35	12.97	17.36	68.48	87.58	51.58	4.38	6.60	7.09	34.14	15.66	35.02	4.29	5.24
Karachi	25.95	0.39	4.74	0.47	0.57	2.43	3.15	37.05	74.54	45.12	0.69	0.50	0.54	14.94	15.14	16.16	0.53	1.11
Karachi	22.67	0.42	4.85	0.57	0.64	2.86	2.84	41.85	69.70	45.54	0.80	0.60	0.66	15.90	14.22	18.76	0.65	1.13
Karachi	24.05	0.43	4.87	0.60	0.61	2.95	2.31	40.87	65.57	47.70	0.73	0.57	0.62	15.32	12.38	18.48	0.68	1.09
Karachi	26.22	0.55	4.32	0.45	0.57	2.58	3.84	38.53	69.60	33.72	0.58	0.38	0.47	14.32	12.16	13.84	0.48	0.99
Malir	23.09	0.53	5.38	0.56	0.97	3.11	3.75	37.32	60.58	36.52	0.96	0.72	0.74	19.73	10.44	17.47	0.64	1.14
Jakobab	30.31	0.77	1.78	3.03	1.72	1.09	0.89	135.84	41.18	14.41	0.44	2.84	1.97	6.26	3.08	3.18	0.96	1.84
Kashmo	33.51	1.10	2.56	2.85	3.16	1.92	1.62	109.45	36.29	12.91	0.57	3.18	2.23	5.45	5.00	5.65	0.84	1.27
Larkana	29.10	1.24	1.71	3.35	2.42	1.35	1.41	71.21	34.95	10.88	0.45	2.87	0.90	6.56	2.87	3.29	0.88	3.31
Shikarpu	27.58	0.45	1.53	2.52	1.31	0.85	0.69	103.81	40.79	8.80	0.36	2.94	1.27	3.34	2.13	5.21	0.73	1.71
Mirphur	26.12	0.80	1.82	1.98	23.08	13.61	8.09	64.05	115.40	35.95	1.06	3.76	8.05	35.44	14.37	31.47	0.50	1.27
Mithi	51.21	4.22	8.33	10.73	26.79	21.74	31.37	61.05	118.18	44.79	4.49	16.03	19.08	26.26	29.62	26.68	4.62	6.22
Sanghar	24.60	0.35	0.87	1.70	17.56	9.17	6.93	59.21	128.93	31.46	0.64	1.30	5.92	27.64	10.24	24.18	0.14	1.11
Umerko	33.74	1.50	2.76	4.88	26.13	16.81	13.70	62.55	114.17	37.10	1.63	5.91	11.70	29.51	13.88	31.20	1.19	2.00
Ghotki	29.85	0.63	1.70	1.55	6.68	3.25	1.01	72.96	36.17	13.60	0.50	3.56	2.62	2.85	8.18	5.55	0.85	1.63
Khairpur	26.62	0.26	0.64	1.43	8.91	3.47	2.87	59.47	71.25	20.64	0.26	1.43	3.13	8.97	6.27	11.01	0.32	1.16
Naushah	30.49	0.40	0.65	1.83	0.92	0.33	1.64	57.97	85.56	16.99	0.26	0.50	0.98	6.05	4.77	6.54	0.23	1.24
Nawab S	26.35	0.31	0.75	1.65	1.68	1.45	4.55	65.81	130.48	25.33	0.46	0.29	1.12	13.64	3.37	11.77	0.20	1.30
Sukkur	28.49	0.31	1.26	1.19	4.95	2.12	0.92	69.33	37.21	13.84	0.43	2.95	2.17	2.63	4.05	6.13	2.76	1.27

[78] G. Huffman, D. Bolvin, D. Braithwaite, K. Hsu, R. Joyce, P. Xie, 2014: Integrated Multi-satellitE Retrievals for GPM (IMERG), version 4.4. NASA's Precipitation Processing Center, accessed 31 March 2015, ftp://arthurhou.pps.eosdis.nasa.gov/gpmdata/

Annexure VI: Trainings and Capacity Building

a) Exposure Visit (Australia)

Duration of the exposure visit:	5th February to 13th February
Place of the trainings:	Sydney and Melbourne (Australia)
No. of Training:	Four (4)
No. of Participant's:	05 Persons

Day 1 – Thursday 6th February – INTRODUCTION TO WATER MANAGEMENT IN AUSTRALIA INCLUDING THE MURRAY DARLING BASIN			
Time	**Item**	**Content**	**Presenter**
08:15	Walk to Entura office	Office / building induction Room: Derwent Training Room	**Level 8** **530 Collins Street**
08:30 – 11:15	Introductions Topics of Interest	Introductions and areas of special interest by David Fuller, Principal Water Management & Technology Capture topics of special interest	**David Fuller**
11:15 – 11:45	Break	Catered for on site	
11:45 – 13:00	Drought, Weather and Climate Data	Visit to Bureau of Meteorology: • Tour and weather briefing from the National Operations Centre (NOC) • Meeting with flood forecasting team • Presentation on hydrology and Australia's environment	**Alex Rogers**
13:00 – 14:00	Lunch	Catered for on site	
14:00 – 15:15	Drought, Weather and Climate Data (Continued)	Visit to Bureau of Meteorology: • Tour and weather briefing from the National Operations Centre (NOC) • Meeting with flood forecasting team • Presentation on hydrology and Australia's environment	**Alex Rogers**
15:15 – 15:45	Break	Catered for on site	
15:45 – 17:15	Water Management in Australia	Overview of water allocation and management in Australia (Entura) - basic needs, water entitlements, environmental flows, metering, economics, administration and controls Question and Answer Session	**David Fuller**

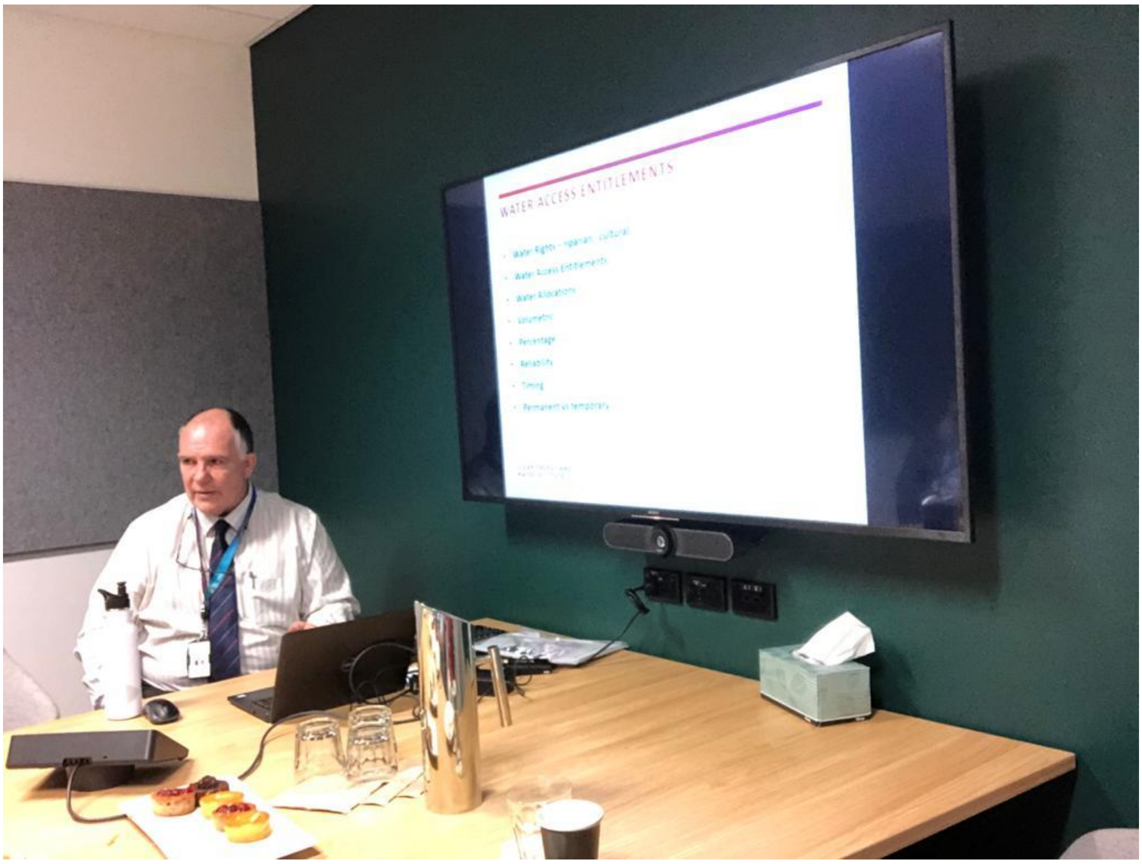
Day 2 – Friday 7th February – INTRODUCTION TO WATER MANAGEMENT IN AUSTRALIA INCLUDING THE MURRAY DARLING BASIN			
Time	**Item**	**Content**	**Presenter**
08:45	Walk to Entura office		
09:00 – 09:30	Welcome Back	• Second day welcome • Discussion on first day • Capture any additional topics of special interest	**David Fuller**
09:30 – 11:15	Murray-Darling Basin and Goulburn-Murray Water	• Overview of irrigation in the Murray Darling Basin and Victoria – what is irrigated where, MDBA role, States • Overview of G-MW • The Millennium Drought and water restrictions • Responding to drought and over-allocation of water • MDBA water savings programs • Channel lining	**David Fuller**
11:15 – 11:45	Break	Catered for on site	
11:45 – 13:00	Murray-Darling Basin and Goulburn-Murray Water (Continued)	• Overview of irrigation in the Murray Darling Basin and Victoria – what is irrigated where, MDBA role, States • Overview of G-MW • The Millennium Drought and water restrictions • Responding to drought and over-allocation of water • MDBA water savings programs • Channel lining	**David Fuller**
13:00 – 14:00	Lunch	Catered for on site	
14:00 **15:15**	Information Systems	• Metering • Information systems • AJENTI & ADMS • AWS, EAGLE.IO	**Alex Rogers**
15:15 – 15:45	Break	Catered for on site	
15:45 – 17:00	Drought, Weather and Climate Data	Respond to topics of interest not covered earlier.	**David Fuller**

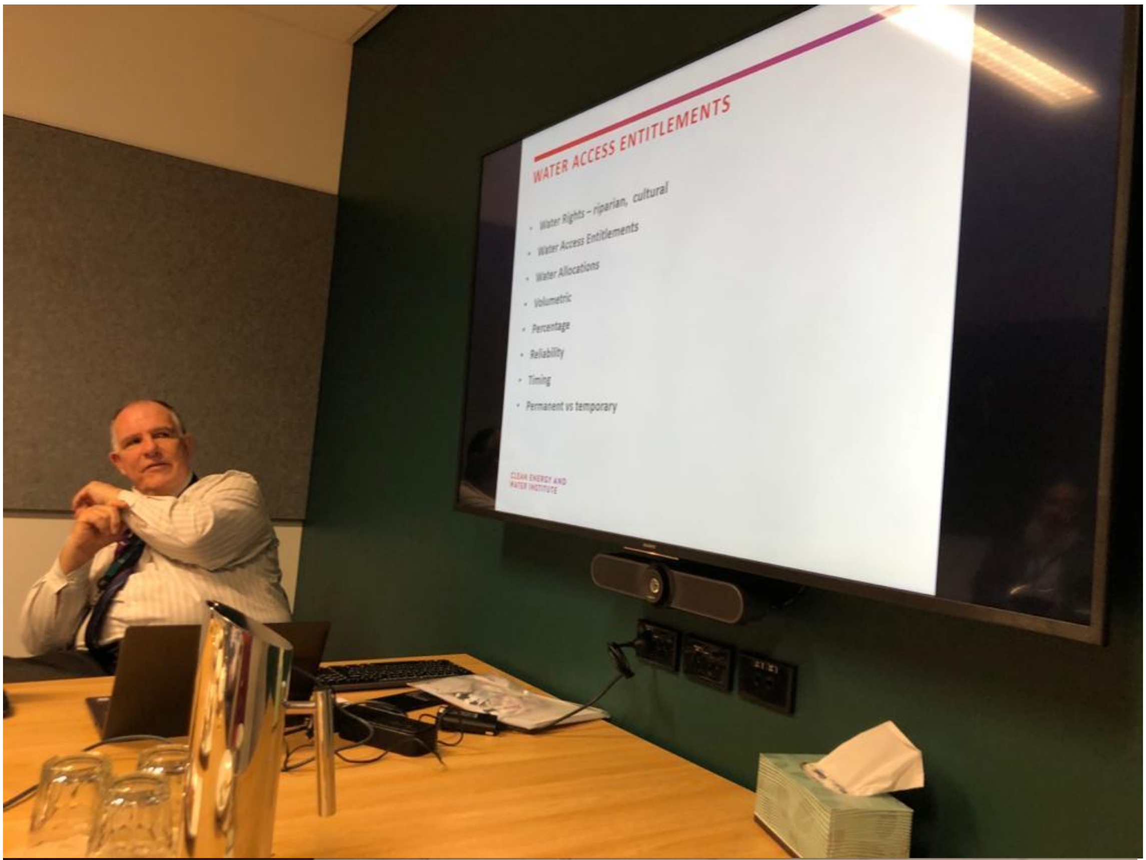
Day 3 – Monday 10th February – INTRODUCTION TO WATER MANAGEMENT IN AUSTRALIA INCLUDING THE MURRAY DARLING BASIN			
08:45	Walk to Entura office		
09:00 – 09:30	Welcome Back	• Third day welcome • Discussion on Second day • Capture any additional topics of special interest	**David Fuller**
09:30 – 10:30	Drought Strategy	• Victorian Drought Strategy and Program presentation by the Department of Environment, Land, Water and Planning	**Luke Pitman and** **Sara Bundze**
10:30 – 11:00	Break	Catered for on site	
11:00 – 11:45	Drought Strategy (Continued)	• Victorian Drought Strategy and Program presentation by the Department of Environment, Land, Water and Planning	**Luke Pitman and** **Sara Bundze**
11:45 – 12:45	Low by-pass flows	• Flows for the Future program, South Australia	**Alex Rogers**
12:45 – 14:15	Lunch & Prayers	Lunch on Site There is a Prayer room located at the Entura Office	
14:15– 15:45	Low by-pass flows (Continued)	• Flows for the Future program, South Australia	**Alex Rogers**

Day 4 – Tuesday 11th February – INTRODUCTION TO WATER MANAGEMENT IN AUSTRALIA INCLUDING THE MURRAY DARLING BASIN			
08:45	Walk to Entura office		
09:00 – 09:30	Welcome Back	• Fourth day welcome • Discussion on Third day • Capture any additional topics of special interest	**David Fuller**
09:30 – 10:30	Monitoring Instrumentation	• Flow meters and meter standards • Data loggers • Instrumentation • Telemetry - Mesh radio networks, 3G/4G, satellite	**Ugur Zengin**
10:30 – 11:00	Break	Catered for on site	

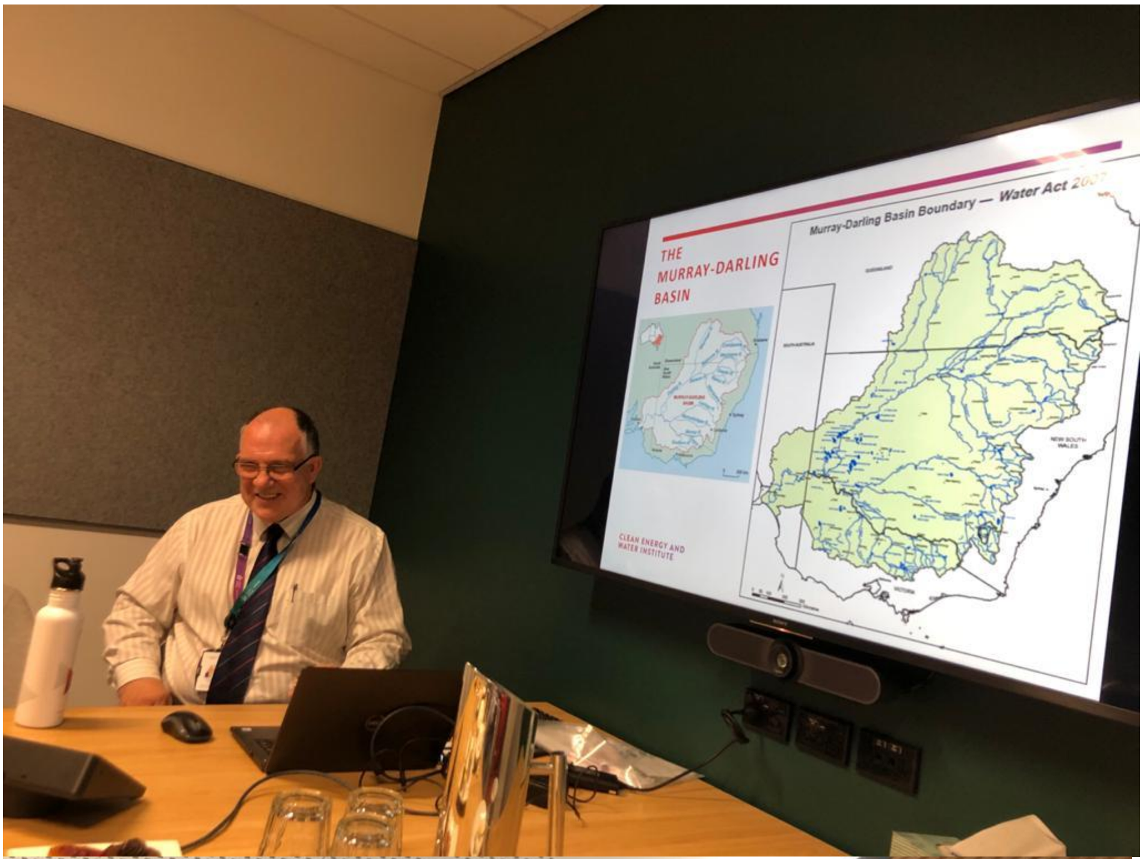
11:00 – 11:45	Monitoring Instrumentation (Continued)	• Flow meters and meter standards • Data loggers • Instrumentation • Telemetry - Mesh radio networks, 3G/4G, satellite	**Ugur Zengin**
11:45 – 12:45	Dam Safety Guidelines	• Guidelines and Risk Management	**Radin Espandar**
12:45 – 14:15	Lunch & Prayers	Lunch on Site There is a Prayer room located at the Entura Office	
14:15– 15:15	Dam Safety Guidelines (Continued)	• Guidelines and Risk Management	**Radin Espandar**
15:15 – 15:45	Program Close	• Course Feedback and presentations	**David Fuller**

Exposure Visit (Australia) Photo Gallery




WATER ACCESS ENTITLEMENTS
Water Rights – riparian, cultural
Water Access Entitlements
Water Allocations
Volumetric
Percentage
Reliability
Timing
Permanent vs temporary
CLEAN ENERGY AND
WATER INSTITUTE


VISITOR


THE
MURRAY-DARLING
BASIN
CLEAN ENERGY AND
WATER INSTITUTE
Murray-Darling Basin Boundary — Water Act 2007
NEW SOUTH
WALES

b) International Training at AIT Thailand

- Program exposure visit and training mission to the Thailand.
- From 29th January 2020 till 4th February 2020.
- Workshops and Trainings on Hydro Meteorological Hazard Assessment of Sindh Province.
- Total 06 Nos Participants.

Purpose of The Visit:

Exposure visit and training mission on Hydro Meteorological Hazard Assessment for Pakistani experts that is organized by Asian Institute of Technology (AIT) in Bangkok.

The exposure visit will introduce to the Pakistani guests to Thailand's Hydro Meteorological Hazard Assessment practices and Thailand's water experts. The exposure visit is scheduled to take place during the period from 29th January 2020 till 4th February 2020 in The Thailand.

The objectives of the exposure visit are to:

- Build capacity of the professionals on Thailand's water resources and disaster risk management.
- Field visit to observe and lessons learned from structural non-structural measures for hydro meteorological hazard Assessment and risk management and learn new technologies for water resources management.

PROGRAMS

DAY 1: Pick up from Hotel, Bangkok

09:00 Depart from Hotel

11:00 Welcome to Asian Institute of Technology (AIT).

Coffee and tea

11:15 Introduction to Hydro Meteorological Hazard Assessment

11:45 Visit facilities

13:00 Lunch

14:30 Presentation on Floods and Droughts

15:00 Coffee and tea

15:30 Departure back to Bangkok

15:45 Arrival in hotel (subject to traffic)

DAY 2: Regional Integrated Multi-Hazard Early Warning System (RIMES)

09:00 Depart from Hotel

11:00 Welcome to RIMES

Coffee and tea

11:15 Visit to Research and Development Faculty

11:45 Opening ceremony

12:15 Lunch

13:30 Presentation on National Meteorological and Hydrological Hazards

14:30 Coffee and tea

14:45 Presentation on Development of Early Warning System

15:30 Departure back to Bangkok

17:00 Return at hotel (subject to traffic)

DAY 3: ESSOM

09:00 Depart from Hotel, Check out

11:00 Arrival at ESSOM

12:30 Visit to Laboratories

13:00 Lunch

14:00 Equipment's and Product's Specifications and Testing Examples

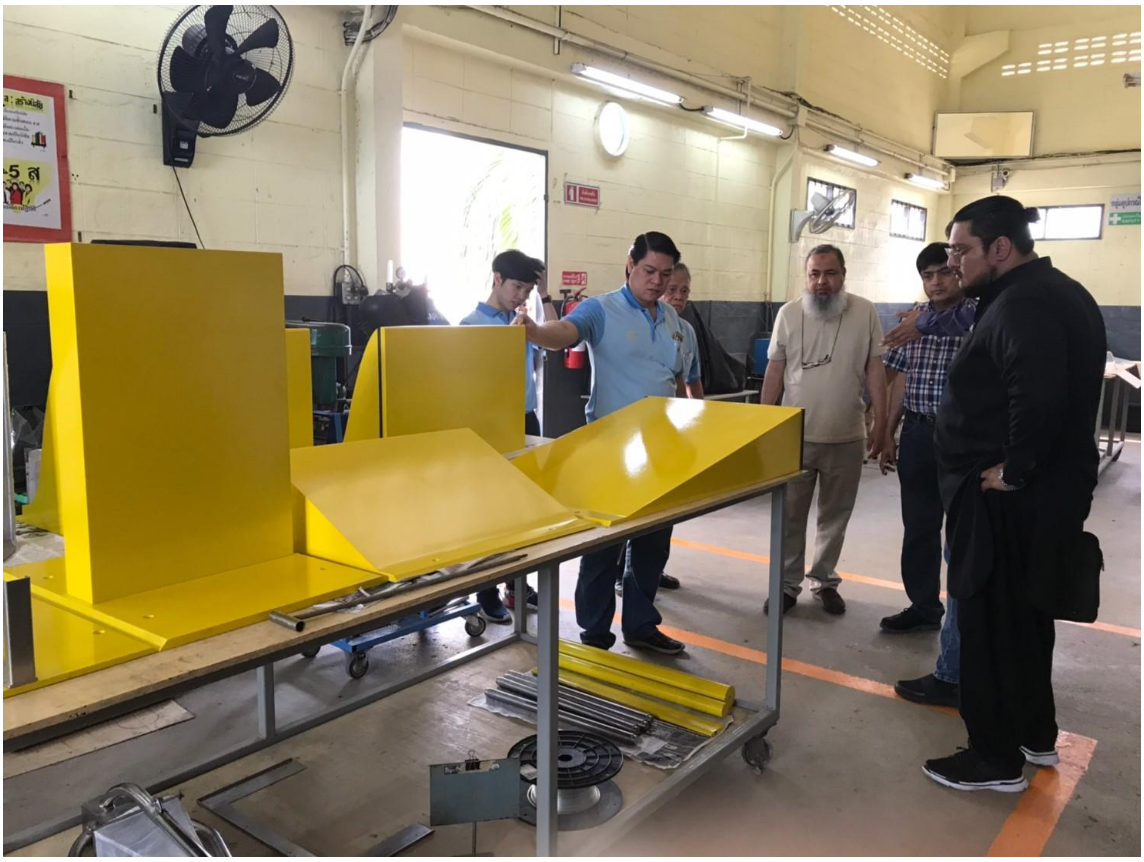
15:00 Products Application and Importance in Hydro Meteorological Hazard Assessment

Coffee and tea

17:50 Dropoff at Suvarnabhumi International Airport (BKK)

International Training at AIT Thailand Visit Photo Gallery


ESSOM
ISO 9001
HF 560 TILTING FLOW CHANNEL
600 mm wide




HF 560 TILTING FLOW CHANNEL
600 mm wide


ESSOM
ISO 9001

c) <u>Local Training</u>

Topic: Professional Course on Basic Satellite Data Processing for Geospatial Applications Under "Hydro Meteorological Hazard Assessment of Sindh Province"

Objectives:

After the end of this training participants can perform various geospatial data and understanding satellite image processing activities using GEE platform.

Outcomes:

This training will offer participants (SRP Engineers) an opportunity to gain hands-on experience using GEE to complete a series of real-world environmental remote sensing projects for beginners, and intermediates. Participants will be able to perform basic image processing operations using GEE and will finally be able to develop a time series of image derived vegetation index in advance course followed by basic.

Contents:

Total Duration: **07 days Program**
Total Number of Participants: **15**

Level I: **Basics: Geospatial data and Visualization** [03 Days]

- Introduction to Google Earth Engine?
- Uploading Shapefiles / Geotiffs in Assets.
- Generate Histogram in Google Earth Engine.
- Add Title and Legends
- Add Two Charts
- Add Grid Lines to your map
- Create a Chart to show Landsat 8 TOA Spectra at three points

Level II: **Time series analysis** [03 Days]

- Write a code to Download 30m DEM for any country.
- Calculate Annual Time Series NDVI

- Develop a Harmonic Model: Original vs Fitted NDVI values
- Using Landsat Images to calculate NDVI

Level III: **Project Presentation** [01 Day]

- Group Presentations
- Closing of program

OVERVIEW OF TRAINING SESSIONS

Day / Levels	SESSIONS	PRESENTER
Day 1	1. Opening Remarks	Dr. Jonathan Shaw
	2. Program Orientation (Dr. Jonathan Shaw)	Dr. Jonathan Shaw
	3. Project Overview and Hydro-Meteorological Assessment of Sindh	Dr. Willem van Deursen
Day 2	1. Flood and Drought Assessment	Dr. Ahmed Ali Gul
Day 3	1. Data Analysis Tools and Techniques	Dr. Gautham and Dr. Babur
Day 4	1. Time Series Analysis	Dr. Gautham and Dr. Babur
	2. Closing Ceremony	