VULNERABILITY OF AGRICULTURE TO CLIMATE CHANGE IN CHAKWAL DISTRICT: ASSESSMENT OF FARMERS' ADAPTATION STRATEGIES

SARAH AMIR

Reg. No. 4-FBAS/PHDES/F13

Department of Environmental Science

Faculty of Basic and Applied Sciences

INTERNATIONAL ISLAMIC UNIVERSITY ISLAMABAD

2020

VULNERABILITY OF AGRICULTURE TO CLIMATE CHANGE IN CHAKWAL DISTRICT: ASSESSMENT OF FARMERS' ADAPTATION STRATEGIES

A thesis submitted to the Department of Environmental Science, Faculty of Basic and Applied Sciences in fulfillment of the requirement for the award of degree of Doctor of Philosophy of International Islamic University, Islamabad.

SARAH AMIR
Registration No: 4/FBAS/PHDES/F13

Supervisor
Dr. Muhammad Irfan Khan
Professor
Department of Environmental Science

Co-supervisors

Dr. Zafeer Saqib
Assistant Professor
Department of Environmental Science

Dr. Muhammad Azeem Khan
Chairman
Pakistan Agricultural Research Council

Spring 2020

Department of Environmental Science
Faculty of Basic and Applied Sciences
INTERNATIONAL ISLAMIC UNIVERSITY ISLAMABAD

In the name of Allah,

The Most Gracious and

The Most Merciful.

DEDICATION

I dedicate my work to my beloved parents, husband, children, family members, friends and respectable teachers for their unconditional support and love.

ACCEPTANCE BY THE VIVA VOCE COMMITTEE

Title of Thesis: Vulnerability of Agriculture to Climate Change in Chakwal District: Assessment of Farmers' Adaptation Strategies

Name of Student: Sarah Amir

Registration No: 4/FBAS/PHDES/F13

Accepted by the Doctoral Research Committee of the Department of Environmental Science, Faculty of Basic and Applied Sciences, for the award of degree of Doctoral of Philosophy (PhD) of International Islamic University, Islamabad.

VIVA VOCE COMMITTEE

____

Dean

____

Incharge, DES

____

External Examiner

____

Research Supervisor

____

Co-Supervisor

____

Co-Supervisor

____

Internal Examiner

DECLARATION

I *Sarah Amir*, PhD scholar in the Department of Environmental Science enrolled under registration No. 4-FBAS/PHDES/F13, hereby declare that the knowledge contributed by analyses of data collected and results derived to draw conclusions presented in this thesis titled "*Vulnerability of Agriculture to Climate Change in Chakwal District: Assessment of Farmers' Adaptation Strategies*" is my own original work and has not been submitted as research work or thesis in any form in any other university or institute in Pakistan or abroad for the award of any degree. The output from this thesis so far published/accepted are following three research papers in 2019 and 2020.

Amir, S., Saqib, Z., Khan, M. I. Khan, M. A., Bokhari, S. A., Haq, Z. and Majid, A. (2020). Farmers' perceptions and adaptation practices to climate change in rain-fed area. A case study from District Chakwal, Pakistan. *Pak. J. Agri. Sci.*, **57**(2): 465-475.

Amir, S., Saqib, Z., Khan, A., Khan, M. I. Khan, M. A. and Majid, A. (2019). Land cover mapping and crop phenology of Potohar Region, Punjab Pakistan. *Pak. J. Agri. Sci.*, **56**(1): 187-196.

Amir, S., Saqib, Z., Khan, M. I., Ali, A., Khan, M. A., Bokhari, S. A. and Haq, Z. (2020). Determinants of farmers' adaptation to climate change in rain-fed agriculture of Pakistan. *Arabian Journal of Geosciences (accepted for publication)*.

Dated: 20-08-2020

____

Deponent

Sarah Amir

ABSTRACT

With the dawn of 21st century, the world has witnessed the distressingly increasing effects of climate change on almost all sectors of society manifested by rising temperature, melting glaciers, intruding seas, erratic rainfall, frequent floods, cyclones and intermittent droughts. Both the global and national security paradigms are at great risk due to devastating impacts of climate-induced anomalies, if required measures to mitigate and adapt to such changes would not be taken both by developed and developing countries. Due to poor resource-base, technical and financial constraints, inadequate adaptive capacity and above all heavy reliance on climate-sensitive sector like agriculture in South Asia, makes it the most vulnerable region. Therefore, it is incumbent to carry out research on climate change perception, its bearings on human health, crops and livestock productivities, vulnerability assessments and adaptation of the rain-fed rural communities in response to climatic variabilities in countries like Pakistan, where sizeable population is reliant on agriculture for their bread and butter. Although there are constraints like availability of data, limited literature on perception, vulnerability assessment and response to climatic variabilities in Pakistan, but still it is of great importance to conduct such studies. Similarly, the assessment of capabilities for adaptation to those impacts for the agricultural sector, especially in rain-fed regions is not only a need of the hour but a very challenging research question as well. Therefore, this study was carried out with objectives; i) to get an insight of farmers' cognizance to climate-related events; ii) mapping changes in land use land cover with historical perspective and to elucidate its causal factors; iii) assessment of the households' vulnerability to climate-related events; and iv) to find out factors influencing farmers' selection of farm and non-farm based adaptation strategies or measures in the face of climate change. This study focused on perception analysis of communities in rain-fed areas about climate change by exploring household social vulnerability, biophysical vulnerability and measures taken in a rain-fed district of Chakwal in Punjab, Pakistan. To comprehend the complexity, this study adopted an interdisciplinary approach and methodology by using specially designed survey instrument for data collection, GIS and Remote Sensing tools and statistical techniques for principal component and multivariate analyses. This study considered historical climate data (temperature and precipitation) of Chakwal District and focused on household survey of 475 respondents in the rain-fed rural zone (Barani) of Pakistan. The results indicated that 96% of farmers perceived climate change as reality and experienced climate-related hazards (drought, erratic rainfall, temperature rise, hailstorm, fog etc.) over the last twenty years or so. Such findings are quite comparable with scientific observations of climate data of the study area. For example, farmers reported uncertainty and decrease in farm productivities; animal diseases; human health impacts; changes in sowing times and dwindling water due to detected climatic hazards. In response, farmers have changed sowing dates of their crops, followed improved crop production practices and some invested in water ponds to irrigate their crops. Further, it was found that shortage of water, poverty and weak institutional set-up increased the household susceptibility to climatic threats. The study also assessed the social vulnerability of household by Principal Component Analysis using SPSS Version 21 and spatial vulnerability mapping of Chakwal District by GIS. The results showed that tehsils Talagang and Lawa have high vulnerability, whereas Kallar Kahar has low-medium level vulnerability and Chakwal and Choa Saiden Shah have low level vulnerability to climate related hazards. The biophysical vulnerability assessment was also analyzed by mapping land cover dynamics in the study area using Landsat images (1985-2018) in Google Earth Engine. The findings of integrated vulnerability assessment revealed that rain-fed cropping area of the total land cover area is still the dominant land cover type (54%) and remains same for the last two decades depicting its vulnerability to climatic variabilities and reliance of rain-fed farm communities on agricultural activities for their livelihood. The determinants of adaptation strategies made by farmers toward climate-induced anomalies was analyzed using multivariate probit model. The results showed that rural communities particularly farmers perceived alterations in climate very well but could not adapt accordingly due to different resource impediments and lack of awareness and information. Therefore, adoption rate of various adaptation strategies was confined to low-costly measures or rather simple measures and generally could not include radical and innovative tools. It was further noted that various factors such as socio-economic parameters, agro-ecological factors, institutional support etc. influenced the choice of adaptation measures. On the basis of the results of this study, it is recommended that it is important to extend scientific, technical, financial and institutional support to farmers in rain-fed areas not only to improve agricultural production for ensuring food security but also to make their livelihoods resilient to climate change. Such support to farmers in rain-fed areas should include strategic interventions suggested to achieve UN sustainable development goal, SDG 2- "end hunger, achieve food security, improve nutrition and promote sustainable agriculture" and SDG 3 –"taking urgent actions to combat climate change and its impacts" in the National Sustainable Development Strategy, 2017 of Pakistan.

ACKNOWLEDGEMENTS

First and foremost, I want to thank my supervisor, Prof. Dr. Muhammad Irfan Khan for being my first mentor and advisor and providing me a place in his excellent research group, where I learned how good research is done. I appreciate all his contributions of time, ideas, and support to make my research experience productive and giving me room for developing and accomplishing my own ideas. I am also very much thankful to my co-supervisors Dr. Zafeer Saqib and Dr. Muhammad Azeem Khan who have not only provided me enough support throughout my work but also taught me GIS, remote sensing and statistical techniques. I owe special thanks to Dr. Abdul Majid, Country Manager, ICARDA-Pakistan whose support, motivation and constructive feedback on my research work will always be remembered.

I am grateful to my colleague Dr. Syed Atif Bokhari who has helped me a lot in reviewing, revising and imparting valuable wisdom of knowledge to my thesis and research papers in true letter and spirit. I am also thankful to Dr. Akhter Ali, Agricultural Economist, CIMMYT-Pakistan for extending his support to learn statistical software STATA and applying MVP model. Particularly, I thank my fellow PhD scholar, colleague and best friend Ms. Nadia Akhter, for her unconditional support, intellectual input and motivation throughout my studies.

The field research would have not been possible without help from several people in the study area. I am thankful to Mr. Ahsan Amir, Ms. Saba Bashir, Ms Aniqa Fatima, Mr. Muhammad Iqbal, Mr. Ibrar Ahmed, Mr. Amir Iqbal and Mr. Waqar Haider for their dedication and hard work in assisting me during data collection despite the harsh weather. I am grateful to the local agriculture departments and their staff for providing me required information. I am highly indebted to local farming communities in the study area for their hospitality and giving their precious time to complete my field research. I gratefully acknowledge all funding sources that made my PhD work possible particularly ICARDA-Pakistan.

Most importantly, I am highly indebted to my husband, Chaudhry Farhat Abbas for accompanying me in field visits and continuously stood beside me during course of studies for PhD. Finally, I am thankful to my parents, my in-laws, brothers and sisters for their unconditional love, support and prayers throughout my career and this work.

TABLE OF CONTENTS

ABSTRACT……………………………………………………………………………i
ACKNOWLEDGEMENGTS…………………………………………………………………iii
LIST OF FIGURES…………………………………………………………………viii
LIST OF TABLES………………………………………………………………….....x
LIST OF APPENDICES………………………………………………………………xi
LIST OF ABBREVIATIONS…………………………………………………………...xii
CHAPTER 1 1
INTRODUCTION 1
1.1 Background 1
1.2 Rationale 4
1.3 Research questions 5
1.4 Aim and objectives of the study 5
1.5 Organization of thesis 5
1.6 Limitations of the study 6
CHAPTER 2 8
LITERATURE REVIEW 8
2.1 Historical perspective 8
2.2 Climate change and food security threats in dry lands 10
2.3 Perceptions of climate change 12
2.4 Climate change vulnerability assessment in agriculture sector: evolution, definitions, importance, approaches and methods 13
2.4.1 Evolution of vulnerability concept 13
2.4.2 Definitions of vulnerability 14
2.4.3 Importance of vulnerability assessment 17
2.4.4 Approaches and methods 17
2.4 Adaptation to climate change in agriculture sector 18
2.5 Overview of the agricultural vulnerability and adaptation to climate change in Pakistan 20
2.5.1 Introduction 20
2.5.2 Agricultural vulnerability and adaptation to climate change in Pakistan 23
2.5.3 Response to climate change issues 25
CHAPTER 3 29
METHODOLOGY 29
3.1 Study Area 29
3.2 District Profile – Chakwal 30

3.2.1 Historical background ... 30
3.2.2 Area and land utilization ... 31
3.2.3 Climate ... 32
3.2.4 Topography ... 32
3.2.5 Geology ... 33
3.2.6 Population ... 33
3.2.7 Education ... 34
3.2.8 Health and sanitation ... 34
3.2.9 Economy ... 34
3.2.10 Agriculture ... 36
3.2.11 Livestock ... 37
3.2.12 Forest ... 38
3.2.13 Water resources ... 39
3.2.14 Road Network ... 40
3.2.15 Disasters ... 41
3.3 Data sources ... 41
3.4 Methods adopted ... 41
CHAPTER 4 ... 44
FARMERS' PERCEPTION TO CLIMATE CHANGE AND OBSERVED SCIENTIFIC TRENDS IN TEMPERATURE AND PRECIPITATION ... 44
4.1 Introduction ... 44
4.2 Materials and Methods ... 46
4.2.1 Data collection ... 46
4.2.2. Data analysis ... 47
4.3 Results ... 48
4.3.1. Socio-economic and demographic characteristics ... 48
4.3.2. Characteristics of farming systems ... 50
4.3.3. Limitations and impediments for the farmers ... 51
4.3.4. Livelihood strategies and food security ... 53
4.3.5. Farmers' perception about climate change ... 53
4.3.6. Climatic hazards and their impacts ... 56
4.4 Discussion ... 59
4.5 Conclusions ... 61
CHAPTER 5 ... 62
THE ASSESSMENT OF LAND USE LAND COVER CHANGES ... 62
5.1 Introduction ... 62
5.2 Materials and Methods ... 66

5.2.1 Data acquisition and source ... 67
5.2.2 Spectral Indices ... 67
5.2.3 Software used ... 68
5.2.4 Development of a classification scheme ... 68
5.2.5 Classification of the images ... 69
5.2.6 Methods of Data Analysis ... 70
5.3 Results ... 70
5.3.1 Quantitative assessment of LULC classes of study area (2018) ... 70
5.3.2 Gain and loss magnitude of land cover classes (1985-2018) ... 74
5.3.3 Gain and loss of LULC classes during (2010 - 2017) ... 75
5.3.4 Gain and loss of LULC classes during (2000-2009) ... 75
5.3.5 Gain and loss of LULC classes durning (1990-1999) ... 76
5.3.6 Agricultural productivity of *Kharif* crops ... 80
5.3.7 Agricultural productivity of *Rabi* crops ... 80
5.4 Discussion ... 83
5.5 Conclusions ... 87
CHAPTER 6 ... 88
HOUSEHOLD SOCIAL VULNERABILITY TO CLIMATIC HAZARDS ... 88
6.1 Introduction ... 88
6.2 Materials and Methods ... 91
6.2.1 Data collection ... 91
6.2.2 Choice of approach for vulnerability assessment ... 93
6.2.3 Choice of framework for vulnerability assessment ... 94
6.2.4 Choice of indicator method for vulnerability assessment ... 95
6.2.5 Normalization of indicators ... 101
6.2.6 Principal Component Analysis (PCA) ... 102
6.2.7 Geographic Information System (GIS) ... 102
6.3. Results ... 103
6.3.1 Principal Component Analysis ... 103
6.3.2 The vulnerability index ... 108
6.4 Discussion ... 112
6.5 Conclusions ... 114
CHAPTER 7 ... 115
DETERMINANTS OF FARMERS' CHOICE OF ADAPTATION STRATEGIES TO CLIMATE CHANGE ... 115
7.1 Introduction ... 115
7.2 Material and methods ... 117

7.2.1 Data collection and analysis....117
7.2.2 The econometric model....117
7.3.3 Selection of explanatory (independent variables)....118
7.3 Results and discussion....119
7.3.1 Farmers' perception to climate-related events and their impacts....119
7.3.2 Adaptation strategies and Respondents....123
7.3.5 Perceived barriers to adaptation....124
7.3.6 Determinants influencing farmers' adaptation measures....124
7.4 Conclusions....135
CHAPTER 8....138
CONCLUSIONS AND RECOMMENDATIONS....138
8.1 Conclusions....138
8.2 Recommendations....140
8.2.2 Research recommendations....142
REFERENCES....144
APPENDIX-A: Instrument for data collection....156
APPENDIX-B: LULC bases sub-divisonal gain and loss....161
APPENDIX-C: Latitude/Longitude coordinates of the surveyed villages....175
APPENDIX D: Research Publication....180

LIST OF FIGURES

Figure 1.1: A schematic representation of the four dimensions of nutrition and food security impacted by the quality, quantity and price effects and cascading effects of climate change........3
Figure 2.1: The major milestones in the history of climate change science……………………9
Figure 2.2: Work program for climate compatible development in Pakistan........27
Figure 3.1: Location map of the study area........31
Figure 3.2: Hierarchy of Department of Agriculture, District Chakwal, Government of Pakistan........37
Figure 3.3: Evaluation framework based on questionnaire………………………………..42
Figure 4.1: Sampling framework of the study........47
Figure 4.2: Demographic and socio-economic statistics of the sample........49
Figure 4.3: Limitations and impediments in study area........52
Figure 4.4: Livelihood strategies of respondents........53
Figure 4.5: Year-wise precipitation variability in study area over the period of 1977-2018...54
Figure 4.6: Monthly precipitation variability in study area over the period of 1977-2018......55
Figure 4.7: Year-wise temperature variations in study area over the period of 1999-2018.....55
Figure 4.8: Monthly temperature variations in study area over the period of 1999-2018.......56
Figure 5.1: Flow diagram of methodology........66
Figure 5.2: Land use Land cover map of Chakwal District (2018)........71
Figure 5.3: Bar graph showing the percentage of LULC classes of Chakwal District........72
Figure 5.4: Percentage area of LULC classes of Chakwal (sub-divisions)........72
Figure 6.1: Study area map showing surveyed union councils........92
Figure 6.2: Study area map showing sampling points (households)........92
Figure 6.3: Study area map showing number of villages surveyed........93
Figure 6.4: Contribution of different indicators to vulnerability........98
Figure 6.5: Vulnerability indices across the farming regions in Chakwal District........108
Figure 6.6: Map of vulnerability indices across Chakwal sub-divisions (tehsils)........109
Figure 6.7: Exposure indices across the tehsils in Chakwal District........109
Figure 6.8: Map of the exposure indices across the tehsils of Chakwal District........110
Figure 6.9: Sensitivity indices across the tehsils of Chakwal District........110
Figure 6.10: Map of sensitivity indices across the tehsils of Chakwal District........111
Figure 6.11: Adaptive capacity indices across the tehsils of Chakwal District........111
Figure 6.12: Map of adaptive capacities indices across the tehsils of Chakwal District.......112
Figure 7.1(a): Climate-related events experienced by farmers in the last 20 years or so in the study area........120

Figure 7.2(b): Rate of change (increase/decrease) of climate-related events perceived by farmers in the last 20 years or so in the study area. 120
Figure 7.3(a): Impacts of climate-related events on human health (disease/illness etc.) as perceived by farmers over the last 20 years or so in the study area. 121
Figure 7.4(b): Impacts of climate-related events on crop yield/productivity (uncertainty/decline etc.) as perceived by farmers over the last 20 years or so in the study area. 122
Figure 7.5(c): Impacts of climate-related events on livestock (death/disease etc.) as perceived by farmers or so in the study area. 122
Figure 7.6: Barriers to adaptation as perceived by farmers 124

LIST OF TABLES

Table 2.2: Poverty variations by size of farm across agro-climatic zones 2014 24
Table 3.1: Tehsils and Union Councils (UCs) of Chakwal District 31
Table 3.2: District and tehsil level population statistics 33
Table 3.3: Industry-wise installed capacity 35
Table 3.4: Mineral production 35
Table 3.5: Establishment of Private Poultry Farms 38
Table 3.6: Forest area by administrative jurisdiction and enactment 39
Table 3.7: Small dams and their storage capacity in Chakwal District 40
Table 4.1: Characteristics of the farming systems of the surveyed households 50
Table 4.2: Climatic fluctuations and their impacts on farmers over the last 20 years or so (1997-2017) 58
Table 5.1: Satelllite data characteristics 67
Table 5.2: Interpretation of LULC Classification 69
Table 5.3: Land use/land cover (LULC) classes of Chakwal District (2018) 71
Table 5.4: Land use/land cover classes of Chakwal (sub-divisions) of year 2018 (km^2) 72
Table 5.5: Agricultural land statistics of Chakwal District 80
Table 6.1: Description of indicators selected for vulnerability assessment in the study area .. 99
Table 6.2: Descriptive statistics of exposure, sensitivity and adaptive capacity indicators ... 104
Table 6.3: PCA analysis constituting household vulnerability index, details of eight components retained 105
Table 7.1: The sampling framework of the study 117
Table 7.2: Farmers' adaptation strategies (farm-based and non-farm based) 123
Table 7.3: Description of explanatory variables and descriptive statistics 125
Table 7.4: Determinants of household farm-based adaptation strategies by using multivariate probit model 126
Table 7.5: Determinants of household non-farm adaptation strategies by using multivariate probit model 128

LIST OF APPENDICES

Appendix-A: Instrument for data collection……………………………..………161

Appendix-B: LULC bases sub-divisional gains and losses in the study area ……...166

Appendix-C: Latitude/Longitude coordinates of the surveyed villages…………….180

Appendix-D: Research publications…………………………………………...185

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AEZs	Agro-ecological zones
AR5	Fifth Assessment Report
BARI	Barani Agriculture Research Institute
BHCs	Basic Health Centres
CAP	Crop Agronomic Practices
CART	Classification and Regression Tree Classifier
CC	Climate Change
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of Parties
CPEIR	Climate Public Expenditure and Institutional Review
DCR	District Census Report
ETM+	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
F-gases	Fluorinated gases
GCC	Global Climate Change
GDP	Gross Domestic Product
GEE	Google Earth Engine
GHGs	Greenhouse Gases
GIS	Geographic Information System
GoP	Government of Pakistan
GPS	Ground Positioning System
Ha	Hectares
HHs	Households
ICA	Integrated Content Analysis
ICARDA	International Centre for Agriculture Research in Dry Areas
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change

LD	Land Degradation
LU	Land use
LULCC	Land Use Land Cover Change
M2	Motorway
Mha	Million hectare
MICS	Multiple Indicator Cluster Survey
MNDWI	Modified Normalized Difference Water Index
MRV	Monitoring, Reporting and Verification
MVP	Multivariate Probit Model
N_2O	Nitrous oxide
NAMA	National Appropriate Mitigation Actions
NAP	National Adaptation Plan
NCCP	National Climate Change Policy
NDBI	Normalized Difference Built Index
NDMA	National Disaster Management Authority
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NGOs	Non-governmental Organizations
OECD	Organization for Economic Cooperation and Development
PARC	Pakistan Agriculture Research Council
PBS	Pakistan Bureau of Statistics
PDMA	Punjab Disaster Management Authority
PDS	Punjab Development Statistics
PKR	Pakistan Rupees
PMD	Pakistan Meteorological Department
PVT	Private
REDD	Reducing Emissions from Deforestation and Forest Degradation
RHCs	Rural Health Centres
RS	Remote sensing
SAWCRI	Soil and Water Conservation Research Institute
SCWD	Seasonal Crop Water Deficiency
SDGs	Sustainable Development Goals
SSA	Sub-Saharan Africa

TFP	Total Factor Productivity
tGE	Tons of Grain Equivalent
TLUs	Total Livestock Units
TM	Thematic Mapper
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
USDA	United States Development Agency
WB	World Bank
WFP	World Food Program
WMO	World Meteorological Organization
WRS	Worldwide Reference System

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Background

Climate change, recognized as a daunting and challenging global phenomenon (IPCC, 2014b; Pan et al., 2014) defined by 'Article 1 of UNFCCC' (United Nations Framework Convention on Climate Change) of 1992 as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".

Global climate change (GCC) is an externality (Janjua et al., 2014) and a complex multivariate dependent phenomenon (Abas et al., 2017). This externality is primarily due to industrial and agricultural activities which alter the composition of greenhouse gasses (GHGs) in the atmosphere (Janjua et al., 2014). Short-term climate change continues, but long-term alterations are initiated by atmospheric GHGs. The main GHGs comprised of "carbon dioxide (CO2: 76%)", "methane (CH4: 16%)", "nitrous oxide (N2O: 6%)" and "fluorinated gases (F-gases: 2%)". Of the total CO2 emissions of 76 percent, 65 percent emit during the combustion and industrial processes of fossil fuels and 11 percent through land use and forestry. It is pertinent to mention that economic activities that lead to GHG emissions consist of "energy (25%), agriculture (24%), industry (21%), transport (14%), energy related activities (10%) and buildings (6%)" (Abas et al., 2017; IPCC, 2014b).

This high GHG concentration is primarily because of two reasons. Firstly, developed countries accelerate growth through various activities in production and consumption arenas by taking advantage of natural resources to increase their international export share. The climate change impacts (through temperature rises, changes in precipitation patterns, frequent floods, droughts, cyclones, extreme weather events etc.) is, however, primarily confronted by tropical region of the developing countries, which are mainly located in tropical regions and are mainly dependent on agriculture for their livelihood (Janjua et al., 2014; Pan et al., 2014). Secondly, UNFCCC does not have strictly enforceable policies on climate change. For these reasons, the mean GHG concentration is 430 ppm and since the industrial revolution, the concentration of CO_2, which is the main constituent of GHG, has risen to 402 ppm. According to Fifth Assessment Report launched by IPCC (Intergovernmental Panel on Climate Change) in 2013, that the average temperature increased to 1 °C from 1880 to 2015, which is halfway to the IPCC set target of 2 °C by 2100 (Abas et al., 2017).

There is a clear and growing consensus among numerous researchers in the arena of climate change on two vital concerns. Firstly, GCC is constantly increasing due to economic activities with potentially far-reaching insinuations resulting more frequent extreme weather events (Ali & Erenstein, 2017; IPCC, 2014b) and weather-related calamities (Abas et al., 2017). Due to GHGs emissions, the average Earth temperature has risen by about 0.8 °C since the beginning of the 20th century (IPCC, 2014b). Due to climate change, the number and severity of warm/hot days and nights have increased since 1950. It is also reported that the pattern, timing and intensity of the precipitation has also got altered, and it is expected that heat waves will increase in length, frequency and intensity in most parts of the globe (Pan et al., 2014).

Secondly, agriculture is acknowledged as one of the most vulnerable sectors to global climatic variabilities, particularly in developing countries (Africa and South Asia), although they share only 10 percent to the annual global CO_2 emissions (Lal, 2011). Agricultural productivity depends heavily on weather and climate, and variations in either can interpose crops growth, reduce yields and destroy harvests, affect irrigation and soil quality (Bandara & Cai, 2014). Climate change is therefore, expected to influence food production, food costs and potentially threaten food safety. The demand for food is anticipated to increase by about 300 percent by 2080. If, as expected, food production declines due to global warming, there is likely to be further pressure on food prices, increasing the current threats to food security (Bandara & Cai, 2014). Food and Agriculture Organization (FAO) illustrated that four dimensions of nutrition and food security i.e. “availability, access, utilization and stability” has been impacted by the quality, quantity and price effects and cascading effects of climate change (Figure 1.1).

Pakistan is an agro-based country, therefore, agriculture is the lifeline of Pakistan's economy, encompassing 18.5 percent of its GDP (gross domestic product), employing 38.5 percent of the labor force. It plays a pivotal role in national raw materials to a number of value- added industries. It plays a cardinal role in national development, food security and the alleviation of poverty (GOP, 2019). According to Pakistan's 6th Population and Housing Census 2017, the country's population grew by 207.774 million at a rate of 2.4 percent per year over the period 1998-2017, making it the world's sixth largest populous country. Due to swift increase in population, demand for agricultural products is rising (GoP, 2017a). However, the agricultural sector is increasingly getting sensitive to climate-induced anomalies and has thus become major obstacles to attain two most national agendas of Pakistan i.e. food security and poverty reduction (Ali & Erenstein, 2017).

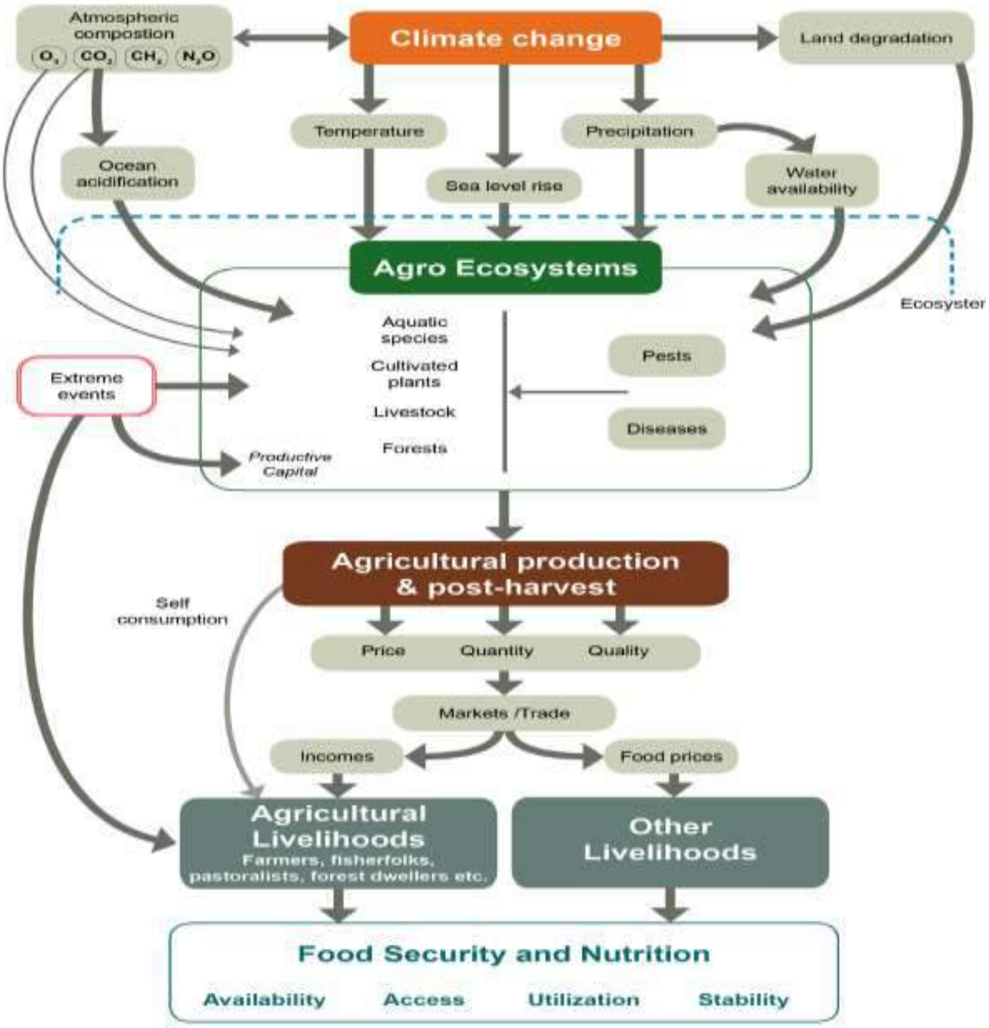


Figure 1.1: A schematic representation of the four dimensions of nutrition and food security impacted by the quality, quantity and price effects and cascading effects of climate change.

Source: (FAO, 2016)

Recognizing the significance of agriculture to Pakistan's economy and associated effects of changes in climate on agriculture, in particular rural rain-fed *(barani)* agriculture, this current study attempted to assess the farmers' perception to climate change, socioeconomic vulnerability of rural households to climatic instabilities, factors influencing their adaptation strategies and also assessed the historical land use land cover changes using remote sensing data in Chakwal District, Punjab, Pakistan.

1.2 Rationale

Pakistan is located in the region susceptible to natural calamities such as earthquakes, floods, droughts, cyclones, land and soil erosion. It is pertinent to mention that Pakistan is continuously being ranked among top ten countries most vulnerable to climate change due to low adaptive capacity, poor infrastructure and financial resource base. The reported rise in the temperature and unpredictability about the patterns of precipitation in Pakistan are also adversely impacting the per acreage yield of food crops. Resultantly, the supply-demand gap for food crops is widening in magnitude overtimes. The National Disaster Management Authority (NDMA) of Pakistan estimated an approximate loss of about 4 billion US dollars to national economy in the past twenty years (1994-2013) due to extreme weather and climatic anomalies. For these reasons, Pakistan is in need of approximately 07 to 14 billion USD per annum for an integrated response to address the looming challenges linked with the climate change. However, the focus towards these pressing issues is far from satisfactory in Pakistan and, thus, demands immediate attention on climate change research. Therefore, the knowledge about contextual agricultural practices, assessment of perception among farmers about climate change and evaluation of available adaptive measures particularly in rain-fed areas are prerequisites for ensuring the resilience of rain-fed agriculture sector and providing scientific basis to informed policy-making for sustainable agricultural development.

In this regard, analysis of socio-economic factors, historical changes in land use and land cover changes, and identification of sources of information dissemination among stakeholders are essential for developing effective and rational adaptive strategies. In concurrence with existing knowledge and progress in the research of agricultural vulnerability to climate change issues around the world, it is expected that the findings of this research work will provide a meaningful reference for relevant research studies in the future with the same agro-ecological settings.

1.3 Research questions

This thesis is build up on exploration of answers to the following questions:

i. How do farmers perceive climatic changes and compare it with the patterns and trends of temperature and precipitation in the Chakwal District?

ii. What are the main dynamics involved in land use land cover changes in Chakwal District?

iii. What are the socioeconomic vulnerabilities to climatic instabilities of the rain-fed farming community of the study area?

iv. What are the adaptation strategies adopted by the rain-fed farming community in the face of climate change?

1.4 Aim and objectives of the study

The present study was aimed at generating knowledge on climate change vulnerability assessment of the rain-fed agriculture, which may be useful in planning for climate compatible development in Potohar Plateau, Punjab Pakistan. Whereas, the specific objectives of the study were to:

1. get an insight of farmer's cognizance and response by comparing climate variability trends and patterns with farmers' perception about climate change in the study area;
2. map historical changes in land use and land cover in study area by using remote sensing data and elucidate its causal factors;
3. model the vulnerability of households to climate-related events; and
4. analyze determinants of farmers' choice of adaptation strategies or measures in the face of climate change.

1.5 Organization of thesis

The thesis is systematized into eight chapters. Each chapter has a title and subtitles which represent its contextual framework.

Chapter 2 is a review of literature on agricultural vulnerability assessment and adaptation to climate change at national, regional and global scales. This chapter also covers in detail the household social vulnerability assessment tools/methods and results from the empirical analysis of the assessment techniques and land use land cover dynamics using remote sensing.

Chapter 3 describes in detail the study area with a brief overview of the sampling and data collection methods, tools, techniques and approaches used to derive results.

Chapter 4 examines farmers' perception to climate change, their sources of information and observed scientific climatic trends and patterns in the case study area using both qualitative and quantitative research methods and discusses the results in the light of previous available studies.

Chapter 5 assesses the land use land cover changes (LULCC) in the study area over the period of 30 years with respect to climatic variabilities using Google Earth Engine (GEE).

Chapter 6 assesses household social vulnerability to climate-related hazards (such as temperature hike, erratic rainfall, drought etc.) and executed spatial mapping.

Chapter 7 evaluates determinants of adaptation strategies adopted by farming communities using multivariate probit model (MVP).

Chapter 8 finally draws conclusions and implications for future research and give recommendations for farmers and other stakeholders to adapt strategies resilient to climate change and to provide policy recommendations.

1.6 Limitations of the study

The sample population was comprised of male only as in the socio-cultural setting of this region women are not mainly involved in farming, they mostly do household chores, livestock keeping and participate during harvesting season. The present study uses a case-study approach taken Chakwal District as a representative of rain-fed areas of Pakistan. Due to budget and time constraints, other rain-fed regions were not taken into account considering the fact that research findings and policy recommendations suggested for this area might be applicable to other rain-fed farming areas of the region and country having similar agro-ecological rural settings.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 Historical perspective

Climate change refers to "an alteration in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer" (IPCC, 2018b). During the last decade, climate change has been known as foremost scientific, political, economic, and environmental issue (Bandara & Cai, 2014; Gorst et al., 2018; IPCC, 2014b; Žurovec et al., 2017a). The global temperature has been rising for more than hundred years, and the climate change threats are now visible across the globe (natural and human systems) (IPCC, 2014b). The UNFCCC was established in 1992 to look into the debate on climate change and to formulate a strategy to address it. The IPCC came into being in 1988 by two most renowned organizations namely WMO (World Meteorological Organization) and UNEP (UN Environment Programme) to state clear scientific views on global agenda of climate change to the world government. The key events within the climate change history are summarized in Figure 2.1.

Huge political and economic changes in the past 25 years, representing changing trends of production, have altered the rate of emission growth and its distribution. Development has neared zero in developed countries, especially in the face of successive financial crises, while capital and development have shifted to the developing world. Climate risk irony is that it's powered by unimagined prosperity across the developing world, where the middle class continues to grow, consuming more food and fuel (Nelson and Vladeck, 2013).

Since most of the accumulated carbon had been introduced into the environment by the developed countries through industrialization, the developing world argued that such a system would function under a "principle of common but differentiated responsibility". According to this "principle", only the industrialized countries should pursue emission goals for at least a while and developing countries would obtain some kind of fiscal or technology transfer to pay for the additional costs of reducing their emissions (Bandara & Cai, 2014; Janjua et al., 2014; Olmos, 2001)

1861
- JohanTyndall discovered that water vapor and some other gases block infrared radiations and suggested increased concentration may lead to a change in climate.

1896
- The first calculations of human induced climate change (CC) made by Svante Arrhenius.

1988
- Joint UNEP/WMO conference on CC, lead to the formulation of the IPCC.

1990
- Newly formed IPCC releases its first report. It provides evidence that the world is warming and projects further global warming.

1992
- UNFCCC is an outcome of Earth Summit in Rio de Janeiro, Brazil marking a major turning point in modern efforts to combat CC.

1995
- IPCC SAR report released and pointed out anthropogenic global warning: suggests serious warming likely in 21st century.

1997
- Kyoto Protocol is an outcome of UNFCCC. It set goals for developed countries to lessen GHGs emissions provided enough countries sign the treaty. The US Senates rejected to ratify the Protocol.

2001
- Third IPCC report released convinces most scientists about the severity of global warming and the impact that the world will have to face as a consequence.

2005
- The Bali Action Plan was adopted at COP 13. It is divided into five categories: shared vision, mitigation, adaption, technology and financing. Loss and Damage as a term appeared in decisions for the first time.

2007
- Fourth IPCC report released confirms impacts of global warming, it also explains the cost of reducing emissions will be far less than the damage anticipated.

2013
- Launch of IPCC AR5 states that scientistif community is 95% certain that anthropogenic factors are the "dominant cause" of global warming since the 1950s.

2015
- The Paris Climate Agreement is seen as a landmark development, which has been a strategic milestone to develop a unanimous agreement worldwide to address the challenge of global warming.

2018
- IPCC special report on the "impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty".

Figure 2.1: The major milestones in the history of climate change science
Source: Chronology based on IPCC Reports

The release of the IPCC first assessment report in 1990, followed by the first Rio Summit hold by United Nations in Rio de Janeiro, Brazil in June 1992, is seen as two turning points making the beginning of the modern global effort to fight against climate change. Since 1992, as the world has attempted to define and execute a strategy to react to the reality of global climate change, the global negotiations progressively focused on three major responses; mitigation, adaptation and more recently in the context of the latter, addressing “Loss and Damage” associated with climate change (Kakakhel, 2015).

2.2 Climate change and food security threats in dry lands

More than 40% of the world's land surface is covered by dry areas and approximately 2.5 billion people are residing there which means dry lands are inhabited by almost one-third of the global population. Dry land people faces rapid population growth, food security challenge, poverty, biodiversity loss, frequent drought and environmental degradation (Intercooperation, 2006; Pedrick, 2012). As far as developing world is concerned, nearly 3 billion hectares is occupied by it, and 16% of the population lives in extreme poverty, particularly in marginalized rain-fed areas. It is estimated that rain-fed production will drop to "28% for wheat", "16% for maize", and "13% for rice" in 2050 compared to a no-climate change scenario in 2050. In case of mitigation scenario, meagre productivity escalates food prices which is projected to decrease calorie intake by 22% in poor countries in 2050 and will cause child malnutrition to increase by 21%. Ultimately, all these repercussions would greatly impact food security, particularly for the marginalized, poor, deprived and vulnerable sections in rural hinterland (Mckhann, 2012).

It is incumbent to mention here that nearly 641 million are found in Asia-Pacific and agriculture (70% of the poor) is their dominant source of livelihood. The outcomes of globalization and global environmental and climate change repercussions have made the poor people more susceptible. It is anticipated that the problem is much more noticeable in the rain-fed locales and drought susceptible areas, having serious implications that these same locales will be more affected (more drier) in the face of climatic variabilities (Devendra, 2012). The significant climate change impact on rain-fed farming is the decline of crop productivity which is linked to crop efficiency in fixing CO_2 by the process of photosynthesis (Al-Bakri et al., 2011).

According to Pachauri and Meyer, (2014), SSA (Sub-Saharan Africa) is considered as most affected regions because of highest world's malnourished population. In addition to that, a notable segment of its national economies are relying on agriculture, with dependency on 85% of its available water resources (Derbile et al., 2016; Harvey et al., 2014). In terms of farming methods/techniques, they are also found to be comparatively primitive. Most of the continent 'Africa' is already arid and the dominant smallholder farming systems have very limited capacity to respond to externalities (Harvey et al., 2014; Senbeta, 2009). South Asia is no exception because on rain-fed agriculture, livestock keeping and forestry for their bread and butter (Arshad et al., 2017; Bandara & Cai, 2014).

Countries like Pakistan, the situation is not very different from other South Asian countries because less than 250 mm of annual rainfall is received by 75% of the country's total area. Dry zone of Pakistan covered most parts of Sind, Baluchistan, NWFP and southern areas of Punjab which is a home to over three million people. People in these areas relies on the natural resources for their food, livestock (fodder), cooking and heating (fuel), and drinking purposes(water). In addition to that rural people are also involved in the sale of plants and herbs having medicinal values, livestock, and wildlife and dairy products. All of them contribute to their insufficient earnings (Intercooperation, 2006).

According to IPCC AR4 for South Asia, regional projections say that global warming is expected to be over the global mean (Pachauri & Meyer, 2014). Further, summer rainfall, tropical cyclones, the frequency, severity, patterns and intensity of precipitation are all likely to increase in South Asia (IPCC, 2018b). According to global assessments an overall mean yield decline of 8% was identified in South Asia, with pronounced reductions projected for major crops i.e. "wheat (12%)", "maize (7%)", "sorghum (3%)" and "millet (9%)" (Lal, 2011).

Global climate change will certainly pose threats to poor farming communities and their livelihoods in South Asia, mainly because climate and soils are getting worse for production and where meagre access to innovative technology and agricultural knowledge will obstruct their capacities to cope with (Abid et al., 2019; Ali & Erenstein, 2017).

With respect to Asian farming systems, it is imperative to consider that majority of the farmers have small farms, mixed farming systems also prevails, involving complexities between crops and animals interrelationships across a range of agro-ecological zones (Devendra, 2012). It is noticeable that at the global level, farms size with less than two hectares with about 2.6 billion farmers have been producing main bulk of food, other products as well as services in agriculture sector worldwide. A large majority of small farms holders' i.e. 87% of 470 million farms globally is found in Asia (Nagayets, 2005). In Asia, China alone encompassed for about 40.2% of the farms, followed by India (23%). According to IFAD (2009), it is expected that climate change will out 49 million additional people at risk of hunger by 2020, and 132 million by 2050 (Devendra, 2012).

The need to focus on rain-fed areas for food production and security demands immediate and urgent actions due to two key issues:

- Climate induced anomalies due to anthropogenic activities with an expected harsher climate will increase extreme poverty and survival; and
- Consistency of soil-crop-animal interactions need to be ensure with productivity enhancement, environmental veracity and sustainable development of rain-fed areas for getting efficiency in the use of available natural resources and desired benefits (Devendra, 2012).

Rain-fed areas of the world have a significant potential for food production which is underestimated. In a larger perspective, management of rain-fed areas will be a step forward to combat climate change impacts in the form of temperature hike, erratic precipitation, frequent droughts and poor soil quality. Farming communities belonging to the developing world are cognizant about climatic fluctuations, which provides an edge in devising adaptation measures/strategies of rain-fed farming for its improvement. It is also important to mention here that due to poor resource-base, many farmers are experiencing changes in climatic conditions, but a large majority are not well equipped to fight against new threats and challenges of climate change (Devendra, 2012).

2.3 Perceptions of climate change

Research using environmental behavior theories has manifested the link between perceptions, knowledge and awareness of environmental externalities, and change in behaviors. In case of climate change, adoption (intended or actual) of climate adaptation and mitigation behaviors is dependent on perceived individual experiences that affect climate change belief (Woods et al., 2017). As far as developing countries are concerned, where climate change is recognized as a major threat for the economic growth, little information/research has been found about climate change from local level perspectives. The understanding of farmers regarding climate change plays a key role in effective adaptation and mitigation plans concerning land use and decision-making in agricultural practices (Tesfahunegn et al., 2016).

Many studies indicate that farmers consider climate change to alter and respond to the the adverse effects of climate change (Abid et al., 2019; Tesfahunegn et al., 2016; Woods et al., 2017). Studies further show that the understanding or knowledge of climate change (Abid et al., 2015; Ayanlade et al., 2017; Ullah et al., 2018; Woods et al., 2017)and the development of adaptation measures (Ali & Erenstein, 2017; Asrat & Simane, 2018; Aydogdu & Yenigün, 2016; Bryan et al., 2009, 2013) are affected by various socio-economic and institutional factors such as political, financial, and educational. Smallholder farmers are especially vulnerable to climate change according to these studies because most of them don't have enough resources to cope with it. Across the globe it is widely claimed that anthropogenic activities are largely responsible for climate change. (Mase et al., 2017; Weber, 2010).

2.4 Climate change vulnerability assessment in agriculture sector: evolution, definitions, importance, approaches and methods

2.4.1 Evolution of vulnerability concept

Research on vulnerability to climate change started in the 1990s (Füssel & Klein, 2006; Hinkel et al., 2014) to identify the magnitude and nature of climate change and its effects, in the hopes of designing policies and initiatives to minimize this vulnerability.

Several widely cited articles took different types, including evaluating the evolution of vulnerability research methods, Füssel and Klein (2006) evaluating the conceptual linkages between vulnerability and adaptation, Gbetibouo et al. (2010) proposing integrative frameworks for vulnerability research and addressing key problems and challenges in vulnerability research. (Wang et al., 2014). More recent studies have continued these discussions (LEE, 2017; X. Li et al., 2015). There has been a wealth of empirical research on vulnerability to climate change since the mid-2000s, particularly in relation to smallholder agricultural systems which is also the subject of this study.

There is substantial research activity in the field of climate change vulnerability (Adger 2006), much of it focused on vulnerability conceptualizations and their relationship to adaptation. The other themes that emerge are sustainable livelihoods and vulnerability to poverty, and socio-ecological systems' vulnerability and resilience. Many of the studies are basic conceptual diagrams that help to frame the problem of climate vulnerability at global (macro) scales (Füssel 2007a; Heltberg et al. 2009; Ionescu et al. 2009). While others focus exclusively on adaptive strategies (Füssell and Klein 2006; Füssell 2007b; Smit and Wandel 2005; Yamin et al., 2005).

The groundbreaking development in the field of vulnerability assessment is the "vulnerability scoping diagram" (Polsky et al., 2007), which offers a structure for analyzing hazard/risk-specific vulnerability assessments comprising dissimilar risk, susceptibility, and resilience (or adaptive capacity) measurements. This also gives a framework for carrying out these research (Schröter et al., 2005).

During the 1960s and 1970s the social indicators became more common, followed by environmental indicators. Throughout the 1990s more focus was put on the production of environmental protection and vulnerability indicators (Kaly et al., 1999; Esty et al., 2005; Birkmann 2006, 2007; Polsky et al., 2007). In recent years, vulnerability assessments have become a prominent subject in the field of applied global change (McCarthy et al. 2001).

2.4.2 Definitions of vulnerability

Whereas most researchers agree on the general concept of vulnerability as "the capacity to be harmed," the usage of the word varies across disciplines and research areas. According to IPCC AR5, vulnerability to climate change is defined as: *"propensity or predisposition to be adversely affected*" (IPCC, 2014b). The delineation encompasses the associated dimensions of vulnerabilities such as exposure to adverse effects, sensitivity to harm, capacities to cope and adapt with the eventualities. Various definitions and dimensions of 'vulnerability' concept given by scientists over the period of time are given in the following table (2.1).

Exposure is defined as "The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC, 2014b).

Sensitivity is defined as "The degree to which a system or species is affected, either adversely or beneficially by climatic oscillations" (IPCC, 2014b). The consequential effects may be direct such as changes in the temperature etc. or indirect like crop yield variations and sea level rise etc. (IPCC, 2014a). Within the agricultural sector, climate sensitivity refers to the threshold responses of crops to their environment , affecting their production, development and yield (Elum et al., 2017).

Adaptive capacity is the "ability of systems, institutions, humans, and other organisms to adjust with ensuing changes or the capacities to convert such challenges into opportunities" (IPCC, 2014a).

Definitions and dimensions of vulnerability concept given by different scientists

Author	***Definitions/Dimensions of Vulnerability***
Timmermann (1981)	"Vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern".
Anderson and Woodrow's (1989)	They attempted to identify different dimensions of vulnerability such as the "physical and material, social and organizational, and motivational and attitudinal."
Liverman (1990)	"Vulnerability has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk".
Blaikie et al. (1994)	Vulnerability as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural hazards" and states that "vulnerability can be viewed along a continuum from resilience to susceptibility."
Cutter (1996)	Cutter identifies three distinct clusters of definitions for vulnerability: "as risk of exposure to hazards, as a capability for social response (coping or adaptive capacity), and as an attribute of places (e.g., vulnerability of coastlines to sea level rise)". Cutter (1996) proposes a "hazards of place" model that bridges various definitions and states "Vulnerability is the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazards of place (risk and mitigation) with the social profile of communities." She ultimately argues that "it is place that forms the fundamental unit of analysis" for vulnerability.
Ribot (1996)	Vulnerability assessment is described "as extending impact assessment by highlighting who (as in what geographic or socioeconomic groups) is susceptible, how susceptible they are, and why, while climate impact assessment addresses the magnitude and distribution of the consequences of climate variability and change." Ribot (1996) states that "with an

	understanding of causality, appropriate policy responses can be developed to redress the causes of vulnerability, rather than just responding to its symptoms" and "policy analysts must go beyond identifying its proximate causes to evaluating the multiple causal structures and processes at the individual, household, national and international levels."
IPCC (1996)	Vulnerability as "the extent to which climate change may damage or harm a system." It adds that vulnerability "depends not only on a system's sensitivity, but also on its ability to adapt to new climatic conditions."
Downing (1999)	Downing (1999) "separates hazard (as the potential threat to humans and their welfare) and vulnerability (as exposure and susceptibility to losses); together, hazard and vulnerability add up to risk (the probability to hazard occurrence), with disaster as the realization of a risk".
Vogel (1999)	Vogel points to the importance of the relationship between empowerment and vulnerability, e.g., "how do different social actors gain access to and control of various resources."
Reilly and Schimmelpfennig (1999)	Vulnerability is defined as "a probability weighted mean of damages and benefits" and give as examples "yield vulnerability," "farmer or farm sector vulnerability," "regional economic vulnerability," and "hunger vulnerability." They distinguish between famine and chronic hunger, the former being "a shortage of food so severe that many people starve," the latter "limiting mental and physical development of children and impairing function in adults." Causes of and remedies for famine and hunger differ.
Adger and Kelly (2000)	Vulnerability as "the ability or inability of individuals or social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being."
IPCC (2001)	"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity".
IPCC (2007)	Vulnerability to climate change is defined as: "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."
IPCC (2012)	"Vulnerability" is the propensity or predisposition to be adversely affected

Source: (Füssel & Klein, 2006; IPCC, 2014a; Pachauri & Meyer, 2014)

2.4.3 Importance of vulnerability assessment

Measuring the sensitivity of the sector to impacts of climate change may be important to improve resilience of the sector. Vulnerability assessments also establish policy interventions that improve communities' capacity to respond to stressors and secure livelihoods, thereby reducing their vulnerability to future impacts of climate change (Pan et al., 2014).

Bryan et al. (2009) showed that the agriculture sector is vulnerable to climate instabilities across Africa. Likewise, Yiran et al. (2017) found that rain-fed agriculture in Africa (Ghana) is most susceptible to multiple climatic hazards (droughts, floods, windstorms) as compared to other climate-sensitive sectors (water, health, housing and roads). He divided the data into susceptibility and adaptive capacity indicators and adopted spatial mapping vulnerability approach to demonstrate the vulnerabilities of each sector by using ArcGIS 10.2 weighted linear sum aggregation.

Wu et al. (2017) assessed global vulnerability to agricultural drought at a 0.5° resolution and developed drought vulnerability index using GIS technology. The study datasets include climate data, crop data, soil data and irrigation data. The results demonstrated that during the past 30 years global mean seasonal precipitation was less than the average crop water requirement. Nearly half of the world's agricultural area (48.48%) was in crop water deficit status. According to the study, high and very high vulnerabilities zones were mainly distributed in arid and semi-arid regions. The study highlighted most of the Indus Plain (Pakistan mainly Potohar Plateau) falling in high and very high vulnerabilities zones.

2.4.4 Approaches and methods

Several approaches and methods have been used in vulnerability assessment studies. However, no universally agreed approach or method applies as it context, time and place specific. Some of the methods/approaches are delineated below.

2.4.4.1 Indicator method

The assessments regarding vulnerability were made by adopting 'indicator method'. It postulates that an indicator is a functional form of an indicating or theoretical variable (Hinkel et al., 2014) – which , in this case is vulnerability (Mallari

& Ezra, 2016). Therefore, vulnerability indicators are a pragmatic choice for evolving a consensus among the theorists, policy makers and practitioners operating in different hierarchical levels (Mallari & Ezra, 2016).

The careful selection of indicators requires clarity about purpose and scope of the study (Hinkel et al., 2014). The composite process for the selection of indicator was carried out in three inter-linked steps. The first step deals with the scope of the study. In this case, it is the vulnerability of the agricultural sector to climate change. The selection of the indicating variables was made in the second step. It helped to calculate the percentage share of rain-fed agriculture affected by the erratic precipitation. It was used as an indicating variable to measure the sensitivity of agricultural production to erratic rainfall. In the last step, the indicating variables were aggregated for integrated analysis (Hinkel et al., 2014).

2.4.4.2 Geographic visualization

The spatial dimension of the vulnerability were assessed with the help of GIS. The inter-active environment of GIS enable to store, integrate, manipulate, analyze and display spatial data sets (Mallari & Ezra, 2016). Thus, GIS is useful to identify locations susceptible to climate induced vulnerability (Li et al., 2014).

2.4 Adaptation to climate change in agriculture sector

Anthropogenic climate change poses major threats to society and nature. The two main societal response solutions to reduce these threats are climate change mitigation and climate change adaptation. In the context of climate change, mitigation is about limiting global climate change by reducing greenhouse gas emissions or increasing their sinks. Adaptation means actions aimed at the vulnerable system in response to real or planned climate stimuli with the goal of moderating or exploiting climate change harms (Fussel, 2007). Various definitions of 'adaptation' given by researchers over the period of time are given below.

Definitions of adaptation by various authors

Defined by	*Definitions of Adaptation & Coping capacity*
Burton (1992)	"Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides."
Smit (1993)	"Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer-term climate change."
Stakhiv (1993)	The term adaptation means any "adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change."
Smith et al. (1996)	"Adaptation to climate change includes all adjustments in behavior or economic structure that reduce the vulnerability of society to changes in the climate system."
Watson et al. (1996)	"Adaptability refers to the degree to which adjustments are possible in practices, processes or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions."
Folke et al. (1998)	"Coping strategies are differentiated from adaptive strategies on the basis of the time-scale of response, the level of vulnerability, and the type of risk faced by households and communities. Coping strategies tend to be short-term responses in abnormal periods of stress. The continued availability of a range of coping strategies may be necessary for livelihood strategies to remain adaptive in the long term."
Janssen and de Vries (1998)	"They combine response of agents in the form of adaptation to an evolving system (a world with surprises) in their modeling of climate change. They follow the results of Cultural Theory-based hierarchist, egalitarian, and individualist types of rule-based responses of the system to change; they conclude, not surprisingly, that adaptation based on observation and knowledge of changes reduces the risk of a path to catastrophe."
Stern and Easterling (1999)	"Social systems currently cope with climate variability (1) in anticipation of climatic uncertainty and (2) with crisis response strategies."
Reilly and Schimmelpfennig (1999)	They distinguish between adaptation as response to climate change and adjustment. Adaptation in the case of agriculture can mean "finding ways to produce the same crops at no additional cost." It can also mean "relocating and finding employment outside of

	agriculture." And they state that "adjustment costs arise, and are greater, when the adaptation response must be made in a short time period."
IPCC (2001)	"Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."
IPCC (2007)	"The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences".
IPCC (2014)	"Adaptive capacity is the ability of systems, institutions, humans, and other organisms to adjust with ensuing changes or the capacities to convert such challenges into opportunities."

Source: (Füssel & Klein, 2006; IPCC, 2014a; Pachauri & Meyer, 2014)

Whereas, information on adaptation is not only needed for pragmatic policy and decision making to mitigate the impacts of climate change, but, also obligatory for the socio-economic resilience of the farming communities dependent on the agro-based livelihood (Abid et al., 2015, 2016; Ali & Erenstein, 2017; Ashraf et al., 2014). Therefore, the academic and research communities are focusing on the climate related challenges (Abdulrazzaq et al., 2019; Atif et al., 2018; Striebig et al., 2019). The farm based adaptation strategies and their determinants are being focused in the recent scientific investigations (Ali & Erenstein, 2017; Ashraf et al., 2014; Bryan et al., 2009, 2013; Deressa et al., 2009; Islam et al., 2017; Jin et al., 2016; Ndamani & Watanabe, 2016; Sarker et al., 2013; van Dijl et al., 2015; Zia et al., 2015). However, the orientation to decipher the impacts of climate change on the agriculture sector in Pakistan is gaining momentum (Abid et al., 2015, 2016; Ali & Erenstein, 2017) but the rain-fed agriculture seems to be a less priority area for such research initiatives.

2.5 Overview of the agricultural vulnerability and adaptation to climate change in Pakistan

2.5.1 Introduction

Pakistan is covering an area of 796.095 km^2. It has 240,000 km^2 Exclusive Economic Zone and Continental Shelf area of approximately 50,000 km^2. Pakistan is blessed with high mountainous range having many peaks as high as over 8,000 meters (above sea level) and also deserts together covered 14 per cent of the total land mass of the world. The southern coastline extends for around 990 km. The country has the most distinct altitudes as well as geophysical conditions which are complex. Pakistan falls in third polar region of the world because of presence of roughly 15,000 km^2 of glacial area and existence of almost 7000 glaciers making it one of the world's most glacially populated areas. The countries bordering Pakistan include China in the north, India in the east, Afghanistan and Iran in the west. Pakistan is one of the South Asian region's main countries with specific geostrategic and possessed socio-economic realities (Pak-INDC, 2016).

Pakistan, being an agro-based economy, encompassing 18.9% of gross domestic product (GDP), employing 42.3% of labor force (WB, 2014; Abid *et al.*, 2015; GoP, 2017-18). Pakistan has two crop seasons, one being *"Kharif"* beginning from April to June and harvested during October to December. *"Kharif"* crops are “rice, sugarcane, cotton, maize, moong, squash, bajra and jowar”. *"Rabi,"* the second one, starts in October to December and is harvested in April to May. The *"Rabi"* crops are “wheat, gram, lentil (masoor), tobacco, rapeseed, barley and mustard” (GoP, 2016-17). Overall, over 75% of the crop production value comprises of cotton, wheat, rice , sugar cane, maize, fruit and vegetables (GOP, 2019).

Approximately 29.6 Mha are suitable for agriculture, and about 50.4 Mha are uncultivated. 18 Mha of the area of 29.6 Mha is irrigated, and 12 Mha is used for dry land farming (Oweis and Ashraf, 2012). Situated in a sub-tropical arid region, most of the country has a semi-arid climate. Based on physiographical conditions and causes of climate change, the country has been divided into four major climatic regions: 1) the “tropical marine coast”; 2) the “continental subtropical lowlands”; 3) the “continental subtropical highlands”; and 4) the “continental subtropical plateau” (Pak-INDC, 2016).

According to the 6th Population and Housing Census of Pakistan 2017, the country’s population is 207.774 million growing at the rate of 2.4 percent per annum over a period of 1998-2017, making it 6^{th} largest populous country in the world. This speedy increase in population is escalating demand for agricultural products (GoP, 2017-18). Agriculture is important in this context in order to ensure food stability, security and alleviate poverty. However, situation is getting worsen due to increasing climatic instabilities, that have threatened the agricultural sector, and thus have become significant obstacles to achieving food security and poverty eradication in Pakistan. The temperature increase not only affect farming by impacting crop seasons, raising evapotranspiration, raising irrigation requirements and rising heat stress on crops.

The rain-fed areas (barani) are situated in the northern part of Punjab and cover an area of 7 Mha, with over 19 million people living in it. This is equal to around 40 per cent of the Punjab, Pakistan's total territory. The maximum annual rainfall varies from 1000 mm to below 200 mm in northeast to southwest. Nevertheless, these areas contribute less than 10 percent (although having potential) to total agricultural output and rely solely on the rainfall. Whether the rainfall is inadequate or occurs at inconvenient times, this amount is further decreased. The largest contiguous drylands in Potohar Plateau, 1.21 Mha of 2.2 Mha are affected by gully erosion and only 0.61 Mha are cultivated (Oweis and Ashraf, 2012).

Around 90 percent of Pakistan's food production comes from irrigated cultivation, while the dryland (rain-fed) sector accounts for around 40 percent (12 Mha) of Pakistan's total cultivable area. However, dryland (rain-fed) sector contributes 10% in terms of total crop production (Mahmood *et al*., 2015). The principal explanation for poor productivity is the inattention of these areas. The highest investment in Pakistan's agriculture sector has been in the irrigated regions, while the rain-fed regions have been almost ignored. Because of scanty and low rainfall, agriculture contributes just 10 percent.

For the Asia region, the IPCC (AR5) states that exposure to climate induced anomalies in agricultural countries like Pakistan stems from their distinct geography, demographic patterns, socio-economic factors, and inability to respond to climatic fluctuations putting them into vicious cycle of poverty and deprivation all together. The AR5's climate change predictions for South Asia as a whole indicate that warming is likely to be above the global mean, and climate change will affect the melting rate and precipitation patterns of the glaciers, particularly affecting the timing and intensity of monsoon rainfall. This will therefore have a considerable effect on the production and output of water-dependent sectors such as agriculture.

It has been estimated that from these regions about 11 million cubic meters (Mm^3) of water is lost as surface runoff annually, 70 percent of which occurs during the summer months from July to September. Therefore, much of the summer rain is not usable for agriculture because of surface runoff. It is not only a lack of water, but it also results in the depletion of fertile top soils. In addition, given the variability of the rainfall, farmers usually minimize inputs to reduce the risk of loss in the event of drought and depend primarily on off-farm income for their livelihood (Oweis and Ashraf, 2012).

2.5.2 Agricultural vulnerability and adaptation to climate change in Pakistan

Global Climate Risk Index (2017), ranks Pakistan at 7th position among the countries worst impacted by climate change. Given the high risk of potential climate change, Pakistan remains one of the very small GHG-emitting countries (0.2 million metric tons) (GoP, 2016-17) and Pakistan’s response to the issue remains uninspired. Research studies conducted by the NDMA show that extreme climate events between 1994 and 2013 resulted in an average annual economic loss of nearly 4 billion US dollars. With 38.12 million people impacted, 3.45 million homes damaged, and 10.63 million acres of crops lost, the last five floods (2010-2014) resulted in monetary losses of more than US$ 18 billion. More than 1200 people have also lost their lives in 2015 due to the extreme heat wave in Karachi (Abid et al., 2015; A. Hussain, 2014; Pak-INDC, 2016).

Several Pakistani studies have revealed that cereals and other crops are vulnerable to heat stress and increased temperatures. For example, a temperature rise of 1 ^{o}C would result in a decline in the wheat yield of 5–7 per cent (Aggarwal & Sivakumar, 2010). Another study (Sultana and Ali, 2006) found that wheat production in Pakistan's arid, semi-arid and sub-humid regions will decline by 6–9 per cent while it could rise in the wet zone. Likewise, a temperature rise of 1.5 ^{o}C and 3 ^{o}C could decrease the wheat yield by 7% and 21% respectively in Pakistan's Swat district (with an average altitude of 960 masl), while this could rise the wheat yield by 14% and 23% respectively in Chitral district (with an average altitude of 1500 masl) (Hussain & Mudasser, 2007). Studies show rice yield often decreases with temperature increase. In Pakistan's semi-arid regions, rice yields could decline by 15 percent from 2012 to 2039, by 25 percent from 2040 to 2069 and by 36 percent from 2070 to 2099 if temperature rise continues (Ahmed & Ogtrop, 2014). In addition to the rise in temperature, decreasing rainfall is affecting crop production. If rainfall drops by 6%, net water requirements for irrigation in Pakistan could increase by nearly 29%. It would have a negative effect on over 1,3 million farm households in Pakistan and most crops like cereals, fruits and vegetables (Ali & Erenstein, 2017).

Poor practices have exhausted natural resources including soil, water, and air, clubbed with climate change effects present serious threats to productivity in agriculture. The focus of the country's climate change activities is limited solely to water conservation, and so far with minimal effect. Overall productivity is low and there are large gaps between average yields, gradual farm yields, the potential of Punjab, and the best averages in the world. This is due in particular to weak agronomic practices, low adoption of technology and lack of sector innovation. As a result, Punjab's agricultural development has long been on a downward trend. The growth has decreased from 3.3 percent over the last decade to below 3 percent; with a negative growth rate of -0.19 percent in 2015-16. Total Factor Productivity (TFP) in agriculture is currently the lowest in the region; and it has declined since the 1980s, which is otherwise considered Pakistan's agriculture's golden age. Not only is aggregate TFP low and declining, but the aggregate masks large variations across regions and size of farm categories, which means that in terms of TFP and its decline, many regions and categories are worse off than the average. Just 19 per cent of all managed farms were below two Hectare (Ha) sizes in the Agriculture Census of 1960. It had risen to 67 per cent in the 2010 Census. With an approximate poverty rate of 42.6%, Punjab is home to the highest absolute number of poor people in the world, forcing most small-scale farmers to diversify significantly from farming and find additional sources of income just to survive (Table 2.1).

Table 2.1: Poverty variations by size of farm across agro-climatic zones 2014

Size of farm	Rice/Wheat Punjab	Mixed Punjab	Cotton/Wheat Punjab	Low Intensity Punjab	Barani Punjab
More than zero but less than 3 acres	48.9	32	64.2	43.7	65.2
3 to less than 5 acres	21.8	25	15.9	20	16.3
5 to under 12.5	26.5	38.2	16.6	29.2	17
12.5 to under 25	2.8	4.7	2.6	6.5	1.6
25 to under 5	0	0	0.6	0.7	0
50 to under 75	0	0	0	0	0
75 and above	0	0	0	0	0
Total	**100**	**100**	**100**	**100**	**100**

Source: GOP, 2018

Farm-level insufficient access to technical expertise and information about advanced farming practices and technologies is a major cause of low crop yields, productivity and lack of diversification. It is the task of the extension of agriculture (public and private) to give farmers the necessary knowledge and technical skills.

Total GHG emissions from Pakistan in 2015 were 405 million tons of equivalent carbon dioxide, and rise of 87 per cent since 1987 (GoP & UNEP, 2017). Most of these emissions come from the manufacturing and agricultural industries, with 43 per cent of overall GHG emissions from agriculture. Many GHG emissions in agriculture are from enteric fermentation by tillage in animals, chemical fertilizers and manure, paddy rice cultivation, and soil disturbance. As a signatory to the Paris Climate Agreement, Pakistan is pledged to reduce 20 per cent of its estimated emissions by 2030, and a substantial proportion of Pakistan's pledged reduction will have to come from the agricultural sector of Punjab.

The major challenge facing agriculture is by uncertain weather phenomenon in the forms of early onset of the monsoon season, intermittent droughts, erratic rainfall, temperatures hikes, intense rainfall, extreme climatic events like stronger typhoons and floods have become regular climate events in the last decade. All this collectively affected agricultural production and will get worse if no actions taken. The main priorities given in the official document entitled “Climate-Smart Agriculture for Punjab, Pakistan” will be on adaptation strategies to increase agricultural productivity of Punjab province, while protecting farmers from the threatening effects of climate change. The estimated consequences of up to PKR 1.05 trillion in lost income from a 5 % annual decline in agricultural productivity due to climate change, major benefits can be gained from investment in adaptation strategies and substantial expenditure is justified (CIAT:FAO., 2018).

2.5.3 Response to climate change issues

Keeping in view the high vulnerability of Pakistan to climate change, Pakistan's government has established the "National Climate Change Policy (2012)" and the "Climate Change Policy Implementation Framework (2014-2030)" for successful implementation of climate change issues through strategic planning. "Pakistan Climate Change Act 2017" has also passed to materialize measures to combat climate change.

The “Climate Change Fund”, the “Climate Change Council” and the “Climate Change Authority” were established by the legislation to enact the Climate Change Act (GoP, 2016-17). Pakistan’s approach to global agenda of climate has been intimately associated with its environmental conservation policies, United Nations sustainable development goals (SDGs) and the objectives of the UNFCCC.

The Ministry of Climate Change has established the INDCs (Intended Nationally Determined Contributions) for Pakistan with the response strategies challenges it faces, and recommends measures that can help resolve these challenges through domestic and international assistance. Pakistan's government has developed a groundbreaking tool in CPEIR (Climate Public Expenditure and Institutional Review) format. It is a systematic qualitative and quantitative analysis of the state spending on climate change in a country. This also analyses the country's climate change programs and strategies, structural structure and system of public finance to make recommendations for strengthening them. The United Nations Development Program (UNDP) has implemented CPEIR in cooperation with the government to assess the rate of government spending on climate change. It is the first such effort in Pakistan. The findings show that the government's investments are very significant, but not enough to meet the increasing challenges of climate change. Climate-related federal spending is projected at 8.5 per cent of overall national spending (GoP, 2016-17).

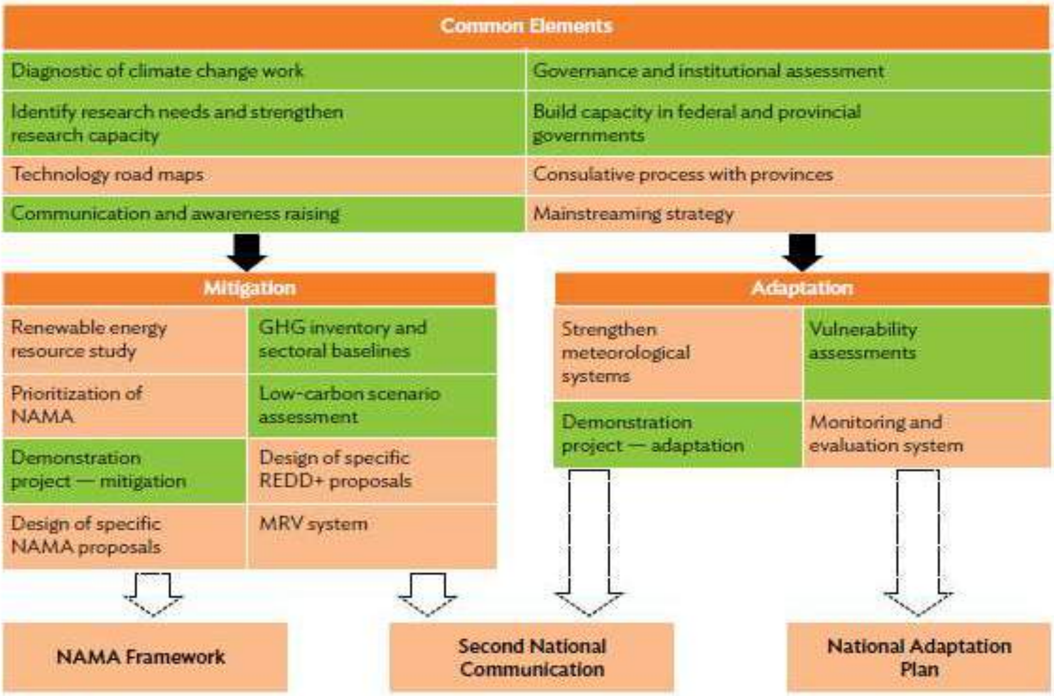
In addition to NCCP, the government of Pakistan has developed and published other key documents, such as the “Climate Change Policy Implementation Framework (2013)” and the “Climate Change Adaptation and Mitigation Work Program in Pakistan”. The responsibility of fulfilling climate change objectives and targets has been given to the concerned departments, organizations, and provinces, who are expected to formulate their own comprehensive doable plans of actions to meet their specific and relevant goals and objectives. The “Work Program on Adaptation and Mitigation to Climate Change in Pakistan” established some significant short-term targets to guide collective efforts towards achieving climate resilience at the national and subnational levels. These include:

i. Preparation of the “National Appropriate Mitigation Actions (NAMA) framework”;

ii. Development of the “second national communication to the United Nations Framework Convention on Climate Change (UNFCCC)”; and

iii. Formulation of a “national adaptation plan (NAP)”.

To meet these objectives and targets, the document laid out a “climate readiness scheme” that would primarily assist the government in carrying out 10 priority actions at the national level. These actions are illustrated in Figure 2.2, highlighted with green color.



GHG = greenhouse gas, MRV = monitoring, reporting and verification, NAMA = national appropriate mitigation action, REDD = Reducing Emissions from Deforestation and Forest Degradation.
Note: Priority actions in green.

Figure 2.2: Work program for climate compatible development in Pakistan
Source: GoP, 2014

The present thesis is in line with the priority actions given in the “Work Program for Climate Compatible Development in Pakistan” particularly ‘vulnerability assessments’. Vulnerability assessment studies are prerequisites for devising adaptation strategies and developing local adaptation plans.

CHAPTER 3

METHODOLOGY

CHAPTER 3

METHODOLOGY

3.1 Study Area

This study focuses on the Punjab province, located in semi-arid lowlands zone, due to its significance for Pakistan's cereal production (74%) and agricultural gross domestic product (GDP) (53%) (Abid et al., 2015). Punjab is the country’s most populous region (Abid et al., 2016; PDMA, 2008) with geographical area of 20.63 million hectares, out of which 59% is cultivated (Abid et al., 2016; GoP, 2017a). The total cropped area of wheat in Punjab is 6,914,000 hectares (42.3% of total) (GOP, 2017). It consists of 36 districts and comprised of four agro-ecological zones according to Pakistan Agriculture Research Council (PARC) namely: Irrigated plains, *Barani* (rain-fed) region, Thal region and Marginal land. The average mean annual temperature in Punjab ranges from 16.3 to 18.2 ^{o}C while the mean annual maximum temperature ranges from 29.3 to 31.9 ^{o}C over the 1970-2001 period. The Punjab rainfall, which is primarily related to monsoon winds, is widespread and the rain-fed *(Barani)* region receives the highest rainfall followed by the Irrigated Plains, Thal Region and Marginal Lands. (Abid et al., 2016). In this study, one agro-ecological zone i.e. *Barani* (rain-fed) region was selected due to its agricultural vulnerability to climate change and excluded remaining three due to budget and time constraints. The agro-ecological zone selected has a distinct climate, ecosystem and geography and is therefore subject to various kinds of environmental and socio-economic constraints. Out of a total of 11.83 million hectares under cultivation in Punjab, the Barani tract contains 3.10 million ha (GOP, 2018).

The present study was carried out in the contextual settings of *Barani* (rain-fed) region of the Northern Punjab, also known as the Potohar Plateau. The geographical region is located in the *Sind-Saghar doab* (river-interfluve) and comprises over five districts Attock, Chakwal, Islamabad, Jhelum and Rawalpindi. The present study taken

Chakwal District as a representative of rain-fed region of Punjab, Pakistan. The rain-fed agriculture of the district is prone to extreme climatic events (NDMA, 2017), and the rain-fed (*Barani*) zone receives the highest rainfall followed by the Irrigated plains, Thal region and Marginal land (Abid et al., 2016). In this study, one agro-ecological zone i.e. *Barani* (rain-fed) region was selected due to its agricultural vulnerability to climate change and excluded remaining three due to budget and time constraints. The selected agro-ecological zone has a distinct climate, environment and geography and hence it is subjected to different kinds of environmental and socioeconomic constraints. *Barani* tract comprises 3.10 million hectares out of total 11.83 million hectares under cultivation in Punjab (GOP, 2018).

The current study was carried out in the contextual settings of *Barani* (rain-fed) region of the Northern Punjab, also known as the Potohar Plateau. The geographical region is located in the *Sind-Saghar doab* (river-interfluve) and comprises over five districts Attock, Chakwal, Islamabad, Jhelum and Rawalpindi. The present study taken Chakwal District as a representative of rain-fed region of Punjab, Pakistan. The rain-fed agriculture of the district is prone to extreme climatic events (NDMA, 2017), making the livelihood of people more fragile and vulnerable (Oweis & Ashraf, 2014). Thus, making it an appropriate contextual environment for assessing socio-economic vulnerability of farmers' to climate-related impacts.

3.2 District Profile – Chakwal

3.2.1 Historical background

The Chakwal district was named after the Chaudhary Chakku, the chief of the Minhas tribe, who migrated from Jammu and founded the town of Chakwal in 1525. During the Mughal Emperor Zaheer-ud-Din Babar's era, Chakwal was the central town of Dhan Chaurasi for many centuries. During the British era (1881), Chakwal was declared as a Tehsil headquarter of district Jhelum. Chakwal was finally declared as a district in 1985 by the former President of Pakistan; General Muhammad Zia ul Haq.

The district is bounded from the north by the Attock and Rawalpindi districts, the Jhelum district on the east side, and the Khushab and Minawali districts on the south side. District headquarter of Chakwal is 17 kilometers from the M2 motorway from the Balkasar interchange. Chakwal is 63 kilometers from Lahore Rawalpindi N5 motorway from Mandra. District Chakwal is 130.6 kilometers from Islamabad by motorway M2 (GoP, 2000).

3.2.2 Area and land utilization

The study area approximately lies across 32°55'29.39" N and 72°51'11.99" E (Fig. 3.1). The reported area of Chakwal district is 669,000 ha (6690 km^2). The field investigations were made in all the five tehsils of Chakwal district i.e. Chakwal, Choa Saiden Shah, Kallar Kahar, Lawa and Talagang. The total *mauzas* (villages) in the district are 461 and total rural union councils in the district are 71 (Table 3.1).

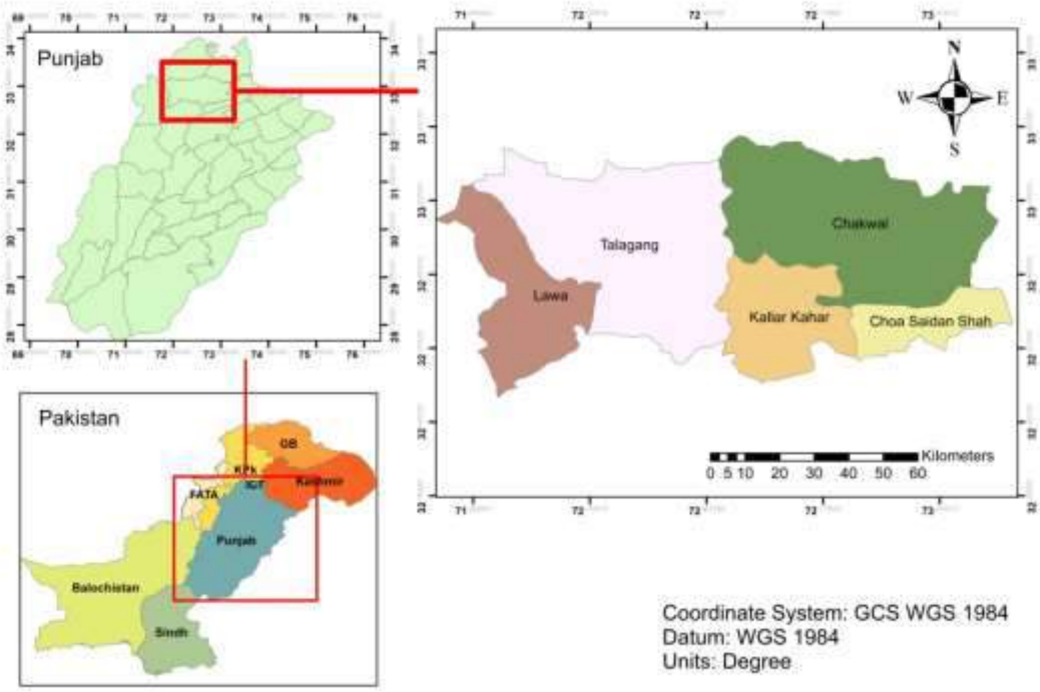


Figure 3.1: Location map of the study area
Source: 'author'

Table 3.1: Tehsils and Union Councils (UCs) of Chakwal District

Sr. No.	Tehsils	No. of Union Councils
1.	Chakwal	32
2.	Choa Saiden Shah	07
3.	Kallar Kahar	07
4.	Lawa	06
5.	Talagang	19
	Total	**71**

Source: 'author'

The total cultivated area is 319,000 ha. The total cropped area is 270,000 ha. The *Kharif* crops area is 102,000 ha and *Rabi* crops area is 158,000 ha. The total rain-fed area of Chakwal district is 259,000 ha and irrigated area is 11,000 ha. The total area sown under wheat crop during 2015-16 was 130,000 ha, out of which only 4,000 ha area sown in irrigated areas. The total wheat production during 2015-16 was 234,000 tons, out of which production of 12,000 tons were from irrigated areas and 222,000 tons were from rain-fed areas. The total forested area during 2015-16 was 61,000 ha. The major crops grown in the area include "wheat (*Triticum vulgare*)," "maize *(Zea mays),"* "barley *(Hordeum vulgare),"* "sorghum *(Sorghum bicolor),"* "millets *(Panicum miliaceum),"* "lentils *(Lens culinary),"* "gram *(Cicer arietinum),"* "groundnut (*Arachis hypogaea)"* and "brassica (*Brassica rapa)"* (GOP, 2017).

3.2.3 Climate

The Chakwal district area is classified ecologically as the subtropical semi-arid and sub-humid zone and sub-mountainous in character. In the northern areas the rainfall ranges from 400 mm in the south to 750 mm. Chakwal's weather is hot in summer, and cold in winter. The temperature is 8 °C in winter, and the temperature increases to 42 °C in the summer. Chakwal falls within the monsoon range and, apart from sporadic rainfall, there are two rainy seasons, the first caused by monsoon winds from the Bay of Bengal, beginning from 15 July and lasting until about 15 September, the second caused by Mediterranean winds during the last two weeks in December and the first two weeks in January (GoP, 2000).

3.2.4 Topography

Geographically located in the salt range and the Potohar plateau, Chakwal's physical characteristics are typical of the region. The south and south east are mountainous and rugged, covered with scrub forest, interspersed with flat lying plains; the north and north east consists of gently undulating plains with patches of rocky terrain, known as *khuddar* in the local dialect, ravines and gorges, and some desert areas. The district's plains are being cultivated, including those in hilly regions and a significant area is covered by forest (FAO, 2014).

3.2.5 Geology

The Chakwal region can be divided into mountains, hills, cliffs, plains, weather-rocked plains, plains in the piedmont and plains in the river. The area's soil has produced material transported from wind and water, consisting of loess alluvial deposits, mountain outwash, and recent stream – valley deposits. And some of the soil was extracted from shale and sand stones. District rangelands are heavily degraded as a result of soil erosion which is a widespread problem. After downpours, rainwater readily runs off in the streams. The southern portion reaches the Salt Range and includes the Chail peak; the district's highest point at 1,128 meters above sea level (FAO, 2014).

3.2.6 Population

The total population of the district is 1.49 million people and out of it 81% are residing in rural areas (PBS, 2017), making it one of the most rural populous district of Punjab. According to Population Census 2017, urban population was 19% and total households (HHs) in the district was 266,109 (Table 3.2). The population density of Chakwal District is greater than 10 persons/km^2 (GoP, 2017b).

Table 3.2: District and tehsil level population statistics

Sr. No.	District/Tehsils	Region	Population	No. of HH
1.	Chakwal District	Total	1,495,9582	266,109
		Rural	1,212,042	217,585
		Urban	282,940	48,524
2.	Chakwal Tehsil	Total	656,978	115,850
		Rural	518,832	92,625
		Urban	138,146	23,225
3.	Choa Saiden Shah	Total	141,844	24,831
		Rural	119,335	21,106
		Urban	22,509	37,25
4.	Kallar Kahar Tehsil	Total	169,660	31,082
		Rural	125,857	23,469
		Urban	43,803	7,613
5.	Lawa Tehsil	Total	125,893	22,596
		Rural	110,266	19,694
		Urban	15,627	2,902
6.	Talagang Tehsil	Total	401,607	71,750
		Rural	337,752	60,691
		Urban	63,855	11,059

Source: Population Census, GOP, 2017

3.2.7 Education

According to Pakistan Education District Rankings, 2017, Chakwal was given 71.88 score in terms of education and 93.84 score to gender parity. According to 1998 census data, literacy ratio in urban areas were 70.7 and in rural areas were 54.8. Male literacy ratio was 73.4 and female literacy ratio was 42.2. The total educational institutions at Primary level are 732 with enrollment of 44039 students, at Middle level are 213 with enrollment of 37937 students, and at High School level are 223 with enrollment of 85625 students. The number of Arts and Science Higher Secondary Schools are 38 with total enrollment of 2903 students. The number of Arts and Science Intermediate, Degree and Post Graduate Colleges are 41 with enrollment of 16638 students. The number of Arts and Science Intermediate Colleges are 16 with enrollment of 3331 students. The number of Arts and Science Degree Colleges are 20 with 8879 students. The number of Arts and Science Post Graduate Colleges are five with total enrollment of 4428 students (GOP, 2017).

3.2.8 Health and sanitation

According to Multiple Indicator Cluster Survey, 2014, the mortality rate of infants was 37% (per 1000 births) and under five years of age was 44% (per 1,000 births). The total hospitals in the district are six, dispensaries are eight, rural health centres (RHCs) are nine and basic health centres (BHCs) are seventy one. According to Punjab Development Statistics (2017), 86% of the population have physical access to drinking water within their dwelling, whereas only 4% population uses properly treated water. As far as sanitation is concerned, 83% population got improved sanitation because water, soap or other cleansing agent are available to 88% population. The use of solid fuels for cooking is 69.9% (GOP, 2017).

3.2.9 Economy

Agriculture is the main activity of the district Chakwal. Farming and farm related activities are the main occupations of the district. Livestock is maintained to a large extent. Chakwal is the army's most recruiting area. There are significant mineral and mining deposits in the area. There are approximately 246 coal mines in Chakwal. Lime stones and marble reserves also exist. There are four cement factories that provide jobs for Chakwal people. People do business as well, and small numbers of people do jobs in health, education, banking sectors etc.

Table 3.3: Industry-wise installed capacity

S. No.	Industries	No. of Units	Installed capacity
1.	Agricultural implements	4	3400 Nos
2.	Cement	4	5700 Th.M.Tons
3.	Ceramic products	1	30,000 Nos
4.	Cold storage	10	1, 5000 Bags
5.	Flour Mills	5	720 M.Tons/Day
6.	Poultry feed	1	97500 M.Tons
7.	Textile spinning	6	184136 Spindles
8.	Tobacco	1	47250 Th. Nos

Source: District Pre-investment Study, 2012

Chakwal has recently bestowed with "Kanaish phone and trade (PVT) limited", Chakwal's first Pay Phone Company authorized by Pakistan telecommunication authority. Bestway cement installed the largest unit of Asia in Chakwal. There are approximately 138 different factories established in the district that provide an estimated 10805 people with employment. "Argillaceous Clay, Antimony, Copper, Gold, Gemstone, Lime Stone, Dolomite, Bentonite, Fireclay, Marble, Rock Salt, Coal, Crude Oil and Natural Gas, Brine, Silica Sand" are the various minerals that exist and are mined at various locations. All these minerals are being successfully mined, with the exception of Gold, Copper and Gemstones. Gold, Copper and Gemstones mining is not feasible due to their small deposits and high extraction costs. Chakwal is also famous for '*pehlwan rewary'*.

Table 3.4: Mineral production

S. No.	Mineral	Production *(Hundred Mertic Tons)*
1.	Argillaceous clay	27202
2.	Bauxite	46
3.	Bentonite	17
4.	Coal	5016
5.	Dolomite	143
6.	Fireclay	34
7.	Gypsum	2544
8.	Iron ore	284
9.	Latrit	310
10.	Limestone	92501
11.	Ochers	13
12.	Rock salt	14164

Source: (GOP, 2017)

3.2.10 Agriculture

Agriculture is the district's main activity, with about 80 percent of the district's total population being agriculture-related. "Wheat, Groundnut, Oilseeds, Grams, Lentils (Masoor, Moong, Mash), Maize, Millets, Jawar" are the main crops grown in the district. The sales of fertilizers reported were 3000 nutrient tons in 2011-12, 5000 nutrient tons in 2012-13, 2000 nutrient tons in 2013-14, 15000 nutrient tons in 2014-15 and 1000 nutrient tons in 2015-16, showing a rapid decline in its sale. Likewise, during 2015-16, total threshers owned were 3170, nine were self-propelled combine harvester, 1449 were tractor mounted reapers/harvesters and only four were cutter binders (GOP, 2017).

According to the 2010 agricultural census, 12% of HHs have less than 1 acre land holding, 28% of HHs have between 1 and 2.5 acres, 25% of HHs have between 2.5 and 5 acres, 6% of HHs have between 5 and 7.5 acres, 11% of HHs have between 7.5 and 12.5 acres, 6% of HHs have between 12.5 and 25 acres, 1% of HHs have between 25 and 50 acres, 302 HHs have between 50 and 100 acres, 379 HHs have between 100 and 150 acres, and 18 HHs have 150 and above acres (GOP, 2010). Eighty-three percent of farmers are self-employed, eight percent are owners cum farmers, and nine percent are tenant farmers. The tenant farmers normally get 2/3 of the crop and the landlords get 1/3 of the crop. There is a trend of lease of land on annual rate of 7000 to 10,000 rupees per acre.

Groundnut and wheat are the major crops cultivated on the large scale. Owing to the shortage of water, fruit orchards, particularly citrus, were planted but only on a small area. Fair size of loquat orchards are found in Tehsils Kallar Kahar and Choa Saidan Shah. In addition to apricot, the district also grows banana, pears, peaches and pomegranate in small quantities.

The conventional methods of farming are used. Chakwal's Barani Agricultural Research Institute (BARI) introduced new techniques and methods in the district. The main vegetables grown in the district are Turnip, Cauliflower, Tomato, Lady Finger, Onion and Carrot. The farmers in Kallar Kahar area have planted a large number of rose gardens and the quality of the roses produced here is probably better than the roses produced anywhere else in the country. The roses are desi (local) and are primarily used for rose water distillation and *Gulqand* preparation (a mixture of rose petal juice and sugar). The Department of Agriculture, Punjab Government, is responsible for agricultural activities in the district (Fig 3.2).

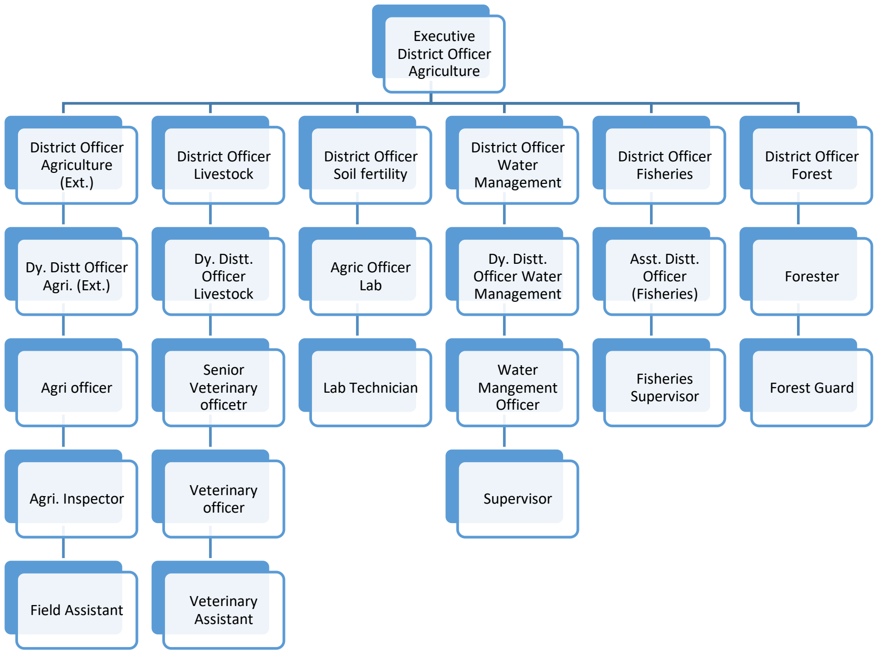


Figure 3.2: Hierarchy of Department of Agriculture, District Chakwal, Government of Pakistan
Source: District Government Chakwal

3.2.11 Livestock

A huge number of Chakwal district populations maintain household-level livestock. In the private sector, however, a number of poultry and dairy farms have been established which are commercially oriented using modern breeding and rearing technology. The hilly prairies and pasture lands provide the livestock with enough fodder. Animals are taken daily for grazing to pastures. Livestock is kept for meat, milk, butter, and yogurt or as an asset. Most farmers keep their own herds of sheep, goat and cattle. The *"Beetal"* breed goat that came from *Rajan Pur* is kept on a large scale in Talagang area. Goats and sheep are kept all year round and sold at the Eid-ul-Azha event. Milk is collected from the various villages on the payment by the milk collectors of 50 rupees per liter of Buffalo milk and 45 rupees for cow milk. Milk is sold domestically and transported to the Chakwal, Rawalpindi and Islamabad district's major cities.

According to the Punjab Livestock Census (2018), the cattle population in the district is 289,400; buffalo population is 83,837; goat population is 366,674; sheep population is 186,930; horse population is 950, camel population is 932, mules' population is 552 and donkey population is 36,066. Poultry farming also takes place in the district of Chakwal on a large scale. Throughout the district, poultry farms ‘Broiler', ‘Layer’ and ‘Breeding’ are established (Table 3.5). There are 14 veterinary hospitals, 58 veterinary dispensaries and 07 veterinary centers in the district (GOP, 2017).

Table 3.5: Establishment of Private Poultry Farms

Broiler Farms		Layer Farms		Breeding Farms	
Number	Capacity to rear birds per annum (thousand)	Number	Capacity to rear birds per annum (thousand)	Number	Capacity to rear birds per annum (thousand)
665	31023	195	2025	21	355

Source: (GOP, 2017)

3.2.12 Forest

Considerably large area of Chakwal district is covered by forests, most of these forests naturally exist and some are planted by the Forest Department. Since Chakwal is situated in the subtropical, semiarid zone, the forests species that exist naturally, are dry deciduous scrub, consisting of typical plant varieties of such forests like “*Acacia nilotica* (Kiker), *Acacia modesta* (Phulai), *Olea cuspidate* (Kau), *Ziziphus mauritiana* (Wild Beri), *Dodonaea viscosa* (Sanatha) *Cycus revoluta* (Pattoki)”. The under bush consists mainly of “*Ovis vignei* (Saryala), *Prosopis juliflora* (mesquite) and *Capparis decidua* (Kareer)”. Trees like *“Dalbargia sissoo* (Shesham), *Eucalyptus camaldulensis* (Sufaida)” and to some extent exotic tree “*Poplar deltoid”s* were also planted by the Forest Department and private farmers, apart from the naturally occurring species of trees.

The Forest Division of Chakwal is spread over an area of 242254 acres that is 14.85 percent of the district's total area. Currently, the district has a total of 101930 acres under reserve forest and 48,706 acres under unclassified forest. The main reserve and unclassified forests in the district are at “*Diljabbah, Surullah, Drangan, Karangal, Gandala, Dalwal, Makhiala, Dandot, Chinji, Kot Kala, Simbli, Nurpur, Bagga, Sammarqand* and *Thirchak”*. The Chakwal Forest Division, headed by the Divisional Forest Officer who is assisted by four Sub-divisional Forest Officers, takes care of forests in Chakwal district.

Table 3.6: Forest area by administrative jurisdiction and enactment

Total compact (Hectares)	Total linear running (Km)	Reserve Forest (Hectares)	Unclassed Forest (Hectares)
60961	415	41250	19711

Source: (GOP, 2017)

3.2.13 Water resources

In particular for irrigation purposes, water resources are not adequate in the district, only four percent of the area receives water for irrigation purposes, 1.1% through canals, 1.8% through wells, and 1.1% through tube wells (GOP, 2017). The underground water level is 130 to 300 feet, according to local communities. There are natural springs in Tehsil Choa Saiden Shah but with the establishment of cement factories in the area, the water level is decreasing in these springs. There is also a natural lake in the Kallar Kahar area, but due to the mountainous nature of the area, the lake water is not used for any purpose.

There is no river passing through the district of Chakwal except *Soan River*. From the Pindi Gheb area, the Soan River enters Chakwal District, passes through Hasli – Warwal into Talagang subdivision, flows through Tamman and finally falls into the Indus on the borders of Mianwali – Kohat Districts. There is a heavy flow of water in the river during the summer and rainy season, but it takes the form of a rivulet in winter. A number of nullahas crossed the district of Chakwal and among those "*Nullah Soj, Wahan, Ghabbir, Tarapi, Dharabi,* and *Banhaa"* are the most important.

According to Punjab Development Statistics (2017), the total tube wells in the district are 7352. Out of these 7350 are private-owned and two are government owned. Diesel powered tube wells are 3447 in number and 3446 are private owned and only one is government-owned. Similarly there are 3905 total electric powered tube wells. 3904 are privately owned and only one is government-owned. According to 2004 census, out of total 6328 tractors, 6315 were privately owned and 13 were government owned. In terms of soil conservation interventions and irrigation purpose, seven mini dams and twenty small dams were constructed in all five tehsils of Chakwal during period 2016-17 (Table 3.7).

Table 3.7: Small dams and their storage capacity in Chakwal District

Sr. No.	Name of Dams	Storage capacity (acre ft)	Area irrigated (acres)
1	Gurabh Dam	922	1604
2	Dhurnal Dam	1950	1416
3	Khokher zer Dam	3601	2137
4	Walana Dam	2193	1203
5	Surla Dam	2219	2100
6	Bhugtal Dam	1140	1406
7	Nikka Dam	1248	1365
8	Dhok Qutab Din Dam	1976	1530
9	Kot Raja Dam	3550	1319
10	Pira Fatehal Dam	7400	1502
11	Mial Dam	3200	1518
12	Minwal Dam	2000	162
13	Khai Dam	5921	182
14	Ghazial Dam	2000	306
15	Dhok Tahlian Dam	1419	1248
16	Dharabi Dam	37000	0
17	Dhok Hum Dam	8000	1667
18	Mundee Dam	450	147
19	Dhok Jhang Dam	2650	2096
20	Uthwal/Lakhwal Dam	18000	0

Source: Punjab Bureau of Statistics, 2017

3.2.14 Road Network

District Chakwal is connected within the district and adjacent areas to the black-toped road network. The metal roads' total length is 2697.24 kilometers. M2 Lahore Islamabad motorway passes within the district. The motorway's length within the district is 79 kilometers. District is accessible from the motorway via the interchange of Balkasar and Kallar Kahar. The length of the district's provincial highways is 501.57 kilometers, and the length of the R&B (Roads and Buildings) sector roads is 91.88 kilometers. The length of the farm to market roads is 1432.18 km and the length of the roads of the district council is 592.61 km (GOP, 2017). There are no rail links and no type of airport within Chakwal District. The facilities of mobile, telephone, internet and postal services are available in district Chakwal. Public transport runs from the main Chakwal district cities to all the country's major cities. People usually use *quiqui* Rickshaws for city travel.

3.2.15 Disasters

There are visible changes in the climate that affect human life and natural resources. Significant changes in rain patterns that cause flash floods and droughts at times. District Chakwal is not worthy of heavy floods, but occasionally heavy rains that cause flash floods. District Chakwal is regarded as no-flood area of the province.

Drought is a slow onset phenomenon in vulnerable areas that affects different sectors. They affect large geographical areas other than floods or other hazards. There is also considerably high variation in rainfall during different seasons. Low rainfall resulted in Pakistan's lowest water levels. The rainfall was 14% lower in the year 2000 than in 1999, following declines of 3.2% and 26.2% respectively in 1999 and 1998. The drought of 1998-2002 affected 21% of the economy of the province of Punjab. The Chakwal district is prone to drought hazard, according to the Pakistan Meteorological Department (PMD).

The growing industries are posing hazard, especially cement factories in Choa Saiden Shah. According to local community, Tehsil Choa Saiden Shah is known for its natural springs but the level of water in springs is decreasing due to the establishment of industries. According to geological survey of Pakistan, District Chakwal falls away from the fault line and is unlikely to be affected by massive earthquake (GoP, 2000).

3.3 Data sources

The thesis uses a mix of primary and secondary data sources and the details of these are found in subsequent chapters.

3.4 Methods adopted

This study uses a spectrum of qualitative and quantitative data collection methods**.** The thesis comprises interdisciplinary research and involves diverse methods from the fields of economics, sociology, statistics, environmental sciences, geographical information system (GIS) and remote sensing (RS). The following chapters cover all the methods deployed during the course of this study. For the purpose of data collection, a structured questionnaire has been developed (Appendix-A) in the light of objectives (Fig.3.3).

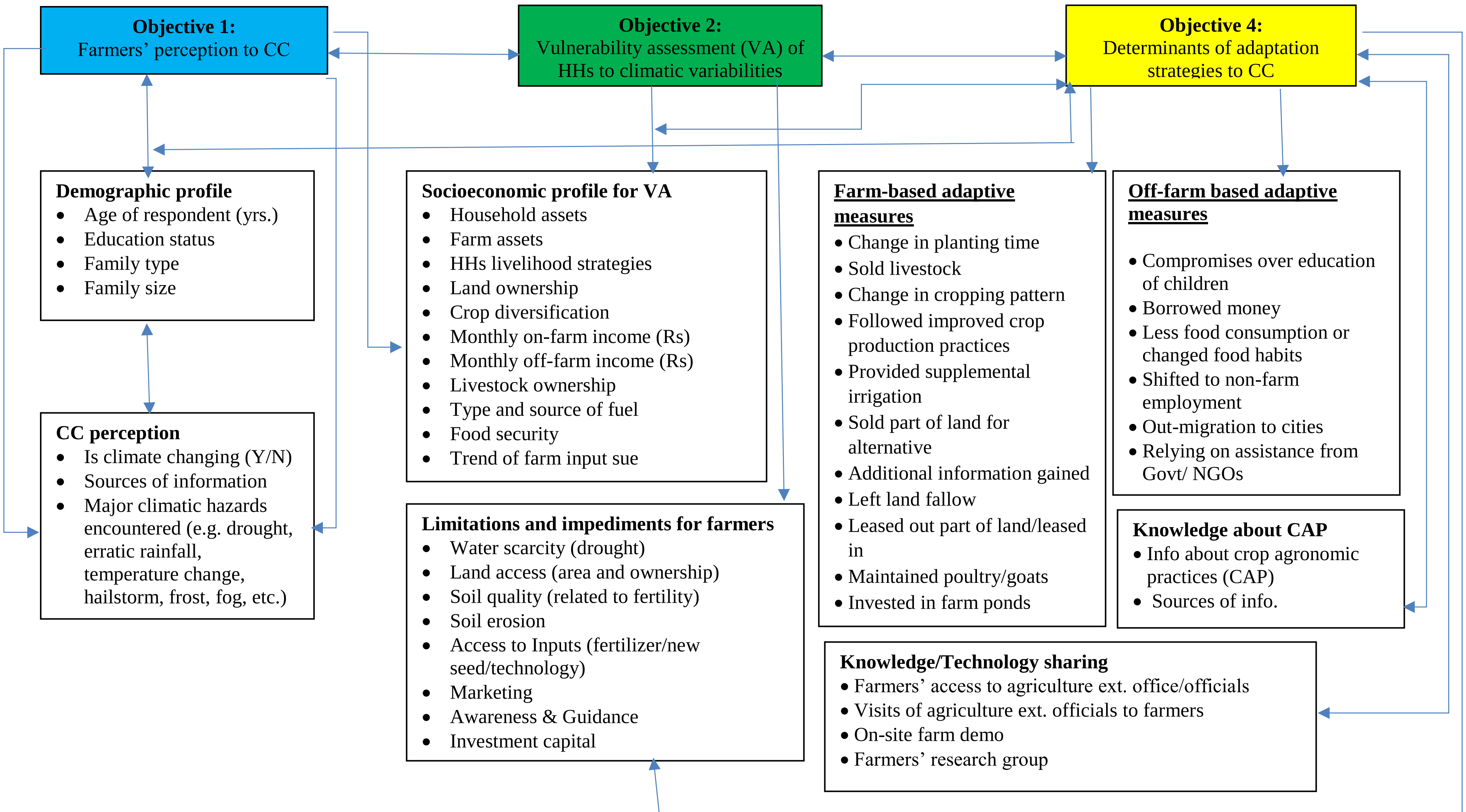


Fig. 3.3: Evaluation framework based on questionnaire

CHAPTERS 4-7
RESULTS & DISCUSSIONS

CHAPTER 4

FARMERS' PERCEPTION TO CLIMATE CHANGE AND OBSERVED SCIENTIFIC TRENDS IN TEMPERATURE AND PRECIPITATION

4.1 Introduction

Climate change is becoming a daunting and challenging threat for the global and national security paradigms. The phenomena is proving burdensome for the natural and human resources and, thus, a real challenge for the social, economic and ecological sustainability of the resource-stricken developing regions such as South Asia (Atif et al., 2018; IPCC, 2014b, 2018b). The researchers such as Abid et al. (2019) and Atif et al. 2018), opined that the consequential impacts of these weather and climatic fluctuations are adversely impacting the environmental resources of these regions. Whereas, the economic and social viabilities of these contextual settings are dependent on the agricultural productivities, therefore, integrated efforts are incumbent for ensuring the resilience of their agro-based economies.

The scientific postulations regarding the likely upsurge in the global surface temperature (IPCC, 2014b, 2018b) and findings of the similar investigations (Choudri et al., 2013; Derbile et al., 2016; Wu et al., 2017) corroborate the notions of Pachauri and Meyer (2014) that the climate-induced anomalies are exasperating the socio-economic stabilities and affecting food-insecurities in the South Asian region. Food and Agriculture Organization (FAO, 2016) reported that approximately 50% of the total land area in the South Asian region is utilized for agricultural activities, thus, integrated efforts for the resilience of the agricultural sector are obligatory.

The growing population density, technological innovations and concomitant lifestyle changes are exerting their own pressures on the rapid Land Use Land Cover (LULC) changes. These LULC modifications are incumbent to fulfilling the growing demands for food and abode in this densely populated region (Dissanayake et al., 2017). The resultant LULC transformations are taking place at the cost of shrinkages in the forested and pastoral lands (Dissanayake et al., 2017; Eniolorunda et al., 2017). These planned and unplanned intrusions in the natural equilibrium are exacerbating the impacts of the weather and climatic anomalies. Thus, the consequential imbalances in the natural environment are proving more stressful for the life and livelihood strategies in this part of the globe.

The conjectures, based upon simulation modelling techniques, indicate that the slightest surge in the surface temperature of the earth will negatively affect the yield and quality of the cereal crops such as wheat, rice and maize etc. (Arshad et al., 2017). The ultimate victim of these corollaries will be the small landholding farmers (Harvey et al., 2014). Their poor economic base, lack of awareness and preparedness further compromises their capacities to address these mounting challenges. Atif et al. (2018) opined that the contemporary environmental degradation necessitates for corrective and remedial measures through identifying context based strategies. These measures are obligatory to moderate the looming impacts of climate induced vulnerabilities for the farming communities (Abid et al., 2016; Bryan et al., 2013; Jin et al., 2016).

Pakistan is located in the region, that is vulnerable to natural disasters such as the earthquakes, floods, droughts, cyclones, land and soil erosion (GoP, 2017a). In this connection, Global Climate Risk Index (2017), ranked Pakistan at the 7th position among the most adversely affected countries by the phenomena of climate change. The National Disaster Management Authority (NDMA) of Pakistan estimated, an approximate loss of 4 billion US dollars, to national economy in the past twenty years (1994-2013) due to such unwarranted events. The reported rise in the temperature (Aggarwal & Sivakumar, 2010; Ahmed & Ogtrop, 2014) and unpredictable patterns of precipitation in Pakistan (Abid et al., 2015; Ali & Erenstein, 2017; Chaudhry, 2017) are badly impacting the per acreage yields of the food crops (Abid et al., 2015; FAO, 2015; Prikhodko, D. & Zrilyi, 2013). Resultantly, the supply-demand gap for the food crops is broadening (GOP, 2018). Whereas, the focus towards this pressing issue is far from satisfactory in Pakistan and, thus, stresses for immediate attention (GOP, 2018; Pak-INDC, 2016).

Pakistan is classified among those countries which are more vulnerable to abrupt climatic oscillations. The lack of orientations towards the above catalogued critical issues allied with low adaptive capacity and compromised financial resource base are further aggravating the situation (Atif et al., 2018; Salman et al., 2018).

Therefore, the country is in the dire need of approximately 07 to 14 billion US $ to address the looming challenges linked with the climate change (Pak-INDC, 2016).

In this connection, the knowledge about contextual agricultural practices and an assessment of the perception about climate change are the prerequisites for postulating doable adaptation strategies (Arshad et al., 2017; Bryan et al., 2009). The analysis of socio-economic factors and the identification of sources through which the information disseminates among the stakeholders are also mandatory for devising pragmatic strategies.

Apropos to this, the present study was conducted to know farmers' perceptions about climate change and its impacts on their lives and livelihoods. The current study tried to decipher the socio-economic conditions of the farming communities and their perception about the fluctuations in the climatic patterns such as droughts, untimely rains, temperature rise etc. It also compares the observed scientific trends in temperature and precipitation with local's perception to climate change.

The rain-fed agriculture of the Chakwal district is dependent upon the *summer monsoons* and the precipitation from the *western depressions* during the winter season. Therefore, the agricultural productivity is subject to extreme weather and climatic fluctuations (NDMA, 2017). The uncertainties about the crop yields/outcomes is making the livelihood of the people more fragile and vulnerable. Thus, the selected geographical location is an appropriate contextual setting for assessing the farmers' perceptions regarding climate-related events and their impacts.

4.2 Materials and Methods

4.2.1 Data collection

The data for this study was collected with the help of a structured questionnaire. This mechanism for the data collection was prepared on the basis of the contextual information obtained through a pilot survey. The questionnaire used for this study was compartmentalized in different sections (Appendix-A). The first part of the questionnaire deals with the demographic and socio-economic characteristics of the respondents. While, the remaining sections of the questionnaire were conceived to acquire information regarding: the availability of basic civic facilities, land-use patterns, agricultural production, perception about climate change, adaptation strategies and access to institutional support etc. The questionnaire was initially developed in the English language and was subsequently translated into Urdu for the convenience of the respondents. However, vernacular was used during the course of interviewing. The field investigations and interviews of 475 respondents were conducted during the months from April to August, 2017. The respondents were selected from 183 villages of the study area through cluster-sampling technique (Fig. 4.1). The individual respondent was approached with the help of snowballing technique on the principle of convenience sampling method.

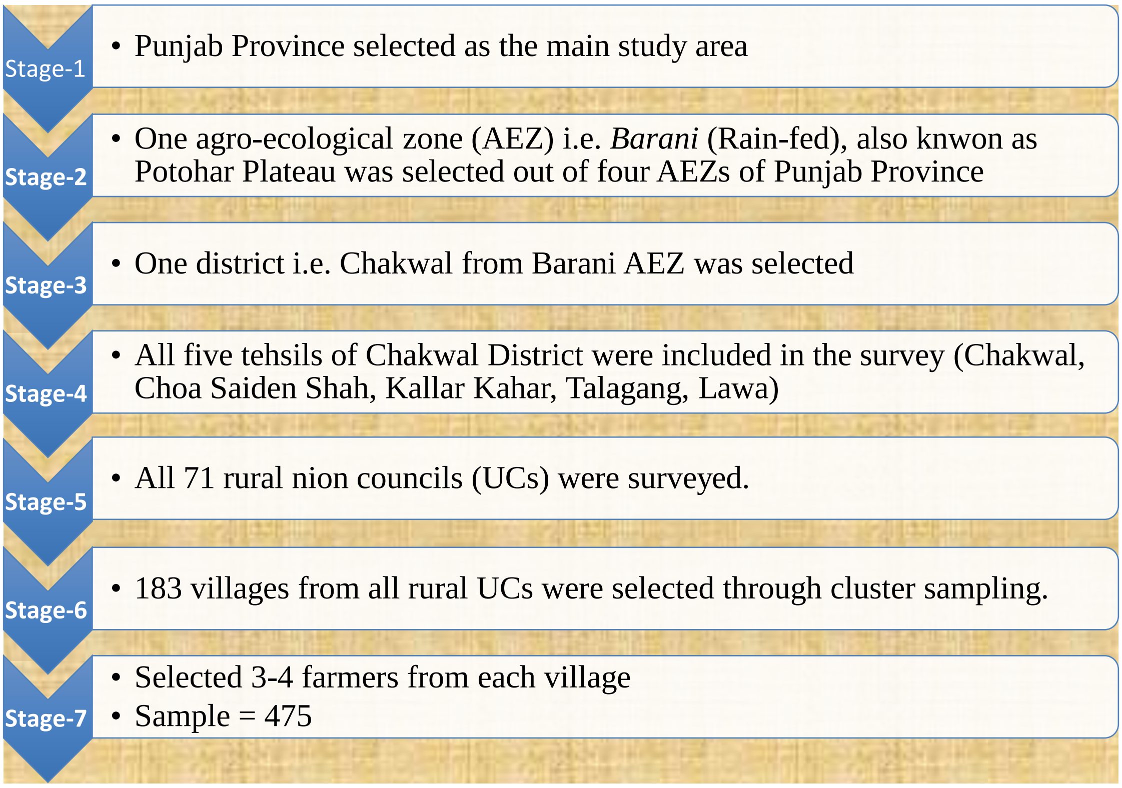


Figure 4.1: Sampling framework of the study
Source: 'author'

4.2.2. Data analysis

Data was condensed in spreadsheet for further processing and subsequent analysis in the Statistical Software 'R' (version 3.4.3). The descriptive statistical methods and techniques such as those dealing with the frequency distribution, median etc. were deployed for the initial probes. In the subsequent stage, the non-parametric Spearman correlation test was relied upon to explore the nature of relationships between the socio-economic status of the household and their farming characteristics.

The cross sectional data collected above was supplemented through time series data set (precipitation and temperature) obtained from Pakistan Meteorological Department (PMD) and Soil and Water Conservation Research Institute (SAWCRI), Chakwal. The rainfall data covers the period from January 1977 to December 2018 and temperature data covers the period from January 1998 to December 2018. The monthly time series data of rainfall and temperature were used to calculate seasonal mean temperature and seasonal rainfall. The data was then subjected to statistical analysis in 'R' software (version 3.4.3).

4.3 Results

4.3.1. Socio-economic and demographic characteristics

The demographic and socio-economic profile of the respondents in (Fig. 4.2) portrays the characteristics of a patriarchic rural society. It is quite evident from the fact that all of the respondents were farmers, mature and experienced with a mean age of 52.9 ± 12 years and the mean household size being 7.5 ± 3.3 members. The preliminary investigations reflected the state of compromised economic base of the respondents. The subsequent dependency ratio for the sampled population was found 1.3. The proportionate share of "nucleated families" was larger (65%) than the "combined families" (35%) indicating socio-economic restructuring of the rural society. Regrettably, the low literacy rate and education level of the respondents is discouraging. The majority of them (93%) rely on firewood for domestic energy needs. However, the modern gadgetries such as television, refrigerator and computers etc. are rapidly gaining acceptance among the study population (Fig. 4.2).

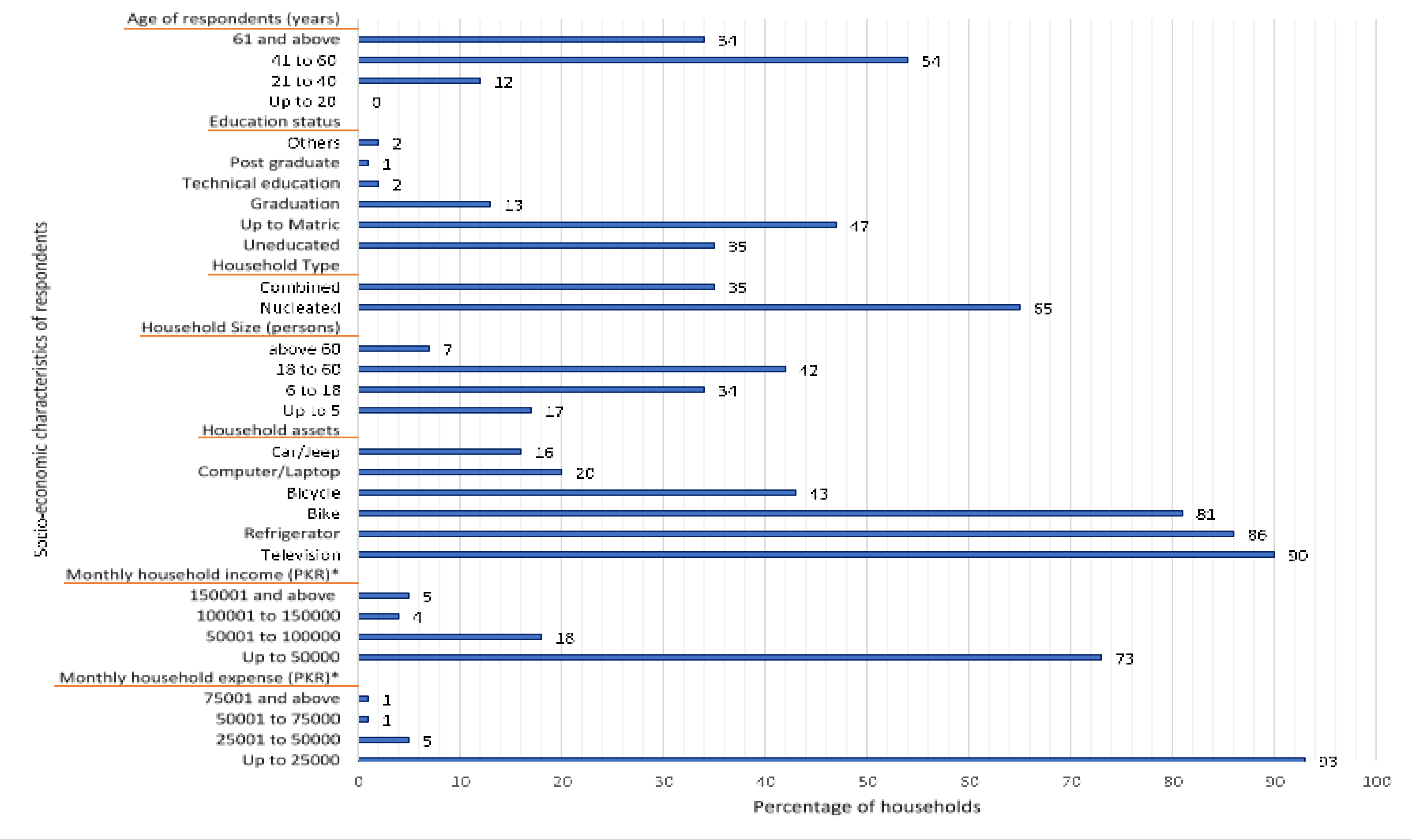


Figure 4.2: Demographic and socio-economic statistics of the sample
(One hundred and forty one Pak rupees are equal to 1$ (United States Dollar) on May, 02, 2019
Source: 'author'

4.3.2. Characteristics of farming systems

The salient characteristics of the farming practices show a consistent biannual cropping pattern of *Kharif* and *Rabi* crops. The crops such as groundnut, maize, Green Gram (*Moong),* Black Gram (*Mash)* and vegetables etc. are produced from May to September in the *Kharif season*. While, the crops like wheat, oilseed, fodder crops, lentils, vegetables etc. are grown from October to April in the *Rabi* season. The size of agricultural tract used for cultivation is small as 53% of the respondents cultivate on less than 2.5 ha of land. In addition to crop production, the majority of respondents also keep livestock for personal use or for supplementary income. In terms of Total Livestock Units (TLUs), it was found that 71% of households had up to 10 TLU. Most small farmers get rental support from service providers as they don't own their machinery. It's evident from the table that only few farmers own tractor (41%) and threshers (19%). However, the majority (90%) of the respondents conveyed that they could not purchase any new asset for farming purposes during the last five years. It was also observed that the use of chemical fertilizers is gaining acceptance as (87%) of the respondents rely on these additional inputs for improving their agricultural yields.

Table 4.1: Characteristics of the farming systems of the surveyed households

Variables		
Farm assets	**N=475**	**% of households**
Tractor	475	41
Thresher	475	19
Tube well (electric)	475	35
Fodder chopper (electric)	475	78
Fodder chopper (manual)	475	06
Land ownership (ha)	**N=475 (% Total)**	**Cultivated (%)**
up to 2.5	206 (43)	53
> 2.5 to 5	142 (30)	28
> 5 to 7.5	54 (11)	09
> 7.5 and above	73 (15)	10
Household Crop diversification	**N**	**Mean**
No. of crops grown per household	475	4.7
Total Livestock Units (TLU)	**N=475**	**% of households**
Up to 10	335	71
> 10 to 20	89	19
> 20 to 30	35	07
> 30 to 40	12	03
> 40 to 50	02	0.4
> 50 and above	07	1.4

Source: 'author'

4.3.3. Limitations and impediments for the farmers

The study also evaluated the impacts of climatic uncertainties in conjunction with contextual impediments on the perception and performance of agricultural sector in the rain-fed areas. The study tried to decipher the causes and consequences of the financial limitations on the produce and perception of the farming communities. The findings identified that water scarcity and drought conditions (98%), land degradation (64%) and soil erosion (32%) are being perceived as the potent threats for the agricultural sector (Fig. 4.3). Besides this, a substantial proportion of (76%) respondents also complained against man-made impediments such as the lack of access to agricultural inputs, absence of a coherent mechanism for financial assistance (49%) and non-availability of technical guidance (39%) for sustained agronomic practices. The findings portray that more than half of the respondents (54%) do not have any access to such vital information. Whereas, the information disseminating through mass media receives due attention in the study area (Fig. 4.3). While, the role and efforts of the agriculture extension department were observed insignificant/unimpressive. The field visits meant to stimulate awareness for promoting increased use of technology are gradually decreasing (Fig. 3.4). The active presence of community based farmer research groups is discouraging as only 11% of the respondents reported the presence of such entities in the area (Fig. 4.3).

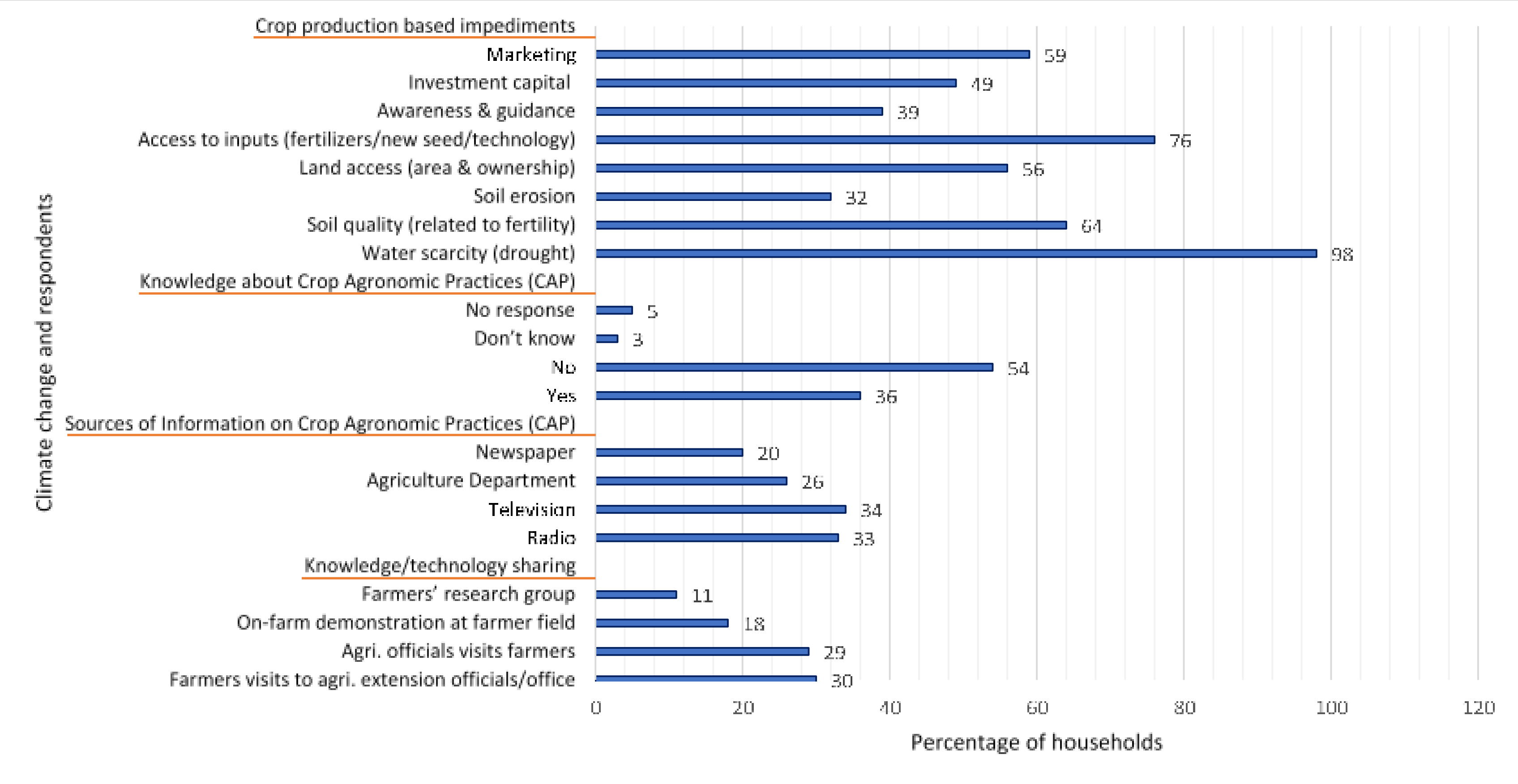


Figure 4.3: Limitations and impediments in study area
Source: 'author'

4.3.4. Livelihood strategies and food security

Rain-fed agriculture is the primary economic activity in the study area. The crop yields and livestock improvement are important for the domestic food needs and contribute significantly to the household income. However, the income from other sources such as livestock, government jobs, private sector and occupations such as part time agricultural laboring also significantly add to the wellbeing of the family (Fig. 4.4). The majority of respondents (66%) claimed their self-sufficiency regarding food availability, while, a sizeable minority (34%) is vulnerable in case of crop failure or food shortage. Loans from acquaintances (14%), selling of livestock (27%) or nonagricultural belongings (6%) and government subsidies (8%) are the most preferred strategies to cope with the scenario. Factors positively related to household food security included livestock ownership ($r = 0.11$, $p = 0.01$), crop diversification ($r = 0.16$, $p < 0.001$) and education level of respondents ($r = 0.04$, $p < 0.0001$).

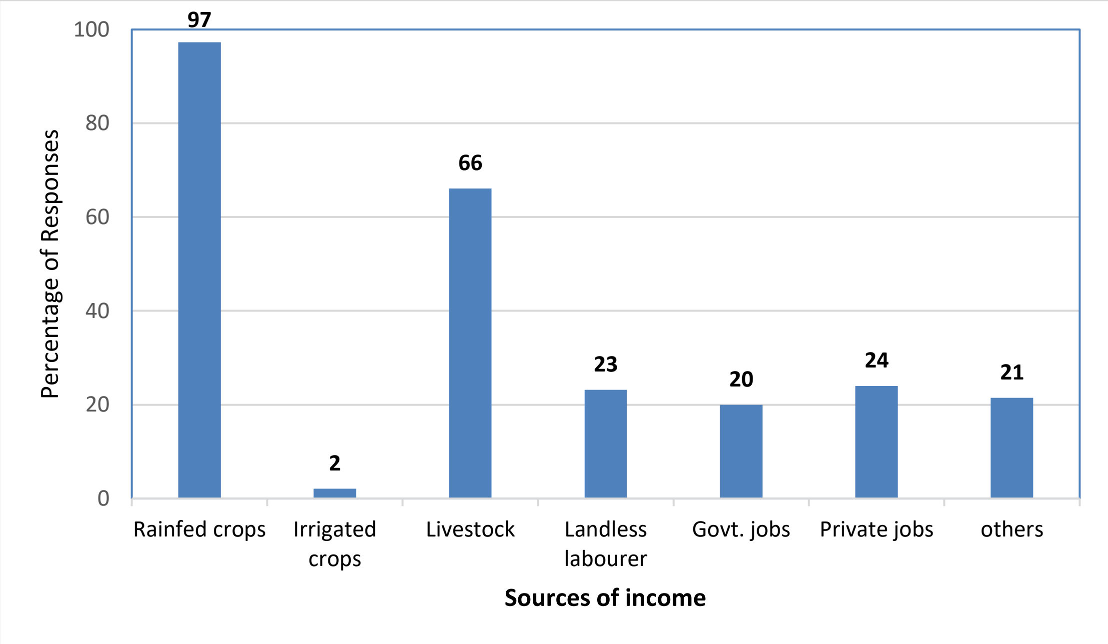


Figure 4.4: Livelihood strategies of respondents
Source: 'author'

4.3.5. Farmers' perception about climate change

The findings of the study showed that 96% of the farmers perceive that the climatic conditions are changing in their surroundings. These climatic variations are being realized in the form of rising temperature (61%), irregular pattern of precipitation

(86%) hailstorm (73%), delay in the start of winter season (71%), incidents of the cold breeze (67%) and heat waves (65%), storms (64%), frost (59%) and an increase in the occurrences of drought conditions (39%) (Table 4.2). The farming community was apprehensive about such weather and climatic anomalies and reported that the frequency and intensity of these phenomena are getting worse with the passage of time. These results are consistent with the real change trend of the average temperature (Figures 4.5 & 4.6), and average rainfall in this region (Figures 4.7 & 4.8) and also reported by Chaudhary et al. (2009), Ashraf (2014) and Chaudhry (2017). The recorded historical rainfall data showed inter-annual variability and temperature data showing an increasing trend.

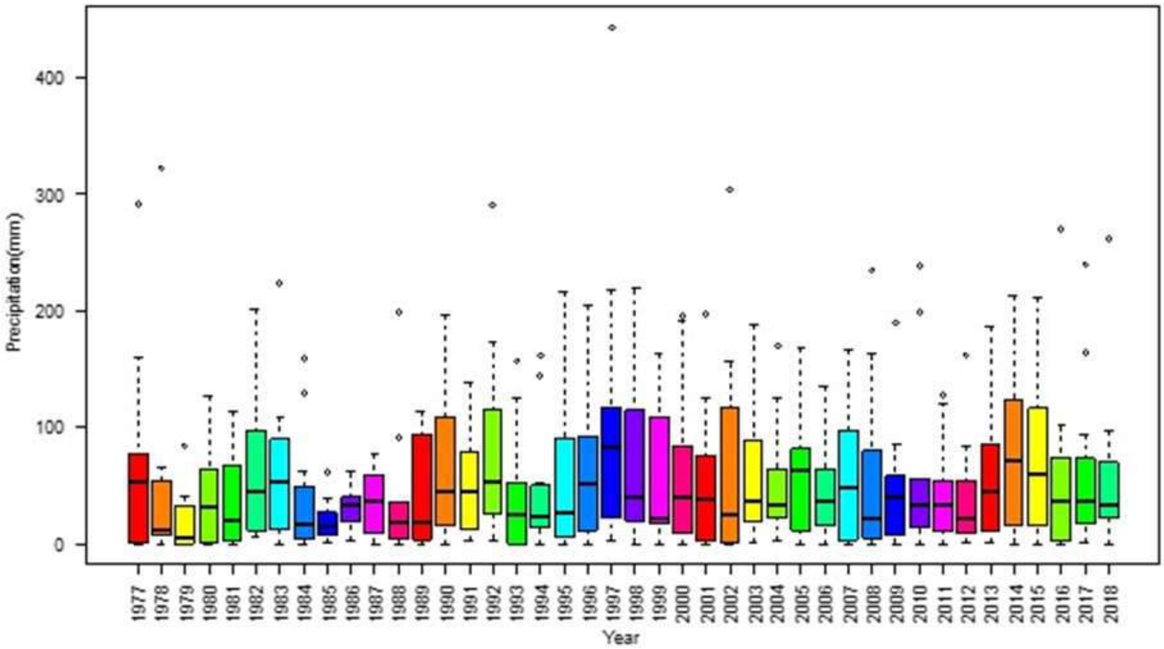


Figure 4.5: Year-wise precipitation variability in study area over the period of 1977-2018

Source: 'author'

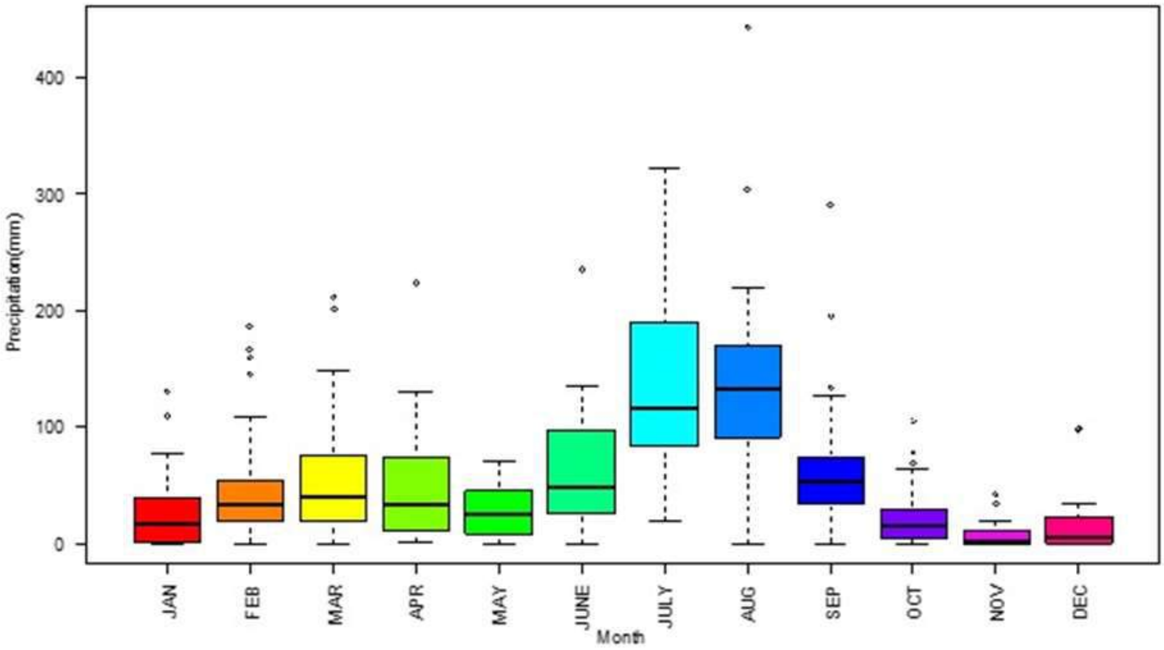


Figure 4.6: Monthly precipitation variability in study area over the period of 1977-2018
Source: 'author'

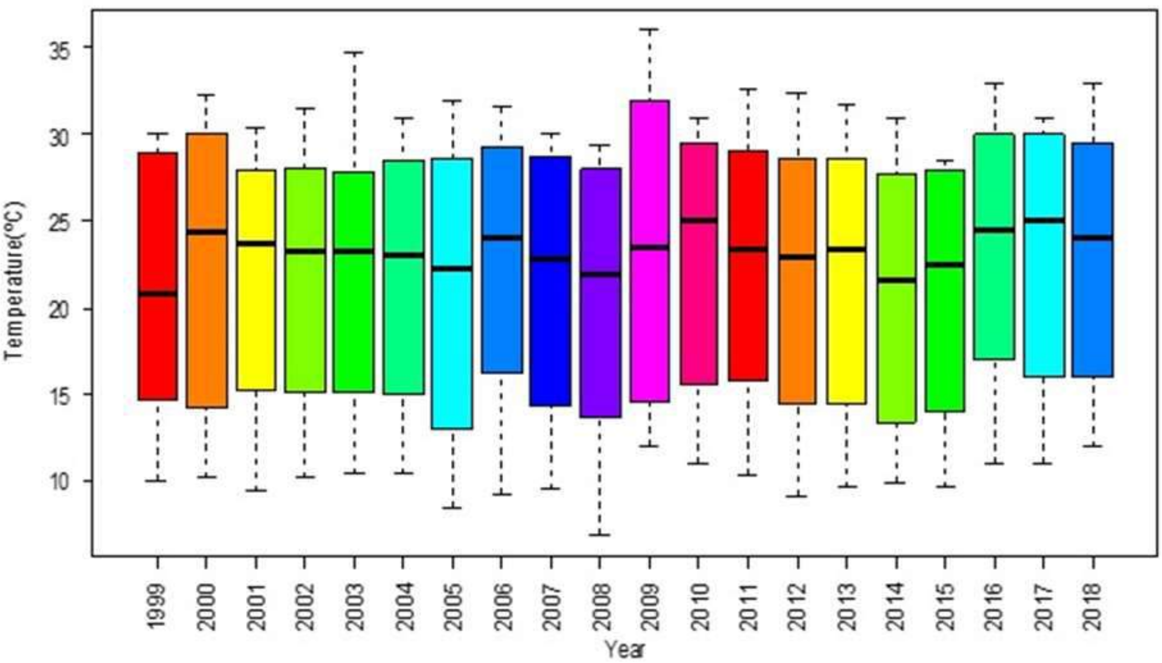


Figure 4.7: Year-wise temperature variations in study area over the period of 1999-2018
Source: 'author'

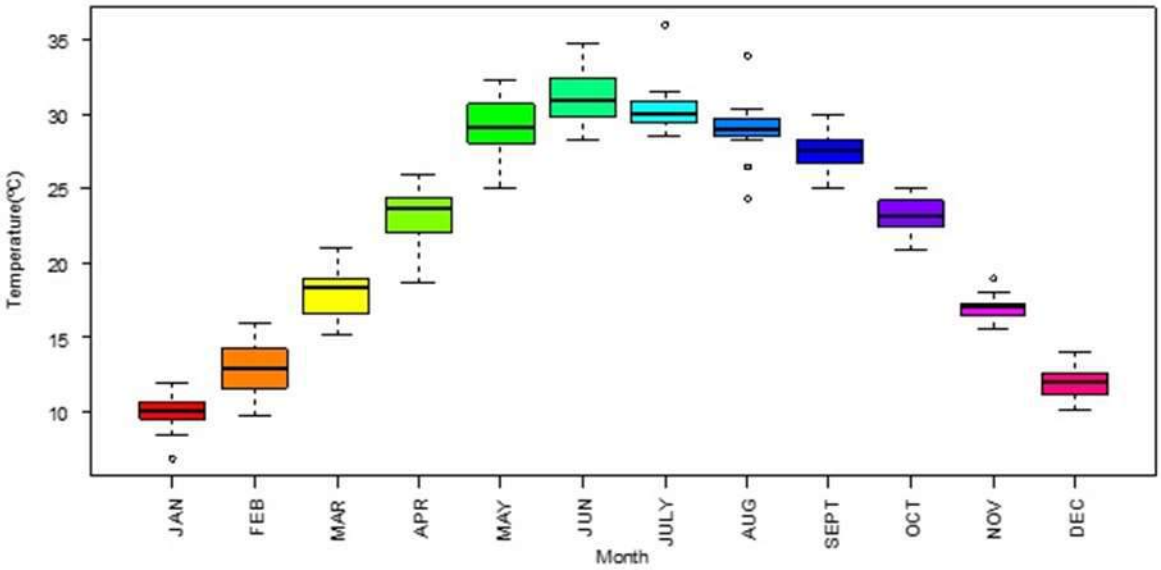


Figure 4.8: Monthly temperature variations in study area over the period of 1999-2018
Source: 'author'

The study also deciphered the sources of their information and knowledge about climate change. The findings elucidated that the majority (57%) of respondents rely on their sensory perception, conventional wisdom and traditional knowledge. The other sources of information include television (48%), newspaper (47%), radio (36%), neighbor (33%), agriculture department (18%), relatives (10%), and meteorological department (9%).

4.3.6. Climatic hazards and their impacts

The farmers were inquired about the nature and consequential impacts of climate-induced hazards for their lives and livelihoods. The majority of respondents were apprehensive about the occurrences of incidents such as the untimely rains, hailstorms, delay in the start of winter season, incidents of the cold and heat waves etc.

The consequential outcomes of these extreme events directly and indirectly influence the socio-economic conditions in such rural environs. The respondents were observed more uncertain and the repercussions of the above mentioned hazards are proving stressful for crop productivity, livestock diseases and human health (Table 4.1). However, the ramifications were adjudged asymmetrical and heterogeneous across the study area. These results are comparable to the studies conducted by ADB (Asian Development Bank), (2017) and WFP (World Food Program), (2017, 2018) in collaboration with Government of Pakistan (GoP). All these studies have ranked vulnerability of Chakwal District as 'Medium to Low Risk' in terms of climate change, agriculture and food insecurity and 'Very High Risk' to land degradation/soil erosion (> 50%).

Table 4.2: Climatic fluctuations and their impacts on farmers over the last 20 years or so (1997-2017)

Climate-related events	Responses			Rate of Change		Impacts on human health (Disease/Illness)			Impacts on crop yield/productivity (Uncertainty/Decline)			Impacts on livestock (Disease/Death)		
	Yes	No	Don't know	Increase	Decrease	Increase	Decrease	No change	Increase	Decrease	No change	Increase	Decrease	No change
	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Drought	39	32	29	30	1	24	0	2	15	15	1	15	13	1
Hailstorm	73	8	18	54	8	48	0	2	38	15	2	35	12	12
Untimely rains	86	3	11	64	2	21	1	2	15	12	0	14	8	8
Winter arrival (late)	71	8	21	42	18	18	0	0	13	8	1	13	6	6
Cold breeze	67	9	24	15	42	18	0	0	14	5	1	14	5	0
Summer arrival (early)	72	7	21	55	4	16	0	0	13	6	2	12	5	5
Heat waves	65	10	25	55	2	16	0	0	13	7	1	12	5	5
Storm	64	11	25	46	3	12	0	1	9	6	0	8	4	4
Frost	59	17	23	41	5	5	0	1	1	6	1	1	4	4
Temperature Change	61	7	31	59	2	32	0	1	17	2	1	16	1	1

Source: 'author'

4.4 Discussion

The current rain-fed agricultural practices are more susceptible to such climate and weather related oscillations. Therefore, the situation warrants for the assessment of preventive and curative strategies deployed by the farming communities. The research based initiatives are incumbent (Abid et al., 2015; Bryan et al., 2013; Harvey et al., 2014; Tran et al., 2017) for addressing the looming threats from climate change. The reported findings such as Ali & Erenstein (2017) and Abid et al. (2019) divulge that the phenomena of climate change is seriously threatening the socio-ecological landscape of Pakistan. The reported weather and climatic abnormalities are jeopardizing the objectives such as food security and poverty reduction in this country (Ali & Erenstein, 2017). The present study was carried out for evaluating the orientations of farming fraternities regarding the phenomena of climate change in the rain-fed rural settings of the Punjab.

The findings of the present study divulge that the socio-economic conditions in the rural settings of the district Chakwal are dependent on the rain-fed agriculture (Fig 4.4). These outcomes corroborate the earlier assertions such as Harvey et al. (2014) and Abid et al. (2016) that agro-based economic activities are the primary source for food and income generation in the rural landscape of Pakistan. The results vindicate the conclusions of IPCC (2014b), Deressa et al. (2009), Wu et al. (2017) and Tesfahunegn et al. (2016) that fragile socio-economic sustainability of such rural settings are dependent upon the agricultural outputs. Whereas, the low agricultural yields in these areas are (Oweis & Ashraf, 2014; Tesfahunegn et al., 2016), still, far from the global standards (Arshad et al., 2017; FAO, 2015; GOP, 2018; Prikhodko, D. & Zrilyi, 2013). The compromised performance of the agricultural sector, thus, further aggravates the socio-economic vulnerabilities of farming communities (Gbetibouo et al., 2010; Liu et al., 2016). The findings substantiate the notions of Chen et al. (2015) and Lal, (2011) that the inadequate resource base, ineffective adaptation strategies and absence/or compromises over the policies are also culpable for the exacerbation. Therefore, making these locations, intrinsically, more prone to the impacts of climatic oscillations and, hence, demand coordinated efforts to ensure their socio-economic resilience (Harvey et al., 2014; Hisali et al., 2011; Senbeta, 2009; Žurovec et al., 2017b).

The findings of the study in (Table 4.1) portrayed that a significant proportion of respondents is susceptible and unprepared to absorb the impacts of abnormal climatic fluctuations or non-climatic shocks. The corollary affects further reduce their agricultural outputs and adversely impact the food availability. The repercussions manifest themselves in the form of malnutrition, compromises over socio-cultural spending and child mortality etc. (FAO, 2016; Pachauri & Meyer, 2014). The small size of fields, inadequate use of agricultural inputs (fertilizers, pesticides, improved seed varieties etc.), less/low reliance on technology, soil/land degradation are the perceptible explanations for the reported low agricultural productivity in the study area. Besides this, the less organized and poorly integrated mechanisms of connectivity between the farms and markets are the other noticeable impediments in the study area. The farmers have to bear extra financial burden on transporting their produce and agricultural inputs. The resultant reduction in the profit margin, ultimately, retards the capacity and will of the farmer for innovative measures to address the looming challenges associated with the climate change (Ali & Erenstein, 2017; Arshad et al., 2017; Gorst et al., 2018; Harvey et al., 2014).

The lack of access to formal safety nets such as the absence of coordinated mechanism for crop/livestock insurance is another critical factor that is also responsible for the socio-economic exacerbation in the study context. The absence of an integrated mechanism forced the agrarian communities to rely on informal support systems i.e. borrowing money/ food from family or friends. Farmers are also further constrained by the limited access to agro-meteorological and market related information (Fig. 4.3). Though, the local NGOs and an agricultural extension department are operating in the study area, yet, a significant proportion (40%) of the respondents reported that they didn’t receive any technical guidance. The technical assistance is a prerequisite for informed decision making concerning the choice of crops, planting dates and devising strategies to overcome/minimize the impacts of droughts and climate-related hazards (Maddison, 2007; Woods et al., 2017).

The findings of the study helped to cognize about the multiple challenges the farmers are facing in the rain-fed rural surroundings, ranging from socio-economic impediments to abrupt atmospheric anomalies. The consequential outcomes are complex, manifold and far-reaching for the agricultural productivity and livelihood. It also transpires that these challenges have an acknowledgment in the study area. The consequential impacts are becoming more detectable and proving detrimental for the small farmers. These marginalized sections of rural landscape are economically more vulnerable, thus, are the apparent victims. Therefore, the growing incidents of crop failures/yield reductions are proving counter-productive for initiatives to reduce poverty in rural areas. Thus, the emerging scenario demands for coordinated efforts for ensuring socio-economic sustainability in the rain-fed rural areas of Pakistan (Abid et al., 2019; Barrucand et al., 2017; Choudri et al., 2013; Mertz et al., 2011).

The projections regarding escalating temperature (Abas et al., 2017; IPCC, 2014b; Janjua et al., 2014) and predictions about fluctuations in the patterns of precipitation in Pakistan (Abid et al., 2015; Ali & Erenstein, 2017; Pak-INDC, 2016) necessitate on postulating measures for the protection of small farmers. There is an urgent need to chalk out the contours of pragmatic strategies based upon the indigenous resources. The outcomes of such an endeavor will help to convert such looming challenges into opportunities.

However, the farmers, particularly the small landholders in the study area are reluctant to experiment with the innovative measures/methods due to the lack of financial support and awareness. The limited exposure and compromised resource base of the farmers makes it difficult and risky for them to improvise. Therefore, proactive engagements from the private sector such as agriculture service providers backed by the public sector are imperative for the desired objectives.

4.5 Conclusions

The findings of the study divulge that the farming communities have an awareness about the weather and climatic abnormalities. The respondents are mindful about the repercussions for their crops, livestock and health. The reported decline in the agricultural production is adversely impacting their livelihoods and making them more vulnerable. The farmers also have a realization that they can adjust with the phenomena through technical and financial support. Therefore, it requires the capacity-building and financial support of the stakeholders to adapt climatic changes. Although, the agricultural departments are operating but its imprints are less visible due to lack of clarity and consistency in policies. Whereas, the Sustainable Development Goals stresses on “taking urgent actions to combat climate change and its impacts” (SDG 3). Therefore, further research initiatives and transferring the technological outputs of the similar orientations are required for ensuring the socio-economic uplift and resilience of the farmers residing in the study area.

CHAPTER 5

THE ASSESSMENT OF LAND USE LAND COVER CHANGES

5.1 Introduction

Population budge and socio-economic transformations are proving stressful for the ecological balance. The focus towards economic development is mandatory for poverty eradication and to fulfill the obligations associated with the United Nations (UN) Sustainable Development Goals (SDGs) by 2030**.** Resultantly, the reliance on technological gadgets for enhancing productivities is, also, gaining focus and impetus in the developing parts of the globe. On one hand, these initiatives supported by the technological advancements, are boon for the economic development. On the other hand, the effects of uncalculated advances may prove bane for the natural environment (Butt et al., 2015). Therefore, the resource exploitation needs careful assessments besides deploying the principles of integrated management practices during execution. These precautions are indispensable for the sustainability of natural resources and their productivity (Eniolorunda et al., 2017).

In the present times, the land resources are an easy prey and a major victim of regulated as well as unregulated attempts for natural resources exploitation (Huang et al., 2017). The manipulation with the land resources are carried out to accommodate the growing demand for food, shelter and to fulfill the demands for the raw material from the industrial sectors. The intrusions in the lithosphere are more pronounced in the developing regions as compared to the developed regions. The causation for such tendencies are rooted in the population pressure, the focus towards infrastructural development and more reliance on the natural resources for the survival and development. Besides this, the opportunities such as the foreign remittances, the enhanced inflow of Foreign Direct Investments (DFIs), technology transfer and access to newfound business and financial openings due to globalization and 'market economy' are stimulating for Land Use Land Cover (LULC) transformations in the developing economies. These actualities are exerting pressures on the land resources and posing challenges for the land management paradigms and practices in the less developed regions (Xiong et al., 2017).

The impacts of LULC changes are accentuating the ensuing phenomenon of global climate change (Eniolorunda et al., 2017; Yin et al., 2018). The environmental repercussions emanating from regulated and unregulated LULC changes are posing threats for the natural and social environment (Atif et al., 2018). The planned and unplanned LULC conversions are causing disturbances for the ecological resources. Resultantly, the reduction in carbon sequestration and oxygen release from the green infrastructure due to ecological degradation is adversely impacting the atmospheric equilibrium. The findings based upon the empirical data corroborate such assertions that the spatial variations in the land surface temperature (LST) is suggestively influenced by the land cover type (Hereher, 2017). Besides this, the speed, scale and nature of influxes between the earth and atmosphere, in the form of mass and energy, are governed and modified by the alterations in the LULC. Herecher, (2017) elaborated that the LULC changes characteristically modified the geophysical processes such as evapotranspiration, hydrological cycle and energy budget of a geographical setting. The LULC changes also impact the social attitude in a geographical region and its proximity. Therefore, the initiatives for LULC changes should be taken after prior assessments and scrupulous decision making process (Mu et al., 2017).

The transformations in the LULC have bearings on the phenomenon such as deforestation, soil erosion, land fragmentation and realign the contours of water budget etc. The cumulative outcomes exert their own pressures on the natural and social environment. Resultantly, the initiatives which are primarily designed to ensure human wellbeing and environmental sustainability fail to yield dividends. The consequential impacts in the form of rising temperature, declining soil fecundity and increasing soil/land erosion add up the miseries for the natural and social systems. The outcomes prove more stressful for the economically deprived and socially marginalized segments of the social fabric. Besides this, the repercussions of such planned and unplanned LULC transformations are more detrimental for the agrarian settings as compared to urban areas (Dissanayake et al., 2017). As the majority of population in the developing countries such as Pakistan, are residing in the rural areas, therefore, the looming impacts will prove more devastating.

Whereas, the environmental degradation and climatic disruptions escalate the expenditure for survival but also cause reduction in the yield and value of the agricultural produce. As a result, the socio-economically marginalized groups, in the agrarian contextual settings of the developing countries are forced to leave their hearth and move towards urban centers. These environmental migrant are contributing towards uncontrolled urbanization in these less developed countries. Besides this, these economically deprived and unskilled “newcomers” fail to assimilate in the city life and cause exacerbation for the urban social life. Thus, to ensure the resilience of agricultural sector and socio-economic sustainability in the rural surroundings is a question of environmental equity and justice debate as well.

The situation is posing far reaching complications for those who are directly and indirectly dependent on the agricultural sector. The situation warrants to synchronize the orientations of LULC changes and agricultural practices for improving the land productivity without compromising its resilience. The initiatives are incumbent to ensure the conservation of vegetative resources, agricultural productivity and resilience of land and ecological resources. The focus is more needed in the contextual settings where the economies are hooked on the primary economic activities such as mining, forestry and agricultural sectors (Dissanayake et al., 2017).

However, the lack of awareness, compromises over policies and absence of a coherent mechanism to deal with such challenges are the noticeable hindrances in the developing regions. Besides this, the knowledge-gaps, limitations linked with the resources availability and capacity building are adversely impacting the situation. The scenario warrants for preventive and corrective measures for ensuring the resilience of natural environment, social uplift and sustainable economic progression.

The optimal utilization and resilience of land resources requires the contextual knowledge about land use practices and precise the information about the existing LULC. The scholastic debates for promoting sustainable agricultural development also stress on deciphering the dynamics which influence the decision making regarding the land resources. It necessitates to comprehend the trajectory of land use and land cover changes. The spatial-temporal analysis of LULC changes is, thus, obligatory in order to interpret the orientation and magnitude of such changes (Huang et al., 2017). Therefore, the information and knowledge is obligatory for pragmatic decision making.

The information will also contribute towards land productivity and for ensuring the integrity of the environmental resources.

However, the prevalent conventional methods relied upon for the land use mapping are labor intensive, time consuming and less amenable to statistical procedures. Besides this, these maps soon become outdated in a rapidly changing scenario (Eniolorunda et al., 2017; Mashame & Akinyemi, 2016). While, the recent advances in the domain of Remote Sensing (RS) and Geographic Information System (GIS) techniques have proved catalyst for making accurate LULC maps (Yin et al., 2018). The increased accessibility to Google Earth Engine (GEE) due to information technology have made this task much easier. The GEE is a cloud computing platform designed to store and process huge spatial-temporal data sets (at petabyte-scale) for analysis and decision making. The easily accessible and user-friendly front-end features of its environment provides a convenient space for interactive data management and algorithm development (Midekisa et al., 2017; Xiong et al., 2017).

Despite such revolutionary advances, assessments regarding LULC are still carried out with primitive methods in the less developed regions. Therefore, the accuracies of the findings are disputed and further investigations are needed to ascertain the validities. Whereas, the studies are required to identify cost-effective and time-saving options to map the land cover changes in these countries on a regular interval. This will enable to detect the orientation and magnitude of human interventions in the natural environment. It will provide up-to-date information regarding LULC changes for preventive and curative measures required for the resilience of land resources in such areas (Eniolorunda et al., 2017).

The focus of this study is to document the spatial-temporal changes in the LULC of the Chakwal District for the last 30 years. The study was designed to achieve the following objectives (i) to identify and map the prevalent land use/ land cover categories in the Chakwal District during 2018; (ii) to compile the spatial and temporal LULC changes in the study area and assess the magnitude and orientation of such changes for the last 30 years; and (iii) to evaluate the agricultural potential and productivity of the study area during the selected time period.

The findings of the study will help to construe about the dynamics that stimulate and influence the LULC changes in this region. The documentation of such trends will enable to design the frameworks for the socio-economic and environmental sustainability of this agrarian contextual setting of Pakistan.

5.2 Materials and Methods

The figure 5.1 shows the procedures and measures used for LULC assessments. The flow chart explicitly portrays the methodological measures relied upon to quantify and analyze the orientation of such changes in the selected land cover classes of the study area.

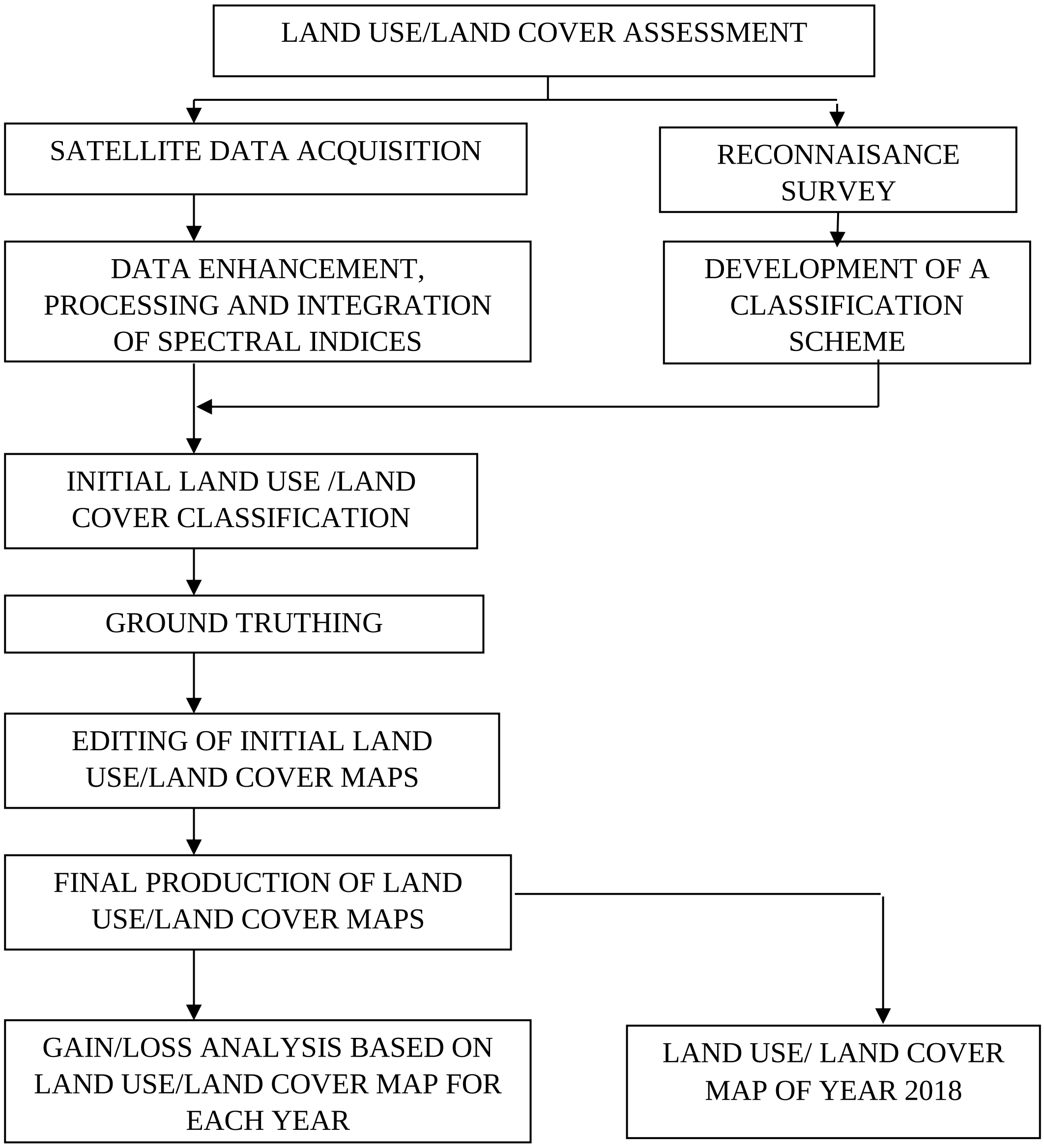


Figure 5.1: Flow diagram of methodology
Source: 'author'

5.2.1 Data acquisition and source

The remotely sensed data were used. For the purpose, Landsat satellite imageries were relied. The study area, Chakwal District, is located at (Path 150/Row 37) according to the Landsat Worldwide Reference System (WRS). Landsat time-series data from 1989 to 2018 was obtained for extracting information regarding LULC changes through Google Erath Engine (GEE). The medium scaled Landsat TM and ETM satellite imageries were used. The trajectory-based change detection approach was deployed by developing algorithm to map the land cover changes in the GEE (Kennedy et al., 2018).

We use Landsat 5, 7 and Landsat 8 as inputs for image classification. The composite includes pixels with the lowest cloud cover, computed as per-band percentile values and scaled to 8 bits. We select the lowest possible range of cloud scores and compute per-band percentile values from the accepted pixels. The salient characteristics of the remotely sensed data have been condensed (Table 5.1). The values were scaled to 8 bits for ensuring precision and accuracy. Administrative map of Chakwal District was retrieved from Open street freely available data source.

Table 5.1: Satelllite data characteristics

Year	Satellite Sensor	Spatial Resolution	Bands Used	Worldwide Reference System (WRS)
1988-05	Landsat 5 TM	30 m × 30 m	1, 2, 3, 4, 5 & 7	WRS 2: 150/37
2006-13	Landsat 7 ETM+	30 m × 30 m	1, 2, 3, 4, 5 & 7	WRS 2: 150/37
2014-18	Landsat 8 TM+	30 m × 30 m	1, 2, 3, 4, 5 & 7	WRS 2: 150/37

Source: 'author'

5.2.2 Spectral Indices

The spectral indices were calculated by using the following equations:

(I): ***Normalized Difference Vegetation Index (NDVI):***

$$NDVI\left(\frac{B5-B4}{B5+B4}\right)$$

(II): ***Normalized Difference Water Index (NDWI):***

$$NDWI\left(\frac{B3-B5}{B3+B5}\right)$$

(III): Modified Normalized Difference Water Index (MNDWI):

$$MNDWI\left(\frac{B5-B4}{B5+B4}\right), MNDWI\left(\frac{B3-B7}{B3+B7}\right)$$

(IV): *Normalized Difference Built Index (NDBI):* This model is used in conjunction with the traditional NDVI for the detection of urban areas, for a single Landsat scene.

$$NDBI\left(\frac{B7 - B4}{B7 + B4}\right)$$

5.2.3 Software used

The following softwares were used for measurements, assessments and portraying findings of the investigation. These are:

(a) Google Earth Engine: This online spatial data sources was relied upon for data acquisition and subsequent processing. The GEE, a cloud computing platform, was used to develop LULC classes and change detection analysis in the study.

(b) ArcGIS 10.3 – was also used for assessments and to portray the final data products.

(c) R (Version 3.4.3) – The change detection (Gain/Loss) analysis were performed through R machine learning scripts.

(d) Microsoft word – was used to present the research.

(e) Microsoft Excel was used to display the findings.

5.2.4 Development of a classification scheme

Based on the priori knowledge about the contextual settings of the study area and based upon the information from previous research, a classification scheme was conceived for the current study. The classification scheme is developed to identify a particular LULC class by a single digit. For the purpose, the field observation from 600 sites were made with the help of Geographic Positioning System (GPS). In addition, a total of 1835 sample plots, were manually observed from 1989 to 2018 through higher resolution images in GEE. Both the training and validation samples of each year were separately uploaded to the GEE via the Google Fusion Tables (GFT). The primary objective of this technique was to classify the land cover of a respective year. The classes and their interpretations were carried out to display the contextual settings to ensure the accuracies of the findings (Table 5.2).

Table 5.2: Interpretation of LULC Classification

Sr. No.	Classes	Description
1.	Cropland	Mostly rain-fed cropping areas
2.	Grasses	The land areas dominated by natural grass cover
3.	Shrub land	The areas covered by the shrubs and tall herbs
4.	Trees/Forest	The forest covers in the study area
5.	Water	The natural and man-made water cover and hydrological systems in the study area
6.	Built-up	The rural and urban settlements and infrastructures
7.	Bare soil/rocks	Barren land with extremely low vegetative cover and rocky land surfaces

Source: 'author'

5.2.5 Classification of the images

To classify the land cover of the study area, complex pixels of satellite image containing multiple spectral bands and colors were classified into definite number of classes. Classification and Regression Tree classifier (CART) package proposed by Breiman in 1984 (Hu et al., 2018) was deployed to generate land cover maps.

The CART enables to classify images and collect required data for the selected land cover classes. The method does not require parameters. Besides this, it is easier to manipulate and quicker to operate. Therefore, the CART is gaining rapid acceptance as a reliable tool for classification with the remotely sensed images (Hu et al., 2018). The CART algorithm are embedded in dichotomous recursive segmentation technique that refer to the Gini coefficient as the criterion for optimal test variances and segmentation. It, ultimately, generates a binary tree-based decision tree for classification. The Gini coefficient is defined as follows:

$$\text{Gini Index} = 1 - \sum_j^h p^2\,(j|h)$$

$$p(j|h) = \frac{n_{j(h)}}{n(h)}$$

$$\sum_{j=1}^{J} p\ (j|h) = 1$$

"Where $p(j|h)p(j|h)$ is a sample that is randomly selected from a training set $n_j(h)$. $n_j(h)$ is the number of samples that belong to category j when the test variable value is h in the training set. $n(h)$ is the number of samples with the test variable value of h in the training set, and j represents the category number".

5.2.6 Methods of Data Analysis

(i) In the first step, the classified images were downloaded and processed in the ArcGIS 10.3 for further processing and analysis.

(ii) In the next stage, the calculation pertaining to the selected LULC types were made in km^2 for the subsequent comparison.

(iii) In the last step, R Packages were used to compute, calculate and plot the gains/losses for each of the selected LULC class. The information were cartographically portrayed to illustrate the spatial-temporal fluctuations in the land cover of study area.

5.3 Results

5.3.1 Quantitative assessment of LULC classes of study area (2018)

The land use land cover map of the study area was prepared to quantify the share of each selected class (Fig 5.2). The assessments were also made to decipher the orientation of spatial changes in order to illustrate the gains and losses in the categories of the land cover classes (Fig 5.5 & 5.6). Figure 5.2 shows that the largest share of the total land area is occupied by the croplands. The share of this category was observed approximately 3633.928 km^2 (54.32%). It is followed by the shrub land (22.08%), grassy surfaces (8.83%), trees covers (5.53%), bare land (5.34%), built-up areas (2.8%) and water surfaces (1.28%). The percentage share and total area of each land cover class have been condensed in Table 5.3. While, the *tehsil-wise* (sub-division) break-up of each land cover was also made (Table 5.4) and percentage distribution of these land cover class in the respective tehsils of the district Chakwal were portrayed (Fig.5.4).

The findings rendered that the tehsil Chakwal, the largest administrative sub-division in terms of area, occupies the largest share in the categories of agricultural area (1377.384 km^2), shrub land (419.6982 km^2) and in the built-up areas (68.923632 km^2) as compared to the other sub-divisions of the district. While, the least share of cropland was found in the sub-division of Choa Saiden Shah i.e. 123.4409 km^2. However, the sub-divisions Choa Saiden Shah (109.5564 km^2) and Kallar Kahar (103.2416 km^2) hold the largest share of trees/forest resources of the district. The share of Lawa tehsil was alarmingly found very low in this regard i.e. 13.94495 km^2. The largest share in the category of water bodies is occupied by the Talagang tehsil i.e. 40.9817 km^2 followed by the Chakwal sub-division i.e. 19.71269 km^2. The Lawa (166.5283 km^2) and Talagang (160.7216 km^2) have the largest cover of grasses surfaces in the study area.

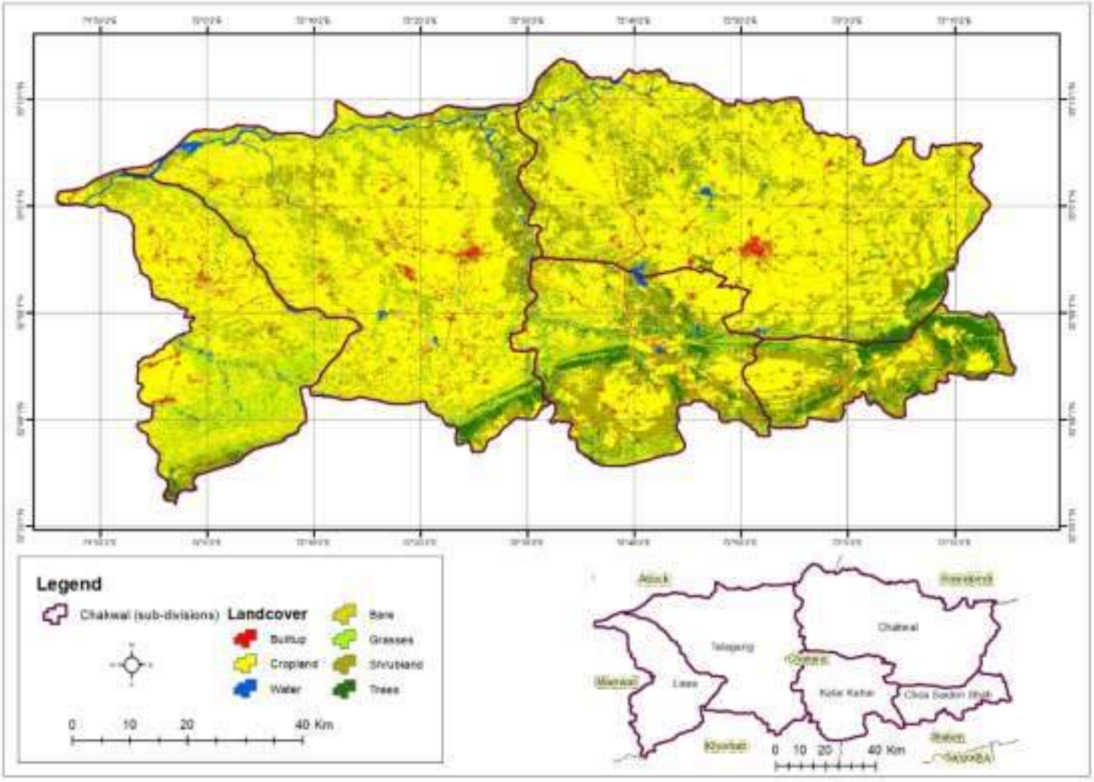


Figure 5.2: Land use Land cover map of Chakwal District (2018)
Source: 'author'

Table 5.3: Land use/land cover (LULC) classes of Chakwal District (2018)

Sr. No.	LULC Classes	Area (km^2)	%age
1.	Built-up	189.5201	2.83
2.	Cropland	3633.928	54.32
3.	Water	85.48074	1.28
4.	Bare	356.9638	5.34
5.	Grasses	590.7543	8.83
6.	Shrubland	1476.849	22.08
7.	Trees	356.5041	5.33

Source: 'author'

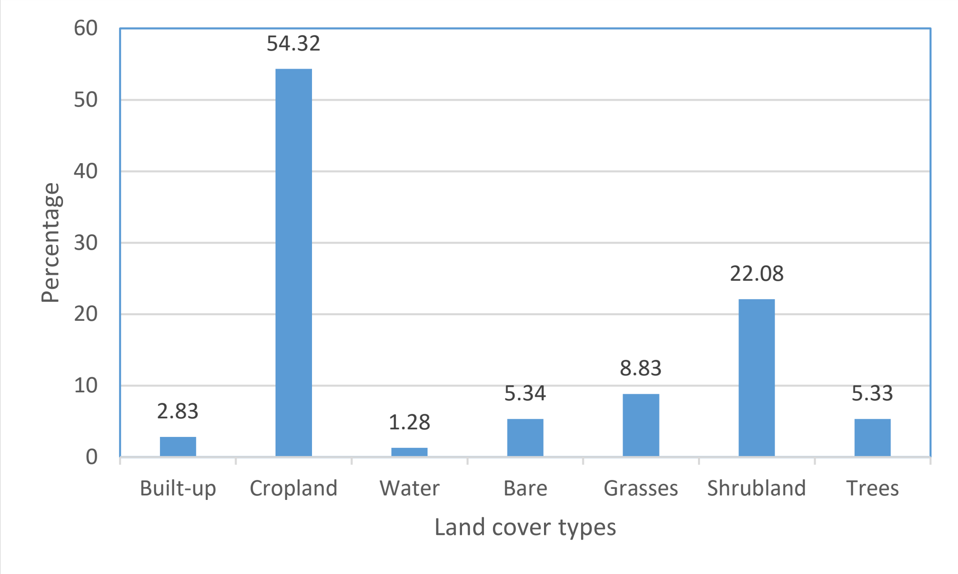


Figure 5.3: Bar graph showing the percentage of LULC classes of Chakwal District
Source: 'author'

Table 5.4: Land use/land cover classes of Chakwal (sub-divisions) of year 2018 (km^2)

Zone	Built-up	Cropland	Water	Barren	Grasses	Shrub land	Trees
Chakwal	68.923632	1377.384	19.71269	79.80031	149.8709	419.6982	71.58484
Choa Saiden Shah	7.8168235	123.4409	0.456032	10.51017	24.95017	178.3439	109.5564
Kallar Kahar	21.962244	348.4883	8.216234	45.8917	88.46646	322.0599	103.2416
Lawa	31.682008	530.7612	16.04683	125.9843	166.5283	152.7724	13.94495
Talagang	59.431119	1254.206	40.9817	94.87845	160.7216	403.3813	58.30022

Source: 'author'

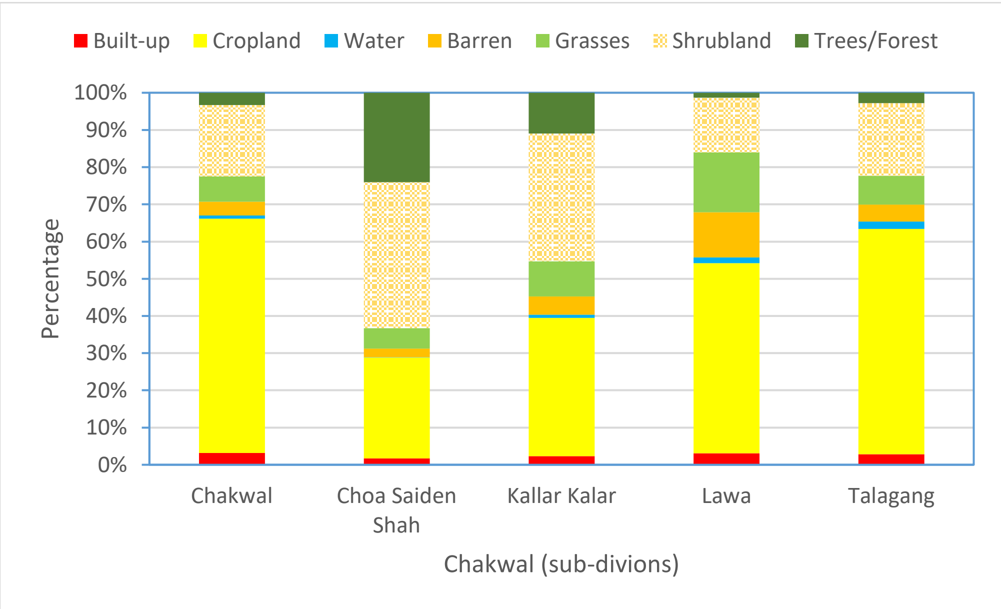


Figure 5.4: Percentage area of LULC classes of Chakwal (sub-divisions)
Source: 'author'

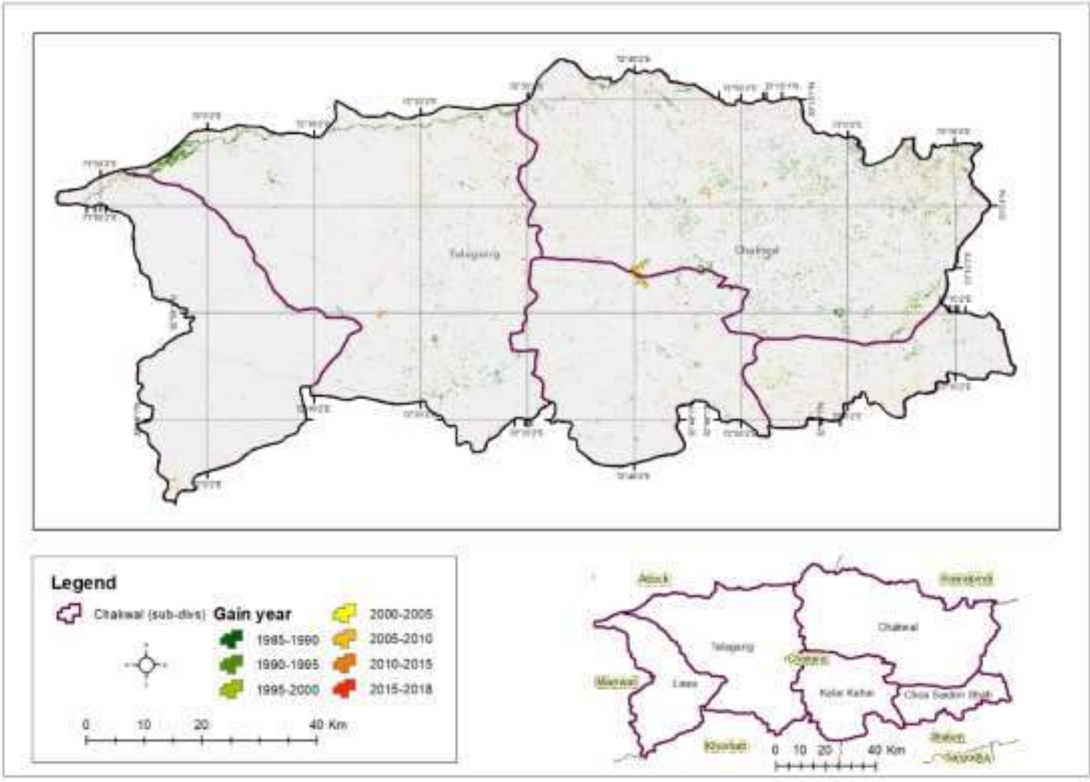


Figure 5.5: Year-wise gain magnitude of land covers of Chakwal District (1985-2018)
Source: 'author'

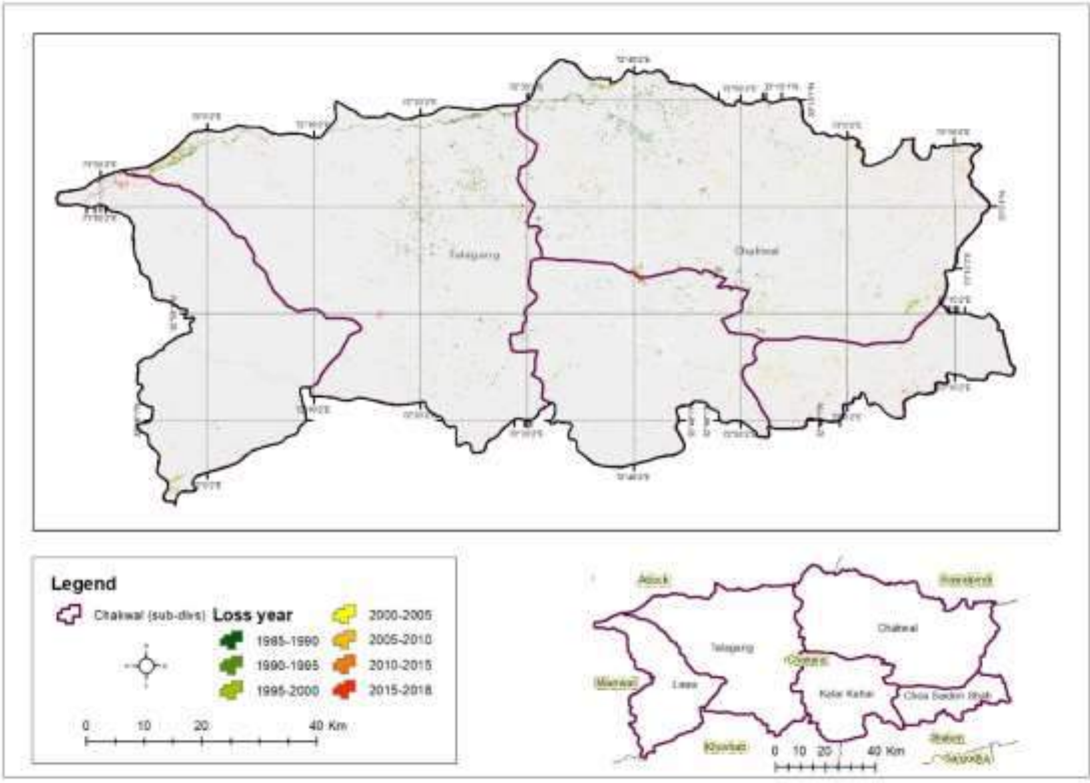


Figure 5.6: Year-wise loss magnitude of land covers of Chakwal District (1985-2018)
Source: 'author'

5.3.2 Gain and loss magnitude of land cover classes (1985-2018)

The cartographic illustrations (Fig 5.7 and Fig 5.8) and findings in (Appendix B) reveal the gains and losses that have occurred in each of the selected land cover type during the last 30 years (1985-2018). The green colour (Fig 5.7) reflect the highest gain in the area of a specific land cover class, while, the red colour in (Fig 5.5) portray the lowest transformation in a particular category of the land cover during this time period. The yellow colour depicts the moderate changes in the area of a specific land cover class. The schematic map (Fig 5.7) describes the quantum of such modifications in the entire study area and its constituting units i.e. the administrative sub-divisions of the Chakwal district.

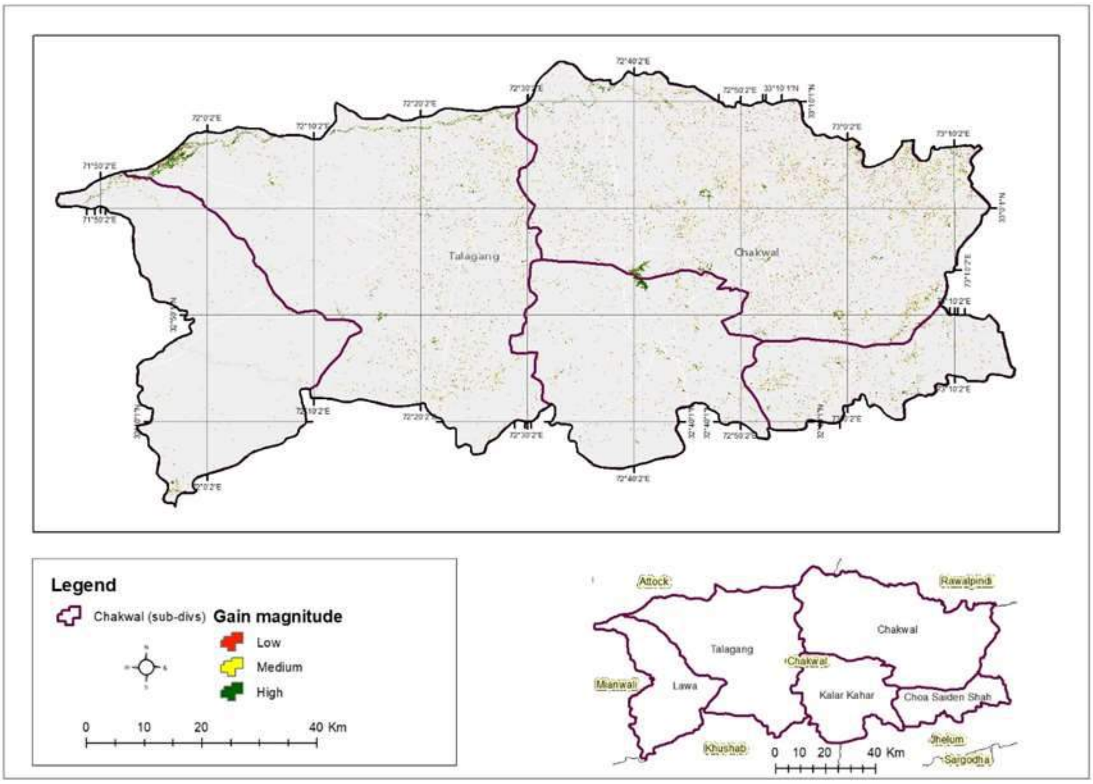


Figure 5.7: Overall magnitude of gain in land covers of Chakwal District (1985-2018)
Source: 'author'

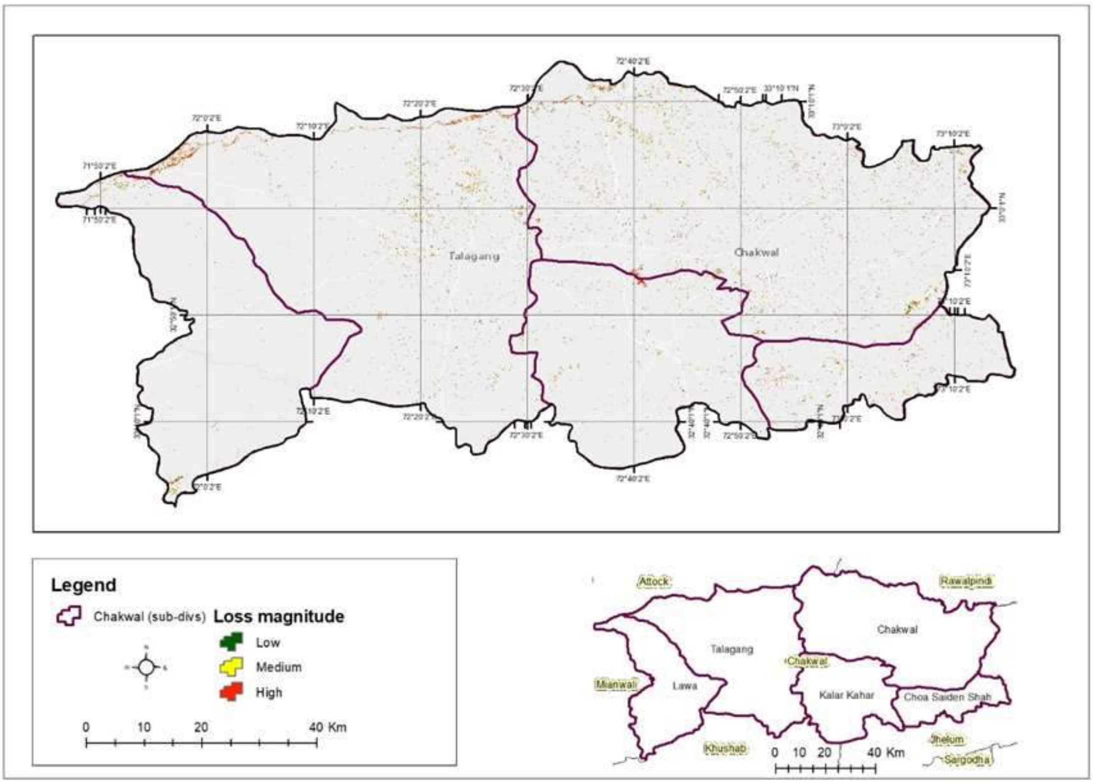


Figure 5.8: Overall magnitude of loss of land covers of Chakwal District (1985-2018)
Source: 'author'

5.3.3 Gain and loss of LULC classes during (2010 - 2017)

Figure 5.9 shows that the area for cropland and water surfaces significantly increased during the early years of the selected time period (2010-2017). During the similar time-interval, the noticeable increases in the share of tree cover, shrubland and grass land were also observed (Fig 5.9). However, a visible decline in the proportion of tree cover, shrubland and grassy surfaces is noticeable during the years 2016 and 2017 (Fig.5.9). It has been found that the share of built up area is constantly inreasing in the study area. The oscillations in the proportion of the remaing land cover classes have been summarized in Fig.5.9.

5.3.4 Gain and loss of LULC classes during (2000-2009)

The share of the tree cover increased during the early years from 2000 to 2009. Similarly, the significant increases in the share of shrubland were observed in the years 2002 and 2007. However, the noticeable reduction in the proportion and area of cropland surfaces was also observed (Fig 5.10).

5.3.5 Gain and loss of LULC classes durning (1990-1999)

The significant declines in the shares of tree cover, shrubland and croplands areas have been found. The tendencies became more noticeable in the last year of this decade (1990-1999). However, a conspicuous oscillation in the case of cropland was also observed. The share of this category stretched in the year 1995 but inverted to the previous pattern in the suceeding years of this time-interval (Fig.5.11).

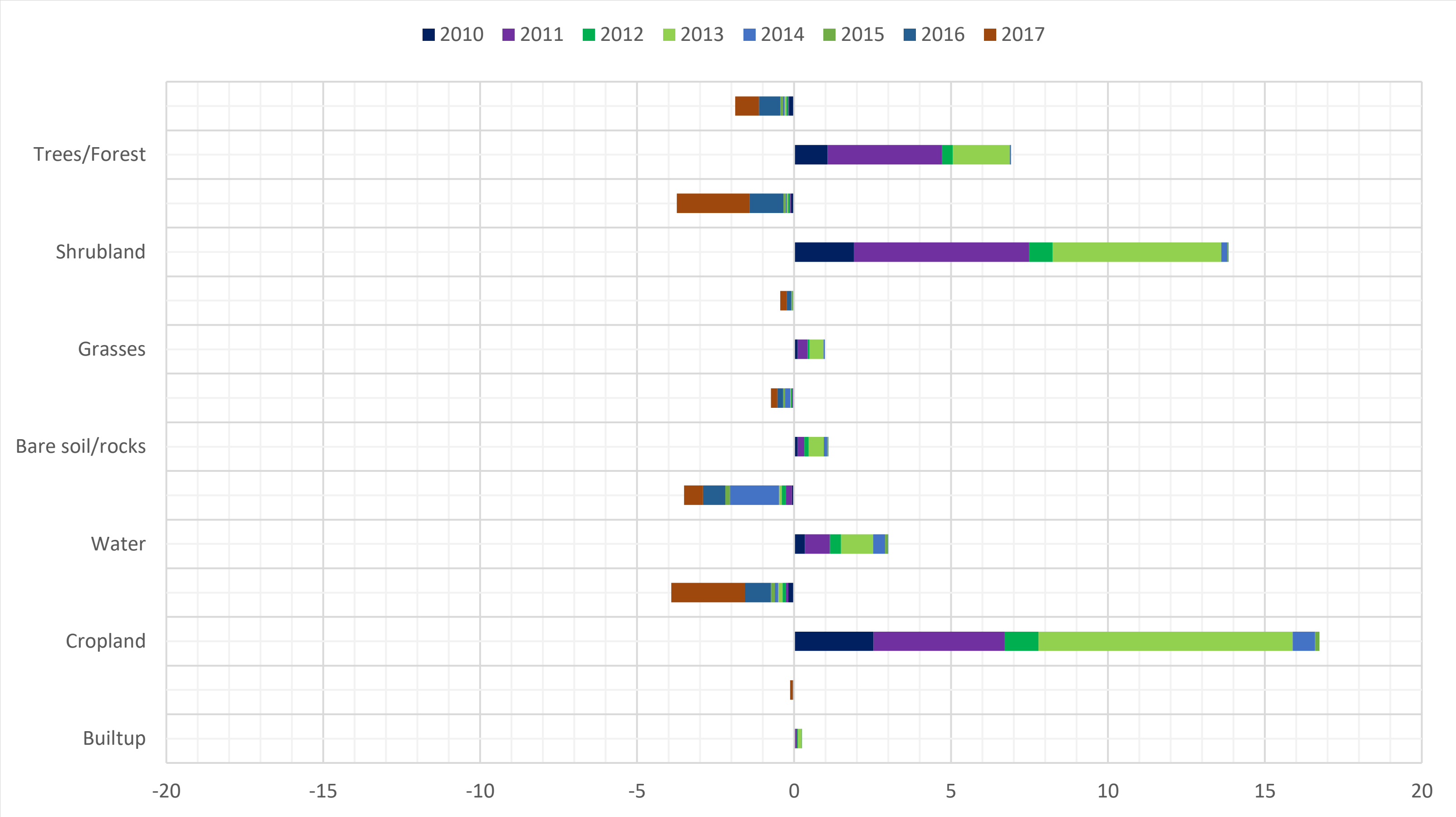


Figure 5.9: LULC gain and loss during 2010 to 2017

Source: 'author'

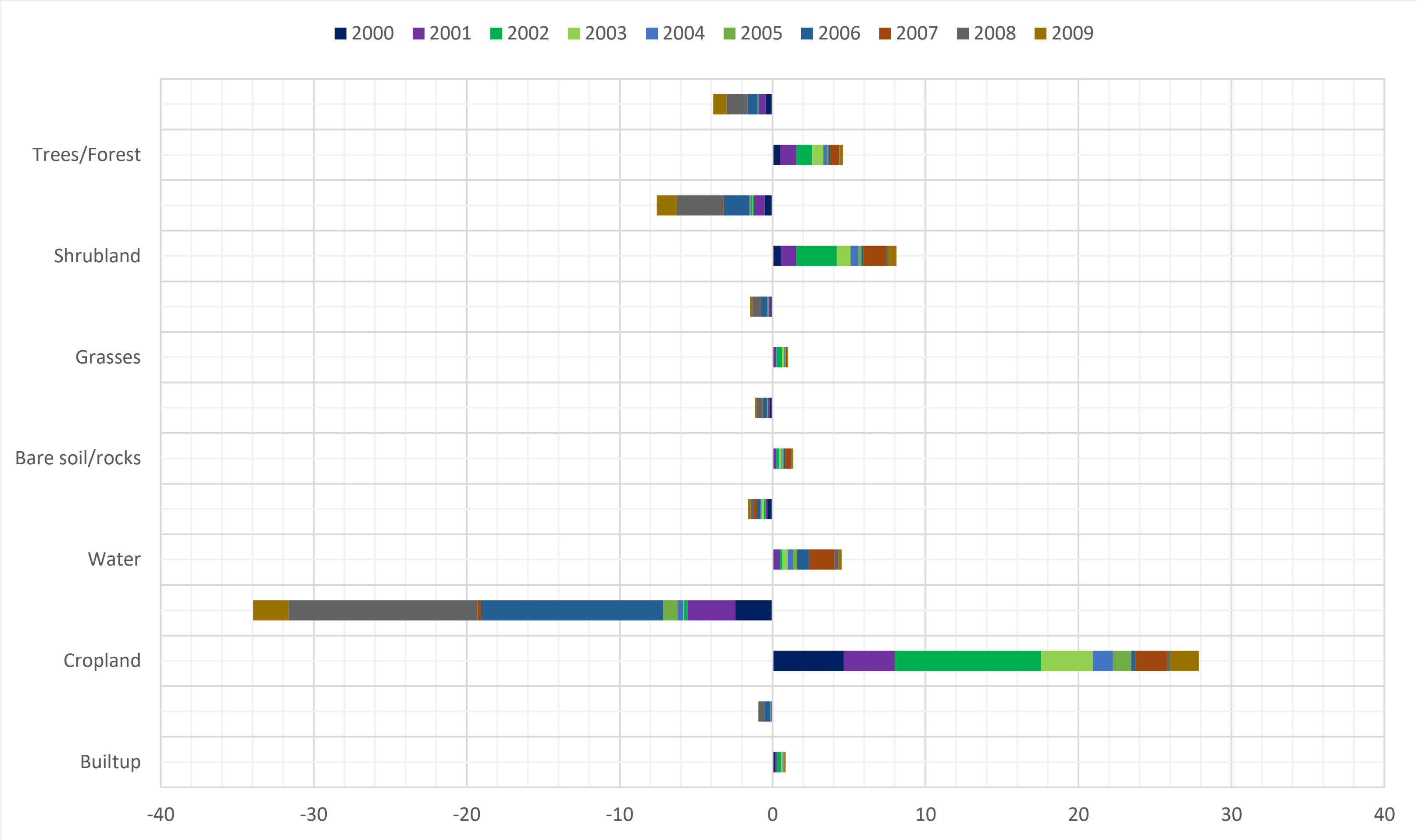


Figure 5.10: LULC gain and loss during 2000 to 2009

Source: 'author'

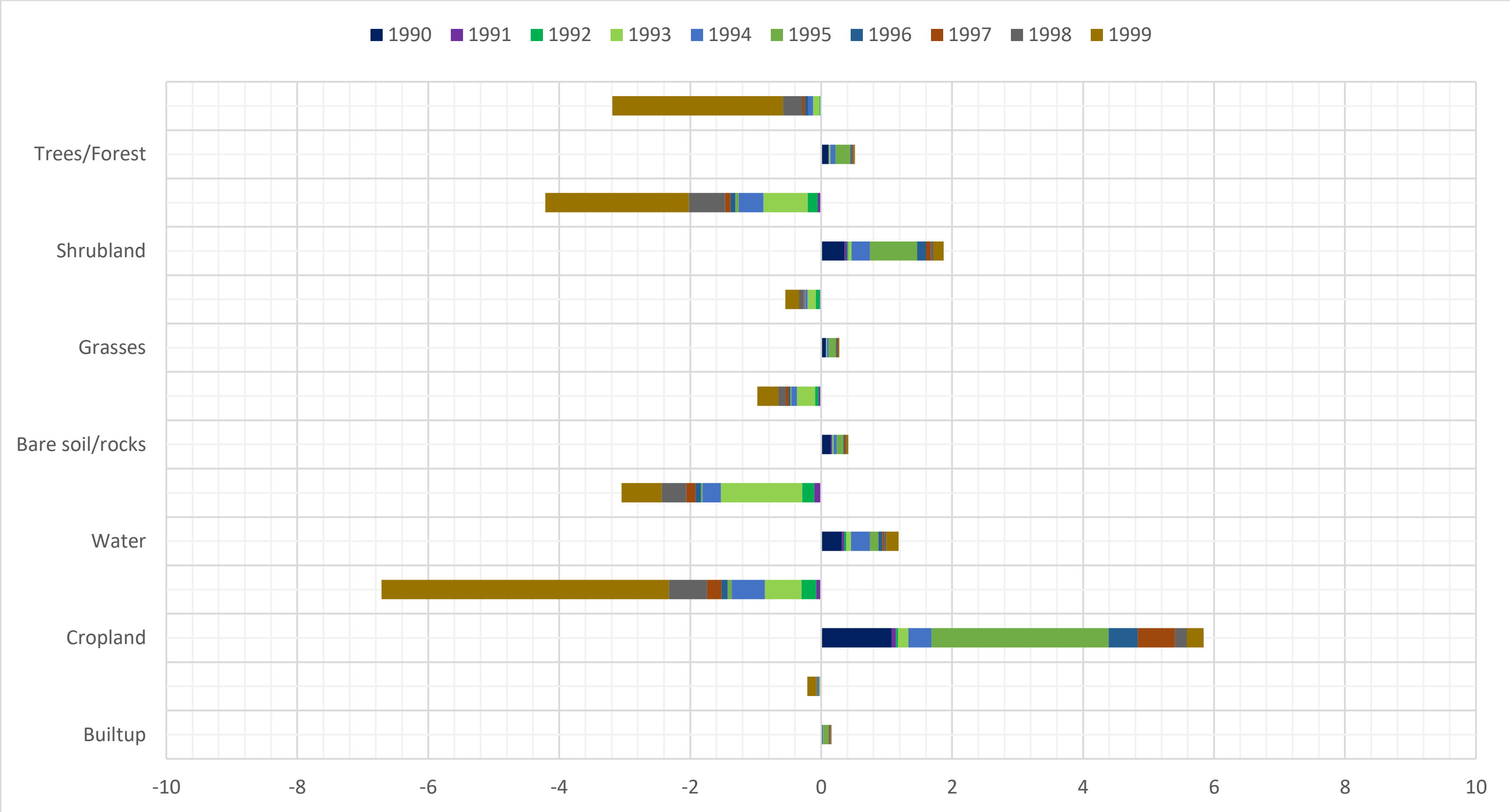


Figure 5.11: LULC gain and loss during 1990 to 1999
Source: 'author'

5.3.6 Agricultural productivity of *Kharif* crops

Table 5.5 shows that the total area of the district is 669,000 ha (GOP, 2017). The area for cropping is fluctuating between 239,000 ha to 270,000 ha from 2003 to 2017 (GOP, 2017). The assessments were made to assess the agricultural productivity of the study area. The data obtained from Pakistan Bureau of Statistics (Fig 5.12) reveal that the agricultural productivity for the *kharif* crops significantly reduced during the three decades. The major *kharif* crops in this region are groundnuts, *bajra* (millet), jowar (sorghum), lentils (*mash, moong*), maize, guar seed etc. show a substantial reduction in the yield. While, the signs of improvements are visible in the case of sun hemp production.

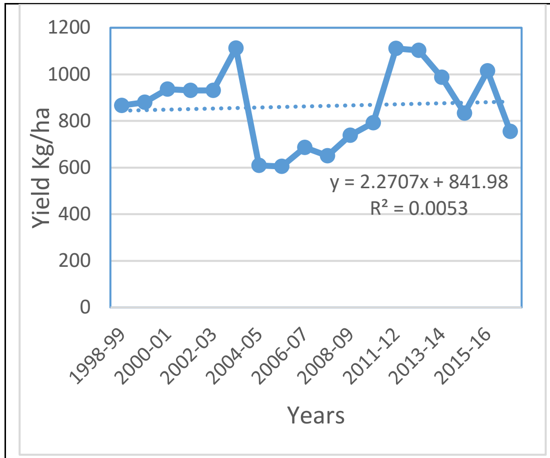
5.3.7 Agricultural productivity of *Rabi* crops

The data was also obtained from the Pakistan Bureau of Statistics (Fig 5.13) to evaluate the agricultural productivity of *rabi* crops. The most prominent *rabi* crops in this region are wheat, gram, barley and lentils. The significant reductions in the yields of these crops were observed during the similar time period of the last 30 years. These assessments portray a dismal about the agricultural productivity for the *rabi* crops as well.

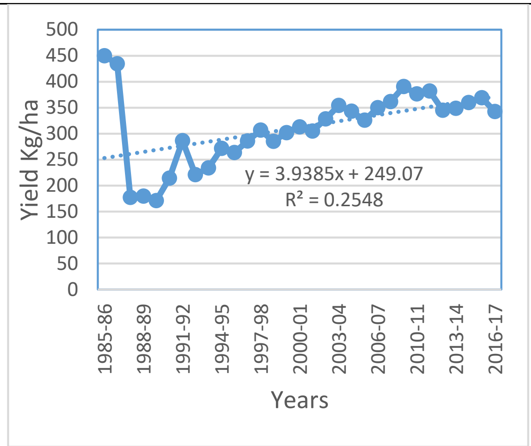
Table 5.5: Agricultural land statistics of Chakwal District

Years	Reported area	Cultivated area '000' hectares			Cropped area
		Total	Net sown	Current fallow	
2003	720	326	237	89	239
2004	720	327	235	92	259
2005	720	327	245	82	276
2007	669	318	261	57	260
2008	669	319	248	71	270
2009	669	319	253	66	250
2010	669	319	226	93	257
2011	669	319	244	75	176
2012	669	319	175	144	180
2013	668	318	242	76	245
2014	668	319	242	77	243
2015	668	318	270	48	262
2016	669	319	272	47	259
2017	669	319	247	72	270

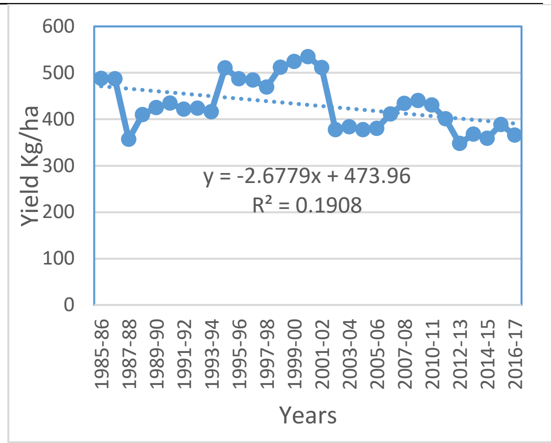
Source: Punjab Development Statistics, 2017



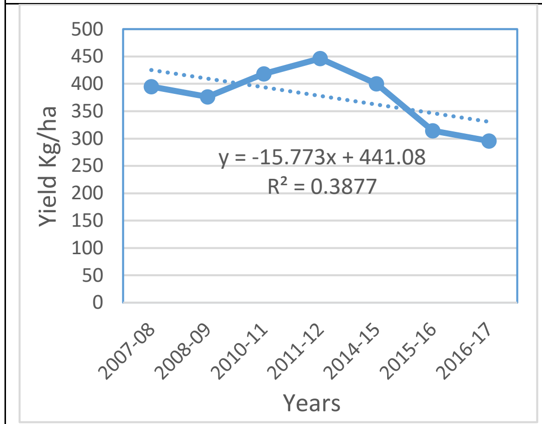
A. Groundnut



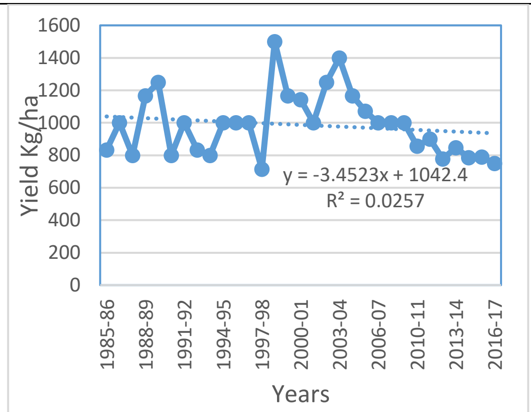
B. Bajra (Millet)



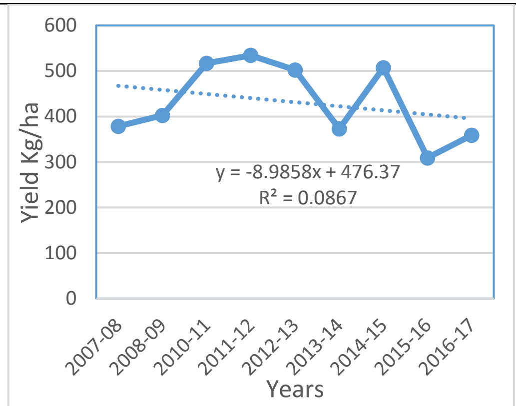
C. Jowar (Sorghum)



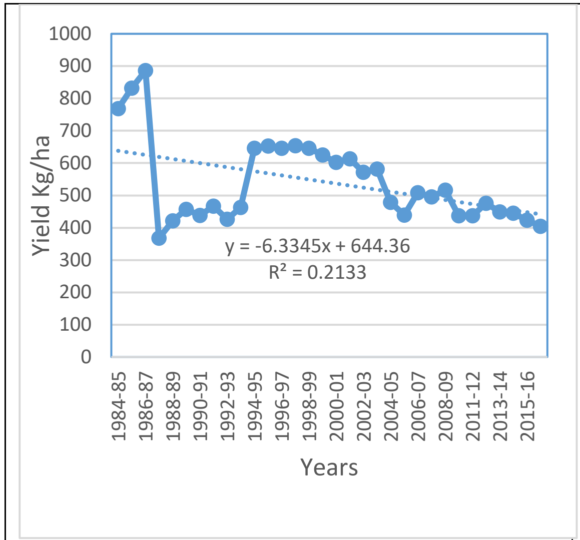
D. Mash



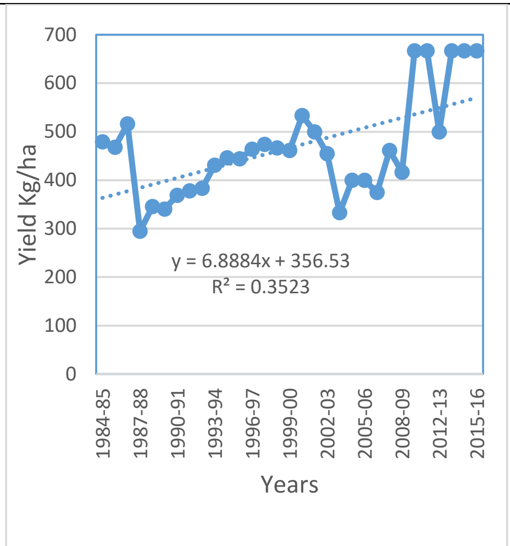
E. Maize



F. Moong



G. Guar seed



H. Sun hemp

Figure 5.12: Yield of major *Kharif* crops during the last 30 years in the study area
Source: Pakistan Bureau of Statistics (www.pbs.gov.pk)

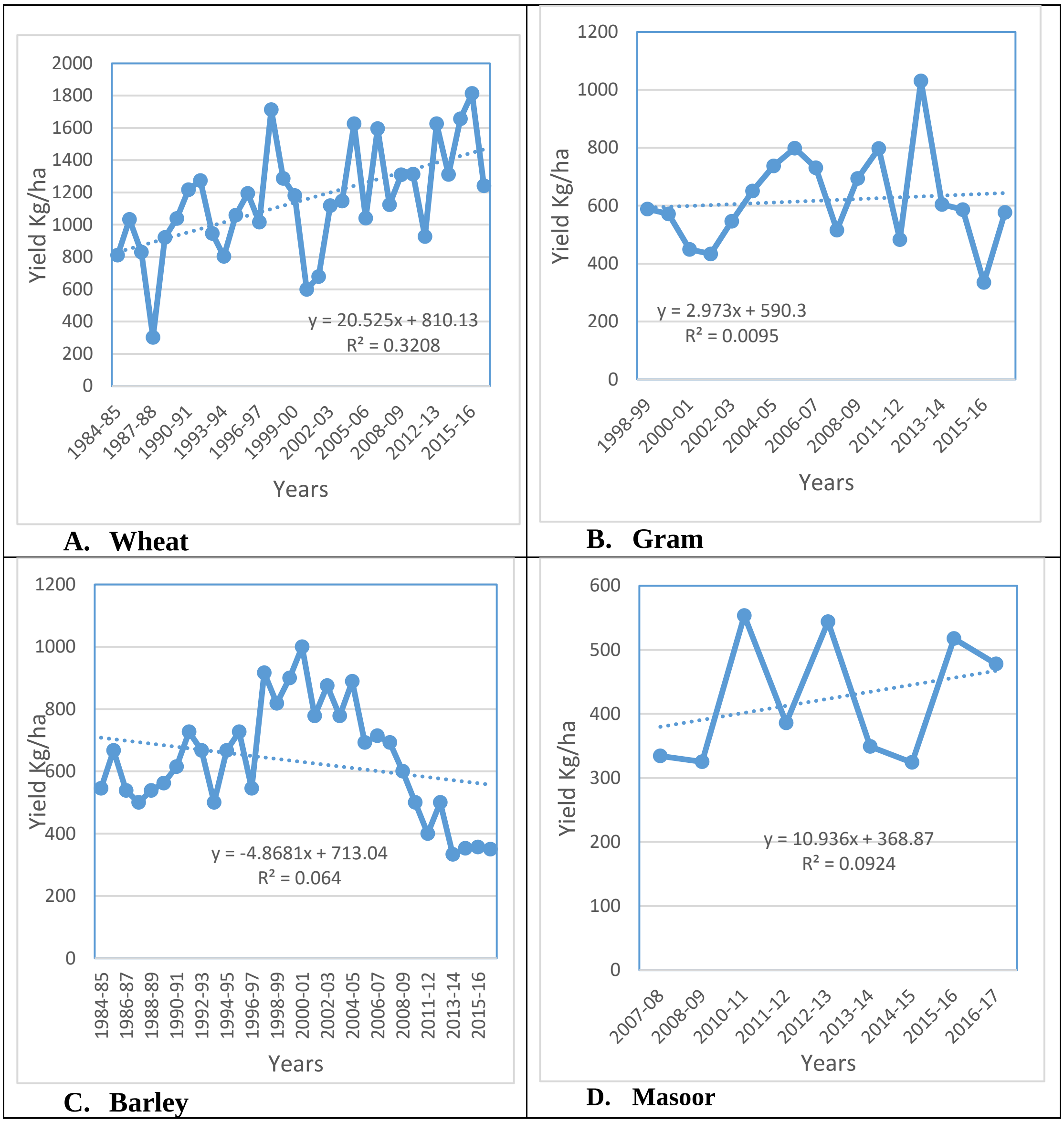


Figure 5.13: Yield of major *Rabi* crops in the study area.
Source: Pakistan Bureau of Statistics (www.pbs.gov.pk)

5.4 Discussion

The rapid LULC changes are unfolding innumerable repercussions for the developing countries (Yin et al., 2018). Mashame and Akinyemi (2016) supports the claims that land degradation is accelerated by the poor LU practices in these regions. The investigations validate that such changes suggestively modify the socio-economic and physical characteristics of a region. The resultant impacts adversely causes distortions in the bio-geophysical and chemical processes in the land and aquatic environment (Hereher, 2017; Huang et al., 2017; IPCC, 2014b). The consequential outcomes are more devastating for the fragile ecosystems of arid and semi-arid regions (Mashame & Akinyemi, 2016).

The socio-economic resilience of Potohar plateau is dependent on rain-fed agriculture. The water is scanty and associated weather and climatic anomalies also have marked imprints on the agricultural practices in this dissected and undulating geographical region. Despite, these unfavorable and non-conducive topographical and environmental conditions for the cropping, the agricultural sector is substantially contributing towards the livelihood and socio-economic resilience (Qasim et al., 2016). In this connection, the contributions of groundnut is widely referred. The groundnut is an important cash crop of this rain-fed region (Qasim et al., 2016). The official statistics and study conducted by Qasim et al. (2016) reveals that the per unit area yield of the groundnut is very discouraging, though having significant productivity potentials, which may significantly contribute in the rural economies of Potohar plateau.

However, the findings based upon the empirical studies infer that the agricultural production in such contextual settings are more exposed to weather climatic abnormalities as compared to the developed nations. In this connection, the scholars such as Dissanayake et al. (2017), Deressa et al. (2009) and Derbile et al. (2016) deliberated to assess the ensuing threats for the agro-based economies of the South Asian region. They conjectured about a substantial decline in the crop yields by the 2050s. In this connection, Bandara & Cai (2014) and Cai et al. (2016) focused to construe about the climate-induced impacts on the food prices in this region. They feared that a surge in the climatic abnormalities will cause a rise in the food prices. The resultant decline in the crop productivity will unfold incalculable implications for the land resources and socio-economic landscape. The consequential impacts will transpire in the form of deforestation, soil and land erosion. The repercussions warrant careful assessments and focused response to curtail the magnitude of ensuing environmental degradation. Besides this, the efforts are also needed for postulating a strategy to mitigate the adverse impacts of anthropogenic interventions in the land environment. However, the inclinations to conserve and ensure land productivity have less acknowledgement in this region.

Whereas, the socio-economic sustainability demands the conservation of land resources and inclinations towards the protection of land resources are not encouraging.

The situation stresses for enhanced focus, coordinated efforts based upon empirical evidences and patronization for ensuring the sustainability of the natural and social environment. Therefore, the assessments based upon the information pertaining to land resources of the study area and the orientation of spatial-temporal transformations in these resources are obligatory. These information enable to decipher the conversions of the land among and between the selected LU categories of the study area. The assessments are vitally required to ensure the integrated and coordinated management of land resources for the protection of ecological, social, economic and natural environment. Thus, the present study was designed to assess the use of land resources in the study area and to evaluate the trajectory of LULC changes for selected time interval. The findings of the study will provide the base line information about the land resources of the study area. The absence of such data is a missing link and needed for conclusive assessments, planning and for coordinated management of land resources.

The findings of the present study indicate that the croplands (54.32%) are the predominant land cover type of the study area. The findings also construe that the share of this category in the land cover of the study area remained stable during the last decade. The findings of similar nature were reported by the Punjab Development Statistics in 2017 (GOP, 2017). The stability in the share of cropping land is credited to the efforts initiated by the ICARDA-Paksitan (International Centre for Agricultural research in Dry Area and USDA (United States Development Agency) (Oweis & Ashraf, 2014). These interventions were focus to shield the rain-fed agriculture from the impacts of climate related anomalies. The adaptation of these strategies indicate that the rural population is willing and ready to accept the innovation for the socio-ecological resilience. Tran et al. (2015) reported that the absence of a coherent mechanism accentuate the gravity of the situation and causes incalculable stresses on the land resources. Therefore, the stakeholder responsible to ensure the integrity of the land resources should include the component of awareness in their frame of actions. It also implies that the participatory mode of action yield better dividends as compared to the decision making based upon the top-down approach.

The critical finding portray that during the year (2016-17), seven mini-dams and 20 small dams were constructed in Chakwal District to overcome is water scarcity (GOP, 2017). However, due to lack of awereness, planning and coherence in the implementation, the imprints of these initiatives are, still, far from the desired level.

The majority of the population (Fig 4.4), still, forced to rely on the rain water for the agriculture. The findings transpire that the initiation of new project for water conservation is needed in the study area. Besides this, the awarness and training of the farmers is more important to ensure the efficicent and effective use of the available water. It also require an enhance focus towards the prospects of water scarce crops through bio-technological innovation as a measure to ensure agricultural productivity in the face of looming water scarcity.

The decline in the forest cover is a global phenomenon (Keenan et al., 2015). The findings of the study also portrayed that the share of forested cover significantly dropped from 63658 ha in 2011 to 60961 ha in 2017 (GOP, 2017) (Table 3.6). Ahmad (2001) postulated that there is a correlation between the decline in the semi-natural forest cover and roads. The researcher estimated that the degradation is more acute near the road networks but decreases as the distance increases. The development of infrastructure stimulate for development activities and forested cover are the prime victims of such intrusions in the agrarian settings as the farmer try to save the agricultural land. Resultantly, the forests situated closer to roads and developed sites are likely to be highly disturbed and fragmented. The findings based upon the present study substantiate these observations. The similar nature of situation was observed during field survey and detected through remote sensing results that the areas closer to M-2 motorway were significantly cleared from tree cover during the construction of the project and after the start of the venture. The progress without infrastructural development is impossible, therefore, the dichotomy of the interests, demands that focus efforts should be made for the protection of agriculture, conservation of vegetation cover and environmental resilience. The situation demand the integration of efforts to stimulate public attention towards forestation and afforestation activities in the study area. However, the recent empirical formulate that the land-based mitigation are a cost-effective portfolio of mitigation strategies to ensure the long-term climate stabilization (Hu et al., 2018). The innovation in the technologies is also required to cope with the emerging pressures on the land resources.

The assessments based upon the findings of this study construe that the agricultural sector is under-performing as compared to its potential. The land productivity during the *rabi* and *kharif* seasons is very low. It helped to infer that the human factor is also responsible for the situation. In this regard, the researcher such as

Oweis & Ashraf (2014) and Qasim et al. (2016) extensively probed/ assessed and enlisted the causes and factors impeding the contributions of the agricultural sectors in alike situations. However, there is a concurrence of opinion that through research, informed decision making and improved governance the situation can be reversed. It requires the change of perspective about the environment, land resources and the role of people for the protection of natural resources and socio-economic resilience.

5.5 Conclusions

The current study demonstrate that the LULC of Chakwal District significantly changed during the period from 2010 to 2017. The investigation is the first detailed LULC analysis of the study area. The findings portrayed that LULC changes were observed in the selected categories. A noticeable decline was observed in the cropland area during the time interval from 2000 to 2009. While, the significant decrease occur approximately in all the land cover classes during 1990-1999. While the tree cover, shrubland and cropland were the major victims. Whereas, a noticeable increase was also observed in the share of cropland during 1995 year. The study transpire the usefulness of RS and GIS resources in such type of investigation. The findings of the study establish that an understanding about the drivers of land use change is a prerequisite for informed decision making.

CHAPTER 6

HOUSEHOLD SOCIAL VULNERABILITY TO CLIMATIC HAZARDS

6.1 Introduction

The climate is warming, a trend that is projected to continue with increasing frequency and magnitude. The consequential manifestations such as droughts; abnormal climatic oscillations; floods and the reported increases in the phenomenon of desertification etc. have become more recurrent (REMA, 2015; Wang et al., 2014; Yiran et al., 2017). The Intergovernmental Panel on Climate Change (IPCC) have reported that the rain-fed economies of the tropical and subtropical regions are more susceptible to climatic abnormalities. The concomitant population growth, penchant for socio-economic development and increasing reliance on soil and water resources are exacerbating the environmental and ecological balance in these regions (Liu et al., 2016). Thus, posing serious implications for the sustainability of resource stricken economies of the developing countries. The majority of such agro-based economies are located in the South Asian and African regions. The climate-sensitive livelihood activities in these fragile economies are, thus, emphasizing on proactive measures to address the emerging challenges associated with the unpredictable climatic fluctuations (Lal, 2011; Yiran et al., 2017).

In response to these stresses on agricultural productivities, an understanding of prevailing dynamics pertaining to ensure agricultural development through integrated management practices is imperative. It requires empirical information for conclusive assessments to cope with the impacts of climatic vulnerabilities. Thus, the focus in research is being laid on assessing the prevailing perceptions and practices in the agrarian settings for informed decision making (Deressa et al., 2009). The evaluations based upon the data from grass root levels is obligatory for the success of the designed efforts based upon top-down policy mechanism (Senbeta, 2009). These initiatives are primarily conceived to mitigate the ensuing impacts of climatic vulnerabilities.

The conceptual paradigm of "vulnerability" is gaining recognition in research to comprehend the impacts of climatic fluctuations on environmental changes (Füssel & Klein, 2006). However, the inclusiveness and overlapping strings of the approach makes it complicated and complex. Thus, triggering scholastic contestations among the researchers pertaining to the definition and interpretations of the concept for making it more palatable for stakeholders (Hinkel et al., 2010; Olmos, 2001; Wiréhn et al., 2015). The lack of consensus is generating dichotomies regarding vulnerability assessments. The degree or level of vulnerability is primarily measured by deploying one of the two prevailing assessment techniques i.e. quantitative and qualitative mode of assessments. In this connection, the most commonly used quantitative method is the composite index. The measurements are made on the basis of a predefined set of indicators. The index is suitable for assessing climate related vulnerabilities as it simultaneously focuses on the biophysical and socio-economic dimensions (Füssel & Klein, 2006; Wiréhn et al., 2015).

The formulation of a composite index demands the selection of indicators, the determination of weightage for a specific indicator and clarity in procedures for executing methods. These steps are mostly conceived and carried out through judgmental arguments. Indicator selection is generally based on either theoretical understanding of relationships or through statistical arguments. The former is considered a deductive approach and the latter is classified as an inductive approach (Tran et al., 2017). However, most of the times the intended studies rely on pre-existing indicators (Li et al., 2014).

There is a growing realization towards contextualization of indicators for pragmatic assessments (Ghimire et al., 2010). The mechanisms such as arbitrary choice of equal weights and expert based opinions are losing significance as they spark controversies (Gbetibouo et al., 2010). Besides this, the subjective orientation of such techniques kindle differences among the unlike stakeholders (Chen et al., 2015). Therefore, the statistical methods such as Principal Component Analysis (PCA) is gaining recognition to determine weights of the selected indicators (e.g., Chen et al., 2015; Deressa et al., 2009). The indicators and their weightages are amalgamated by deploying mathematically based summarizing techniques.

Quantitative assessments pertaining to vulnerability are mapped and illustrated with the help of cartographic techniques (Mallari & Ezra, 2016). These visual representations facilitate to explore the associated dimensions of such a multifaceted, intricate and continuously changing phenomena like vulnerability (LEE, 2017; Mallari & Ezra, 2016). It also helps to effectively communicate the observed findings in a subtle manner for clarity and understanding (Chen et al., 2015; Murthy et al., 2015).

The extreme weather fluctuations have inflicted severe economic losses on the economy of Pakistan in the recent decades. The reported projections based on the recent studies infer that the scale and speed of such incidents will increase in future (Chaudhry, 2017). Approximately, two thirds of the population in Pakistan, live in rural areas and dependent on land productivities (Abid et al., 2019; Chaudhary et al., 2009). The rural population in these regions is more vulnerable to climate change due to their dependence on climate sensitive livelihood options and limited adaptive capacity to cope with the ensuing challenges (Abid et al., 2015; Aggarwal & Sivakumar, 2010; Ali & Erenstein, 2017; Žurovec et al., 2017). Thus, the consequential impacts on these agro-based and vulnerable regions will have domino effects for the social and demographic fabrics. The economically and socially marginalized segments of the society may be the worst victims of such climate propelled calamities.

However, the awareness about the impacts of climate change is growing in Pakistan. It is evident from the growing number of scientific studies and strategic documents in which climate change is being acknowledged as an issue of vital importance for the country (Chaudhry, 2017; FAO-UN, 2019; GoP, 2018; Qureshi & Ashraf, 2019). The orientation of these efforts are more focused on assessing the repercussions of climate change on vulnerable sectors and to postulate the remedial measures and strategies. Whereas, there is a concurrence of opinion pertaining to basic contours of response strategies to ensure resilient development but coherence of efforts and integration of focus at the local level are still modest and insufficient (Abid et al., 2015; Abid et al., 2019, 2016; Ali & Erenstein, 2017; Arshad et al., 2017). It is pertinent to mention that local governments and communities have a critical role in executing the strategies to mitigate the impacts of climate change for the resilience of people and infrastructure (Sarker et al., 2013; Acheampong et al., 2014; Alayón-Gamboa & Ku-Vera, 2011; Aleksandrova et al., 2016).

Therefore, making vulnerability assessment a pragmatic option as a reliable tool to comprehend the impacts of phenomena on human and ecological systems for integrated responses (Jiao & Moinuddin, 2016; Žurovec et al., 2017b). It requires careful assessments based upon holistic approaches by integrating relevant factors and stakeholders (Jiao & Moinuddin, 2016; Pan et al., 2014; Richter, 2010).

For the purpose, the spatial analysis in vulnerability assessments is gaining acceptance to comprehend the impacts of climate change (De Sherbinin, 2014). The spatial vulnerability assessments carried out with the help of Geographic Information System (GIS) enable to evaluate the magnitude and spatial distributions of potential impacts. Besides this, the flexible environment in GIS also facilitate to integrate the relevant biophysical and socio-economic determinants for extrapolation and elucidations (Jiao & Moinuddin, 2016; Žurovec et al., 2017b).

The current study was designed to quantify the spatial impacts of climate change on the vulnerability of the rural population residing in the Chakwal district. The findings of the study will stimulate the desired discussions among the researchers and stakeholder for integrated efforts to ensure the socio-economic resilience in this part of the globe. The focus towards such dimensions of climate change is, still, in the embryonic stages and limited in the developing countries like Pakistan (Jiao & Moinuddin, 2016).

6.2 Materials and Methods

6.2.1 Data collection

The data for current study was retrieved through household survey. For the purpose, 475 farmers from 71 UCs from all the five tehsils (sub-divisions) of Chakwal District were selected (Fig 6.2). These respondents are scattered in the 183 villages of the entire study area (Fig 6.3).

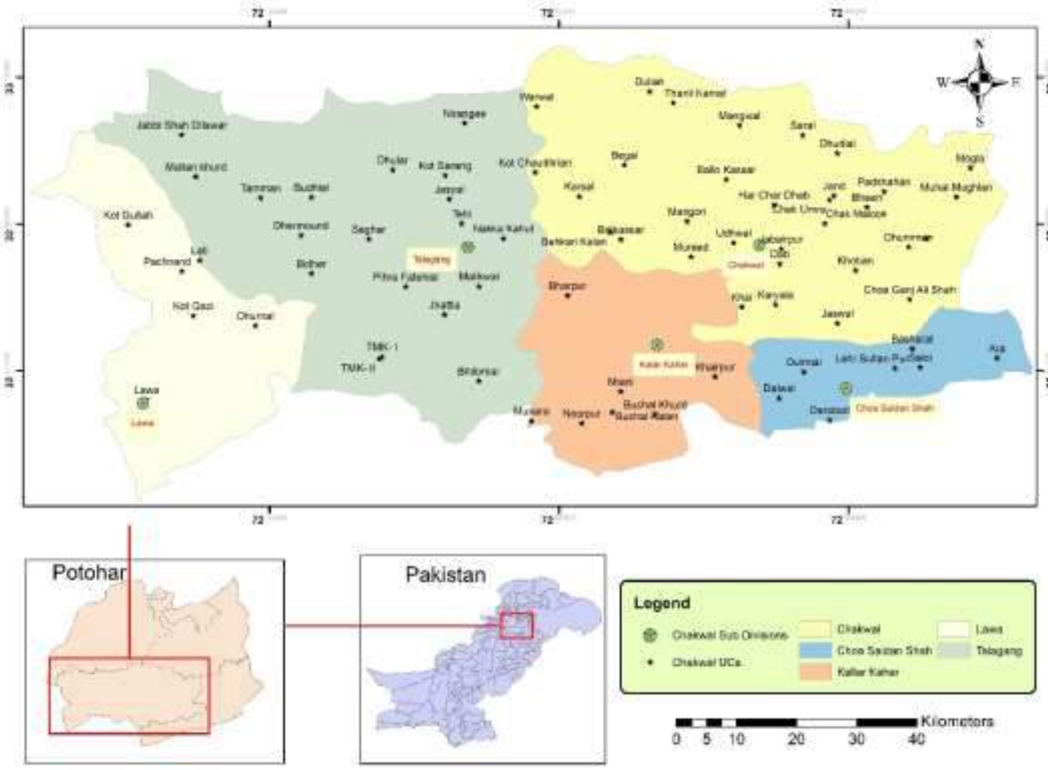
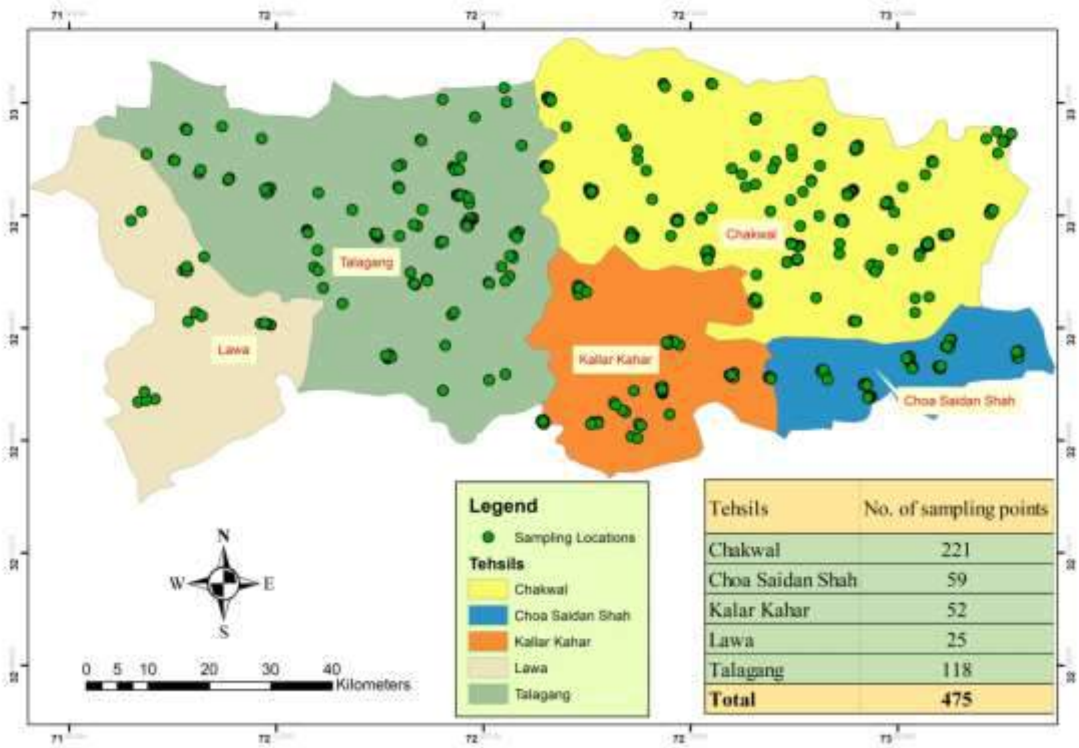


Figure 6.1: Study area map showing surveyed union councils
Source: 'author'



Tehsils	No. of sampling points
Chakwal	221
Choa Saidan Shah	59
Kalar Kahar	52
Lawa	25
Talagang	118
Total	**475**

Figure 6.2: Study area map showing sampling points (households)
Source: 'author'

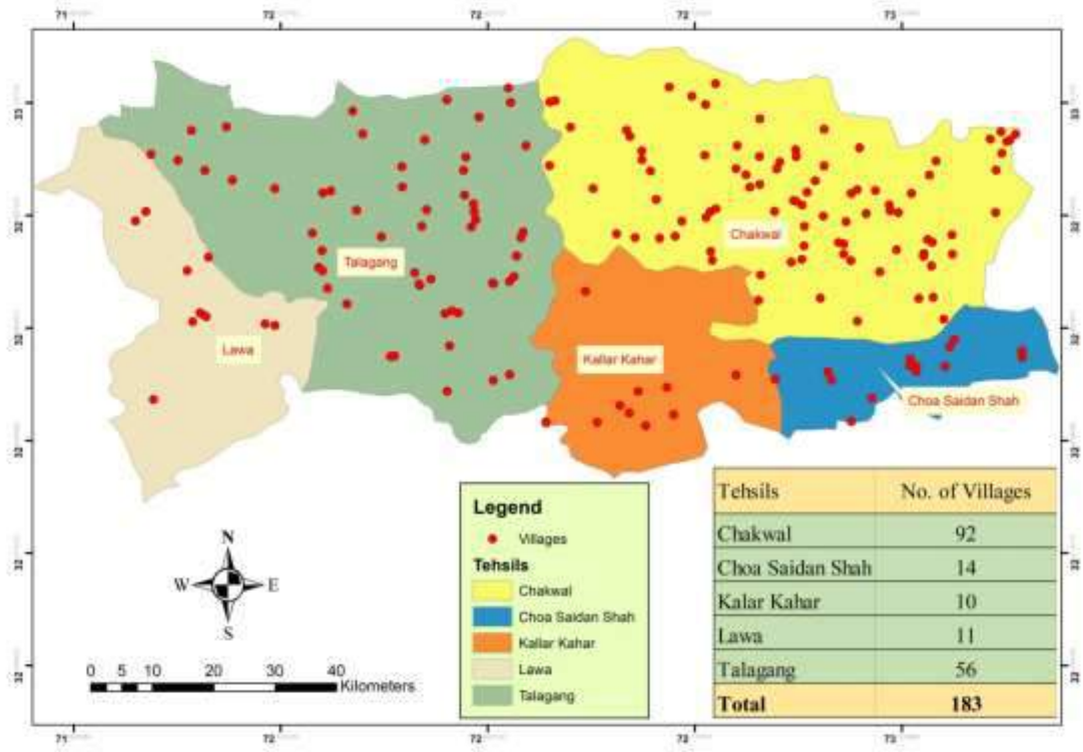


Figure 6.3: Study area map showing number of villages surveyed
Source: 'author'

6.2.2 Choice of approach for vulnerability assessment

Vulnerability assessments are distinguished as top-down or bottom-up approaches. Top-down approach mainly focuses on the analysis of climate change and its impacts, while the bottom-up approaches give more attention to people affected by such climatic transformations (Arif et al., 2017). Besides this, the expressions such as 'end-point' versus 'starting-point'; 'biophysical' versus 'social' or 'outcome' versus 'context' are profusely relied upon in the scientific literature (Füssel & Klein, 2006).

There is no universally accepted ready-made method for vulnerability assessments. Therefore, several methods from divergent research domains are combined for conclusive valuations. However, such unifications of techniques require clarity and systematic understanding of contextual requirements (Hinkel et al., 2014). The present study was carried out by deploying the conceptual paradigm of 'bottom-up approach'.

Bottom-up approaches to vulnerability assessments more focus on the causations of vulnerability by natural hazard. The embedded inclinations associated with this approach recognize that the adverse impacts of natural calamities are not symmetrical and homogenous on all the components of social fabric. The socio-economic determinants such as occupation, gender, age and the nature and extent of social networks adequately moderate the consequential outcomes (Hinkel et al., 2014).

Besides this, the bottom-up approaches are also compatible with quantitative data for simulations and scenario building.

6.2.3 Choice of framework for vulnerability assessment

The assessment of vulnerability requires a clear definition of the scope of study and its parameters i.e. type of hazard (slow-onset or rapid-onset); geographical scale of assessment (national, regional, local and household/individual) and perspective (retrospective or prospective) of investigation (Füssel & Klein, 2006; Tran et al., 2017). The present study focused on vulnerability of households related to climatic hazards (e.g. drought, erratic rainfall and temperature increase). In terms of timescales, the attention is on the current state of vulnerability rather than the future prospects.

The framework of investigation in this study is based on the IPCC AR5 definition of vulnerability. It describes vulnerability as the *"propensity or predisposition to be adversely affected*" (IPCC, 2014b). The delineation encompasses the associated dimensions of vulnerabilities such as exposure to adverse effects, sensitivity to harm, capacities to cope and adapt with the eventualities. According to this paradigm the exposure in conjunction with sensitivity represents the predisposition of the system to be adversely affected by the abnormalities of climate change. However, the adaptive capacity mitigate the ensuing effects. Therefore, vulnerability can be expressed as the positive function of exposure and sensitivity, but meaningfully tailored by the adaptive capacity (Li et al., 2015):

$$\text{Vulnerability} = f\,(\text{Exposure, Sensitivity, Adaptive capacity})$$
$$= (\text{Exposure} \times \text{Sensitivity})/\text{Adaptive capacity}$$

Thus, the vulnerability studies focus on triangulation of biophysical and social-economic metrics pertaining to exposure, sensitivity, and adaptation, (Gbetibouo et al., 2010; Li et al., 2015). As the climate change have different connotations for different socio-economic groups, so, making it more complex and complicated for postulations (LEE, 2017; Tran et al., 2017). Therefore, the scenario demands dexterity to operationalize the procedures and methods those deal with the biophysical (e.g. climatic conditions, natural hazards, topography, land cover) and socio-economic (e.g.

demography, poverty, employment, gender) determinants. In response to these obligations, the study rely on integrated mode of assessments by selecting indicators that are capable to reflect the biophysical and socio-economic conditions of the study area.

6.2.4 Choice of indicator method for vulnerability assessment

The assessments regarding vulnerability were made by adopting 'indicator method'. It postulates that an indicator is a functional form of an indicating or theoretical variable (Hinkel et al., 2014) – which , in this case is vulnerability (Mallari & Ezra, 2016). Therefore, vulnerability indicators are a pragmatic choice for evolving a consensus among the theorists, policy makers and practitioners operating in different hierarchical levels (Mallari & Ezra, 2016).

The careful selection of indicators requires clarity about purpose and scope of the study (Hinkel et al., 2014). The composite process for the selection of indicator was carried out in three inter-linked steps. The first step deals with the scope of the study. In this case, it is the vulnerability of the agricultural sector to climate change. The selection of the indicating variables was made in the second step. It helped to calculate the percentage share of rain-fed agriculture affected by the erratic precipitation. It was used as an indicating variable to measure the sensitivity of agricultural production to erratic rainfall. In the last step, the indicating variables were aggregated for integrated analysis (Hinkel et al., 2014).

The variables relied upon in the study were identified through review of literature concerning to climate change vulnerability. The selection of these variables was finalized after successive brain storming sessions with the subject experts to depict contextual parameters. The initial selection of the indicating variables is inherently based on deductive arguments. This mode of argumentation is obligatory to synchronize the orientation of scientific frameworks for protecting the interests of vulnerable system (Hinkel et al., 2014; Tran et al., 2017).

6.2.4.1 Exposure

Exposure is defined as "The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC, 2014b). The selected indicators in this investigation mainly focus on the exposure to drought, erratic rainfall, and temperature hike.

6.2.4.2 Sensitivity

Sensitivity is defined as "The degree to which a system or species is affected, either adversely or beneficially by climatic oscillations" (IPCC, 2014b). The consequential effects may be direct such as changes in the temperature etc. or indirect like crop yield variations and sea level rise etc. (IPCC, 2014a). The variables selected for assessing propensities/ sensitivities of the household to climate induced hazards such as soil erosion, and proportion of arable land (net sown areas).

6.2.4.3 Adaptive capacity

Adaptive capacity is the ability of systems, institutions, humans, and other organisms to adjust with ensuing changes or the capacities to convert such challenges into opportunities (IPCC, 2014a). The adaptive capacity are compartmentalized on the basis of livelihood assets (Arif et al., 2017; Bouroncle et al., 2016; Gbetibouo et al., 2010; Ghimire et al., 2010; Keshavarz et al., 2017; Tran et al., 2017; Wiréhn et al., 2015). These assets are also termed as capitals as well.

- **Social capital** is represented by farmers' access to agriculture extension office/officials and frequency of contacts between farmers and agriculture extension personnel. It also include the reliance on relatives/neighbors for financial support (loans), access to market, technical guidance and awareness. It is hypothesized that social capital positively influences the adaptation to change.
- **Human capital** is represented by the age of farmers (respondents), household size, dependency ratio, and literacy rate.
- **Financial capital** is represented by the income of farm; employment opportunities and diversifications; household and farm assets and access to investment.
- **Physical capital** is represented by total livestock units (TLUs); total land holding (ha); access to farm inputs (technology, fertilizers, seeds etc.) and energy sources (mainly fuel wood) etc.

The indicators used and relied upon for subsequent processing and assessments have been condensed (Table 6.1). The cartographic depiction in Figure 6.4 succinctly portray the indicators used in the study and their linkages.

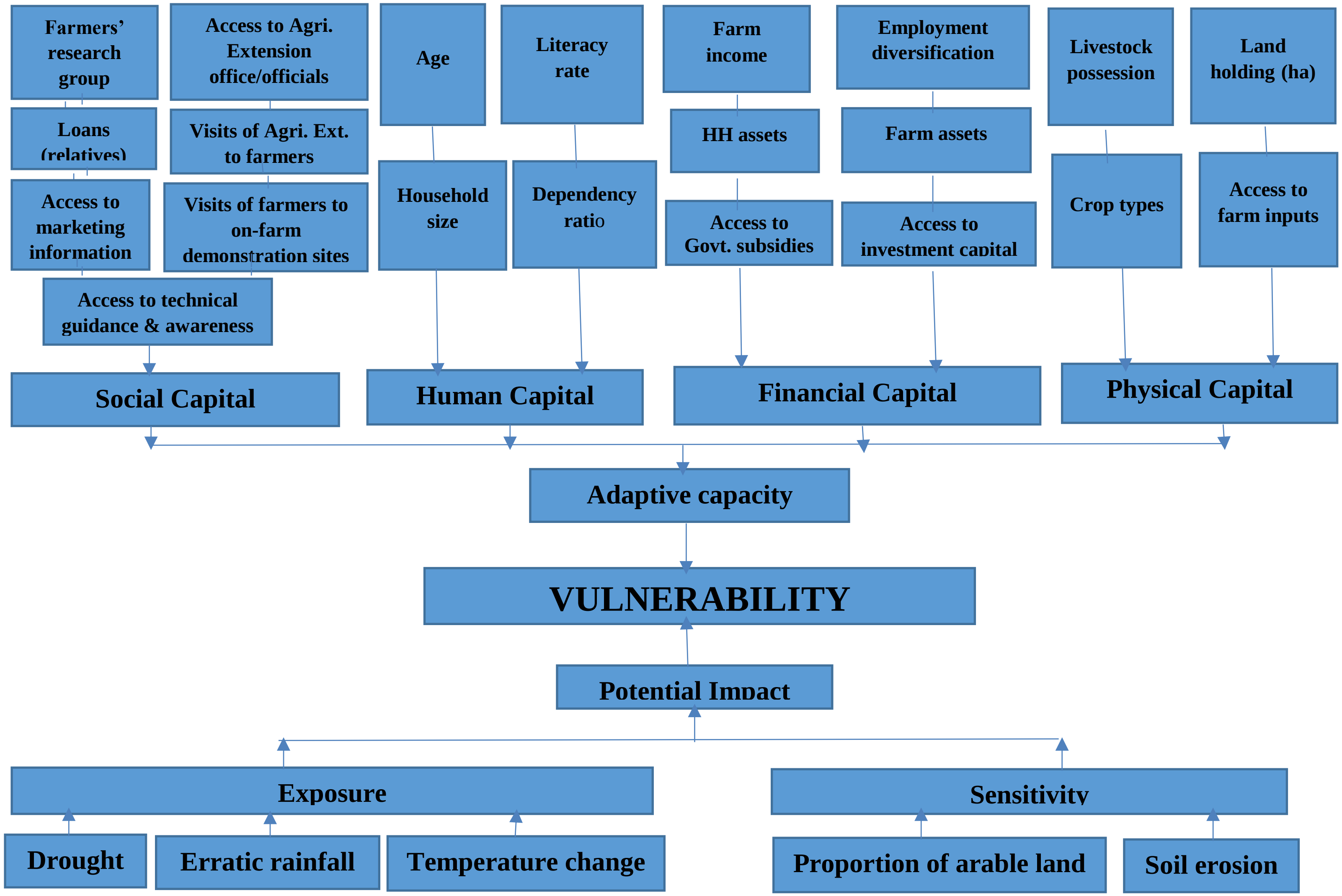


Figure 6.4: Contribution of different indicators to vulnerability
Source: 'author'

Table 6.1: Description of indicators selected for vulnerability assessment in the study area

Components of vulnerability	Indicators	Type	Unit of measurement	Hypothesized functional relationship between indicator and vulnerability
EXPOSURE	Drought	Binary	Responses of farmers experiencing drought during the past 20 years or so (Binary yes/no, 1/0)	The higher the exposure, the higher the vulnerability.
	Erratic rainfall	Binary	Responses of farmers experiencing erratic rainfall during the past 20 years or so (Binary yes/no, 1/0)	The greater the inter-annual rainfall changes, the higher the vulnerability.
	Temperature change	Binary	Responses of farmers experiencing temperature change during the past 20 years or so (Binary yes/no, 1/0)	The greater the changes experienced by the farmers, the higher the vulnerability.
SENSITIVITY	Proportion of arable land	Continuous	Net cultivated land (ha)	The larger the size of farm, the lower the vulnerability.
	Soil erosion	Binary	If farmer experiencing soil erosion (Binary yes/no, 1/0)	The greater the soil erosion, the higher the vulnerability.
ADAPTIVE CAPACITY	Age (farming experience)	Continuous	Age of the farmer (years)	The greater the farming experience, the lower the vulnerability.
	Education status	Continuous	Education status of the farmers (illiteracy(1), matric(2), graduation(3), postgraduate (4), technical/professional(5)	The higher the literacy rate, the lower the vulnerability.
	Household size	Continuous	Number of family members	The greater the labor force, the lower the vulnerability.
	Dependency ratio	Continuous	Number of people under 15 and over 65)/(Number of people aged 15–65)	The higher the dependency ratio, the higher the vulnerability.
	Land holding	Continuous	Total land holding (ha)	The larger the size of land, the lower the vulnerability.
	Access to farm inputs (seed, fertilizers, technology etc.)	Binary	Farmers’ access to farm inputs (Binary yes/no, 1/0)	Access to farm inputs decreases vulnerability
	Total Livestock	Continuous	Total domestic animals possessed by farmers measured in total livestock units (TLUs)	The greater the number of livestock, the lower the vulnerability.
	Crop types	Continuous	Number of crop types	The greater the number of crops grown, the lower the vulnerability.

	Employment diversification	Continuous	Number of livelihood activities	The greater the employment diversity, the lower the vulnerability.
	Farm assets	Continuous	Total value of farm assets (Rupees)	The greater the worth of farm assets, the lower the vulnerability.
	Household assets	Continuous	Total value of HH assets (Rupees)	The greater the worth of HH assets, the lower the vulnerability.
	Farm income	Continuous	Net farm income (Rupees)	The higher the farm income, the lower the vulnerability.
	Access to Govt. subsidies	Binary	If farmers have access to govt. subsidies (Binary yes/no, 1/0)	Access to government subsidies reduces vulnerability.
	Access to investment capital	Binary	If farmers have access to investment capital (Binary yes/no, 1/0)	Access to investment capital lowers vulnerability.
	Farmers' research group	Binary	If there is any farmers' research group (Binary yes/no, 1/0)	Presence of farmers' research group helps to reduce vulnerability.
	Visits of farmers to Agri. Ext. office/ officials	Binary	If farmers visit Agri. Ext office (Binary yes/no, 1/0)	Access to agriculture extension office or officials can help to lower vulnerability.
	Visits of Agri. Ext. officials to farmers	Binary	If agriculture extension personnel visits farmers (Binary yes/no, 1/0)	Visits of agriculture extension officials to farmers introducing climate compatible technologies can help them to lower vulnerability.
	Loans from relatives/neighbors	Binary	If farmers get loans from their relatives etc. (Binary yes/no, 1/0)	Getting loans from relatives/neighbors etc. during the hour of need can help to reduce vulnerability.
	Access to marketing information	Binary	If farmers have access to market information (Binary yes/no, 1/0)	Access to market information can lessen the vulnerability.
	Visits of farmers to on-farm demonstration sites	Binary	If farmers ever visited farmer field school for demonstration purpose (Binary yes/no, 1/0)	On-farm demonstration visits by farmers help to reduce vulnerability.
	Awareness & technical guidance	Binary	If farmers lack awareness or technical guidance (Binary yes/no, 1/0)	Awareness and technical guidance reduces vulnerability.

Source: 'author'

6.2.5 Normalization of indicators

The vulnerability studies are inherently cumulative assessments; based on divergent parameters and variables. These variables are measured on different scales. Therefore, normalization of indicators i.e. standardization of all data values according to a uniform scale is imperative to ensure meaningful appraisals. This was ensured by devising a mechanism based upon the methodologies deployed by (Ramachandran & Rao, 2016; Wiréhn et al., 2015; Žurovec et al., 2017b) during the similar nature of studies. The required modifications to reflect contextual realities were incorporated.

There are two types of functional relationship between the indicators and vulnerability. In case of positive correlation the vulnerability increases or decreases simultaneously with a corresponding increase or decrease in the value of the indicator. While, the functional relationship will depict a negative correlation if the association between vulnerability and indicator are reflecting opposing trends. Thus, the index value indicate about the greater propensity towards vulnerability and vice versa. The theoretical assumptions in (Table 6.1) helped to conceive the functional relationships between indicators and vulnerability for the study. The study hypothesizes that vulnerability increases with an increase in the value of the indicator. It will indicate a positive functional relationship.

The subsequent normalization process was carried out by using the following equation:

$$\text{Index} = (Y_i - Y_{min}) / (Y_{max} - Y_{min}) \qquad \text{eq. (6.1)}$$

Where Yi is the original value of the indicator, Y min is the lowest value for the selected variable and Y max is the highest possible value for that variable. The quantum of negative functional relationship was determined with the help of the following equation:

$$\text{Index} = (Y_{max} - Y_i) / (Y_{max} - Y_{min}) \qquad \text{eq (6.2)}$$

The next step after normalization of indicators was to summarize indicators into composite indices. The indices are assigned weightages, based upon their degree of influence on vulnerability. The different approaches and strategies are relied upon for the purpose (De Sherbinin, 2014; Olmos, 2001; Richter, 2010; Žurovec et al., 2017b). The statistical findings of this study are based on the PCA (Principal Component Analysis). The PCA is a quantitative analysis tool used for correlation analysis among multiple quantitative variables. These statistical procedures are suitable to extract the linear combinations based upon the information from a large group of variables (Bouroncle et al., 2016; Ghimire et al., 2010; Keshavarz et al., 2017; Tran et al., 2017) (See heading 6.2.6 below).

6.2.6 Principal Component Analysis (PCA)

The relative impacts of an individual variable on selected vulnerability components such as exposure, sensitivity and adaptive capacity etc. were determined through PCA (Chen et al., 2015; Mallari & Ezra, 2016). The required procedures pertaining to PCA were performed through SPSS version 21. The process helped to identify those principal components responsible for observed variations in the data (Table 6.3). The findings were subsequently relied upon to formulate a composite index with the help of the following equation. The similar procedures were deployed by Gbetibuou et al. (2010) and Zurovec et al. (2017).

$$V_{t=} \sum_{i=0}^{k} [w_i(a_{ti} - x_i)] / s_i \quad i = 1 \ldots \ldots k; t = 1 \ldots \ldots T \qquad eq\ (6.3)$$

Where *V* is a vulnerability index, *w* is the weights from PCA, *i* is the indicator, *a* is the value of indicator, *t* is a specific tehsil (sub-division), *x* is the mean indicator value, and *s* is the standard deviation.

6.2.7 Geographic Information System (GIS)

The spatial dimension of the vulnerability were assessed with the help of GIS. The inter-active environment of GIS enable to store, integrate, manipulate, analyze and display spatial data sets (Mallari & Ezra, 2016). Thus, GIS is useful to identify locations susceptible to climate induced vulnerability (Li et al., 2014). Therefore, ArcGIS 10.3 was used to develop the vulnerability index map of Chakwal District. The results were cartographically displayed with the help of ESRI ArcGIS Spatial Analyst Tool.

6.3. Results

6.3.1 Principal Component Analysis

The mean and standard deviation among selected indicators regarding three components of vulnerability i.e. exposure, sensitivity and adaptive capacity were calculated (Table 6.2). The PCA identified eight significant factors that approximately constitute 63.14% of all the variance within the dataset of 26 variables. The findings are based on a sample of 473 households (Table 6.3).

The first principal component explained (20.83%) of the variation, the following second (9.65%), the third (7.25%), the fourth (6%), the fifth (5.88%), the sixth (5%), the seventh and eighth respectively indicated only 4% variation. The significant findings of the PCA describing the factors, Eigen values, cumulative percentages and explaining the specific influence of a representative variable have been condensed in the table 6.3.

The findings divulge the visits of farmers to agriculture extension office/officials (0.819), visits of officials to farmers (0.732) and soil erosion (0.729) have significant imprints on study area. Besides this, the visits of farmers to on-farm demonstration sites (0.689), marketing information (0.616) also have visible connotations. All of these variables had a communality greater than 0.6. While, the variables such as farmers' research group (0.568), access to Govt. subsidies (0.531), awareness and guidance (0.495), crop types (-0.488), dependency ratio (0.470) access to investment capital (0.482), temperature change (0.396), Total Livestock Units (-0.402), household size (-0.346), and education status (-0.366) depicted the communalities less than 0.6 but greater than 0.3 (Table 6.3).

Table 6.2: Descriptive statistics of exposure, sensitivity and adaptive capacity indicators

S. No.	Indicators	Mean	Standard Deviation
1.	Drought	0.99	0.121
2.	Erratic rainfall	0.86	0.347
3.	Temperature change	0.61	0.488
4.	Proportion of arable land (ha)	3.98	5.068
5.	Soil erosion	.32	0.468
6.	Age (years)	52.89	12.094
7.	Education status	1.93	0.967
8.	Household size	7.05	3.380
9.	Dependency ratio	0.43	0.674
10.	Landholding (ha)	5.18	6.510
11.	Access to farm inputs (seeds, fertilizers, technology etc.)	0.76	0.426
12.	Total Livestock units (TLUs)	8.99	8.88
13.	Livelihood diversification	2.54	.904
14.	Crop types (No.)	4.79	2.390
15.	Farm assets (Rs.)	395348	409627
16.	Household assets (Rs.)	245866	314112
17.	Farm income (Rs)	25759	24938
18.	Access to Govt. subsidies	0.08	0.279
19.	Access to investment capital	0.50	0.513
20.	Farmers’ research group	0.11	0.308
21.	Visits of farmers to Agriculture Extension Office/Officials	0.10	0.191
22.	Visits of Agriculture Extension Office/Officials to farmers	0.07	0.165
23.	Getting loans from relatives/ neighbors	0.14	0.345
24.	Access to marketing information	0.41	0.492
25.	Visits of farmers to on-farm demonstration sites	0.18	0.386
26.	Awareness and guidance	0.32	0.466

Source: ‘author’

Table 6.3: PCA analysis constituting household vulnerability index, details of eight components retained

PC/Factors	Eigen Values	% of Variance	Cumulative %	Representative variables and loadings
1.	5.418	20.837	20.837	Visits of farmers to Agriculture Extension Office/Officials (0.819)
				Visits of Agriculture Extension Office/Officials to farmers (0.732)
				Soil erosion (0.729)
				Visits of farmers to on-farm demonstration sites (0.689)
				Access to marketing information (0.616)
				Farmers' research group (0.568)
				Access to Govt. subsidies (0.531)
				Awareness and guidance (0.495)
				Crop types (-0.488)
				Dependency ratio (0.470)
				Age years (0.452)
				Farm income (-0.404)
				Access to investment capital (0.482)
				Temperature change (0.396)
				Total Livestock Units (TLUs) (-0.402)
				Household size (-0.346)
				Getting loans from relatives/neighbors (0.379)
				Education status (-0.366)

2.	2.510	9.653	30.490	Awareness and guidance (0.340)
				Crop types (0.331)
				Farm assets (0.545)
				Farm income (0.543)
				Access to investment capital (0.529)
				Land holding (ha) (0.558)
				Proportion of arable land (ha) (0.579)
				Access to farm inputs (-0.398)
				Temperature change (-0.376)
				Total Livestock Units (0.347)
3.	1.885	7.250	37.740	Access to marketing information (-0.423)
				Access to investment capital (-0.369)
				Land holding (ha) (0.712)
				Proportion of arable land (0.690)
				Access to farm inputs (0.567)
4.	1.563	6.013	43.753	Awareness and guidance (0.422)
				Access to farm inputs (0.429)
				Temperature change (-0.569)
				Total Livestock Units (TLUs) (-0.314)
				Erratic rainfall (-0.438)
				Livelihood diversification (0.310)

5.	1.531	5.887	49.639	Farmer research group (0.470)
				Access to Govt. subsidies (0.412)
				Dependency ratio (-0.326)
				Farm assets (-0.389)
				Total Livestock Units (TLUs) (0.435)
				Household size (-0.337)
				Livelihood diversification (0.356)
6.	1.311	5.041	54.680	Household assets (0.515)
				Household size (0.418)
				Getting loans from relatives/neighbors (0.387)
7.	1.138	4.378	59.058	Drought (0.604)
				Education status (0.433)
				Erratic rainfall (-0.312)
8.	1.063	4.089	63.147	Dependency ratio (0.335)
				Education status (0.431)
				Erratic rainfall (0.548)
				Livelihood diversification (0.536)

Source: 'author'

6.3.2 The vulnerability index

The first principal component is, therefore, used to construct the vulnerability index (Table 6.3). As expected, all indicators with the exception of crop types, farm income, TLUs, HH size and education status are loaded positive. Soil erosion, temperature change, visits of farmers to agricultural extension office/officials, farmers' research group, visits of agriculture extension officials to farmers, access to marketing information, access to government subsidies, dependency ratio, getting loans from relatives/neighbors, access to investment capital, dependency ratio, farmers' age (years), awareness and guidance and visits of farmers' to on-farm demonstration sites are the variables with the highest weight, above 0.3.

We further classify tehsils with an index range below -2 as "low vulnerability"; those with an index range from -2 to 0 as "low-medium vulnerability"; those with a range from 0 to 2 as "medium vulnerability"; and those with an index above 2 as "high vulnerability" as used by Gbetibouo et al. 2010. The results of the overall vulnerability index for each tehsil (sub-divisions) of Chakwal District are depicted in Figure 6.5.

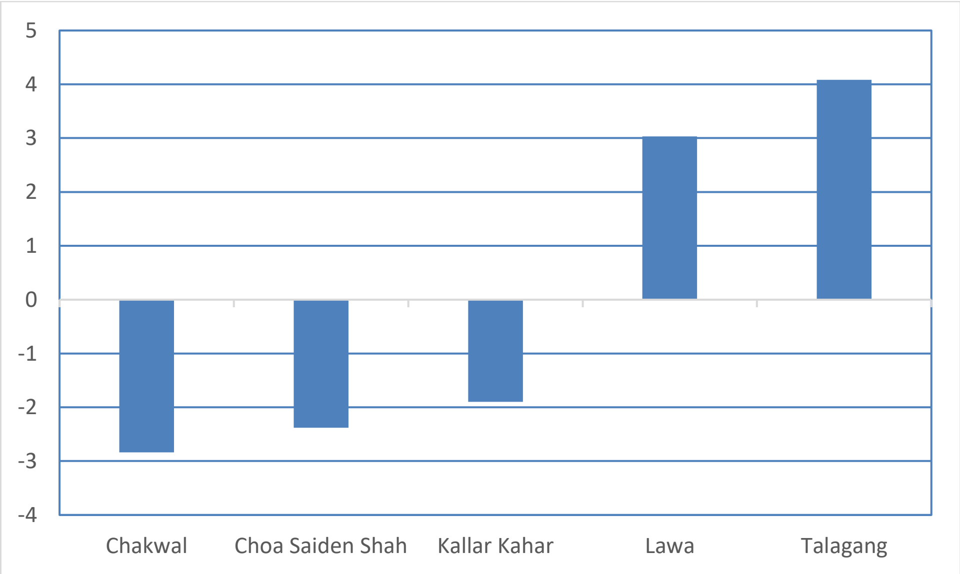


Figure 6.5: Vulnerability indices across the farming regions in Chakwal District
Source: 'author'

The results show that tehsil Chakwal and Choa Saiden shah have a "low vulnerability index", scoring -2.38 and -2.38, respectively. Kallar Kahar is "low-medium vulnerability" tehsil scoring -1.89. Finally, the two most vulnerable tehsils are Lawa and Talagang, scoring 3.03 and 4.08 respectively (Fig 6.6).

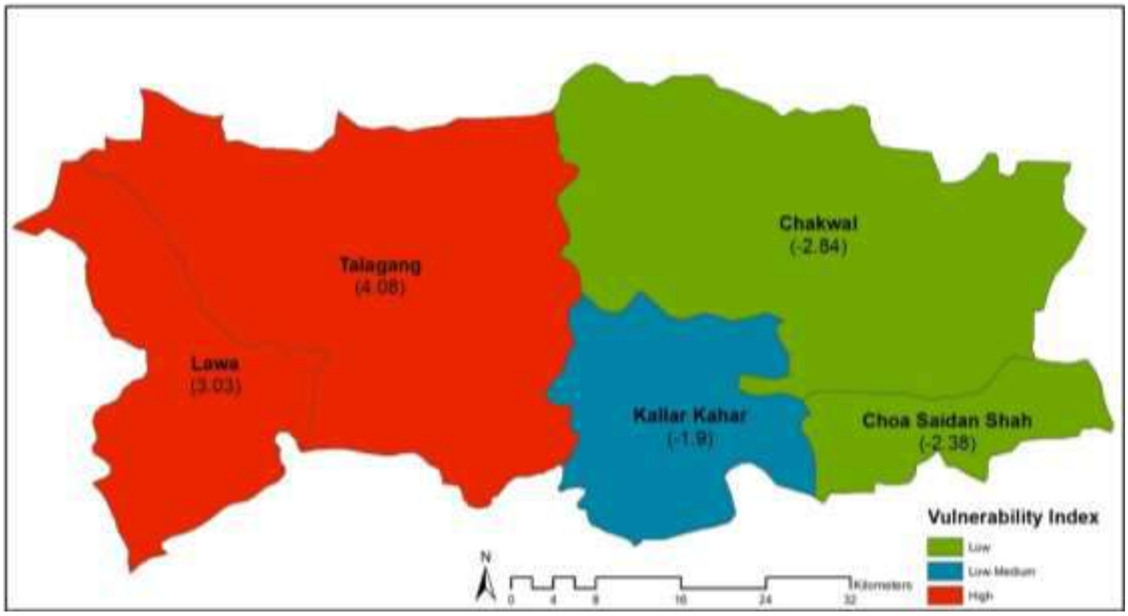


Figure 6.6: Map of vulnerability indices across Chakwal sub-divisions (tehsils)
Source: 'author'

For more insights into the three dimensions of vulnerability, an exposure index, sensitivity index and adaptive capacity index were calculated. The results are depicted in Figures 6.7 to 6.12. The largest tehsils of district Chakwal in terms of area i.e. Chakwal and Talagang have the highest exposure index i.e. 0.28 and 0.49 (Figures 6.7 &6.8).

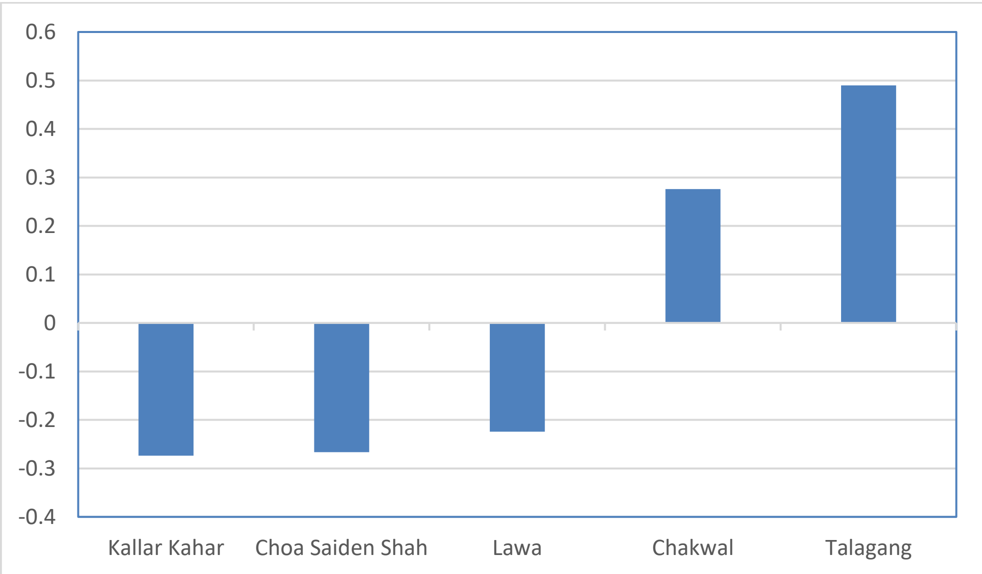


Figure 6.7: Exposure indices across the tehsils in Chakwal District
Source: 'author'

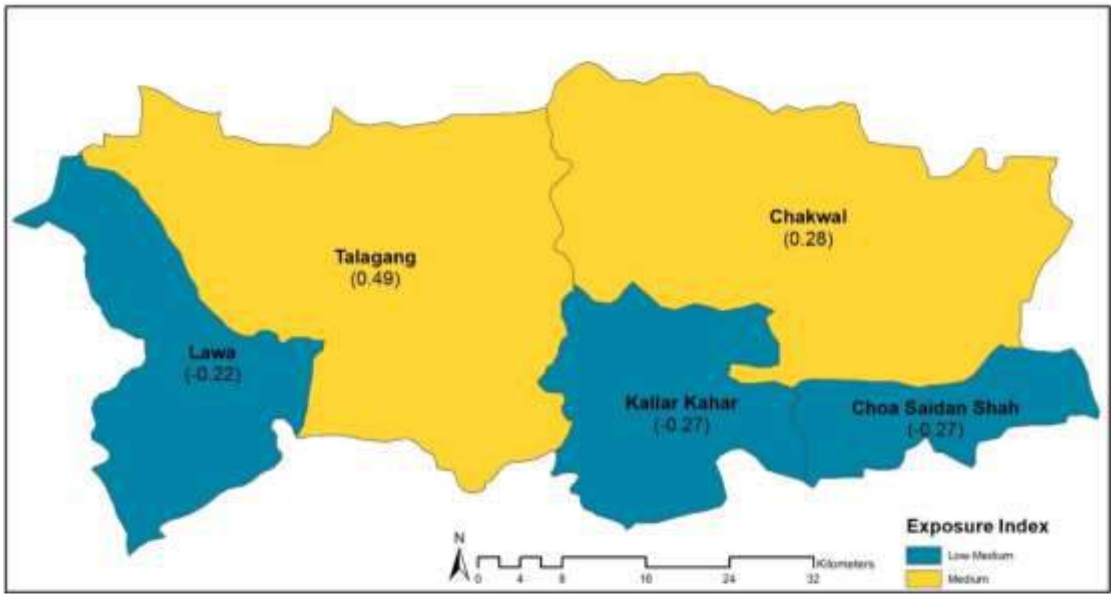


Figure 6.8: Map of the exposure indices across the tehsils of Chakwal District
Source: 'author'

The most sensitive regions are Lawa (0.74) and Talagang (0.65), whereas, Chakwal and Choa Saiden Shah are least sensitive regions scoring -0.65 and -0.51 (Figures 6.9 & 6.10).

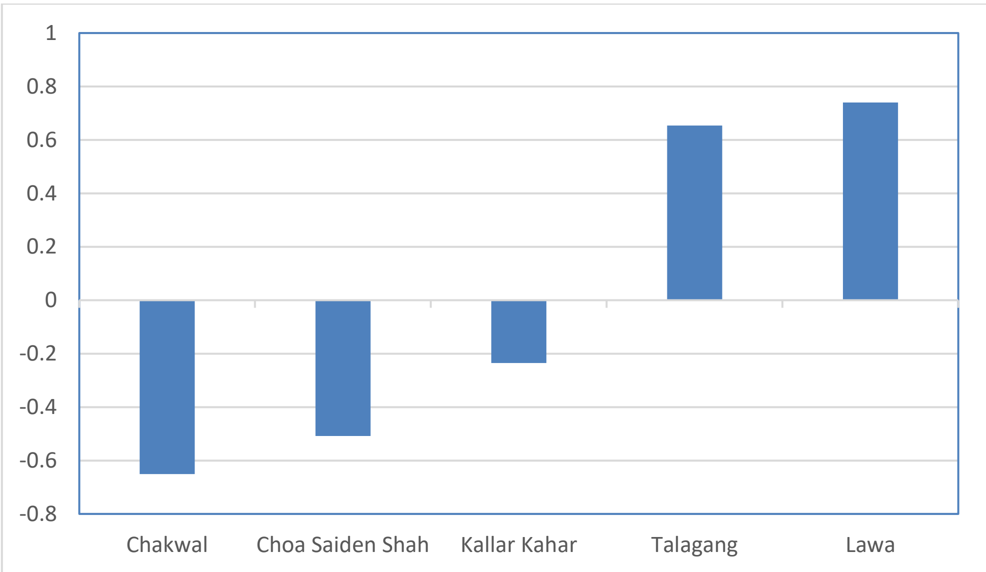


Figure 6.9: Sensitivity indices across the tehsils of Chakwal District
Source: 'author'

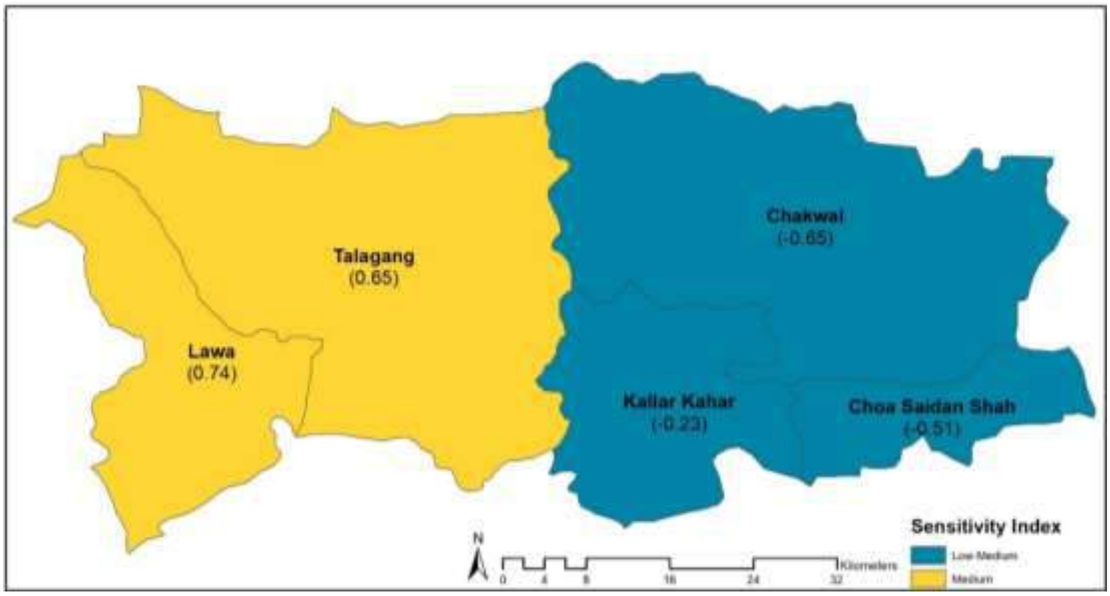


Figure 6.10: Map of sensitivity indices across the tehsils of Chakwal District
Source: 'author'

The adaptive capacity index is highest for Talagang (2.94), then comes Lawa (2.51). Chakwal stands at low level of adaptive capacity (-2.46), while Choa Saiden Shah and Kallar Kahar stands at low-medium level of adaptive capacity (Figures 6.11 & 6.12).

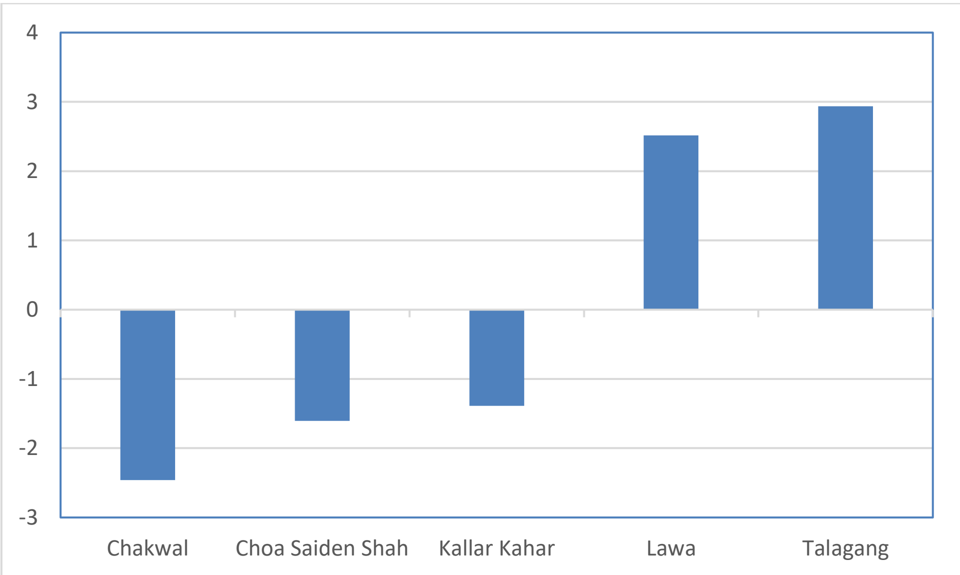


Figure 6.11: Adaptive capacity indices across the tehsils of Chakwal District
Source: 'author'

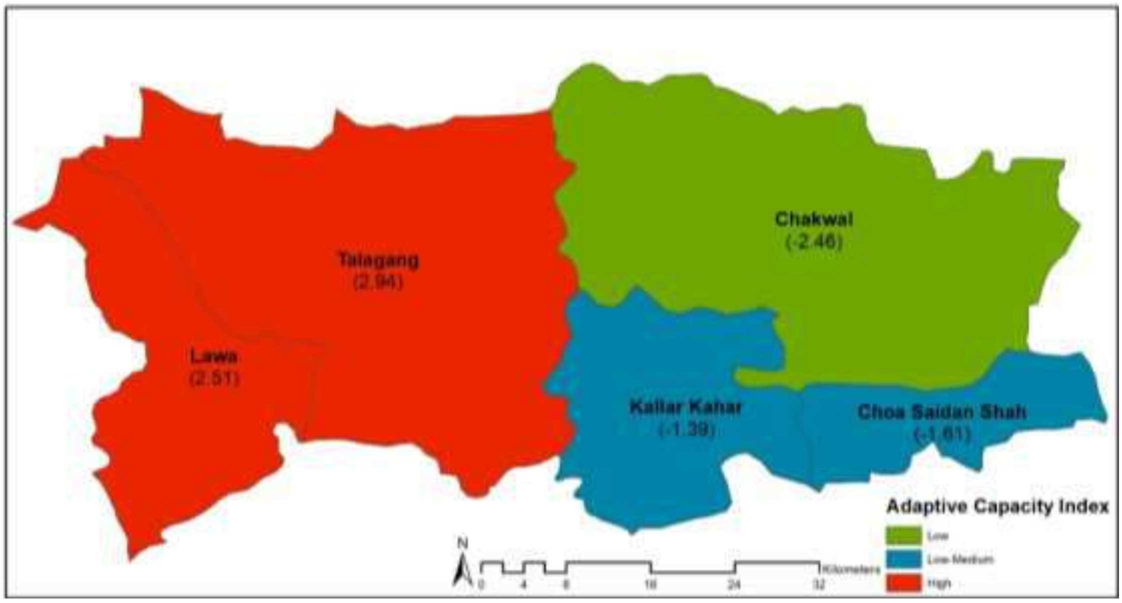


Figure 6.12: Map of adaptive capacities indices across the tehsils of Chakwal District
Source: 'author'

Thus, our results show that tehsil Talagang with the highest climate exposure index also rank highest on the vulnerability index, whereas, tehsil Chakwal which comes next in terms of exposure to climatic hazards do no rank highest on the vulnerability index. Farmers in tehsils Chakwal and Talagang are confronted with high exposure to extreme events and climate change and experiencing adverse impacts on the farming sector, though in terms of vulnerability tehsil Chakwal falls in 'low vulnerability index'.

6.4 Discussion

This study is a first attempt of its sort that analyzes the impacts of climatic fluctuations on the rain-fed contextual settings of Chakwal district. The empirical data was collected to assess the role of determinants on the socio-economic vulnerability of the study area. Access to resources, financial constraints, and capacity to cope with the ensuing anomalies were identified as the cardinal factors. The study formulate that institutional and policy neglect are adversely impacting the life and infrastructure in this area.

The present study, specifically, focuses the imprints of climate induced abnormalities on the socio-economic vulnerabilities. The quantitative assessments pertaining to selected variables were made from across the five tehsils (sub-divisions) of Chakwal district. These measurements were, subsequently, relied upon for qualitative interpretations. The susceptibilities or vulnerabilities were inferred from three perspectives: exposure to atmospheric irregularities; sensitivity; and adaptive capacity of the respondents. For the purpose, 26 environmental and socio-economic indicators were adjudged relevant to the objectives of the investigation. The findings based upon Principal Components Analysis (PCA) were used to formulate a vulnerability index.

The outcomes construed about the following ramifications/characteristics of climate related impacts on the socio-economic resilience of the study area. Firstly, the vulnerability to climate change was observed asymmetrical and spatially heterogeneous across the study area (Fig 6.8, 6.10 and 6.12). The less prepared and marginalized sections are more prone to impacts as compared to resourceful segments. It formulates that the policy framework should accommodate spatial disparities for integrated management. Secondly, the findings articulate that the regions exposed to climate change and variability do not, always, overlap the areas suffering from high sensitivity or low adaptive capacity. These assertions corroborate the reported findings of similar nature of studies. Gbetibouo et al. (2010) observed linkages between medium-level risk exposure and medium to high levels of social vulnerability in the agrarian settings of South Africa. However, risk to exposure, prevailing environmental and socio-economic conditions characteristically influence the orientation and magnitude of vulnerability. The evaluations portrayed a higher exposure index value for Talagang and Chakwal sub-division as compared to Choa Saiden Shah and Kallar Kahar. The scenario warrants for preventive measures to ensure socio-economic resilience for calamity prone areas. For the purpose, the priority should be given to capacity building and socio-technological innovations based upon contextual requirements. It entails more focus towards the drought-resistant crop varieties, enhanced monitoring and efficient weather forecasting. Besides this, the dissemination of information pertaining to innovations, relief measures and programs are obligatory for the integrity of social, economic and ecological infrastructure.

Thirdly, the findings divulge that the vulnerability to climate change is intrinsically linked with level of development. Therefore, the macro and micro economic development and social uplift are the fundamental requirements to cope with the looming scenario. Talagang and Lawa sub-divisions were identified as the most vulnerable parts of the study area. The higher population density; low level of literacy and limited/dilapidated civic infrastructure etc. are making these sub-divisions more vulnerable. It necessitates for a comprehensive policy framework based upon the paradigm of "triple bottom line". The holistic appraisals are needed to synchronize the demands from such regions within the ambit of broader development perspective. These regions are more vulnerable due to poor/mismanagement and creeping socio-economic development. Therefore, cognizable measures are required to rectify the trends.

The initiatives are incumbent for the effective management of environmental resources (e.g., soil, vegetation and water resources). A farmer friendly market mechanism is, also, required for economic buoyance in such subsistence farming areas. Thus, the investment in social sector such as the health, education and infrastructure seems to be a pragmatic option. In addition, the strengthening of the farmers' associations is a prerequisite for sustainability. These social organizations act as a safety networks and support the disadvantageous segments during financial stresses. These measures are incumbent for the protection of such fragile surrounding. Besides this, these are required to mitigate the adverse impacts of climate related vulnerabilities.

6.5 Conclusions

The vulnerability assessments are obligatory to insulate the farming sector from the impacts of climate change. The index method in conjunction with GIS proved vibrant options for vulnerability assessment. The results of the assessment formulated that coordinated efforts are needed to protect the agriculture sector from the ensuing impacts of climate change. The awareness and capacity building of the stakeholders, based upon the contextual needs and potential, are required that will productively contribute towards the best use of available resources in agrarian settings. Albeit, this study has its own limitations as the vulnerability assessment tools have time and context specific implications. However, the empirical findings of the study will fulfill the needs for baseline information. The postulations of the study will complement the efforts meant to ensure the resilience of rain-fed agriculture in the face of climate change.

CHAPTER 7

DETERMINANTS OF FARMERS' CHOICE OF ADAPTATION STRATEGIES TO CLIMATE CHANGE

7.1 Introduction

The global atmospheric temperature may escalate up to 1.5°C between 2030 and 2052 (Oo et al., 2019) due to consequential impacts of anthropogenic activities (IPCC, 2018). Resultantly, the phenomenon is redefining the orientation of agricultural practices in the world. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) delved on the ensuing impacts and construed about negative repercussions for the agro-based economies of the Asian region such as Pakistan. The economic productivities of these countries are more vulnerable due to their peculiar socio-economic settings and demographic pressures. The lack of vision, compromises over policies, low adaptive capacities and level of preparedness may exacerbate the prevailing scenario. The observed weather and climatic anomalies will trigger glacial melting and can disturb the spatiotemporal setting of the monsoon system in this region. Thus, the ensuing outcomes will prove counterproductive for the performance and productivity of water-dependent sectors such as agriculture and hydropower generation (Chaudhry, 2017).

The increasing demands for food due to population growth and ensuing lifestyle changes are making the fragile economies of such regions more vulnerable (Abid et al., 2015; Ashraf et al., 2014). The ensuing repercussions are proving more stressful for the rain-fed agrarian communities. Albeit, the agrarian communities in these areas are striving hard to cope with the emerging scenario, yet, their efforts are less organized and integrated. Resultantly, the lacunas and gapes in the individual and collective responses have failed to reverse the decline in agricultural productivity and environmental degradation (Abid et al., 2019, 2016).

Pakistan's vulnerabilities to climatic fluctuations are well documented and acknowledged (Chaudhry, 2017). During the last century, Pakistan's average annual temperature increased by 0.57°C. Besides this, an increase of 25% in average annual precipitation was also observed. The consequential impacts of weather and climate related anomalies such as floods, droughts, cyclones, heat waves and incidents of glacial lake outbursts have become frequent. These occurrences have negative imprints on the economic growth and human development of the country (GoP, 2012). Consequently, the per acreage yield of wheat and rice crops are declining and share of per capita water availability is dwindling (Chaudhry, 2017; Zahid & Rasul, 2012).

The rise in the atmospheric temperature (Ahmad et al., 2013; Aggarwal & Sivakumar, 2010) and oscillations in the patterns of precipitation in Pakistan (Abid et al., 2015; Ali & Erenstein, 2017; Hussain, 2014; Pak-INDC, 2016) are proving disastrous for the food crops (Abid et al., 2015; FAO, 2015; Prikhodko & Zrilyi, 2013). It is adversely impacting the supply-demand gap in the provisioning of food crops (Zulfiqar & Hussain, 2014). However, the focus towards such pressing issues is far from satisfactory in Pakistan and, thus, demands immediate corrective measures (Atif et al., 2018; Bokhari et al., 2018).

For the purpose, the knowledge about farmers' perceptions pertaining to climate change; their adaptation strategies and identification of the factors that tailor their response capabilities are imperative (Bryan et al., 2013). Whereas, this information is not only needed for pragmatic policy and decision making to mitigate the impacts of climate change, but, also obligatory for the socio-economic resilience of the farming communities dependent on the agro-based livelihood (Abid et al., 2015, 2016; Ali & Erenstein, 2017; Ashraf et al., 2014). Therefore, the academic and research communities are focusing on the climate related challenges (Abdulrazzaq et al., 2019; Atif et al., 2018; Striebig et al., 2019). The farm based adaptation strategies and their determinants are being focused in the recent scientific investigations (Ali & Erenstein, 2017; Ashraf et al., 2014; Bryan et al., 2009, 2013; Deressa et al., 2009; Islam et al., 2017; Jin et al., 2016; Ndamani & Watanabe, 2016; Sarker et al., 2013; van Dijl et al., 2015; Zia et al., 2015). However, the orientation to decipher the impacts of climate change on the agriculture sector in Pakistan is gaining momentum (Abid et al., 2015, 2016; Ali & Erenstein, 2017) but the rain-fed agriculture seems to be a less priority area for such research initiatives.

There is a growing realization that different climatic conditions and socio-economic needs necessitate for context based interventions for the resilience of agricultural sector (Hisali et al., 2011). Hence, there is a need for area-specific studies for postulating adaptive measures to mitigate the impacts of climate-related anomalies on the rain-fed agriculture in Pakistan. The objectives of this study were to identify farmers' ongoing adaptation strategies toward climate change in the contextual settings of Chakwal District in Punjab province. It focuses to determine the factors which symptomatically influence their decision making.

The rain-fed agriculture of the district is prone to extreme climatic events (Amir et al., 2019, 2020; NDMA, 2017). The consequential impacts of reported weather and climatic anomalies will make the livelihood of people more fragile and vulnerable (Oweis & Ashraf, 2014). Thus, making it an appropriate contextual environment for assessing the farmers' perceptions regarding climate-related impacts and factors influencing farmers' decisions to adapt in the vulnerable area of rain-fed region.

7.2 Material and methods

7.2.1 Data collection and analysis

The cross-sectional data was collected from all the 71 rural UCs of the Chakwal District and 475 respondents were interviewed during the course of the study (April – August 2017) (Table 7.1). The data analysis was done by descriptive statistics and econometric model (multivariate probit model) was applied using STATA 12.

Table 7.1: The sampling framework of the study

Sr. No.	Tehsils	No. of Union Councils surveyed	No. of villages selected	No. of farmers interviewed
1.	Chakwal	32	92	221
2.	Choa Saiden Shah	07	14	59
3.	Kallar Kahar	07	10	52
4.	Lawa	06	11	25
5.	Talagang	19	56	118
	Total	**71**	**183**	**475**

Source: 'author'

7.2.2 The econometric model

Econometric based analysis was performed in this study. The econometric model facilitate to delineate the role of factors (determinants) which influence the adaptation strategies of farmers. In terms of mathematical framework, the adaptation decisions are predominantly binary cases, to adapt or not to adapt (0, 1), therefore, the Multivariate Probit model (MVP) was deployed. The Multivariate probit model has been deployed for interpreting the relationship between adaptation strategies and explanatory variables (Abid et al., 2019; Ali & Erenstein, 2017; Ashraf et al., 2014). This technique is not only capable of modeling the effect of predictor variables on each of the response variable (adaptation practices) but also allows error terms to be freely correlated simultaneously (Greene, 2003; Lin et al., 2005). The source of correlation between the error terms is due to positive correlation (complementarities) and negative correlation (substitutability) between different adaptation options (Belderbos et al., 2004). Multivariate probit model takes into account the correlation between error terms.

y_in=1 if x_in β_n + ∈_n > 0,…………………… Eq (1)

y_in=0 otherwise i=1,2…..N,n=1,....,17

εin are the error terms ~N (0, V) is the covariance matrix of the error term. Where V on the leading diagonal has values of 1 and correlations ƿjk = ƿkj as off-diagonal elements.

The consequent reactions are statistically validated through likelihood ratio (LR) and Wald $\chi 2$ tests. Thus, assuming multivariate normality, the unknown parameters in Eq (1) were estimated by maximizing simulated likelihood (SML). SML uses the Geweke–Hajivassiliour–Keane (GHK) simulator to estimate the multivariate normal distribution. The technique is considered appropriate for drawing inferences (Abid et al., 2019; Ashraf et al., 2014).

7.3.3 Selection of explanatory (independent variables)

The selection of explanatory variables in this study are based on review of literature and data availability. A set of independent variables were included in the model i.e. the socio-economic such as (the age of respondents, education level and monthly farm income etc.); institutional factors (e.g. access to extension services and marketing information etc.); agro-ecological factors (e.g. information on crop agronomic practices) and respondents' perception and knowledge about climate-related events like untimely rains and temperature changes etc. Subsequently, each variable was included in all equations for empirical analysis in order to determine the magnitude of variation pertaining to explanatory variables (Abid et al., 2019; Ali & Erenstein, 2017; Ashraf et al., 2014). The findings (Table 4 & Table 5) were relied upon for qualitative and quantitative assessments.

7.3 Results and discussion

7.3.1 Farmers' perception to climate-related events and their impacts

The findings of the study showed that 96% of the farmers perceive that the climatic conditions are changing in their surroundings. These climatic variations are being realized in the form of rising temperature (61%), irregular pattern of precipitation (86%) hailstorm (73%), delay in the start of winter season (71%), incidents of the cold breeze (67%) and heat waves (65%), storms (64%), frost (59%) and an increase in the occurrences of drought conditions (39%) (Figures 7.1a, 7.2b).

The negative bearings of these extreme weather events on the human health, crop yield, livestock production directly and indirectly influence the socio-economic conditions in the rural settings. However, the repercussions of the reported weather and climatic anomalies were not found symmetrical and homogenous across the study area. Whereas, the majority of farmers reported negative consequences of climatic fluctuations in terms of lower crop productivity, loss of income due to livestock diseases and death. Besides this, the consequential impacts are indicating stressful for the human health (Figures 7.3a, 7.4b & 7.5c). These results are comparable to the studies conducted by ADB (Asian Development Bank), (2017) WFP (World Food Program), (2017, 2018) in collaboration with Government of Pakistan (GoP). All these studies have ranked vulnerability of Chakwal District as 'Medium to Low Risk' in terms of climate change, agriculture and food insecurity and 'Very High Risk' to land degradation/soil erosion (> 50%).

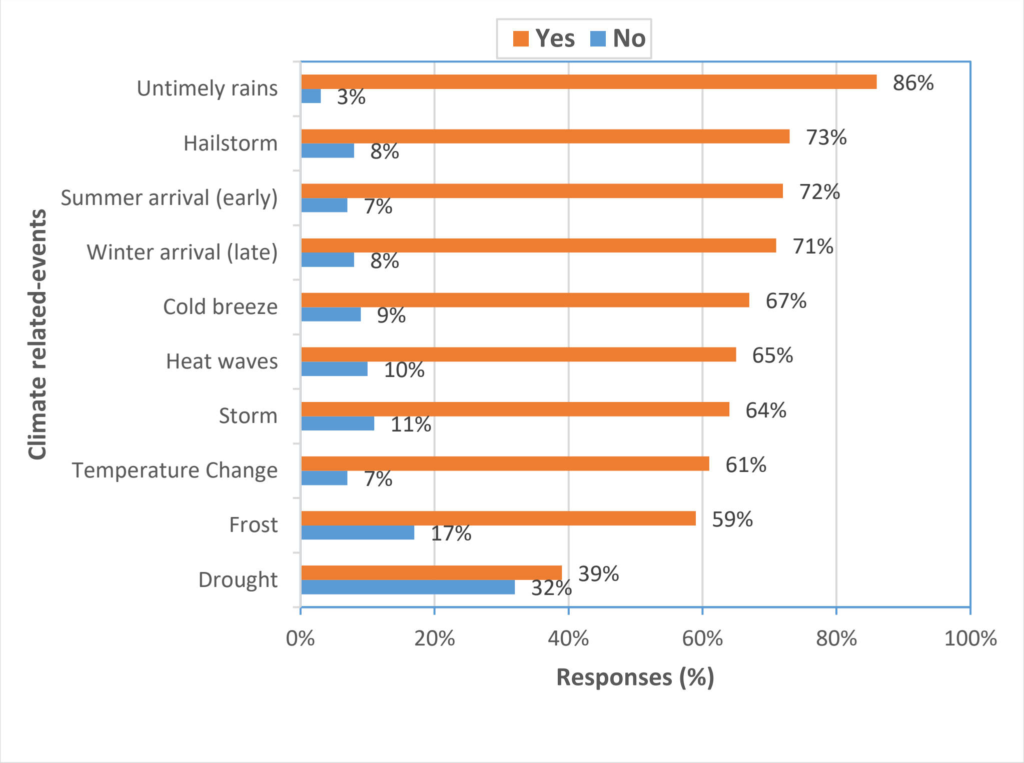


Figure 7.1(a): Climate-related events experienced by farmers in the last 20 years or so in the study area

Source: 'author'

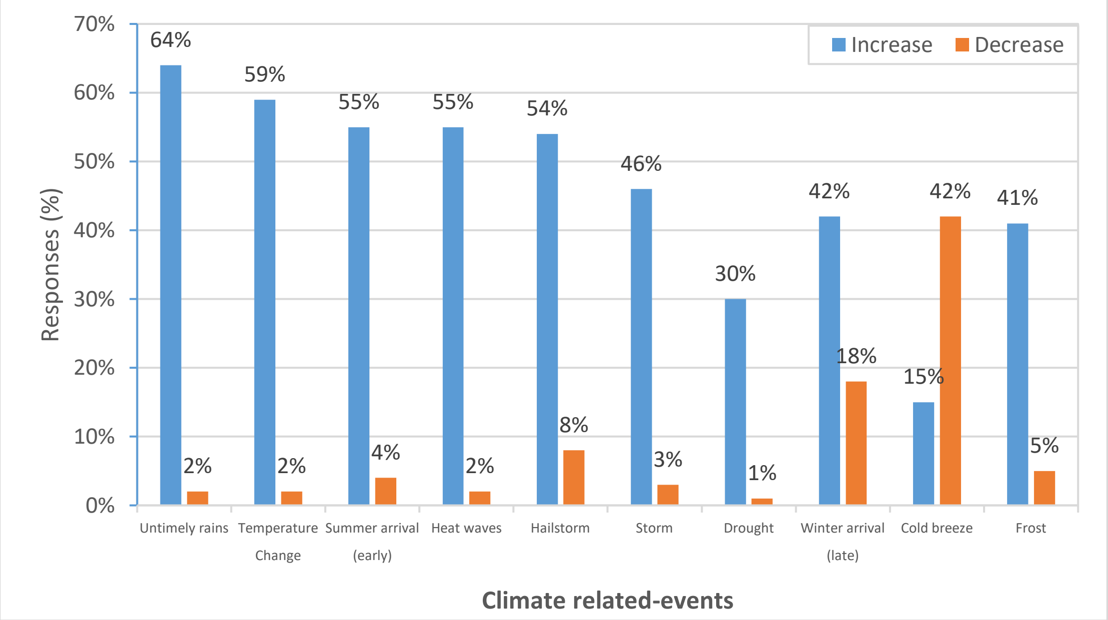


Figure 7.2(b): Rate of change (increase/decrease) of climate-related events perceived by farmers in the last 20 years or so in the study area.

Source: 'author'

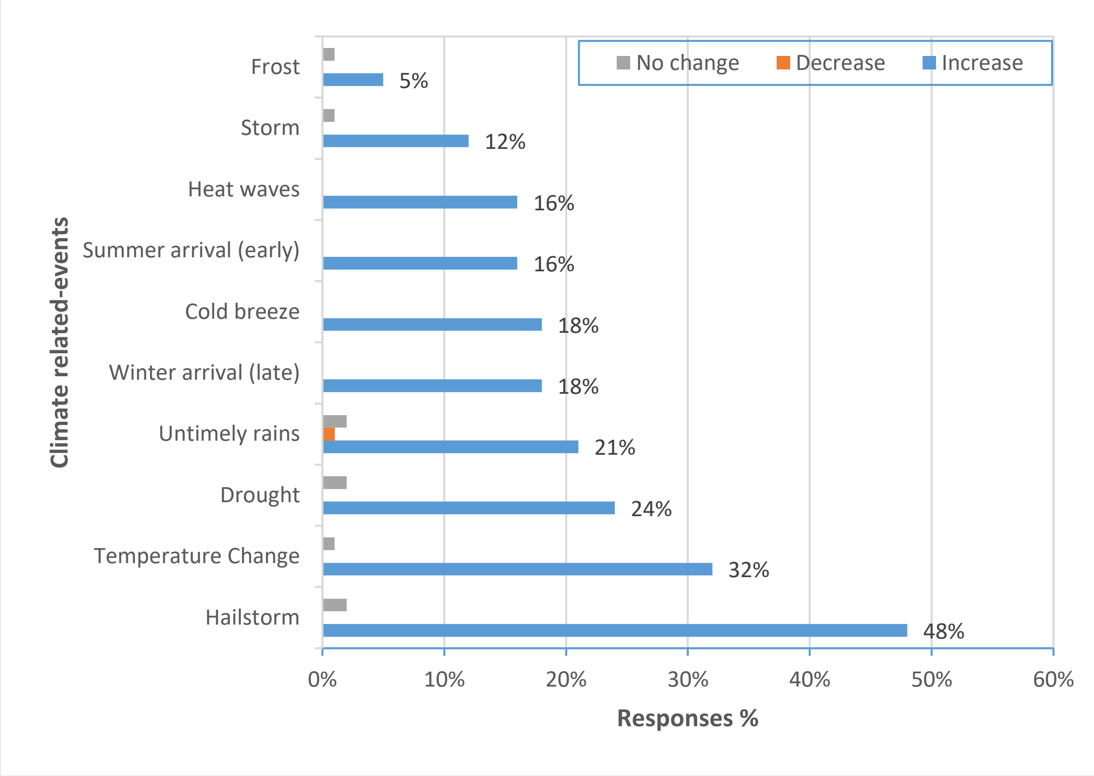


Figure 7.3(a): Impacts of climate-related events on human health (disease/illness etc.) as perceived by farmers over the last 20 years or so in the study area.

Source: 'author'

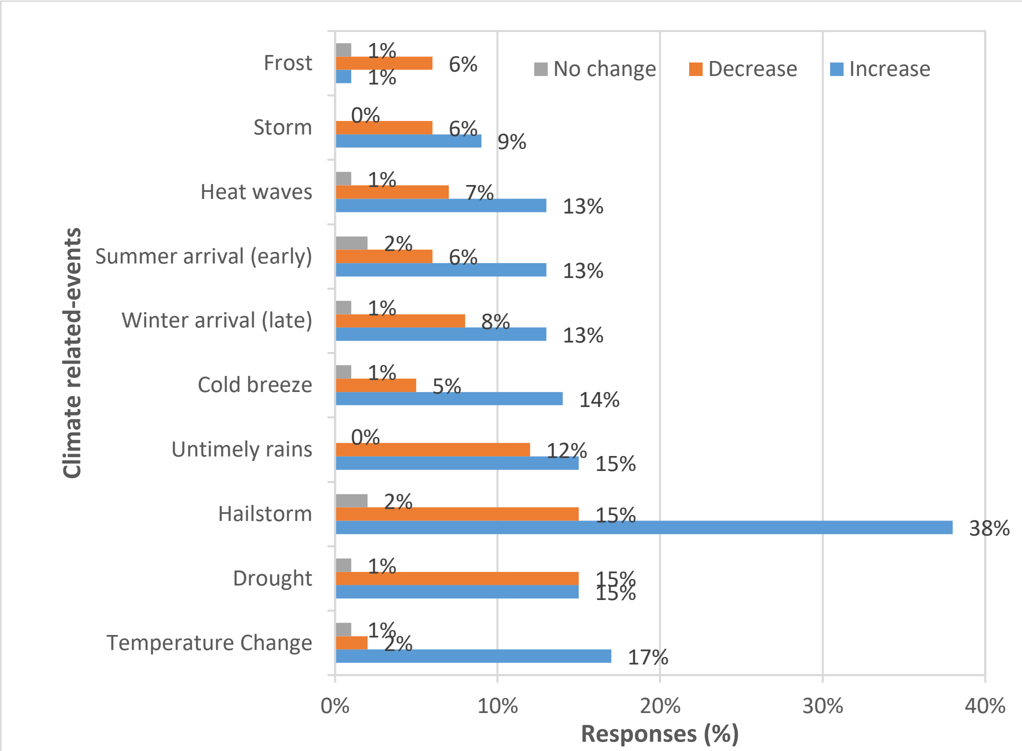


Figure 7.4 (b): Impacts of climate-related events on crop yield/productivity (uncertainty/decline etc.) as perceived by farmers over the last 20 years or so in the study area. *Source: 'author'*

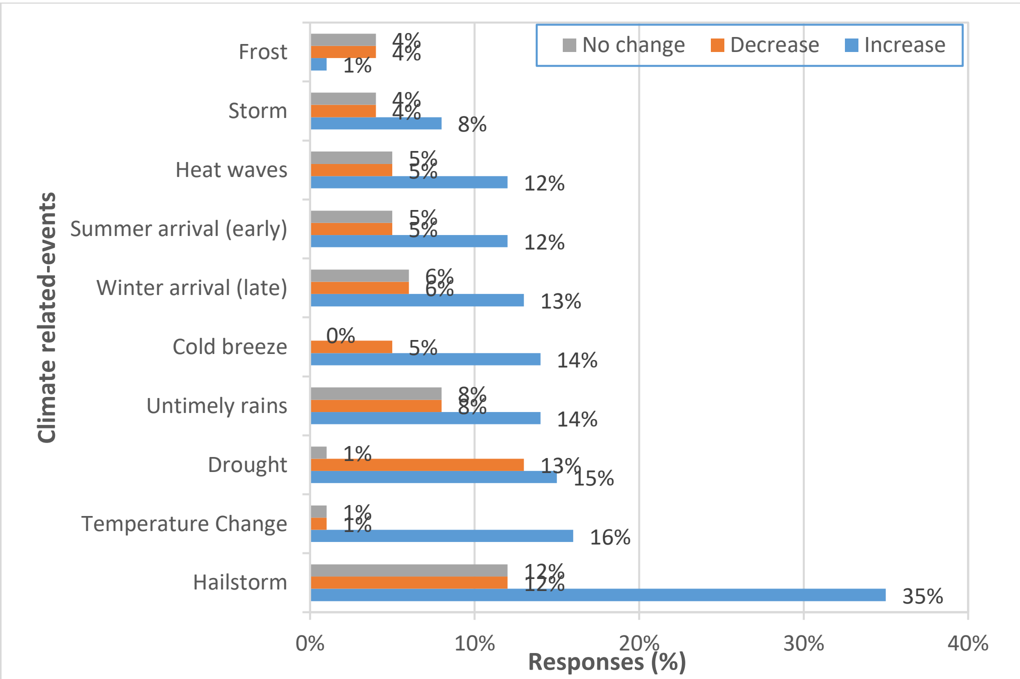


Figure 7.5(c): Impacts of climate-related events on livestock (death/disease etc.) as perceived by farmers over the last 20 years or so in the study area.
Source: 'author'

7.3.2 Adaptation strategies and Respondents

The assessments pertaining to adaptation strategies deployed by the respondents to cope with the climate induced abnormalities (Table 2). The findings formulate that majority of respondents (76%) considered that changes in the planting time is more efficient and costs effective measure. While, changes in the cropping pattern (46%) is also a common practice in the study area to cope with stress. However, the majority of the respondents rely on their local ecological knowledge and conventional wisdom. The similar conclusions were also drawn in the comparable studies carried out by Abid et al. (2016), Thoai et al. (2018) and Ali and Erenstein, (2017). The findings (Table 2) transpire that selling of livestock is the preferred strategy to cope with emergency in the study area. While, a size proportion (33%) of respondents also compromise over the education of their children; borrow money (32%) from acquaintances; compromise over the food consumption (19%) or migrate to urban areas (17%). However, these outdated and non-productive endeavors adversely impacts their potentials. The migration to urban areas by (17%) respondents is also gain momentum to ensure socio-economic sustainability. These types of climate-induced relocations are stressing the social, economic and ecological infrastructures in urban areas of Pakistan.

Table 7.2: Farmers' adaptation strategies (farm-based and non-farm based)

Farm-based adaptation strategies	Percent of respondents	Non-farm based adaptation strategies	Percent of respondents
Change in planting date	76	Reduction in education level of the children	33
Sold livestock	55	Borrowed money from relatives/others	32
Change in cropping pattern	46	Less food consumption or changed food habits	19
Followed improved crop production practices	28	Shifted to non-farm employment	18
Provided supplemental irrigation	27	Out-migration to cities	17
Sold part of land for alternative	25	Relying on assistance from Govt/NGOs	16
Additional information gained	25		
Left land fallow	24		

leased out part of land for alternative/leased in	23
Maintained poultry/goats	19
Invested in farm ponds	13

Source: 'author'

7.3.5 Perceived barriers to adaptation

Lack of access to agricultural inputs, inadequacies in extension services, soil erosion and lack of capital are the cardinal barriers in the way to effective adaptation strategies (Fig. 7). Besides this, the small size of landholdings, absence of irrigation facilities, ineffective mode of technical guidance and awareness as reported by Sarker et al. (2013), Abid et al. (2015) and Ashraf et al. (2014) are adversely impacting the initiatives for socio-ecological resilience. The findings substantiate the postulations rendered by of Eakin, (2003); Roncoli et al., (2002); Sarker et al., (2013); Ziervogel et al., (2006) that lack of coordination among institutions and accessibility to information are major stumbling blocks towards agricultural resilience in the face of looming climate change.

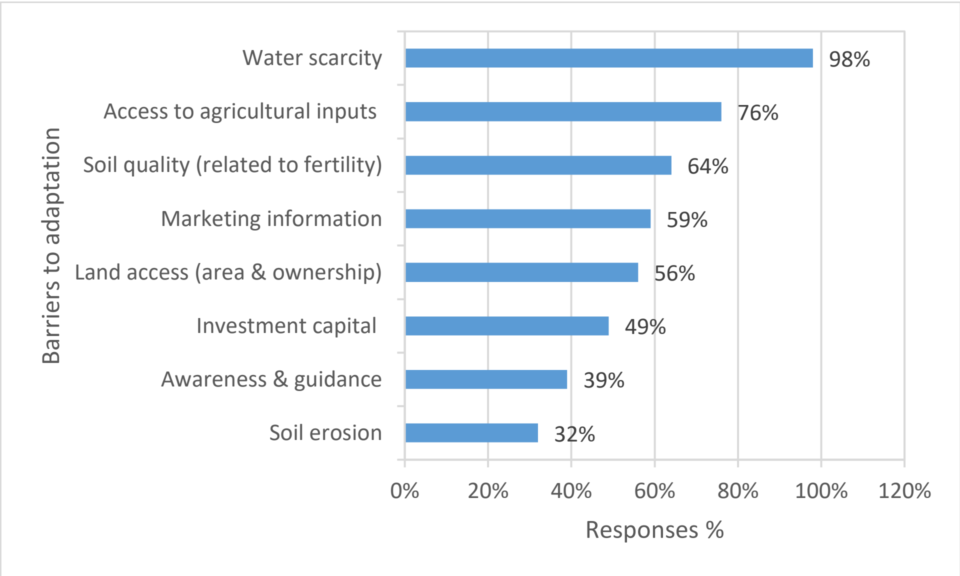


Figure 7.6: Barriers to adaptation as perceived by farmers
Source: 'author'

7.3.6 Determinants influencing farmers' adaptation measures

The dependent variable in the empirical estimation is the choice of an adaptation option from the set of adaptation measures listed in Table 7.2, whereas, definitions of the explanatory variables used for estimation as well as their major statistical values are given in Table 7.3. The explanatory variables for this study include the respondent's age, education level, household size, farm size, farm income, income diversification, livestock ownership, tube well ownership, informal credit, soil quality, access to extension services, government subsidies and market information, perception on climate-related events namely; untimely rains, temperature change, late arrival of winter season, early arrival of summer season, drought.

Table 7.3: Description of explanatory variables and descriptive statistics

Explanatory variables	Mean	SD	Description
Age (years)	52.96	12.12	Continuous
Education	0.65	0.47	Dummy takes the value of 1 if literate and 0 otherwise
Household size (No.)	7.07	3.38	Continuous
Landholding (ha)	5.18	6.510	Continuous
Household assets (Rs)	247157.9	315332.6	Continuous
Livestock ownership (No.)	9.03	8.90	Continuous
Farm income (Rs)	26037	25255	Continuous
Farmers' research group	0.11	0.31	Dummy takes the value of 1 if exists and 0 otherwise
Access to extension services	0.29	0.45	Dummy takes the value of 1 if have access and 0 otherwise
Income diversification	2.54	0.90	Continuous
Access to market information	0.05	0.22	Dummy takes the value of 1 if have access and 0 otherwise
Information on crop agronomic practices	0.36	0.48	Dummy takes the value of 1 if have information and 0 otherwise
Untimely rains	0.64	0.47	Dummy takes the value of 1 if farmer experienced and 0 otherwise
Temperature change	0.61	0.49	Dummy takes the value of 1 if farmer experienced and 0 otherwise
Drought	0.39	0.49	Dummy takes the value of 1 if farmer experienced and 0 otherwise

Source: 'author'

The results of the regression analysis on the determinants of adaptation are shown in Table 7.4 and 7.5 respectively.

Table 7.4: Determinants of household farm-based adaptation strategies by using multivariate probit model

Explanatory variables	Left land fallow	Sold part of land for alternative	Leased out part of land/leased in	Sold livestock	Maintained poultry/ goats	Supplemental irrigation	Invested in farm ponds	Change in cropping pattern	Followed improved crop production practices	Additional information gained	Changing planting dates
Age (years)	-0.012	0.005	0.006	-0.002	0.011*	0.009	-0.002	-0.006	0.004	0.008	0.001
	(-1.82)*	(0.76)	(0.93)	(-0.31)	(1.64)	(1.47)	(-0.25)	(-1.02)	(0.63)	(1.16)	(0.19)
Education	0.074	-0.066	0.219	-0.127	0.092	0.241	0.284	-0.230*	-0.144	0.137	0.025
	(0.44)	(-0.43)	(1.30)	(-0.91)	(0.57)	(1.55)	(1.46)	(-1.62)	(-0.94)	(0.78)	(0.16)
Household size (No)	0.026	-0.007	0.037*	-0.005	0.002	0.070***	0.046**	0.051***	0.014	0.005	0.007
	(1.16)	(-0.31)	(1.65)	(-0.29)	(0.11)	(3.43)	(1.97)	(2.62)	(0.69)	(0.24)	(0.35)
Landholding (ha)	0.007	0.005	-0.004	0.000	-0.055***	0.001	0.004	0.007	0.003	-0.018	0.006
	(1.22)	(0.93)	(-0.77)	(0.05)	(-2.78)	(0.13)	(0.63)	(1.12)	(0.59)	(-1.26)	(0.56)
Household assets (Rs)	4.67e-07**	7.17e-08	4.37e-07**	-3.86e-08	2.35e-07	3.47e-08	2.15e-07	-6.4e-07***	-3.7e-07	3.94e-07*	-4.6e-08
	(2.12)	(0.33)	(2.01)	(-0.19)	(1.05)	(0.17)	(0.89)	(-3.01)	(-1.56)	(1.62)	(-0.20)
Livestock ownership	-0.004	2.67e-05	4.94e-05	-0.009	0.007	0.002	6.94e-05	0.000	-3.8e-05	-4.7e-05	0.013
(TLUs)	(-0.5)	(0.17)	(0.22)	(-1.12)	(0.72)	(0.25)	(0.33)	(-0.05)	(-0.31)	(-0.40)	(1.32)
Farm income	-3.7e-06	1.05e-06	1.89e-06	-8.25e-07	6.25e-06*	6.44e-06**	3.06e-06	7.96e-06***	1.21e-05***	9.17e-06***	2.46e-06
	(-1.11)	(0.37)	(0.63)	(-0.28)	(1.79)	(2.13)	(0.95)	(2.62)	(4.01)	(2.74)	(0.74)
Farmers' research group	0.934***	0.816***	1.265***	-0.032	0.247	0.387	0.094	-0.520**	-0.451*	0.058	-0.071
	(3.8)	(3.56)	(5.11)	(-0.14)	(1.00)	(1.59)	(0.38)	(-2.32)	(-1.97)	(0.26)	(-0.31)
Access to extension	0.051	-0.092	-0.030	0.413*	0.329	-0.361	0.098	0.127	-0.193	0.301	0.195
services	(0.2)	(-0.40)	(-0.12)	(1.79)	(1.24)	(-1.44)	(0.35)	(0.54)	(-0.81)	(1.27)	0.80)
Access to market	0.015	0.206	-0.158	-0.359***	-0.450***	-0.147	-0.156	-0.303*	0.053	0.178	-0.230
information	(0.09)	(1.27)	(-0.87)	(-2.44)	(-2.43)	(-0.90)	(-0.76)	(-1.93)	(0.31)	(0.99)	(-1.42)
Income diversification	0.254***	0.056	0.077	0.086	0.006	-0.027	-0.080	0.076	-0.042	-0.050	-0.035
	(2.99)	(0.70)	(0.92)	(1.18)	(0.08)	(-0.35)	(-0.85)	(1.05)	(-0.52)	(-0.56)	(-0.43)

Information on crop	0.070	0.286	0.074	-0.211	0.082	-0.076	0.434*	0.516**8	1.226***	1.265***	-0.826***
agronomic practices	(0.33)	(1.48)	(0.35)	(-1.12)	(0.38)	(-0.37)	(1.88)	(2.77)	(6.06)	(6.31)	(-4.27)
Untimely precipitation	0.236	-0.206	0.302	0.172	-0.382*	-0.175	-0.180	-0.157	-0.498**	-0.158	-0.334
	(1.05)	(-0.98)	(1.38)	(0.87)	(-1.66)	(-0.82)	(-0.68)	(-0.79)	(-2.20)	(-0.62)	(-1.39)
Temperature change	-0.442***	0.178	-0.529***	-0.098	0.304	0.151	0.009	-0.270*	0.246)	0.123	0.066
	(-2.39)	(1.00)	(-2.83)	(-0.61)	(1.52)	(0.87)	(0.04)	(-1.64)	(1.31)	(0.60)	(0.36)
Drought	0.997***	0.669***	1.029***	0.506***	0.018	-0.254*	-0.218	-0.642***	-0.367***	0.054	0.307*
	(5.98)	(4.35)	(6.16)	(3.61)	(0.11)	(-1.66)	(-1.17)	(-4.35)	(-2.34)	(0.31)	(1.94)
Constant	-1.592***	-1.562***	-2.448***	0.046	-1.469***	-1.629***	-1.508***	0.196	-0.943*	-2.141***	1.016**
	(-3.08)	(-3.20)	(-4.66)	(0.10)	(-2.82)	(-3.34)	(-2.58)	(0.44)	(-1.92)	(-3.88)	(2.05)
Log likelihood	**-2375.1003**										
Wald X^2 (165)	**521.57**										
Prob > X^2	**0.0000**										
Observations *(N)*	**475**										

Source: 'author'

***, **, * indicate $p < 0.01$, $p < 0.05$ and $p < 0.1$, respectively; *t-values* are given in parenthesis.

Likelihood ratio test of rho21 = rho31 = ……. = rho32 = rho42 =……. = rho43 = rho53 = ……. = rho54 = rho64 = …….. = rho65 = rho75 =……..= rho76 = rho86 = ……..= rho87 = rho97 = ………. = rho98 = rho108 = ……= rho109 = rho119 = rho1110 = 0: X^2 (55) = 362.927 Prob. > X^2 = 0.0000

Table 7.5: Determinants of household non-farm adaptation strategies by using multivariate probit model

Explanatory variables	Borrowed money (relatives/others)	Relying on assistance from Govt/NGOs	Less food consumption	Shifted to nonfarm employment	Reduction in education level of children	Out-migration to cities
Age (years)	-0.012*	-0.008	0.011	0.009	0.005	-0.004
	(-1.96)	(-0.84)	(1.57)	(1.26)	(0.8)	(-0.51)
Education	-0.133	0.250	0.239	-0.079	0.383***	0.144
	(-0.90)	(1.06)	(1.33)	(-0.47)	(2.45)	(0.85)
Household size (No)	-0.034*	0.016	0.033	0.049**	0.042	0.016
	(-1.62)	(0.59)	(1.46)	(1.99)	(2.05)	(0.67)
Landholding (ha)	-0.032**	-0.004	-0.011	-0.006	-0.009	0.004
	(-2.32)	(-0.20)	(-0.99)	(-0.83)	(-1.12)	(0.8)
Household assets (Rs)	-1.7e-07	-3.7e-07	1.52e-07	3.59e-07	-1.8e-07	4.75e-09
	(-0.73)	(-0.99)	(0.62)	(1.54)	(-0.81)	(0.02)
Livestock ownership (TLUs)	-4.3e-05	0.041***	-0.008	0.001	-0.020**	-2.2E-05
	(-0.23)	(3.96)	(-0.86)	(0.07)	(-2.18)	(-0.04)
Farm income	8.38e-06***	-6.6e-07	3.43e-06	1.09e-06	1.9e-06	-3.9e-06
	(2.62)	(-0.17)	(1.04)	(0.25)	(0.58)	(-1.01)
Farmers' research group	-0.151	0.568**	0.292	-56.867	0.764***	-0.632
	(-0.64)	(2.28)	(1.23)	(-0.07)	(3.23)	(-1.45)
Access to extension services	0.472**	0.735***	1.008***	-1.005***	0.437*	0.103
	(1.98)	(2.38)	(3.67)	(-3.03)	(1.73)	(0.33)
Access to market information	0.046	0.522**	-0.028	-0.063	-0.330**	-0.355*
	(0.29)	(2.21)	(-0.15)	(-0.33)	(-1.98)	(-1.88)
Income diversification	0.086	-0.160	-0.098	-0.221**	0.017	0.019
	(1.14)	(-1.31)	(-1.07)	(-2.38)	(0.22)	(0.22)
Information on crop agronomic practices	-0.183	0.436	-0.065	0.108	-0.372*	-0.582**
	(-0.91)	(1.61)	(-0.28)	(0.46)	(-1.77)	(-2.26)
Untimely precipitation	0.103	-1.101***	-0.017	-0.332	-0.065	0.002

	(0.50)	(-3.30)	(-0.07)	(-1.4)	(-0.31)	(0.01)
Temperature change	-0.037	0.533*	-0.125	0.821***	-0.155	0.073
	(-0.22)	(1.76)	(-0.61)	(4.03)	(-0.89)	(0.39)
Drought	0.463***	0.252	0.472***	0.335*	1.047***	0.317*
	(3.17)	(1.13)	(2.72)	(1.95)	(6.90)	(1.91)
Constant	-0.105	-1.376*	-2.109***	-1.398***	-1.365***	-0.848
	(-0.22)	(-1.91)	(-3.84)	(-2.54)	(-2.81)	(-1.58)
Log likelihood	**-1215.4382**					
Wald X^2 (90)	**346.17**					
Prob > X^2	**0.000**					
Observations *(N)*	**475**					

Source: 'author'

***, **, * indicate $p < 0.01$, $p < 0.05$ and $p < 0.1$, respectively; *t-values* are given in parenthesis.

Likelihood ratio test of rho21 = rho31 =rho41=rho51=rho61= rho32 = rho42 = rho52=rho=62= rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0: $X^2 (15) = 33.0525$ Prob > $X^2 = 0.0046$

7.3.6.1 Age of the respondents

The age is an important factor that characteristically determine the proclivities pertaining to innovation and change. The findings of this study portrayed a positive relationship between age and farm-based adaptation strategies to cope with climate induced anomalies. The relationship is stronger among the more experienced farmers. Nhemachena and Hassan, (2007) also opined that experience in farming increases the probability of acceptance for adaptation measures. Similarly, the findings of present study also corroborate the reported conjectures pertaining to experience in agriculture and adoption of improved agricultural technologies (Sarker et al., 2013; Deressa et al., 2009). Whereas, Shiferaw and Holden (1998) observed a negative association between age and adoption of improved soil conservation practices, while, van Dijl et al. (2015) perceived no significant relationship between age and approval of rainwater harvesting. Besides this, the age have significant imprints on tendencies for borrowing money; migration and on cropping patterns in the study area (Table 7.4 & 7.5).

7.3.6.2 Education

Education play an important role in disseminating awareness about climate change. The knowledge and informed decision making is obligatory for the resilience of agricultural sector. The recent studies depict a positive correlation between education and adoption of climate risk management (Abid et al., 2015; Ali & Erenstein, 2017; Bryan et al., 2013; Deressa et al., 2009; Maddison, 2007; Nhemachena & Hassan, 2018). The finding of this study infer a positive correlation between education and inclinations for irrigated water for fields. However, the Integrated Content Analysis, Pakistan (2017) portrayed a dismal picture about the state of education in the study area. Therefore, focus on the access to universal education is needed. The lack of education and financial limitations are the major obstacles for the socio-economic sustainability of this agro-based contextual setting.

7.3.6.3 Household size

The population density in Chakwal district is approximately more than 10 persons/km^2 (ICA, 2017). The family size in the agrarian rural setting is big across the country. The size of family have strong imprints on the human interactions with the environment. The large sized families are more vulnerable to sudden environmental shocks as compared to small families. Therefore, they strive to safeguard their socio-economic resilience in the face of abrupt climatic instabilities. For the purpose, large sized families try to enhance productivities through improved agricultural inputs and innovations. While, the members of less privileged families switched over to non-farm employment for survival (Table 7.5). However, such families are forced to compromise over essential needs such as food and education of new generation (Table 7.5). The similar conclusions about household size and adaptation strategies were reported by Abid et al., (2015); Ali & Erenstein, (2017); Croppenstedt et al., (2003) and Deressa et al., (2009).

7.3.6.4 Landholding

Land is a major immovable asset of agrarian communities and wealth indicator. Land holding size is not very impressive in the study area as survey revealed that 43% farmers owned up to 2.5 ha of land. The results of multivariate probit analysis showed that farmers with less landholding size maintained poultry/goats and others borrowed money from their friends/relatives and neighbors in the hour of need. Other studies reported positive association between farm size and technology adoption (Abid et al., 2015; Bryan et al., 2013; Tiwari et al., 2009). Farmers with large landholdings are likely to have more capacity to try out and invest in climate risk coping strategies (Ali & Erenstein, 2017).

7.3.6.5 Household assets

In addition to land, moveable assets like television, refrigerator, car, motor bike, cycle, computer etc. also indicates farmers' wealth. Farmers with more worth of household assets tend to leave their land fallow for a year or so. They also leased out part of their land (positively significant relationship). A negative significant correlation was found between this variable and bringing changes to cropping pattern and following improved crop production practices possibly farmers with less worth of fewer household assets tried to sustain their livelihoods through improved agronomic practices. These results are consistent with the findings of Ali and Erenstein (2017).

7.3.6.6 Livestock ownership

The findings transpired that the livestock ownership meaningfully determine the socio-economic conditions in the study area. It characteristically influence the orientations of respondents for financial and technical assistances from government or non-governmental organizations. The farmers with less livestock resources are forced to compromise over the education of their childern. The plausible explanation lies in the fact that the fight against hunger is more important than any other thing. The similar nature of notions were extended by Ashraf et al. (2014) and Ali and Erenstein (2017).

7.3.6.7 Farm income

Farm income have strong imprints on the nature and scale of adaptive measures. Ali and Erenstein, (2017) opined that households with sufficient financial resources are more willing for adopting innovations. The respondents from high farm income groups were motivated for investments in irrigation facilities. Besides this, these were eager to experiment with cropping pattern and to deploy innovative techniques for enhancements in agricultural productivity. These findings are consistent with verdicts reported by Jin et al. (2016) and Ali and Erenstein, (2017). These economically stable segments of rural society are in a comfortable situation to invest for better prospects. The types of initiatives are obligatory for the resilience of agricultural sector. These drives stimulate socio-economic transformations in the agricultural areas for productive outcomes.

7.3.6.8 Farmers' research group

Research productively contribute to cope with climatic oscillations. Bryan et al. (2013) assert that the presence of community-based research groups in agrarian surroundings yield socio-economic dividends for rural communities. The findings infer that only 11% of the respondents are aware about the presence of such groups in the study area. However, these community based consultative/research groups are contributing towards agricultural resilience (Table 4). Their contributions and role towards the uplift of agrarian communities in this contextual setting demand formal recognition. For the purpose, integrated efforts and investments in formal education are obligatory to achieve the objective of socio-economic progressions in the study area.

7.3.6.9 Access to extension services

The findings conjecture about the less impressive role of the Agriculture Extension Department towards agricultural uplift in this area. The lack of coordination, absences of social security networks and fragile economic health of farmers' are the cardinal reasons for observed state of affairs. It is evident from the fact that those having access to extension services, also, borrowed money, compromised over education and food intake, and sought refuge in non-farm based employment during financial stresses. The observations substantiate the reported assertions of Abid et al. (2015) that efforts from the agricultural department in Punjab are not encouraging. While, the studies carried out by Maddison (2007), Nhemachena and Hassan (2007), Deressa et al. (2009) Ali and Erenstein (2017) found positive correlations between the efforts rendered by agricultural institutions and adaptation by agrarian communities. The plausible explanation for the observed variation is rooted in the contextual differences and level of coordination between institutions for integrated efforts.

7.3.6.10 Income diversification

The diverse sources of income significantly contributed towards strategies for the resilience of livelihood. Ashraf et al. (2014) perceived that household income and adaptation strategies are positively correlated. The findings substantiate the notions that the farming communities having diverse sources of income can manage to leave their land fallow for a year or so (positive correlation). Income diversifications smoothens income fluctuations and allows for relatively regular flow of resources to go for innovative strategies but in case of Chakwal District 97% households are dependent on rain-fed agriculture.

7.3.6.11 Access to market information/marketing

The physical connectivity and access to information categorically influenced the perceptions and adaptation strategies of the farmers in the agrarian surroundings. Although, the impediments in the way of farmers' connectivity are disappearing in the study area, yet, the optimal utilization of the available potentials stresses for more integrated efforts. The trickle down effects of these efforts will corroborate the initiatives for socio-economic wellbeing. In the absence of such connectivity, the farmers fail to foster benefits of their efforts. Resultantly, the farmers were forced to compromise over the education of their family, sought jobs in cities, sold livestock and maintained poultry/goats as viable measures to bridge the gap between income and expenditures. These findings substantiate the reported assertions (Abid et al. (2015).

7.3.6.12 Information on crop agronomic practices

Suitable crop agronomic practices enable farmers to cope with climate induced anomalies. This determinant of adaptation strategies was observed positively correlated. Farmers with better knowledge base are more willing to invest in farm infrastructure for better yields. They were observed more willing for changes in cropping patterns; obtaining technical information and getting awareness for better crop productions. While, the illiterate and marginally educated respondents were hesitant to adopt innovations. Besides this, they were assertive about the effectiveness of primitive methods and rely more on experience and traditional knowledge as compared to scientific advancements. It entails focus enhanced focus on education and capacity building for the resilience of agriculture.

7.3.6.13 Untimely precipitation

The uncertain pattern of precipitation forced the farmers to rely on alternative options for survival. The findings depicts that due to such anomalies they are focusing more on improved agronomic practices; maintain poultry and livestock and seek assistance from Govt./NGOs (negative correlation). These results corroborate the reported findings of Deressa et al. (2009) and Abid et al. (2016).

7.3.6.14 Temperature change

The increase in temperature, as perceived by the farmers, has positive association with switching to non-farm employment and relying on assistance from Govt. /NGOs. The assessments based upon coefficient of temperature change portrayed a negative relationship pertaining to the tendencies for fallow land; land leasing and changes in cropping patterns. The similar nature of relation was reported by Deressa et al. (2009).

7.3.6.15 Drought

Due to drought conditions, the assessments portray that farmers experiment changes in sowing times, rely on fallow agricultural mechanisms, sold livestock, sold or leased out part of their land as coping measures. Besides this, they compromise on the family health, education, opt for rural to urban area migration and in some cases look for non-farm employment opportunity as alternatives. Thus, the drought conditions are positively associated with several adaptation strategies in this rain-fed agrarian setting. However, the farming communities are also focusing on improved crop production practices and irrigational facilities to ameliorate the impacts of drought on their lives and livelihood. The similar nature of conclusions were drawn by Ashraf et al. (2014) in their reported findings based on the assessments from the drought-prone areas of Baluchistan province, Pakistan.

7.4 Conclusions

This study analyzed various factors influencing choices of adaptation strategies made by farmers toward climate-induced anomalies. It was found that 96% of the farmers in the study area were feeling climate change and taking several adaptive measures to minimize the actual and potential impacts of climate-related events. From most of the farmers' response based on their experience and perception, it may be concluded that the climate change is posing enormous threat to human health, crops and livestock productivities. There is a strong feeling among the farmers that climatic repercussions are not only making their livelihoods vulnerable but also they lack abilities to cope with the impacts of climate change. Due to poor resource base, lack of knowledge, education and awareness, farmers feel themselves unable to better equip with advanced adaptation strategies leading to unavoidable crop and income losses. Other impediments include but not limited to marketing, institutional support, investment capital, access to farm inputs (seeds, fertilizer, technology etc.), water scarcity, soil erosion etc. All these natural and economic constraints or impediments together with socio-economic vulnerabilities of farmers make the already worse situation susceptible to climatic risks.

From the results of the regression analysis, it is also concluded that factors influencing farmers' adoption of different adaptation strategies also varied. The adaptive strategies followed by farmers were mostly taken in combination with other measures and not alone. The major adaptation options included changing sowing dates, selling their livestock, changing cropping pattern, and compromises on children's education. Farmer's educational status, though not very impressive in the study area was positively and significantly related to providing supplemental irrigation and investment in constructing farm ponds. Farmers having knowledge on better crop agronomic practices also adopted multiple adaptive strategies like invested in farm ponds, brought changes in cropping pattern, followed improved crop production practices and also tried to get additional knowledge on climate risk management strategies. Other factors explaining farmers' choices of adaptation measures include household size, land holding, farm income and perceptions of climate-related events (untimely rains, drought, temperature change etc.).

CHAPTER 8

CONCLUSIONS

AND

RECOMMENDATIONS

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The 21st century has witnessed the distressingly increasing effects of climate change on almost all sectors of society manifested by rising temperature, melting glaciers, intruding seas, erratic rainfall, frequent floods, cyclones and intermittent droughts. Both the global and national security paradigms are at great risk due to devastating impacts of climate-induced anomalies, if required measures to mitigate and adapt to such changes would not be taken both by developed and developing countries. South Asia, being the most vulnerable region due to poor resource-base, technical and financial constraints, inadequate adaptive capacity and above all heavy reliance on climate-sensitive sector like agriculture, warrants urgent actions. Therefore, it is incumbent to carry out research on climate change perception, climate-induced anomalies, vulnerability assessments studies and adaptation measures taken by the rain-fed farming communities in countries like Pakistan, where sizeable majority of the population is dependent on agriculture for their livelihood.

The present study "Vulnerability of agriculture to climate change in Chakwal District: assessment of farmers' adaptation strategies" was designed to evaluate the perceptions of farming community to climatic instabilities and factors influencing the choice of adaptive strategies. The study explored the role of socio-economic factors in shaping the perception of farmers regarding climatic variabilities. It also investigated the impacts of climate-related events on human health, crop and livestock productivities. This thesis provides valuable baseline information necessary to overcome the gaps in research regarding climate change vulnerability studies in Pakistan. The findings of this study will support the concerned authorities in formulating context-based local adaptation plans and interventions. The ultimate goal of this study is to generate knowledge on climate change vulnerability assessment of the rain-fed agriculture, which may be useful in planning for climate compatible development in Potohar Plateau, Punjab Pakistan. From the findings of this study, some conclusions can be drawn.

- **Perception of farmers in the study area about climate change**

Chapter 4 of this study deals with the perception of farmers in the study area about climatic changes. This part of the dissertation focuses on deciphering the impacts of climatic variabilities and role of socio-economic factors in shaping the perception regarding the climate-related events. The findings indicate that farm households are exposed to various climatic risks and highly dependent on access to resources, institutional settings, and geographic locations for their resilience and adaptive ability. Secondly, awareness of climate change is common throughout the study area, and in most cases the expectations of farmers are well matched with scientific climate data of the study area.

- **Spatial-temporal variations in land use land cover (LULC)**

This study evaluates the impacts of spatial-temporal variations in the phenomena of agriculture on the land use land cover (LULC) changes. It also tries to decipher the causes and impulses responsible for the observed tendencies in the LULC patterns of Chakwal District. The outcomes established that the clarity in the land management policy and its compliance is indispensable to ensure sustainable use of land resources. Further, the complexities of land use and land cover must be more thoroughly investigated in the light of climate change or any other drivers involved.

- **Household social vulnerability to climatic variabilities in the study area**

The vulnerability assessments are obligatory to insulate the farming sector from the impacts of climate change. The index method in conjunction with GIS proved vibrant options for vulnerability assessment. The results of the assessment formulated that coordinated efforts are needed to protect the agriculture sector from the ensuing impacts of climate change. The awareness and capacity building of the stakeholders, based upon the contextual needs and potential, are required that will productively contribute towards the best use of available resources in agrarian settings. Albeit, this study has its own limitations as the vulnerability assessment tools have time and context specific implications. However, the empirical findings of the study will fulfill the needs for baseline information. The postulations of the study will complement the efforts meant to ensure the resilience of rain-fed agriculture in the face of climate change.

- **Determinants of adaptation strategies in the face of climate change**

Climate change adaptation in Chakwal District is limited, and farmers only consider less costly and short-term steps such as changing sowing dates, selling their livestock and sacrificing their children's education etc. Finally, the perception and adaptation of climate change are heavily influenced by socio-economic factors (education, farm income, household size, land holdings) and access to institutional services (extension, marketing data).

Agricultural and metrological institutions are not adequately assisting farmers in responding to climate change and are finding several systemic gaps that need to be filled up urgently in the current institutional environment. However, community programs and informal farming initiatives are promising for local adaptation at the farm level and need to be supported by increased funding from institutions of the public and private sectors. Due to indirect effects of climate change on rural livelihoods, the increasing pattern of migration among existing farmers and land borrowing in rural areas needs to be attended by developing effective policies and adaptation plans at different scales.

8.2 Recommendations

Policy recommendations cover various scales, such as at international, regional and national level. Efforts to reduce greenhouse gas emissions and mitigate adverse impacts of climate change are beneficial at international and regional level. It is promising to expand assistance to developing and emerging countries for mitigating and adapting to climate change vulnerabilities.

Mitigation and adaptation to climate change requires consensus at national level for various sectors like agriculture. Notably, adaptation policies need to be developed in the agricultural sector depends on the vulnerability of rain-fed farming communities and livelihoods to climate change in different regions, variations in socio-economic conditions and forms of contextual agro-ecological settings. It is pertinent to mention here that rain-fed agriculture demands adaptation policies, plans and technologies different from irrigated agriculture. Therefore, it is incumbent to raise awareness at farm level so that doable actions pertaining to climate change and adaptive ability needs to be increased in addition through enhanced access to resources and institutional support. In this context, current extension and credit programs must be updated to include workable solutions on climate change and adaptation by making them their integral. In this context, collaborations, coordination, coherence and partnerships between public and private institutions and rural communities may be helpful in devising adaptation plans at the grassroots level and climate change resilience. Failure to implement successful agricultural adaptation plans that increase the vulnerability of farm households to climate change and may affect growth and food security in local and national agriculture. Hence, following recommendations are made to improve the overall situation in the area of study based on the findings of this report.

Sustainable agriculture holds the key to many problems concerning dry land. Urgent agricultural action will help build food and water security and alleviate the negative consequences of climate change. Farmers and other players in supply chains for food production may make important contributions to sustainable food and water protection, provided they have access to technology and support to help them adapt their practices to address changing weather patterns.

8.2.1 Policy recommendations

Following policy measures are suggested based on the findings of the current study.

a) Integrated policy for addressing water shortage, water availability and storage that will be critical to overcoming dry spells in the short and long term.
b) Promoting the efficiency of water use for increased productivity, which will also help to reduce GHG emissions by curbing the need for agricultural land conversions.
c) Create an early warning system and insurance to create targeted safety nets for farmers who are unable to adjust quickly, provide reliable asset loss protection and promote rapid recovery;
d) Ensure that water management strategies to support changes in crop and land use patterns are tailored to local needs and secure carbon storage that would

otherwise emit or remain in the atmosphere, despite animals emitting methane from enteric fermentation.

8.2.2 Research recommendations

Based on the findings of this thesis, suggestions for further research are given for following key areas.

1. Given the socioeconomic and institutional constraints, there is a need to investigate how to enhance local adaptive capacities and the access of farmers to advanced adaptation measures.
2. Can some study be conducted on how to transform local institutions to deliver better services to farmers aimed at enhancing climate change adaptation at the farm level?
3. There is also a need for policy research on how to modify existing policies based on research on the ground to meet current needs and challenges?
4. The use of social capital to increase the access of farmers to on-farm services and to boost agricultural productivity should also be explored given the changing environmental conditions.
5. Given the resource constraints of farming communities, what are the cost-effective adaptation options that could be developed?

REFERENCES

REFERENCES

Abas, N., Kalair, A., Khan, N., & Kalair, A. R. (2017). Review of GHG emissions in Pakistan compared to SAARC countries. *Renewable and Sustainable Energy Reviews*, *80*(January 2016), 990–1016. https://doi.org/10.1016/j.rser.2017.04.022

Abdur Rashid Sarker, M., Alam, K., & Gow, J. (2013). Assessing the determinants of rice farmers' adaptation strategies to climate change in Bangladesh. *International Journal of Climate Change Strategies and Management*, *5*(4), 382–403. https://doi.org/10.1108/IJCCSM-06-2012-0033

Abid, M., Scheffran, J., Schneider, U. A., & Ashfaq, M. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: The case of Punjab province, Pakistan. *Earth System Dynamics*, *6*(1), 225–243. https://doi.org/10.5194/esd-6-225-2015

Abid, Muhammad, Scheffran, J., Schneider, U. A., & Elahi, E. (2019). Farmer Perceptions of Climate Change, Observed Trends and Adaptation of Agriculture in Pakistan. *Environmental Management*, *63*(1), 110–123. https://doi.org/10.1007/s00267-018-1113-7

Abid, Muhammad, Schneider, U. A., & Scheffran, J. (2016). Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. *Journal of Rural Studies*, *47*, 254–266. https://doi.org/10.1016/j.jrurstud.2016.08.005

Acheampong, E. N., Ozor, N., & Owusu, E. S. (2014). Vulnerability assessment of Northern Ghana to climate variability. *Climatic Change*, *126*(1–2), 31–44. https://doi.org/10.1007/s10584-014-1195-z

ADB (Asian Development Bank). (2017). *Climate change profile of Pakistan*. Pakistan.

Aggarwal, P. K., & Sivakumar, M. V. K. (2010). Global Climate Change and Food Security in South Asia: An Adaptation and Mitigation Framework. In *Climate Change and Food Security in South Asia*. https://doi.org/10.1007/978-90-481-9516-9_16

Ahmad, G. (2001). Mapping a Dry Shrub Forest for Biodiversity Mapping a Dry Shrub Forest for Biodiversity. *Distribution*.

Ahmed, M., & Ogtrop, F. F. Van. (2014). Can models help to forecast rainwater dynamics for rainfed ecosystem ? *Weather and Climate Extremes*, *5–6*, 48–55. https://doi.org/10.1016/j.wace.2014.07.001

Al-Bakri, J., Suleiman, A., Abdulla, F., & Ayad, J. (2011). Potential impact of climate change on rainfed agriculture of a semi-arid basin in Jordan. *Physics and Chemistry of the Earth*, *36*(5–6), 125–134. https://doi.org/10.1016/j.pce.2010.06.001

Alayón-Gamboa, J. A., & Ku-Vera, J. C. (2011). Vulnerability of smallholder agriculture in Calakmul, Campeche, Mexico. *Indian Journal of Traditional Knowledge*, *10*(1), 125–132.

Aleksandrova, M., Gain, A. K., & Giupponi, C. (2016). Assessing agricultural systems vulnerability to climate change to inform adaptation planning: an application in Khorezm, Uzbekistan. *Mitigation and Adaptation Strategies for Global Change*, *21*(8), 1263–1287. https://doi.org/10.1007/s11027-015-9655-y

Ali, A., & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management*, *16*, 183–194. https://doi.org/10.1016/j.crm.2016.12.001

Arif, R., Idrees, I., Rehman, A., & Saeed, B. A. (2017). *Climate Change Vulnerability Assessment Toolkit*.

Arshad, M., Kächele, H., Krupnik, T. J., Amjath-Babu, T. S., Aravindakshan, S., Abbas, A., … Müller, K. (2017). Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. *International Journal of Sustainable Development and World Ecology*, *24*(6), 532–544. https://doi.org/10.1080/13504509.2016.1254689

Ashraf, M. (2014). Promising Land and Water Management Practices: A Manual. Country Office, Pakistan: International Centre for Agricultural Research in Dry Areas (ICARDA).

Ashraf, M., Routray, J. K., & Saeed, M. (2014). Determinants of farmers' choice of coping and adaptation measures to the drought hazard in northwest Balochistan, Pakistan. *Natural Hazards*, *73*(3), 1451–1473. https://doi.org/10.1007/s11069-014-1149-9

Asrat, P., & Simane, B. (2018). Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecological Processes*, *7*(1). https://doi.org/10.1186/s13717-018-0118-8

Atif, S. B., Saqib, Z., Ali, A., & Zaman, M. H. (2018). The impacts of socio-economic factors on the perception of residents about urban vegetation: A comparative study of planned versus semi-planned cities of Islamabad and Rawalpindi, Pakistan. *Applied Ecology and Environmental Research*, *16*(4), 4265–4287. https://doi.org/10.15666/aeer/1604_42654287

Ayanlade, A., Radeny, M., & Morton, J. F. (2017). Comparing smallholder farmers' perception of climate change with meteorological data: A case study from southwestern Nigeria. *Weather and Climate Extremes*, *15*(September 2016), 24–33. https://doi.org/10.1016/j.wace.2016.12.001

Aydogdu, M. H., & Yenigün, K. (2016). Farmers' risk perception towards climate change: A case of the GAP-Şanliurfa Region, Turkey. *Sustainability (Switzerland)*, *8*(8). https://doi.org/10.3390/su8080806

Bandara, J. S., & Cai, Y. (2014). The impact of climate change on food crop productivity, food prices and food security in South Asia. *Economic Analysis and Policy*, *44*(4), 451–465. https://doi.org/10.1016/j.eap.2014.09.005

Barrucand, M. G., Giraldo Vieira, C., & Canziani, P. O. (2017). Climate change and its impacts: perception and adaptation in rural areas of Manizales, Colombia. *Climate and Development*, *9*(5), 415–427. https://doi.org/10.1080/17565529.2016.1167661

Belderbos, R., Carree, M., Diederen, B., Lokshin, B., & Veugelers, R. (2004).

Heterogeneity in R&D cooperation strategies. *International Journal of Industrial Organization*, *22*(8–9), 1237–1263. https://doi.org/10.1016/j.ijindorg.2004.08.001

Bouroncle, C., Läderach, P., Martinez-Valle, A., Rodríguez-Sánchez, B., Medellín, C., & Imbach, P. (2016). Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies. *Climatic Change*, *141*(1), 123–137. https://doi.org/10.1007/s10584-016-1792-0

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy*, *12*(4), 413–426. https://doi.org/10.1016/j.envsci.2008.11.002

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., & Herrero, M. (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, *114*, 26–35. https://doi.org/10.1016/j.jenvman.2012.10.036

Butt, A., Shabbir, R., Ahmad, S. S., & Aziz, N. (2015). Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. *Egyptian Journal of Remote Sensing and Space Science*, *18*(2), 251–259. https://doi.org/10.1016/j.ejrs.2015.07.003

Cai, Y., Bandara, J. S., Newth, D., & Asia, S. (2016). Environmental Modelling & Software A framework for integrated assessment of food production economics in South Asia under climate change. *Environmental Modelling and Software*, *75*, 459–497. https://doi.org/10.1016/j.envsoft.2015.10.024

Change, C., & Security, F. (2013). Climate Change Brief, (October).

Chaudhary, Q.-Z., Mahmood, A., Rasul, G., & Afzaal, M. (2009). *Climate change indicators of Pakistan. Technical Report No. 22/2009.*

Chaudhry, Q. U. Z. (2017). *Climate change profile of Pakistan*. *Asian Development Bank* (Vol. 23). https://doi.org/10.1177/103530461202300301

Chen, X., Wang, L., Liu, H.-L., Willems, P., & Bao, A.-M. (2015). Effect of climate change on the vulnerability of a socio-ecological system in an arid area. *Global and Planetary Change*, *137*, 1–9. https://doi.org/10.1016/j.gloplacha.2015.12.014

Choudri, B. S., Al-Busaidi, A., & Ahmed, M. (2013). Climate change, vulnerability and adaptation experiences of farmers in Al-Suwayq Wilayat, Sultanate of Oman. *International Journal of Climate Change Strategies and Management*, *5*(4), 445–454. https://doi.org/10.1108/IJCCSM-11-2012-0061

CIAT:FAO. (2018). *Climate-Smart Agriculture for Punjab , Pakistan. CSA Counry Profiles for Asia Series. International Centre for Tropical Agriculture (CIAT),.*

Croppenstedt, A., Demeke, M., & Meschi, M. M. (2003). Technology adoption in the presence of constraints: The case of fertilizer demand in Ethiopia. *Review of Development Economics*, *7*(1), 58–70. https://doi.org/10.1111/1467-9361.00175

De Sherbinin, A. M. (2014). Mapping the unmeasurable? https://doi.org/10.3990/1.9789036538091

Derbile, E. K., File, D. J. M., & Dongzagla, A. (2016). The double tragedy of agriculture vulnerability to climate variability in Africa: How vulnerable is smallholder agriculture to rainfall variability in Ghana? *Jàmbá: Journal of Disaster Risk Studies, 8*(3), 1–9. https://doi.org/10.4102/jamba.v8i3.249

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Devendra, C. (n.d.). *Climate Change Threats and Effects: Challenges for Agriculture and Food Security*.

Dissanayake, S., Asafu-Adjaye, J., & Mahadeva, R. (2017). Addressing climate change cause and effect on land cover and land use in South Asia. *Land Use Policy*, *67*(June), 352–366. https://doi.org/10.1016/j.landusepol.2017.06.003

Eakin, H. (2003). the social vulnerability of irrigated vegetable farming households in Central Puebla. *The Journal of Environment and Development*, *12*(4), 414–429. https://doi.org/https://doi.org/10.1177%2F1070496503257733

Elum, Z. A., Modise, D. M., & Marr, A. (2017). Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. *Climate Risk Management*, *16*, 246–257. https://doi.org/10.1016/j.crm.2016.11.001

Eniolorunda, N. B., Mashi, S. A., & Nsofor, G. N. (2017). Toward achieving a sustainable management: characterization of land use/land cover in Sokoto Rima floodplain, Nigeria. *Environment, Development and Sustainability*, *19*(5), 1855–1878. https://doi.org/10.1007/s10668-016-9831-6

ESCAP. (2013). *Economic and Social Survey of Asia and the Pacific*.

FAO-UN. (2019). *Climate-Smart Agriculture for Punjab, Pakistan*.

FAO. (2014). *Land cover atlas of Pakistan: The Punjab Province*.

FAO. (2015). *FAOSTAT*, *2015. Database for Database for Wheat Crop, Pakistan.* Rome, Italy. Retrieved from http://www.fao.org/faostat/en/#data/QC

FAO. (2016). *Climate change and food security: Risks and responses*. *Food and Agriculture Organization of the United Nations*. https://doi.org/10.1080/14767058.2017.1347921

FAO, Prikhodko, D., & Zrilyi, O. (2013). *Pakistan: Review of the wheat sector and grain storage issues*. Rome.

Füssel, H. M., & Klein, R. J. T. (2006). Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic Change*, *75*(3), 301–329. https://doi.org/10.1007/s10584-006-0329-3

Gbetibouo, G. A., Ringler, C., & Hassan, R. (2010). Vulnerability of the South African farming sector to climate change and variability: An indicator approach. *Natural Resources Forum*, *34*(3), 175–187. https://doi.org/10.1111/j.1477-8947.2010.01302.x

Ghimire, Y. N., Shivakoti, G. P., & Perret, S. R. (2010). Household-level vulnerability to drought in hill agriculture of Nepal: Implications for adaptation planning.

International Journal of Sustainable Development and World Ecology, *17*(3), 225–230. https://doi.org/10.1080/13504501003737500

GoP. (2000). *District Census Report of Chakwal-1998.*

GoP. (2017a). *Economic Survey of Pakistan (2017-18)*. Islamabad, Pakistan.

GoP. (2017b). *Integrated Context Analysis (ICA) on Vulnerability to Food Insecurity and Natural Hazards, Pakistan.*

GoP. (2018). Punjab Agriculture Policy.

GOP. (2010). *Agriculture Census of Punjab 2010.*

GOP. (2017). *Punjab Development Statistics 2017*.

GOP. (2018). *Punjab Agriculture Policy 2018*.

GOP. (2019). *Pakistan Economic Survey*. *Economic Adviser's Wing, Finance Division, Government of Pakistan, Islamabad*. https://doi.org/10.1038/479299e

Gorst, A., Dehlavi, A., & Groom, B. (2018). Crop productivity and adaptation to climate change in Pakistan. *Environment and Development Economics*, *23*(6), 679–701. https://doi.org/10.1017/S1355770X18000232

Govt. of Pak, & UNEP. (2017). Pakistan National Action Plan on SDG 12 Sustainable Consumption and Production. *Ministry of Climate Change, Government of Pakistan*, 96. Retrieved from http://www.oneplanetnetwork.org/sites/default/files/final_nap_report_aug_2017.pdf

Greene, W. H. (2003). *Econometric analysis* (4th editio). New Jersey: Prentice-Hall.

Harvey, C. A., Rakotobe, Z. L., Rao, N. S., Dave, R., Razafimahatratra, H., Rabarijohn, R. H., … MacKinnon, J. L. (2014). Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639), 20130089–20130089. https://doi.org/10.1098/rstb.2013.0089

Hereher, M. E. (2017). Effect of land use/cover change on land surface temperatures - The Nile Delta, Egypt. *Journal of African Earth Sciences*, *126*, 75–83. https://doi.org/10.1016/j.jafrearsci.2016.11.027

Hinkel et al. (2010). *Review of methodologies for assessing vulnerability – Report submitted to GTZ in the context of the project Climate Change Adaptation in Rural Areas of India*.

Hinkel, J., Schipper, L., & Wolf, S. (2014). *A framework for climate change vulnerability assessments*.

Hisali, E., Birungi, P., & Buyinza, F. (2011). Adaptation to climate change in Uganda: Evidence from micro level data. *Global Environmental Change*, *21*(4), 1245–1261. https://doi.org/10.1016/j.gloenvcha.2011.07.005

Hu, Y., Dong, Y., & Batunacun. (2018). An automatic approach for land-change detection and land updates based on integrated NDVI timing analysis and the CVAPS method with GEE support. *ISPRS Journal of Photogrammetry and Remote Sensing*, *146*(February), 347–359.

https://doi.org/10.1016/j.isprsjprs.2018.10.008

Huang, H., Chen, Y., Clinton, N., Wang, J., Wang, X., Liu, C., … Zhu, Z. (2017). Mapping major land cover dynamics in Beijing using all Landsat images in Google Earth Engine. *Remote Sensing of Environment*, *202*, 166–176. https://doi.org/10.1016/j.rse.2017.02.021

Hussain, A. (2014). Forecasting Wheat Production Gaps to Assess the State of Future Food Security in Pakistan. *Journal of Food & Nutritional Disorders*, *03*(03). https://doi.org/10.4172/2324-9323.1000146

Hussain, S. S., & Mudasser, M. (2007). Prospects for wheat production under changing climate in mountain areas of Pakistan - An econometric analysis. *Agricultural Systems*, *94*(2), 494–501. https://doi.org/10.1016/j.agsy.2006.12.001

Intercooperation. (2006). *Dryland management: A perspective for livelihood improvement in rural areas, experiences from Pakistan*.

IPCC. (2014a). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Annex II - Glossary. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA*, 1757–1776.

IPCC. (2014b). *Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from http://www.tandfonline.com/doi/abs/10.4155/cmt.13.80*.

IPCC. (2018a). IPCC Special Report 1.5 - Summary for Policymakers. In *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,*. https://doi.org/10.1017/CBO9781107415324

IPCC. (2018b). Special Report on 1.5 degrees: Summary for Policymakers. Retrieved from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

Islam, Z., Alauddin, M., & Sarker, M. A. R. (2017). Determinants and implications of crop production loss: An empirical exploration using ordered probit analysis. *Land Use Policy*, *67*(June), 527–536. https://doi.org/10.1016/j.landusepol.2017.06.021

Janjua, P. Z., Samad, G., & Khan, N. (2014). Climate change and wheat production in Pakistan: An autoregressive distributed lag approach. *NJAS - Wageningen Journal of Life Sciences*, *68*, 13–19. https://doi.org/10.1016/j.njas.2013.11.002

Jiao, X., & Moinuddin, H. (2016). Operationalizing analysis of micro-level climate change vulnerability and adaptive capacity. *Climate and Development*, *8*(1), 45–57. https://doi.org/10.1080/17565529.2014.989191

Jin, J., Wang, W., & Wang, X. (2016). Adapting agriculture to the drought hazard in rural China: household strategies and determinants. *Natural Hazards*, *82*(3), 1609–1619. https://doi.org/10.1007/s11069-016-2260-x

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A., & Lindquist, E. (2015). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*, 9–20.

https://doi.org/10.1016/j.foreco.2015.06.014

Kennedy, R. E., Yang, Z., Gorelick, N., Braaten, J., Cavalcante, L., Cohen, W. B., & Healey, S. (2018). Implementation of the LandTrendr algorithm on Google Earth Engine. *Remote Sensing*, *10*(5), 1–10. https://doi.org/10.3390/rs10050691

Keshavarz, M., Maleksaeidi, H., & Karami, E. (2017). Livelihood vulnerability to drought: A case of rural Iran. *International Journal of Disaster Risk Reduction*, *21*(August 2016), 223–230. https://doi.org/10.1016/j.ijdrr.2016.12.012

Lal, M. (2011). Implications of climate change in sustained agricultural productivity in South Asia. *Regional Environmental Change*, *11*(SUPPL. 1), 79–94. https://doi.org/10.1007/s10113-010-0166-9

LEE, Y.-J. (2017). A Synthesized Vulnerability Assessment: Case Study of Biophysical and Social Vulnerability in Taitung County, Taiwan. *DEStech Transactions on Environment, Energy and Earth Science*, (eccsd). https://doi.org/10.12783/dteees/eccsd2016/5845

Li, X., Philp, J., Cremades, R., Roberts, A., He, L., Li, L., & Yu, Q. (2015). Agricultural vulnerability over the Chinese Loess Plateau in response to climate change: Exposure, sensitivity, and adaptive capacity. *Ambio*, *45*(3), 350–360. https://doi.org/10.1007/s13280-015-0727-8

Li, Y., Xiong, W., Hu, W., Berry, P., Ju, H., Lin, E., … Pan, J. (2014). Integrated assessment of China's agricultural vulnerability to climate change: a multi-indicator approach. *Climatic Change*, *128*(3–4), 355–366. https://doi.org/10.1007/s10584-014-1165-5

Lin, C. T. J., Jensen, K. L., & Yen, S. T. (2005). Awareness of foodborne pathogens among US consumers. *Food Quality and Preference*, *16*(5), 401–412. https://doi.org/10.1016/j.foodqual.2004.07.001

Liu, H. L., Willems, P., Bao, A. M., Wang, L., & Chen, X. (2016). Effect of climate change on the vulnerability of a socio-ecological system in an arid area. *Global and Planetary Change*, *137*, 1–9. https://doi.org/10.1016/j.gloplacha.2015.12.014

Maddison, D. (2007). *the perception of and adaptation to climate change in Africa*. https://doi.org/10.1596/1813-9450-4308

Mallari, & Ezra, C. A. (2016). Climate Change Vulnerability Assessment in the Agriculture Sector: Typhoon Santi Experience. *Procedia - Social and Behavioral Sciences*, *216*(October 2015), 440–451. https://doi.org/10.1016/j.sbspro.2015.12.058

Mase, A. S., Gramig, B. M., & Prokopy, L. S. (2017). Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern U.S. crop farmers. *Climate Risk Management*, *15*, 8–17. https://doi.org/10.1016/j.crm.2016.11.004

Mashame, G., & Akinyemi, F. (2016). Towards a remote sensing based assessment of land susceptibility to degradation: examining seasonal variation in land use-land cover for modelling land degradation in a semi-arid context. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *3*(July), 137–144. https://doi.org/10.5194/isprs-annals-III-8-137-2016

Mckhann, H. (2012). *Agriculture Food Security and Climate Change*.

Mertz, O., Sandholt, I., Lambin, E. F., Nielsen, J. Ø., Genesio, L., Diouf, A., … Zorom, M. (2011). Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa. *Atmospheric Science Letters*, *12*(1), 104–108. https://doi.org/10.1002/asl.314

Midekisa, A., Holl, F., Savory, D. J., Andrade-Pacheco, R., Gething, P. W., Bennett, A., & Sturrock, H. J. W. (2017). Mapping land cover change over continental Africa using Landsat and Google Earth Engine cloud computing. *PLoS ONE*, *12*(9), 1–15. https://doi.org/10.1371/journal.pone.0184926

Mu, J. E., Sleeter, B. M., Abatzoglou, J. T., & Antle, J. M. (2017). Climate impacts on agricultural land use in the USA: the role of socio-economic scenarios. *Climatic Change*, *144*(2), 329–345. https://doi.org/10.1007/s10584-017-2033-x

Murthy, C. S., Laxman, B., & Sesha Sai, M. V. R. (2015). Geospatial analysis of agricultural drought vulnerability using a composite index based on exposure, sensitivity and adaptive capacity. *International Journal of Disaster Risk Reduction*, *12*, 163–171. https://doi.org/10.1016/j.ijdrr.2015.01.004

Nagayets, O. (2005). Small Farms: Current Status and Key Trends. *Information Brief*, 1–14.

NCCP. (2012). National Climate Change Policy of Pakistan 2012, (September), 47.

Ndamani, F., & Watanabe, T. (2016). Determinants of farmers' adaptation to climate change: A micro level analysis in Ghana. *Scientia Agricola*, *73*(3), 201–208. https://doi.org/10.1590/0103-9016-2015-0163

NDMA. (2017). Integrated Context Analysis (ICA) on Vulnerability to Food Insecurity and Natural Hazards. National Disaster Management Authority. Government of Pakistan.

Nhemachena, C., & Hassan, R. (2018). Micro-Level Analysis of Farmers ' Adaptation to Climate Change in Southern Africa Micro-Level Analysis of Farmers ' Adaptation to Climate Change in Southern Africa Charles Nhemachena , Centre for Environmental Economics and Policy in Africa (CEEPA), (February 2007).

Olmos, S. (2001). *Vulnerability and adaptation to climate change: concepts, issues, assessment methods*.

Oweis, T., & Ashraf, M. (2014). *Assessment and Options for Improved Productivity and Sustainability of Natural Resources in Dhrabi Watershed Pakistan*.

Pachauri, R. K., & Meyer, L. (2014). *Climate Change 2014: Synthesis Report. Intergovernmental Panel on Climate Change*. *Geneva, Switzerland*. https://doi.org/10.1017/CBO9781107415324

Pak-INDC. (2016). *Pakistan Intended Nationally Determined Contribution*. Pakistan. Retrieved from https://www4.unfccc.int/sites/ndcstaging/.../Pakistan First/Pak-INDC.pdf

Pan, X., Dong, Z., Zhang, J., He, D., Han, H., Wang, L., … An, P. (2014). A novel method for quantitatively evaluating agricultural vulnerability to climate change. *Ecological Indicators*, *48*, 49–54. https://doi.org/10.1016/j.ecolind.2014.07.032

PDMA. (2008). Disaster Risk Management Plan Punjab, 1–89. Retrieved from http//www.ndma.gov.pk

Pedrick, C. (2012). *Strategies for Combating Climate Change in Drylands Agriculture. International Conference on Food Security in Dry Lands, Doha, Qatar*. Retrieved from http://hdl.handle.net/10568/24913

Prikhodko, D. & Zrilyi, O. (2013). *Pakistan: Review of the Wheat Sector and Grain Storage Issues Country Highlights. Rome.* Rome, Italy.

Qasim, M., Bakhsh, K., Tariq, S. A., Nasir, M., Saeed, R., & Mahmood, M. A. (2016). Factors Affecting Groundnut Yield in Pothwar Region of, *29*(1).

Qureshi, R. H., & Ashraf, M. (2019). *Water Security Issues of Agriculture in Pakistan*.

Ramachandran, K., & Rao, C. S. (2016). A district level assessment of vulnerability of Indian agriculture to climate change. *Current Science*, *110*(10), 1939–1946. https://doi.org/10.18520/cs/v110/i10/1939-1946

REMA. (2015). Baseline climate change vulnerability index for Rwanda, 88.

Richter, D. (2010). Mapping vulnerability to climate change in Santiago de Chile, (December), 133. Retrieved from http://othes.univie.ac.at/11511/1/2010-10-06_0307635.pdf

Ringler, C. (2010). Climate Change and Hunger: Africa's Smallholder Farmers Struggle to Adapt. *EuroChoices*, *9*(3), 16–21. https://doi.org/10.1111/j.1746-692X.2010.00175.x

Roncoli, C., Ingram, K., & Kirshen, P. (2002). Reading the rains: Local knowledge and rainfall forecasting in Burkina Faso. *Society and Natural Resources*, *15*(5), 409–427. https://doi.org/10.1080/08941920252866774

Salman, A., Husnain, M. I. ul, Jan, I., Ashfaq, M., Rashid, M., & Shakoor, U. (2018). Farmers' Adaptation to Climate Change in Pakistan: Perceptions, Options and Constraints. *Sarhad Journal of Agriculture*, *34*(4). https://doi.org/10.17582/journal.sja/2018/34.4.963.972

Senbeta, a F. (2009). Climate Change Impact on Livelihood, Vulnerability and Coping Mechanisms: A Case Study of West-Arsi Zone, Ethiopia. *Lund University International Master's Programme in Environmental Studies and Sustainability Science, MSc*, 54.

Shiferaw, B., & Holden, S. T. (1998). Resource Degradation and Adoption of Land Conservation Technologies by Smallholders in the Ethiopian Highlands : By. *Agricultural Economics*.

Tesfahunegn, G. B., Mekonen, K., & Tekle, A. (2016). Farmers' perception on causes, indicators and determinants of climate change in northern Ethiopia: Implication for developing adaptation strategies. *Applied Geography*, *73*, 1–12. https://doi.org/10.1016/j.apgeog.2016.05.009

Thoai, T. Q., Rañola, R. F., Camacho, L. D., & Simelton, E. (2018). Determinants of farmers' adaptation to climate change in agricultural production in the central region of Vietnam. *Land Use Policy*, *70*(November 2017), 224–231. https://doi.org/10.1016/j.landusepol.2017.10.023

Tiwari, V. M., Wahr, J., & Swenson, S. (2009). Dwindling groundwater resources in northern India, from satellite gravity observations. *Geophysical Research Letters*, *36*(18), 1–5. https://doi.org/10.1029/2009GL039401

Tran, H., Nguyen, Q., & Kervyn, M. (2017). Household social vulnerability to natural hazards in the coastal Tran Van Thoi District, Ca Mau Province, Mekong Delta, Vietnam. *Journal of Coastal Conservation*, *21*(4), 489–503. https://doi.org/10.1007/s11852-017-0522-8

Tran, H., Tran, T., & Kervyn, M. (2015). Dynamics of land cover/land use changes in the Mekong Delta, 1973-2011: A Remote sensing analysis of the Tran Van Thoi District, Ca Mau Province, Vietnam. *Remote Sensing*, *7*(3), 2899–2925. https://doi.org/10.3390/rs70302899

Ullah, W., Nihei, T., Nafees, M., Zaman, R., & Ali, M. (2018). Understanding climate change vulnerability , adaptation and risk perceptions at household level in Khyber Pakhtunkhwa , Pakistan. https://doi.org/10.1108/IJCCSM-02-2017-0038

van Dijl, E. A., Grogan, K. A., & Borisova, T. (2015). Determinants of adoption of drought adaptations among vegetable growers in Florida. *Journal of Soil and Water Conservation*, *70*(4), 218–231. https://doi.org/10.2489/jswc.70.4.218

Wang, B., Pan, S. Y., Ke, R. Y., Wang, K., & Wei, Y. M. (2014). An overview of climate change vulnerability: A bibliometric analysis based on Web of Science database. *Natural Hazards*, *74*(3), 1649–1666. https://doi.org/10.1007/s11069-014-1260-y

Weber, E. U. (2010). What shapes perceptions of climate change ?, *1*(June), 332–342. https://doi.org/10.1002/wcc.41

WFP (World Food Program). (2017). *Integrated Content Analysis (ICA) on Vulnerability to Food Insecurity and Natural Hazards*. Government of Pakistan.

WFP (World Food Program). (2018). *Climate Risks and Food Security Analysis: A Special Report for Pakistan*. Islamabad, Pakistan.

Wiréhn, L., Danielsson, Å., & Neset, T. S. S. (2015). Assessment of composite index methods for agricultural vulnerability to climate change. *Journal of Environmental Management*, *156*, 70–80. https://doi.org/10.1016/j.jenvman.2015.03.020

Woods, B. A., Nielsen, H. Ø., Pedersen, A. B., & Kristofersson, D. (2017). Farmers' perceptions of climate change and their likely responses in Danish agriculture. *Land Use Policy*, *65*(May 2015), 109–120. https://doi.org/10.1016/j.landusepol.2017.04.007

Wu, J. J., Geng, G. P., Zhou, H. K., Liu, J. H., Wang, Q. F., & Yang, J. H. (2017). Global vulnerability to agricultural drought and its spatial characteristics. *Science China Earth Sciences*, *60*(5), 910–920. https://doi.org/10.1007/s11430-016-9018-2

Xiong, J., Thenkabail, P. S., Gumma, M. K., Teluguntla, P., Poehnelt, J., Congalton, R. G., … Thau, D. (2017). Automated cropland mapping of continental Africa using Google Earth Engine cloud computing. *ISPRS Journal of Photogrammetry and Remote Sensing*, *126*, 225–244. https://doi.org/10.1016/j.isprsjprs.2017.01.019

Yin, H., Pflugmacher, D., Li, A., Li, Z., & Hostert, P. (2018). Land use and land cover change in Inner Mongolia - understanding the effects of China's re-vegetation programs. *Remote Sensing of Environment*, *204*(August 2017), 918–930. https://doi.org/10.1016/j.rse.2017.08.030

Yiran, G. A. B., Stringer, L. C., Attua, E. M., Evans, A. J., Challinor, A. J., & Gyasi, E. A. (2017). Mapping vulnerability to multiple hazards in the savannah Ecosystem in Ghana. *Regional Environmental Change*, *17*(3), 665–676. https://doi.org/10.1007/s10113-016-1054-8

Zahid, M., & Rasul, G. (2012). Changing trends of thermal extremes in Pakistan. *Climatic Change*. https://doi.org/10.1007/s10584-011-0390-4

Zia, S., Khan, F., & Rehman, S. (2015). *Gender, Climate Change and Adaptation: A study in the selected villages of North Punjab, Pakistan*. Retrieved from https://doi.org/10.13140/RG.2.1.3008.7847

Ziervogel, G., Bharwani, S., & Downing, T. E. (2006). Adapting to climate variability: Pumpkins, people and policy. *Natural Resources Forum*, *30*(4), 294–305. https://doi.org/10.1111/j.1477-8947.2006.00121.x

Žurovec, O., Čadro, S., & Sitaula, B. K. (2017a). Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina. *Sustainability (Switzerland)*, *9*(7), 1–18. https://doi.org/10.3390/su9071208

Žurovec, O., Čadro, S., & Sitaula, B. K. (2017b). Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina. *Sustainability (Switzerland)*, *9*(7), 1–18. https://doi.org/10.3390/su9071208

APPENDICES

APPENDIX-A: Instrument for data collection

District: Chakwal Tehsil: ___________Union Council:________ Village Name:_____

Questionnaire ID No.__________Interviewer: ___________Date of Interview: _________

I. DEMOGRAPHIC PROFILE

1. Name of Respondent & contact number (optional):____________________

2. Age of Respondent (Years):________________________

3. Education of Respondent:

a) Illiterate b) Primary c) Matric d) Graduation
e) Postgraduate f) Technical/Professional g) Any other _______

4. Family Size

Type of farm family 1=joint family, 2=single family			Total family size (no)		
Age group	Male #	Female #	Age group	Male #	Female #
≤ 5 yrs			6-18 Years		
18-60 Years			> 60 Years		

II. VULNERABILITY ASSESSMENT

IIA. <u>Socio-economic Profile</u>

5. Household and Farm Assets

Farm Assets	**Number**	**Household assets**	**Number**
Tractor		Car/jeep	
Thresher		Refrigerator	
Tube well (electric, solar, diesel)		Motorcycle	
Fodder chopper (manual/electric)		Cycle	
		TV	
		Computer	

6. Have you created any farm assets in the last 5 years?

a) Yes b) No

7. If yes, then how much you spend (value in Rs.) on your farm assets? --------------

8. What is your household livelihood strategies?

a) rain-fed crops b) irrigated crops c) livestock d) landless laborer

e) Govt jobs f) Private job g) Any other

9. What is your total land holding?

Farm land	**Total own land______**	
	Cultivated	Non-cultivated
Area (kanal)		

10. Utilization of irrigated and un-irrigated land resources for food and fodder crops production

<table>
<tr><th>Rabi crops 2015-16</th><th>Area (Kanal)</th><th colspan="2">Kharif crops 2015-16</th><th colspan="2">Area (Kanal)</th></tr>
<tr><td>Wheat</td><td></td><td colspan="2">Peanut</td><td colspan="2"></td></tr>
<tr><td>Pulses</td><td></td><td colspan="2">Pulses</td><td colspan="2"></td></tr>
<tr><td>Vegetables</td><td></td><td colspan="2">Vegetables</td><td colspan="2"></td></tr>
<tr><td>Oil seed crops</td><td></td><td colspan="2">Fodder crops</td><td colspan="2"></td></tr>
<tr><td>Fodder crops</td><td></td><td colspan="2">Fallow</td><td colspan="2"></td></tr>
<tr><td>Fallow</td><td></td><td colspan="2">Other</td><td colspan="2"></td></tr>
<tr><td>Orchard Type</td><td>Area (K)</td><td>Plants #</td><td>Orchard Type</td><td>Area (K)</td><td>Plants #</td></tr>
</table>

11. What is the most limiting and restricting factors/resources for crop production-based livelihood?

a) Water scarcity (drought)
b) Water excess (floods)
c) Land access (area and ownership)
d) Soil quality (related to fertility)
e) Soil erosion
f) Any other

12. In your opinion, what are the impediments for crop production-based livelihood?

a) Access to Inputs (fertilizer/new seed/technology)
b) Marketing
c) Awareness & Guidance
d) Investment capital
e) Any other

13. What is the total income from agricultural activities (Rs)? (monthly/six monthly/annual)

14. What is the total off-farm income (Rs)? (monthly/six monthly/annual)

15. What are your major farm related average expenditures (Rs)? (monthly/six monthly/ annual)

a) Crop input (Rs…….)
b) Harvesting/transport (Rs…….)
c) Livestock input (Rs…….)
d) Hired labor (Rs……)

17. What is the type and source of fuel consumed for cooking in your home?

a) Fire wood
b) FYM (farmyard manure)
c) gas
d) Kerosene oil
e) other

18. Does your family remained food secured in the last decade?

a) Yes b) No

19. If 'No' then how do you cover if there is gap/food shortage

a) sell livestock
b) get from relatives
c) purchase using cash from nonagricultural sources
d) government subsidies
e) Purchase from farm income from cash crops
f) others explain

20. What is the overall trend of farm input use over the last five years?

a) increasing b) decreasing c) no change

21. Livestock Composition (Livestock number during last one year period)

Animal type	Present Number	Livestock-trends Over 5 years 1= increase 2=decrease 3= no change	Reason for this trend	Main purpose of keeping
Buffaloes				
Bullocks/ Cows				
Goat/ Sheep				
Donkey/ Horse				
Camel				
Poultry (domestic)				
Any other				

III. CLIMATE CHANGE PERCEPTIONS IN LOCAL COMMUNITY

22. Do you think climate is changing?

a) Yes b) No

23. Where did you get information on climate change?

a) Radio		g) Traditional knowledge	
b) Newspaper		h) Agriculture Department	
c)TV		i) Don't care about climate prediction	
d) Meteorological services		j) Others (specify)	
e) Neighbor		k) Do not know	
f) Relative		l) No response (if all above blank)	

24. Major climate hazards encountered

Over the past 30 years have you observed	Which of the following climate events have your household experienced in the past 30 years? 1=Yes 2=No	Is there any increase in the frequency of these hazards? a) Yes b) No c) Don't Know	Are there any negative impacts of these hazards on your family health status? a) Yes a) No b) Don't Know	Are there any negative impacts of these hazards on your crops productivity? a) Yes b) No c) Don't Know	Are there any negative impacts of these hazards on your livestock? a) Yes b) No c) Don't Kno w
Drought					
Hailstorm					
Untimely rains					
Winter arrival (late/early)					
Cold breeze					
Summer arrival (late/early)					
Heat waves					
Storm					
Frost					
Increase in avg. temperature					

IV. COPING (ADAPTATION) STRATEGIES

25. What are the different adaptation strategies (Farm-based & Non-Farm based)

1.Farming based:	Yes/No	**2. Non-farm based:**	Yes/No
A) Did Nothing	Yes/No	A) Borrowed money from relatives/others	Yes/No
B) Left land fallow	Yes/No	B) Relying on assistance from government/NGOs	Yes/No
C) Sold part of land for alternative	Yes/No	C) Less food consumption or changed food habits	Yes/No
D) Leased out part of land for alternative/leased in	Yes/No	D) Shifted to non-farm employment	Yes/No
E) Sold livestock (cows, buffalos)	Yes/No	E) Reduction in education level of the children	Yes/No
F) Maintained poultry, goats	Yes/No	F) Out migration to cities	Yes/No
G) Provided supplemental irrigation	Yes/No		

H) Invested in farm ponds (water harvesting structures)	Yes/No		
I) Change in cropping pattern	Yes/No		
J) Followed improved crop production practices	Yes/No		
K) Additional information gained	Yes/No		
M) Change in planting date	Yes/No		

26. Do you get any information on cropping patterns/agronomic practices?

a) Yes b) No c) Do not know d) No response

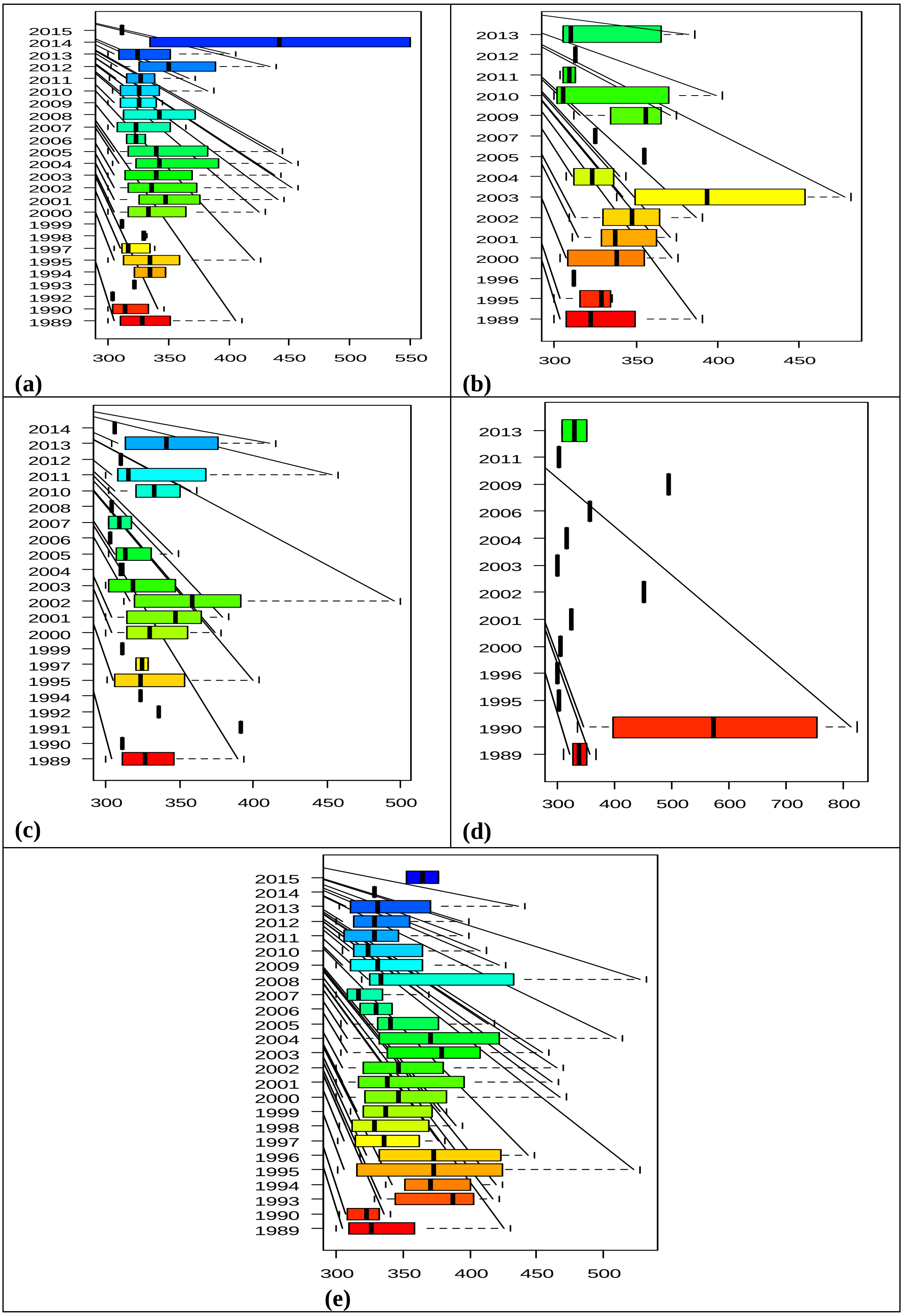
27. What are your sources of information on cropping patterns/agronomic practices?

a) Radio
b) b) Newspaper
c) c) TV
d) d) Meteorological services
e) Agriculture Department
f) f) Others (specify)
g) g) No response

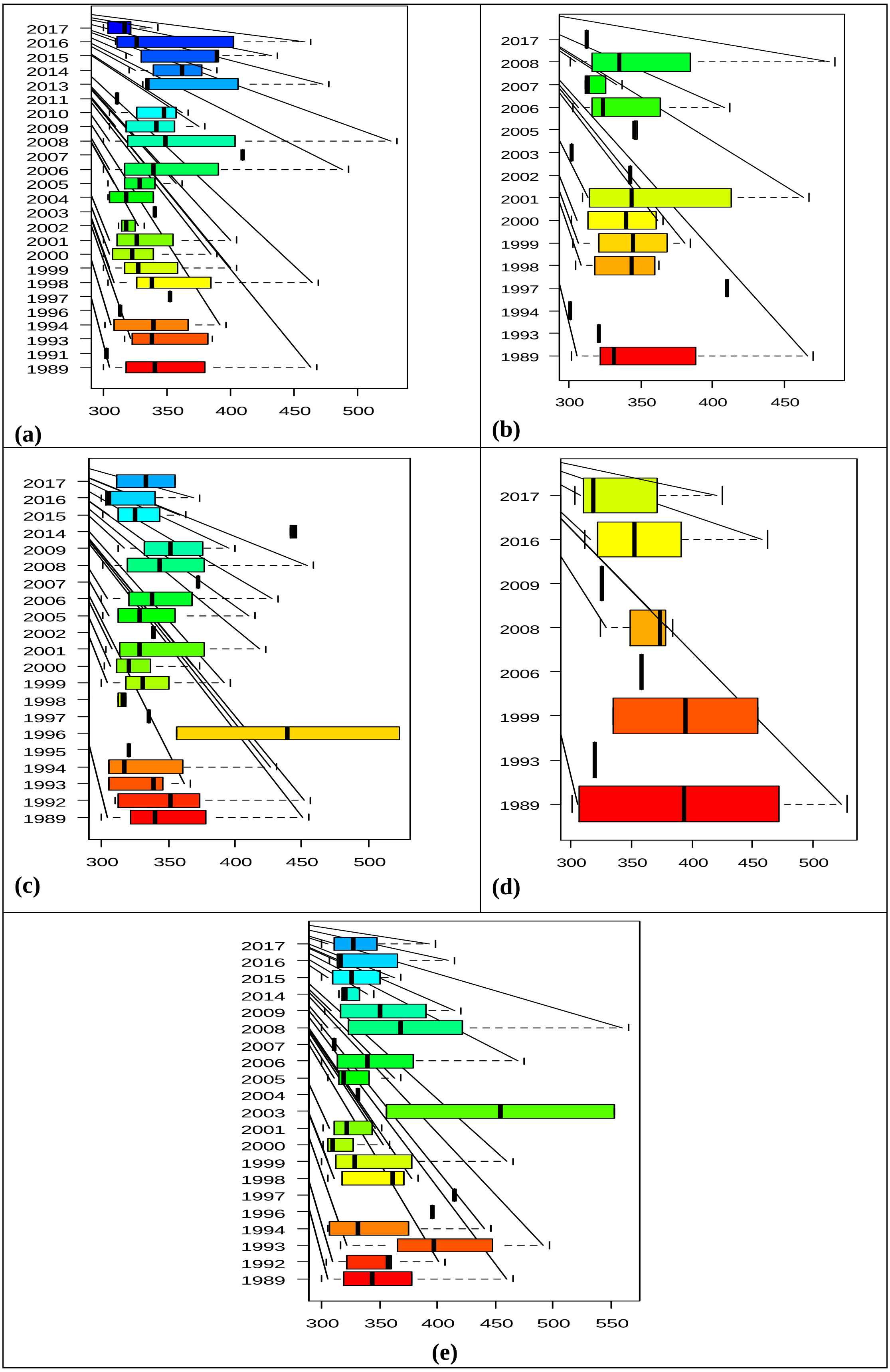
28. Knowledge (technology) sharing (No. of visits /year and sources of information)

a) No. of times the farmers visits the extension officials/office: (Number)		
a) How many times the extension officials/experts visited the farmer: (Number)		
c) Any other farmers research group (Yes / No)		
d) Visited On farm demonstration conducted at some farmer field in your area/Union Council (Yes / No)		

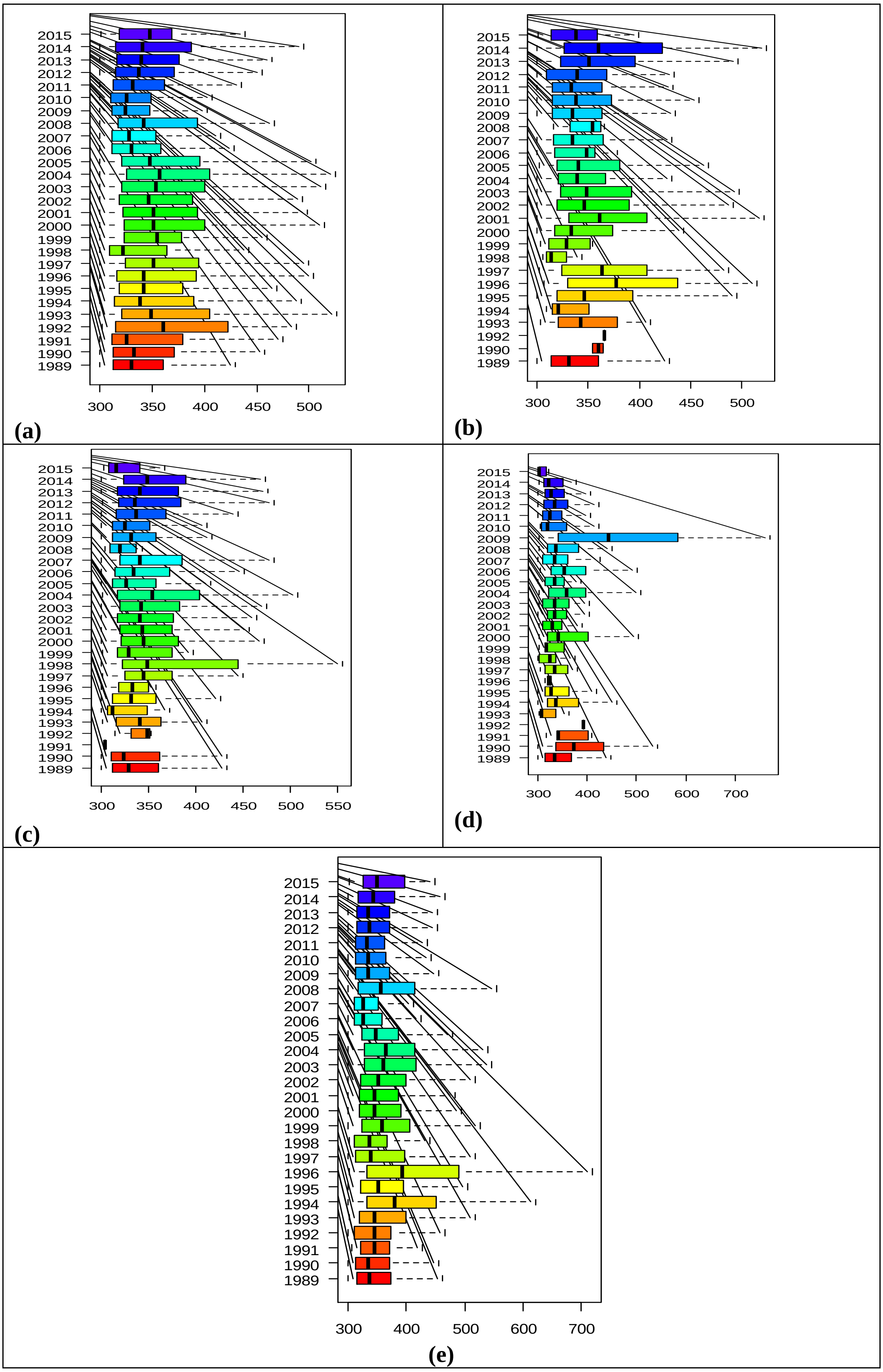
APPENDIX-B: LULC bases sub-divisonal gain and loss



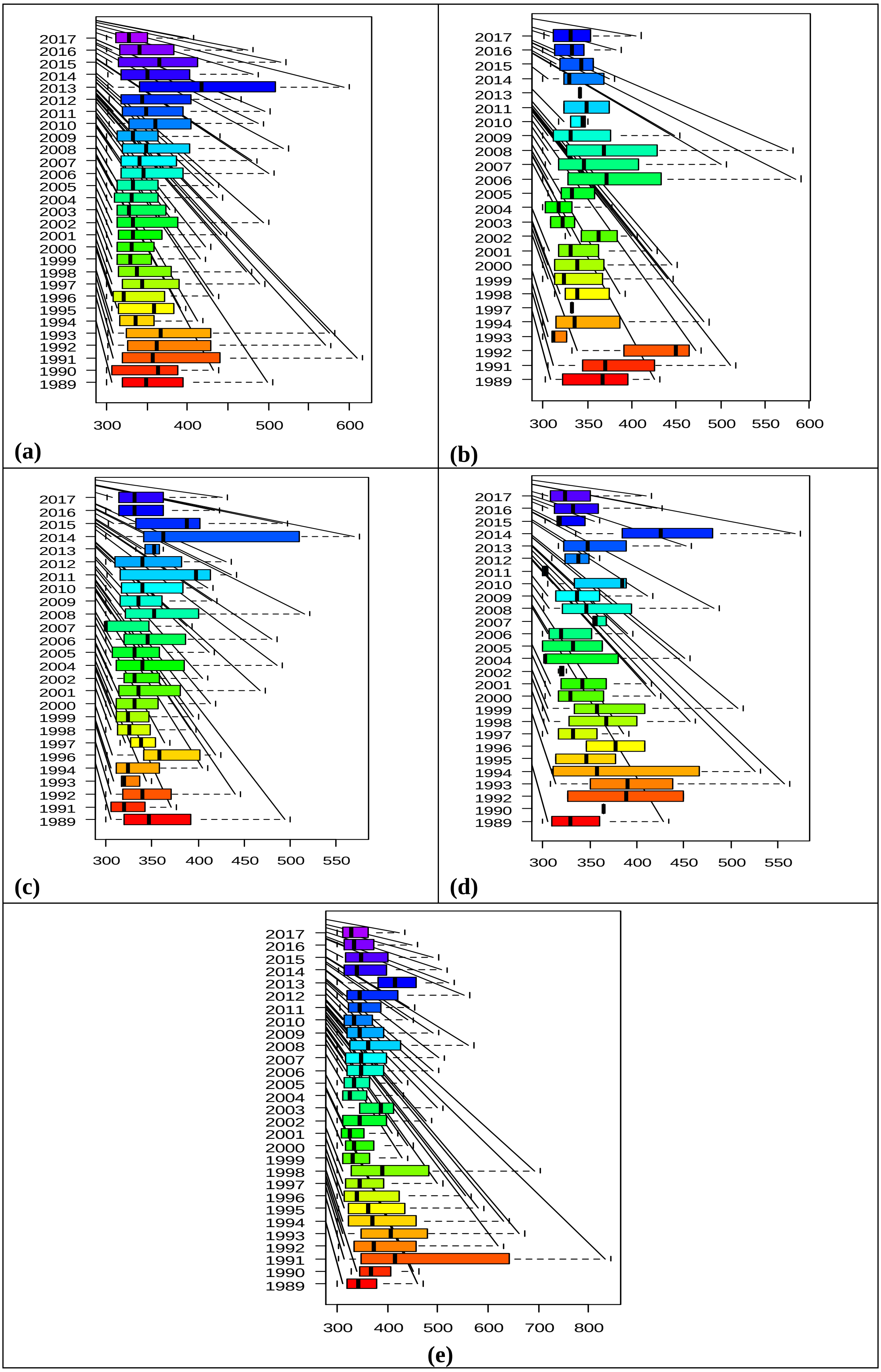
A-1: (a) Gain magnitude of built-up land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



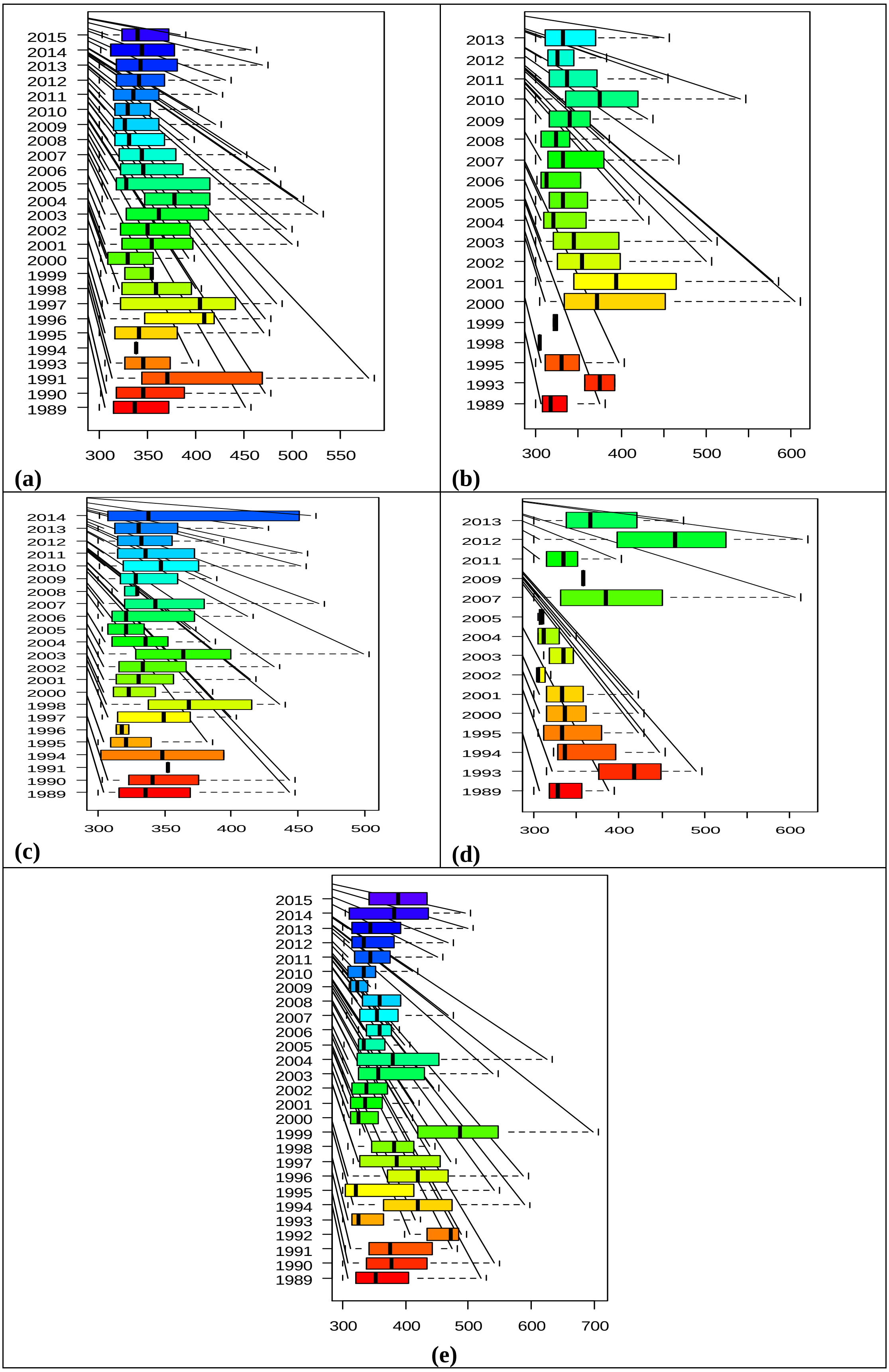
A-2: (a) Loss magnitude of built-up land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



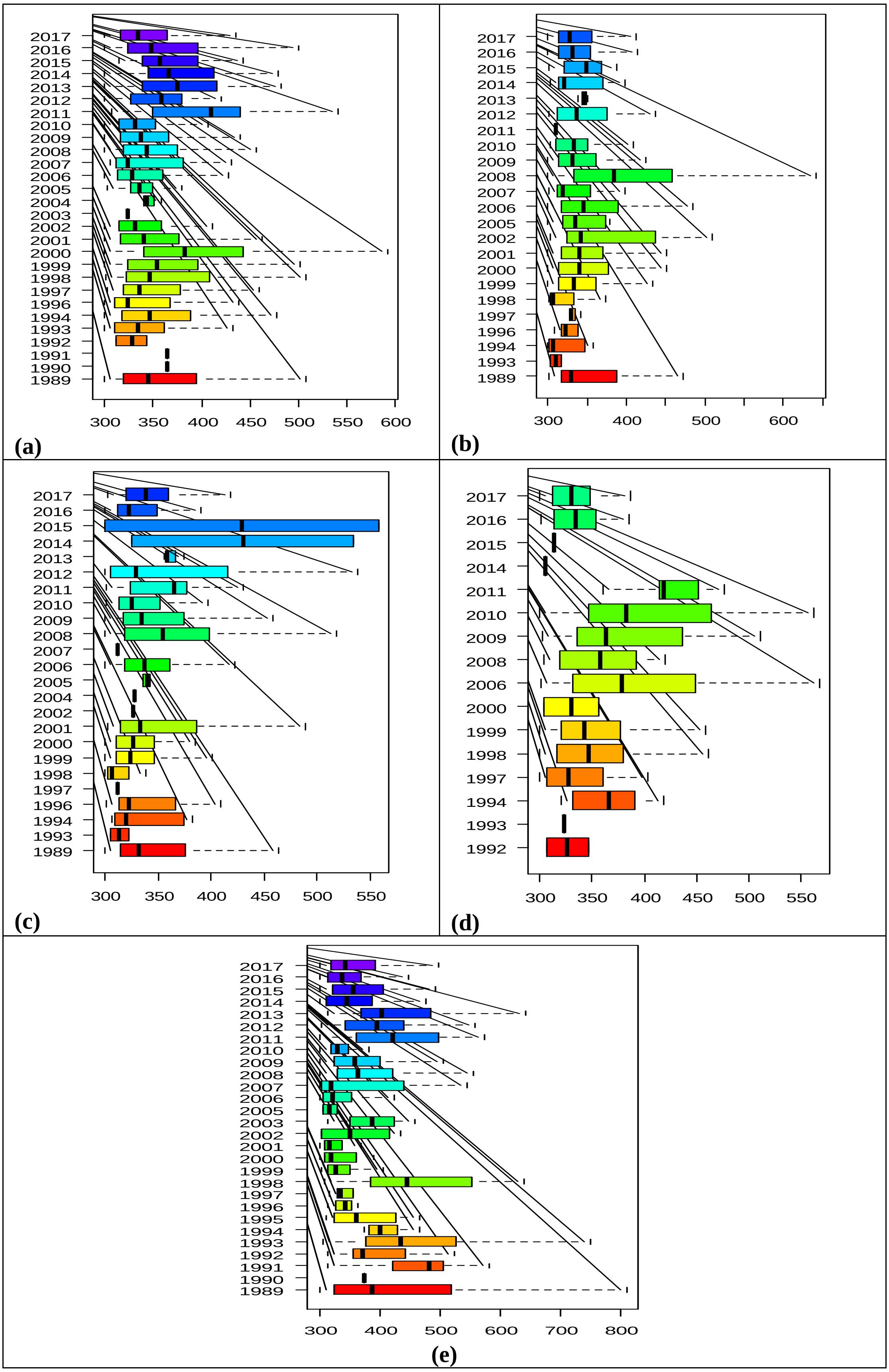
A-3: (a) Gain magnitude of cropland land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2015).



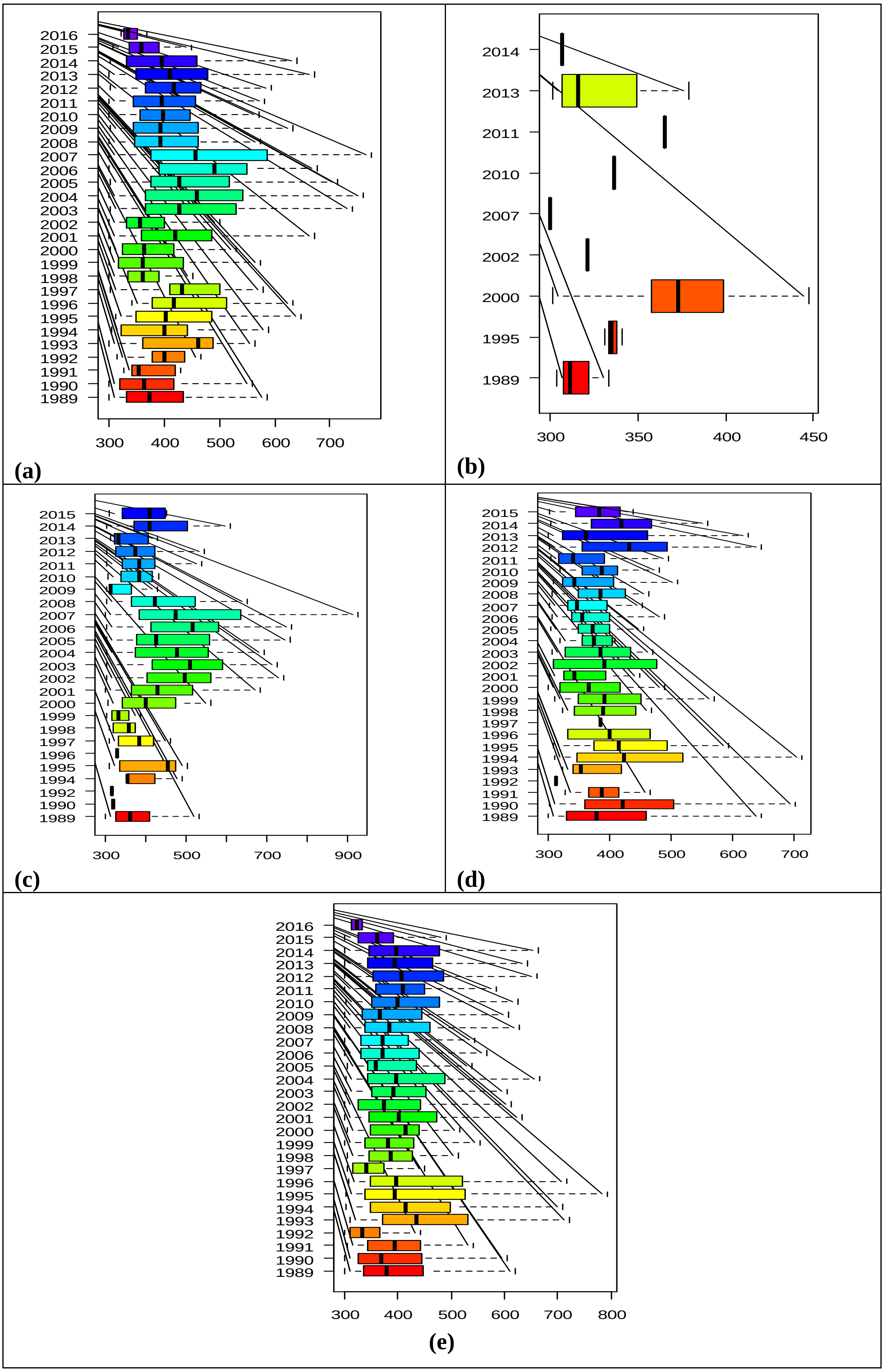
A-4: (a) Loss magnitude of cropland land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



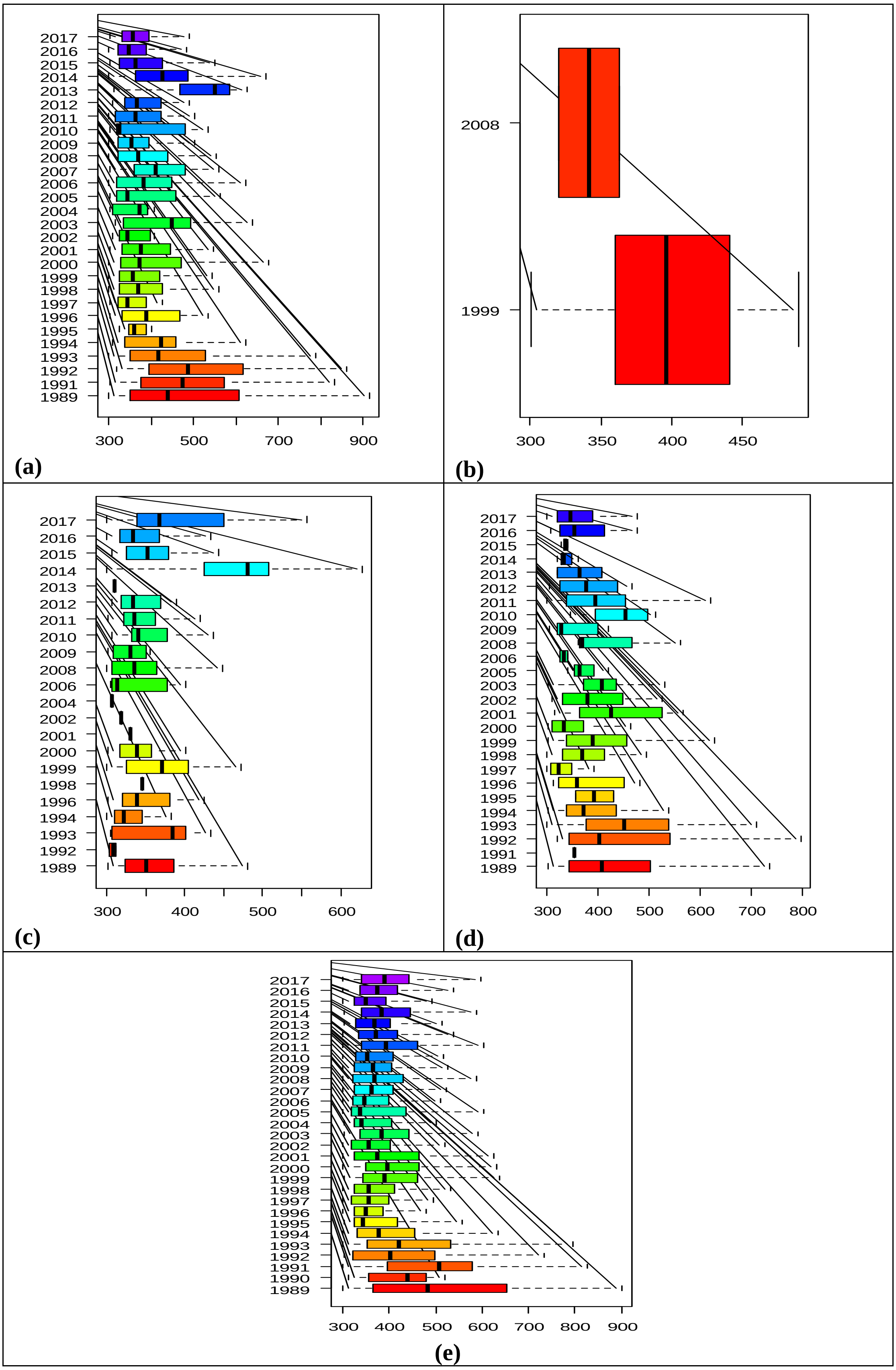
A-5: (a) Gain magnitude of tress/forest land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



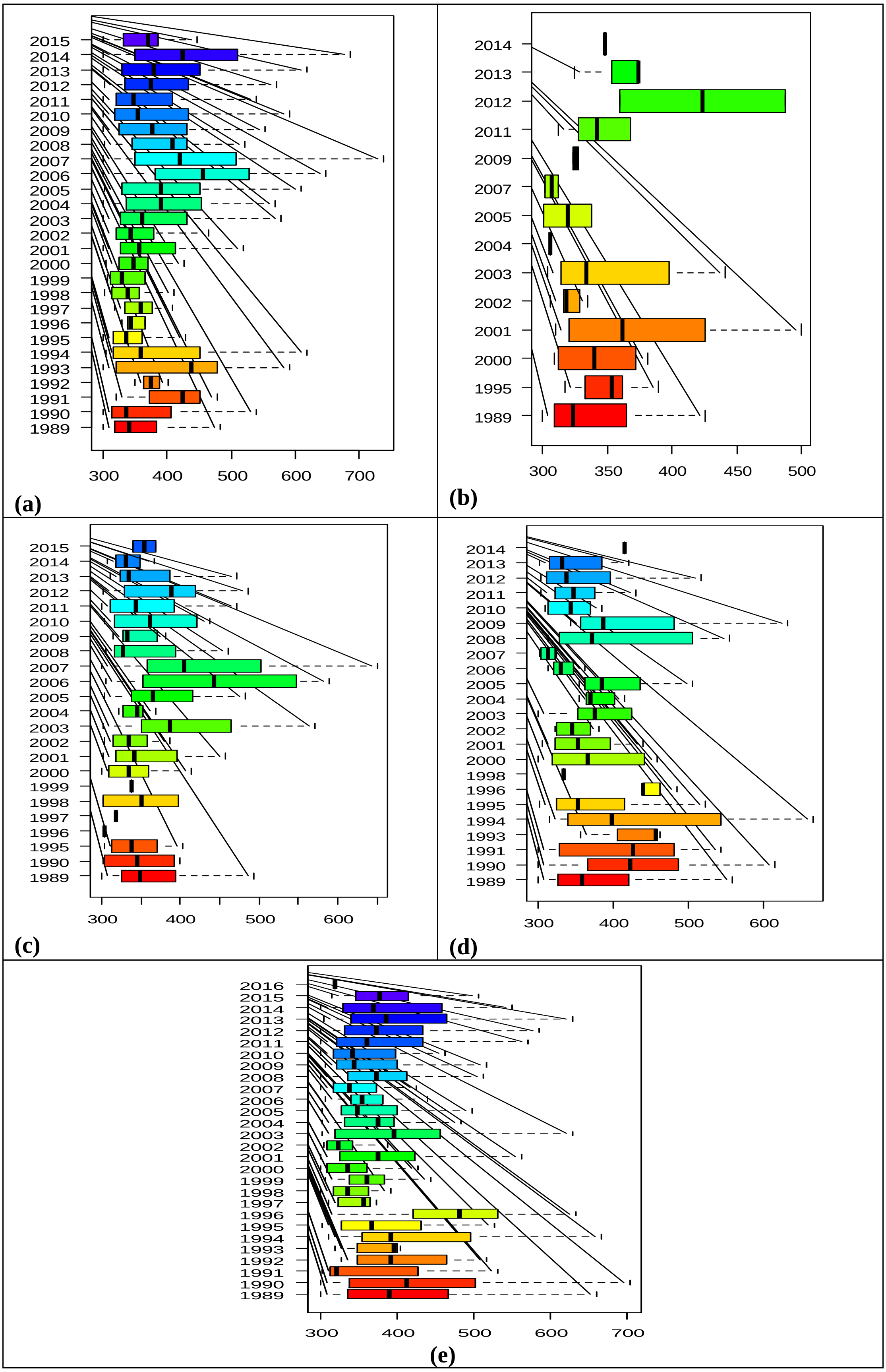
A-6: (a) Loss magnitude of trees/forest land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



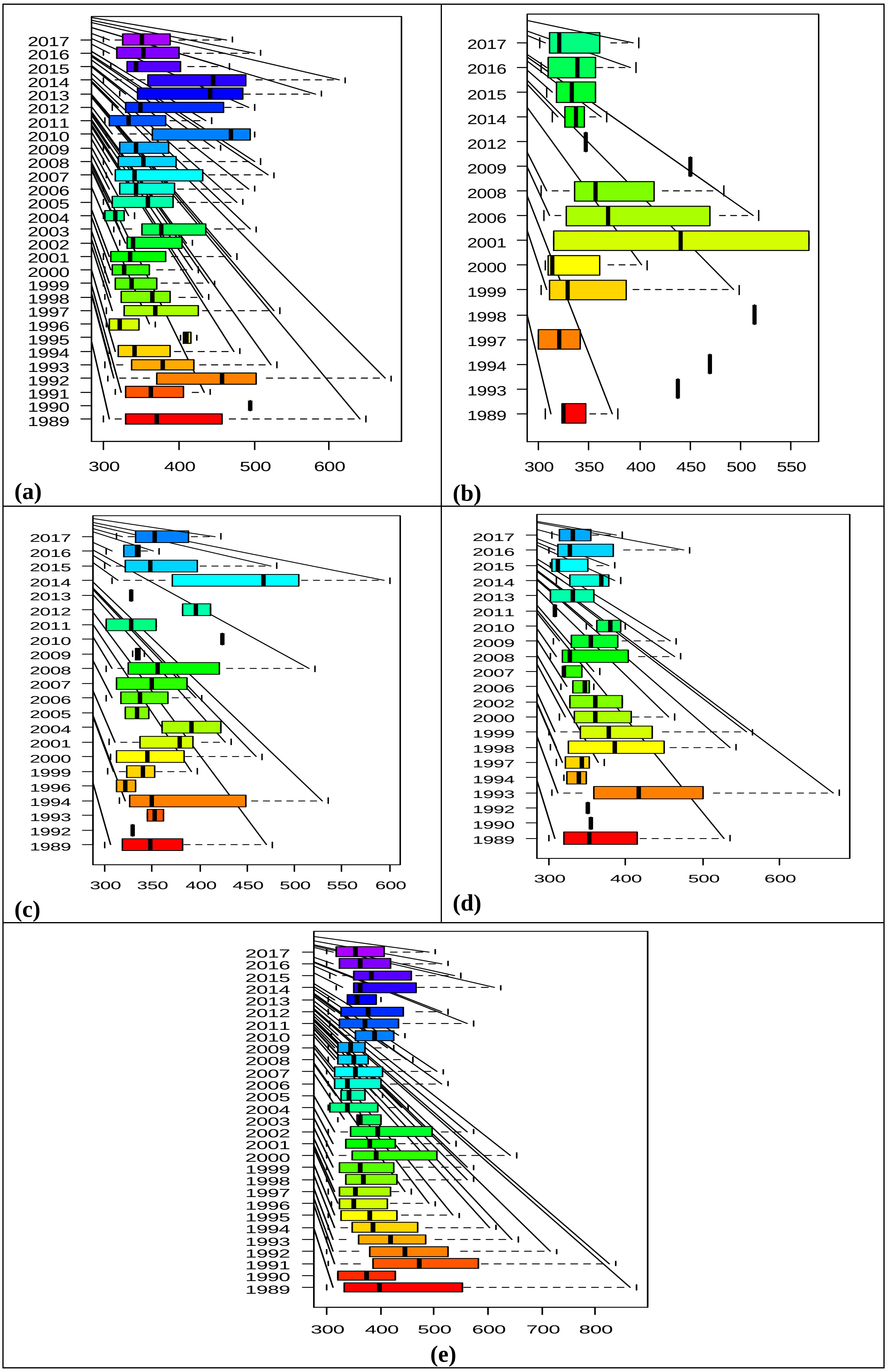
A-7: (a) Gain magnitude of water land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



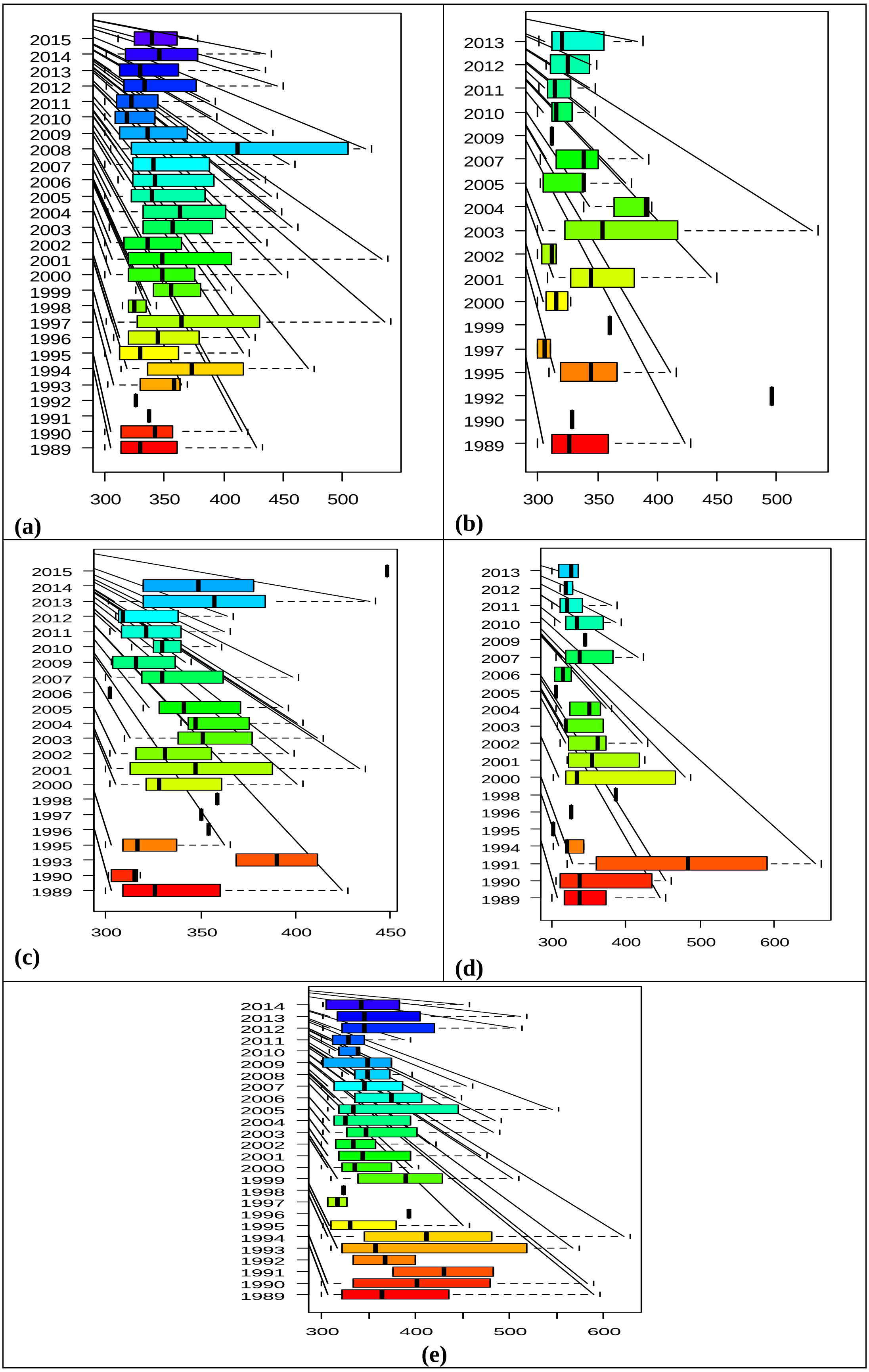
A-8: (a) Loss magnitude of water land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



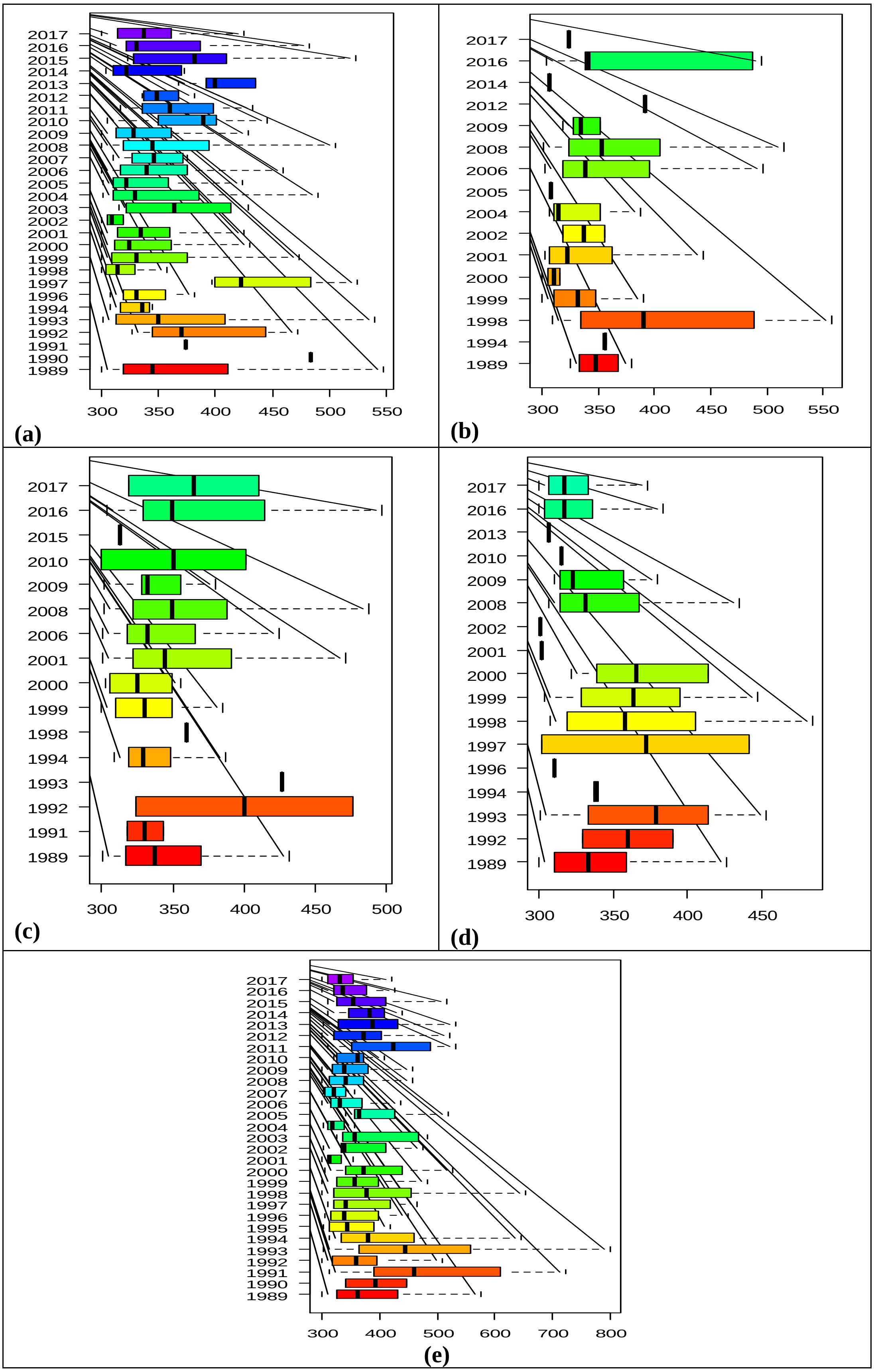
A-9: (a) Gain magnitude of bare land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017)



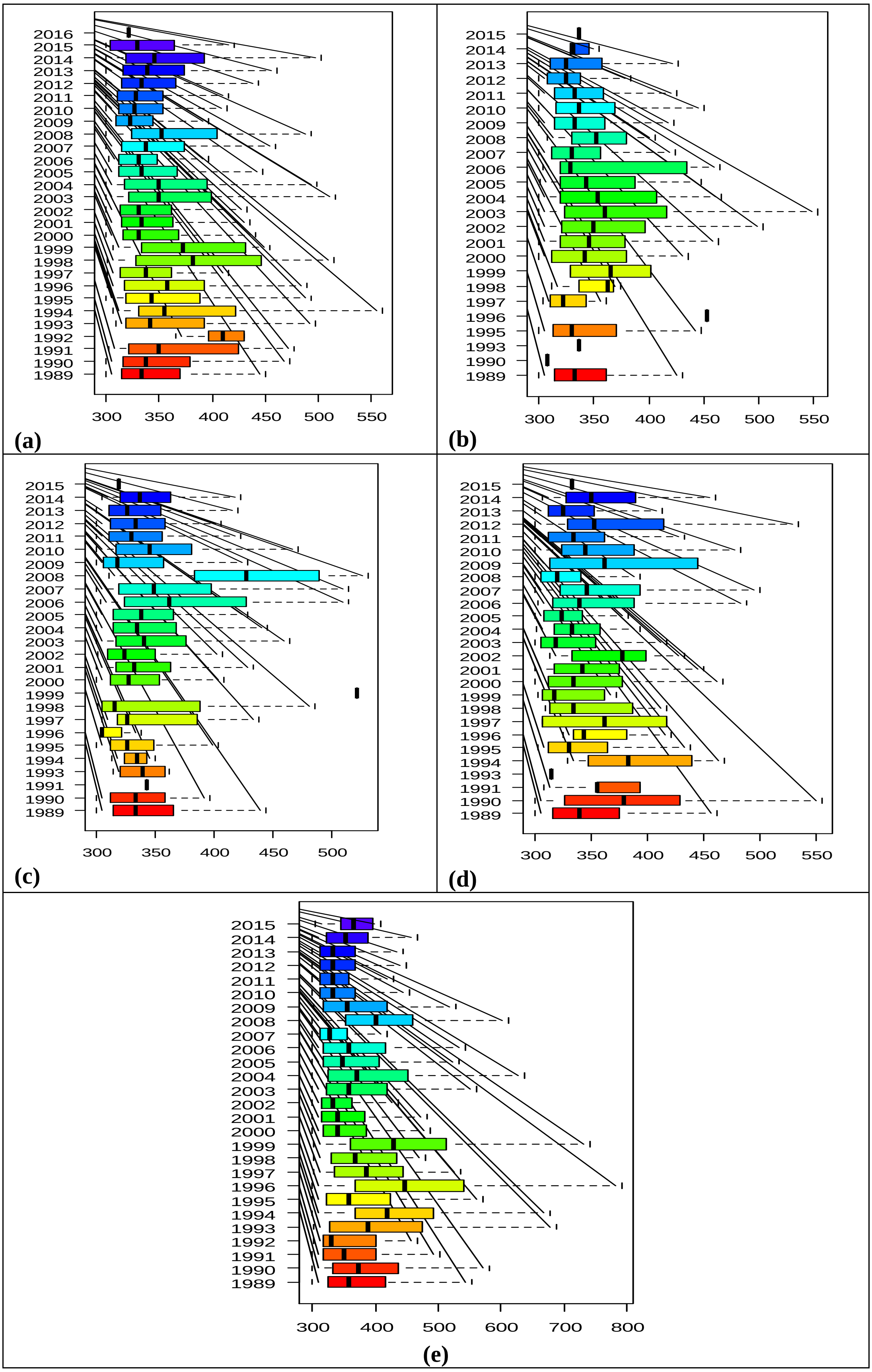
A-10: (a) Loss magnitude of bare land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



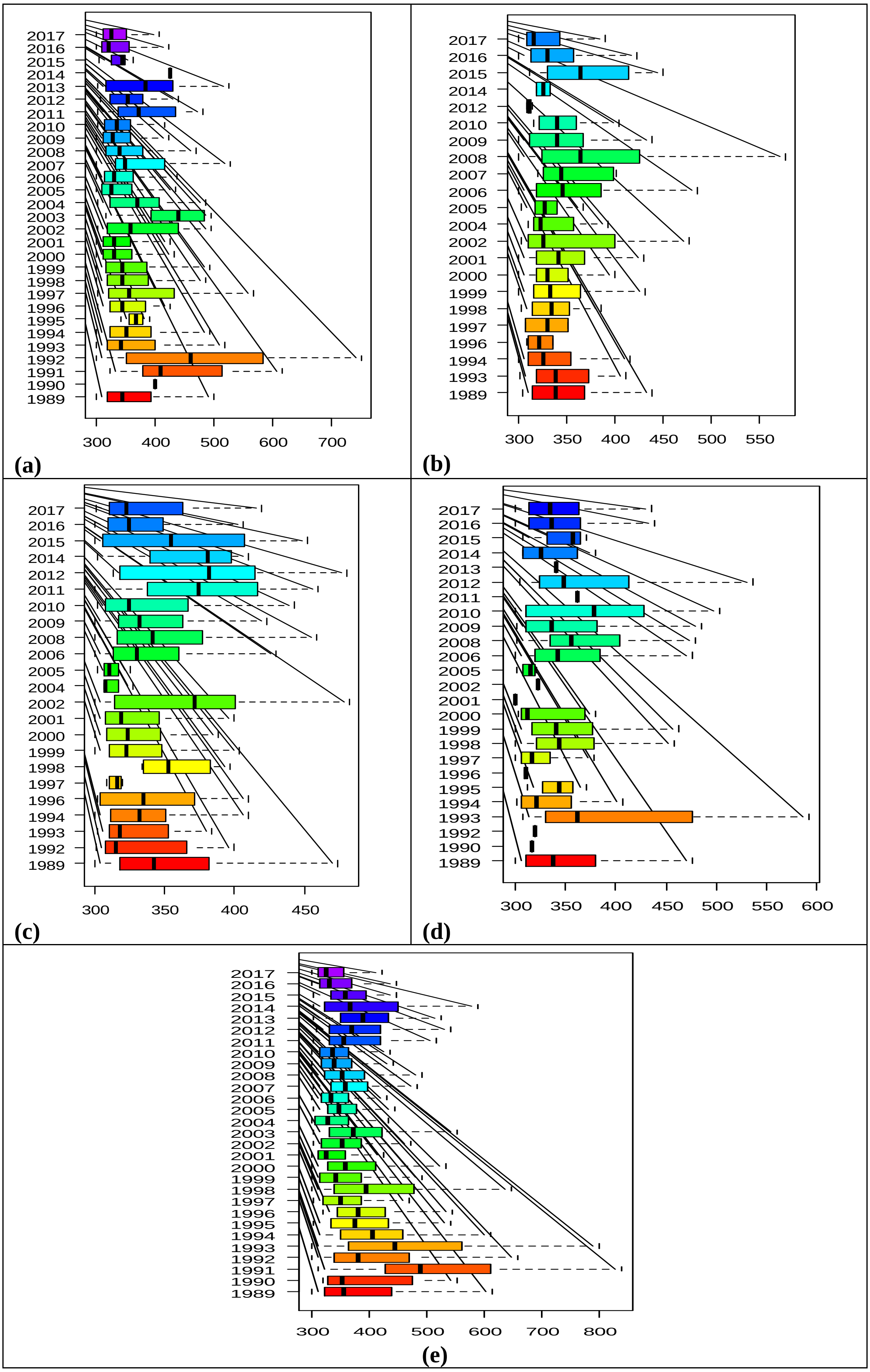
A-11: (a) Gain magnitude of grasses land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



A-12: (a) Loss magnitude of grasses land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



A-13: (a) Gain magnitude of shrub land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).



A-14: (a) Loss magnitude of shrub land cover of Tehsil Chakwal. **(b):** Tehsil Choa Saiden Shah **(c):** Tehsil Kallar Kahar **(d):** Tehsil Lawa **(e)** Tehsil Talagang (1989 - 2017).

APPENDIX-C: Latitude/Longitude coordinates of the surveyed villages

Villages	Longitude	Latitude	Tehsil	Union Council
Achral	72.8786429	33.06398518	Chakwal	Chak Umra
Alawal	72.6657474	33.03304679	Chakwal	Begal
Amirpur Mangan	73.02911332	32.97206157	Chakwal	Bheen
Balkassar	72.64310384	32.93539992	Chakwal	Balkassar
Ballokassar	72.8057879	33.02758686	Chakwal	Ballokassar
Begal	72.65339744	33.04945146	Chakwal	Begal
Bheen	73.01569165	32.9834057	Chakwal	Bheen
Bhullay Bala	72.76175711	32.97782516	Chakwal	Mangon
Bullay Zer	72.75342134	32.9733764	Chakwal	Mangon
Chabbar	73.10799898	32.91118447	Chakwal	Dhumman
Chabbri	73.07180625	32.93251063	Chakwal	Dhumman
Chaician	73.17205716	33.03444059	Chakwal	Mogla
Chak Baqir Khan	73.02628049	32.91757783	Chakwal	Dhumman
Chak gakhar	72.74544071	33.05585068	Chakwal	Ballokassar
Chak karam shah	72.88780734	32.98300107	Chakwal	Har Char Dhab
Chak malook	72.95245103	32.95880491	Chakwal	Chak Malook
Chak qada	73.18785069	33.07620879	Chakwal	Mogla
Chak umra	72.95972405	33.00022506	Chakwal	Chak Umra
Chakora	73.1920867	33.07804472	Chakwal	Mogla
Chakral	72.94900669	32.9260422	Chakwal	Chak Malook
Chattal	72.94858113	32.91138242	Chakwal	Chak Malook
Choa Ganj Ali Shah	73.07993917	32.84823665	Chakwal	Choa Ganj Ali Shah
Chohan	73.07438231	33.02706528	Chakwal	Padshahan
Dab	72.88737538	32.90353468	Chakwal	Dab
Dhab khushal	72.87848528	32.98919574	Chakwal	Har Char Dhab
Dhab pari	72.89529183	33.00206886	Chakwal	Har Char Dhab
Dhok bair	72.91904013	32.96694857	Chakwal	Chak Malook
Dhudial	72.97205852	33.06688715	Chakwal	Dhudial
Dhumman	73.07884267	32.92870385	Chakwal	Dhumman
Dullah	72.6933651	33.15587695	Chakwal	Dullah
Farid kassar	72.92020099	33.04040315	Chakwal	Chak Umra
Gah	72.65302032	33.06249494	Chakwal	Begal
Ghugh	72.74655283	33.13051377	Chakwal	Thanil Kamal
Haphi	73.16382385	33.07987453	Chakwal	Mogla
Haraj	72.76114275	33.16093671	Chakwal	Thanil Kamal
Harchal dab	72.87567514	32.98983715	Chakwal	Harchal dab
Hardo saba	72.98175005	32.97049568	Chakwal	Bheen
Hasoola	73.08408677	33.0476003	Chakwal	Padshahan
Hastal	72.7115948	32.95961408	Chakwal	Mangon

Hoon	73.09548741	32.81587188	Chakwal	Choa Ganj Ali Shah
Jabairpur	72.89087839	32.92351428	Chakwal	Jabair pur
Jand	72.9687871	33.00544786	Chakwal	Jand
Jand khanzada	73.10743741	32.93958741	Chakwal	Jand khanzada
Jaswal	72.96907131	32.81303305	Chakwal	Jaswal
Joiamair	72.81124755	33.00935565	Chakwal	Ballokassar
Jound	72.99542951	33.00434377	Chakwal	Bheen
Kahanpur	73.06646578	32.91210996	Chakwal	Dhumman
Kalas	73.17916456	33.09049468	Chakwal	Mogla
Kalujo	72.75616022	32.90217465	Chakwal	Mureed
Karsal	72.58157058	33.00735952	Chakwal	Karsal
Khai	72.82432882	32.84363108	Chakwal	Khai
Khan pur	73.06576707	32.90819862	Chakwal	Dhumman
Khara	72.6357769	33.08370231	Chakwal	Begal
Khoday	72.82583112	33.01337633	Chakwal	Ballokassar
Khotian	73.0015139	32.88542628	Chakwal	Khotian
Kolian	73.20079551	33.08689497	Chakwal	Mogla
Kot chaudhrian	72.51780491	33.04082063	Chakwal	Kot chaudhrian
Johaiser	73.04799072	33.00031007	Chakwal	Padshahan
Mangon	72.74730557	32.96506215	Chakwal	Mangon
Mangwal	72.82601617	33.1093642	Chakwal	Mangwal
Marith	72.6530438	33.06252289	Chakwal	Begal
Marri	72.6791067	32.93449868	Chakwal	Ballokassar
Mial	73.07744398	32.8940923	Chakwal	Dhumman
Mian miar	72.90723214	33.01877294	Chakwal	Chak umra
Minwal	72.85519995	33.04630017	Chakwal	Ballokassar
Mohra kullathi	73.01686319	32.97508325	Chakwal	Bheen
Mohra malarian	73.05902523	32.84636269	Chakwal	Choa Ganj Ali Shah
Munday	72.67433026	32.99121899	Chakwal	Begal
Mureed	72.75387689	32.91543693	Chakwal	Mureed
Murhal	72.85085381	33.03608341	Chakwal	Ballokassar
Madral	72.87936369	33.05420504	Chakwal	Chak umra
Narra chauntrian	73.18053564	33.05886575	Chakwal	Mogla
Noorpur	73.068914	32.842149	Chakwal	Choa ganj ali shah
Pinwal	72.89126718	32.95190605	Chakwal	Behkari kalan
Potaki	73.17149029	32.97210999	Chakwal	Muhal mughlan
Rakh hosal	72.5185656	33.13418386	Chakwal	Warwal
Rakh jabal	72.79294529	33.07016085	Chakwal	Ballokassar
Ranjha	72.54861669	33.09722439	Chakwal	Warwal
Sadwal	72.82706786	32.88083463	Chakwal	Odherwal
Saral	72.9201189	33.09405452	Chakwal	Saral
Shahpur	72.82546413	33.05434213	Chakwal	Ballokassar
Sidher	72.61602265	32.94095796	Chakwal	Balkassar
Sohair	72.63054574	33.09283136	Chakwal	Begal

Sutwal	72.87212223	32.89953	Chakwal	Dab
Tajbal	72.94127087	32.92829001	Chakwal	Chak Malook
Thanil fathoi	72.84768049	32.97379509	Chakwal	Ballokassar
Thanil kamal	72.72648262	33.14233651	Chakwal	Thanil kamal
Tharpal	72.91471837	32.84690989	Chakwal	Karyala
Thoa bahadur	72.70198903	32.93757425	Chakwal	Mangon
Udhwal	72.95930934	32.90188377	Chakwal	Chak Malook
Uthwal	72.79110775	33.03646927	Chakwal	Ballokassar
Warwal	72.52634619	33.13625258	Chakwal	Warwal
Arra	73.21079547	32.76039772	Choa Saidan Shah	Arra
Dalailpur	72.84826421	32.72828921	Choa Saidan Shah	Dalwal
Dulmial	72.92591527	32.73897018	Choa Saidan Shah	Dulmial
Lahri shah nawaz	73.11107623	32.78607852	Choa Saidan Shah	Basharat
Lehr sultanpur	73.05534356	32.74691281	Choa Saidan Shah	Lehr Sultanpur
Minhala	73.0552149	32.74001422	Choa Saidan Shah	Lehr Sultanpur
Nalli	72.96000728	32.66618161	Choa Saidan Shah	Dandoot
Ratucha	72.99012509	32.70043058	Choa Saidan Shah	Dandoot
Saloi	73.0977147	32.74679605	Choa Saidan Shah	Saloi
Sidhandi	73.21014205	32.76918376	Choa Saidan Shah	Arra
Tatral	72.93116905	32.72698183	Choa Saidan Shah	Dulmial
Waghwal zair	73.10412595	32.77576872	Choa Saidan Shah	Basharat
Wahali hardo	73.04672979	32.75813667	Choa Saidan Shah	Lehr Sultanpur
Watli meh kusah	73.04593565	32.74788903	Choa Saidan Shah	Lehr Sultanpur
Bharpur kalan	72.57049176	32.85648661	KalarKahar	Bharpur
Buchal kalan	72.63468769	32.67872279	KalarKahar	Buchal Kalan
Buchal khurd	72.69971951	32.67622762	KalarKahar	Buchal Khurd
Dharukna	72.62081887	32.6897804	KalarKahar	Miani
Khairpur	72.79145699	32.73421996	KalarKahar	Khairpur
Makhial	72.65857591	32.65990478	KalarKahar	Buchal Kalan
Miani	72.64778521	32.71046667	KalarKahar	Miani
Munara	72.51243398	32.66552239	KalarKahar	Munara
Noorpur	72.58772114	32.66506189	KalarKahar	Noorpur
Ransial	72.68990079	32.7164229	KalarKahar	Buchal Khurd
Balwal	72.11561178	32.80687212	Lawa	Dhurnal
Dhibba	72.00560938	32.82519521	Lawa	Kot Qazi
Dhurnal	72.10128204	32.80905213	Lawa	Dhurnal
Kot gullah	71.91107229	32.9598512	Lawa	Kot Qazi
Kot qazi	72.00860617	32.8237962	Lawa	Kot Gullah
Lawa	71.93750577	32.69840677	Lawa	Lawa Rural
Leti	72.01802814	32.90669595	Lawa	Leti
Markhaki	72.01482512	32.81985036	Lawa	Kot Qazi
Pichnand	71.98696453	32.88699774	Lawa	Pichnand
Sadiqabad	71.92635182	32.97355924	Lawa	Kot Gullah
Sukka	71.99480375	32.81239409	Lawa	Kot Qazi
Adlaka	72.43454033	32.86907761	Talagang	Malikwal
Ali haiderpur	71.97333798	33.04865589	Talagang	Jabbi Shah Dilawar
Baghtal	72.22075008	32.83831852	Talagang	Bidher
Bhilomar	72.43553561	32.72636887	Talagang	Bhilomar
Bidher	72.18515709	32.88685074	Talagang	Bidher

Budhial	72.18531673	33.00089371	Talagang	Budhial
Chakwalian	72.37492517	32.82808987	Talagang	Jhattla
Chatwal	72.40756764	32.97357165	Talagang	Jaysal
Chinji	72.36787113	32.71075005	Talagang	Bhilomar
Chokera	72.33070011	32.95205394	Talagang	Jasyal
Chowkhandi	72.32763304	32.86590987	Talagang	Pihra Fatehial
Dandi	72.33760808	32.97606071	Talagang	Jasyal
Daroot	72.18456123	32.91650791	Talagang	Dhermound
Datwal	72.1972052	33.00393959	Talagang	Budhial
Dhaular	72.30141682	33.03962743	Talagang	Dhaular
Dher mound	72.17021825	32.94193032	Talagang	Dhermound
Dhok afghan	72.39514272	33.0533066	Talagang	Kot sarang
Dhok baz	72.32016468	32.88397328	Talagang	Pihra Fatehial
Dhok ham	72.34400775	32.87461726	Talagang	Pihra Fatehial
Dhok marian	72.45917072	32.87138906	Talagang	Naka Kahout
Dhulli	72.1925364	32.86129437	Talagang	Bidher
diwal	72.48329156	33.07013231	Talagang	Mirjan Niraghee
dudial	72.40323104	32.95114608	Talagang	Tehi
jabbi shah dilawar	71.99313089	33.09256551	Talagang	Jabbi Shah Dilawar
jasyal	72.39334782	32.99772618	Talagang	Jasyal
jhattla	72.38427877	32.82539242	Talagang	Jhattla
khichian	72.37143405	32.777097	Talagang	Jhattla
khoian	72.05306958	33.0195423	Talagang	Multan Khurd
kot sarang	72.39184591	33.03431433	Talagang	Kot Sarang
kotehra	72.04435169	33.09790971	Talagang	Jabbi Shah Dilawar
malikwal	72.43599469	32.86792696	Talagang	Malikwal
mamdoot	72.46576261	32.87839178	Talagang	Naka Kahout
markhal	72.22940167	33.12078775	Talagang	Budhial
mehmood wala	72.36463449	32.82415804	Talagang	Jhattla
mirjan miliar	72.36730562	33.1374401	Talagang	Mirjan Niraghee
mithrala	72.46090687	33.13339874	Talagang	Mirjan Nraghee
mogla	72.30225984	33.00957794	Talagang	Dhaular
multan khurd	72.0129775	33.03402771	Talagang	Multan Khurd
murali	72.45761653	33.1547819	Talagang	Mirjan Niraghee
murat	72.46957752	32.90852806	Talagang	Naka Kahout
naka kahout	72.47916569	32.94381314	Talagang	Naka Kahout
Naraghi	72.41433951	33.11181373	Talagang	Mirjan Niraghee
Pahthar	72.24394525	33.08729937	Talagang	Budhial
Pihra fatehial	72.32624017	32.86739852	Talagang	Pihra Fatehial
Qadarpur	72.45954611	32.73488811	Talagang	Bhilomar
Rakh naka kahout	72.47604738	32.9353346	Talagang	Naka Kahout
Rehman abad	72.33503221	33.07835337	Talagang	Kot Sarang
Saghar	72.27140386	32.93690372	Talagang	Saghar
Shah muhammad	71.93375572	33.05738473	Talagang	Jabbi Shah Dilawar
Singwala	72.23513259	32.97576602	Talagang	Budhial
Tamman	72.11542262	33.00742778	Talagang	Tamman
Taragar	72.40658031	32.98495194	Talagang	Jasyal
Tehi	72.40984213	32.96165804	Talagang	Tehi
Thoa Mehram Khan-I	72.29091541	32.76202393	Talagang	Thoa Mehram Khan-I

Thoa Mehram Khan-II	72.28488717	32.76154837	Talagang	Thoa Mehram Khan-II
Wanhar	72.17936948	32.8917644	Talagang	Bidher

APPENDIX D: Research Publication

Pak. J. Agri. Sci., Vol. 56(1), 187-196; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI:10.21162/PAKJAS/19.7663
http://www.pakjas.com.pk

LAND COVER MAPPING AND CROP PHENOLOGY OF POTOHAR REGION, PUNJAB, PAKISTAN

Sarah Amir[1,*], Zafeer Saqib[1], Amina Khan[1], M. Irfan Khan[1], M. Azeem Khan[2] and Abdul Majid[3]

[1]Department of Environmental Science, International Islamic University, Islamabad, Pakistan; [2]Ministry of Planning, Development and Reforms, Islamabad, Pakistan; [3]ICARDA-Pakistan.
[*]Corresponding author's e.mail: sarah.amir@iiu.edu.pk

Agriculture a major source of food and fibre affects the natural land cover and in turn is affected by climatic factors like temperature and precipitation patterns beside other factors. The soil temperature and moisture, wind, relative humidity and crop water requirements also affect the crop growth. Local farming practices also alter the natural landscape structure and biodiversity in croplands. This study was conducted with the objective to find out seasonality trend and to determine the land cover classification in Potohar region using Normalized Difference Vegetation Index (NDVI). Moreover, random points throughout the study area were selected in order to detect the vegetation index pattern in different land cover types. For land cover classification and acquiring seasonality trend, crop growth patterns were determined by phenological phases of a particular crop. Land cover was classified with standard Level 1 Terrain-corrected (L1T) orthorectified images from Landsat 8 from years 2012 to 2016. Seven land cover classes within the study area were identified namely; agriculture, grasses, forest, shrubs/tall herbs, bare soil, built-up and water bodies. Moreover, the seasonality trend over the study was found related to different land cover classifications using 959 sample plots with 97.81% accuracy. The phase trend analysis determined the change in vegetation cover during the years under study, which was correlated to precipitation patterns in Potohar. The NDVI pattern was highly fluctuating in agricultural land cover due to seasonal crop growth but it remained stable throughout the year in forest covers. Urban land cover was found to have high impact on nearby vegetation as it was related to change in land cover type, which affected the climate of the area. Climate being a vital deriving force, affected precipitation patterns of the rain-fed (*barani*) land which in turn shifted the seasonal growth of various agricultural crops.
Keywords: Agriculture, crop phenology, land cover maps, NDVI, *barani* (rain-fed), seasonality trend

INTRODUCTION

The understanding of dynamics that influence the land use and land cover change (LULC) are imperative for ensuring food security and to address the challenges associated with global climatic changes. The synchronization of societal goals and tripartite linkages among social, ecological and economic domains are essential to achieve the goals of sustainable development (Engstrom *et al.,* 2016; Hegazy and Kaloop, 2015). Land use and land cover are two interchangeable terminologies, where, land cover is described as the physical characteristic of the earth's surface and land use as the way in which that characteristic is used by humans. Land cover are classified into two broad categories i.e. natural (vegetation, forests, shrubs and grasses, water bodies, bare soil etc.) and man-made/human-transformed which reflect anthropogenic interventions in natural environment for economic activities include agricultural lands, settlements etc. (Rawat and Kumar, 2015).

The climate of an area is a product and dependent upon the cumulative behaviour of land use/ land cover types and human interaction in a contextual setting. The vegetative cover of a geographic region help us to decipher the causation and impacts of climate change. In this connection, the role and behaviour of agricultural land cover is unique. It not only contribute in food provisioning but also serve as a natural sink for greenhouse gases such as carbon dioxide (CO_2). It covers more than one third of the land on earth in the form of pastures and croplands. Keeping in view the increasing rate of population, it is vital information to know that only 10% of increase in agricultural land is taking place which makes the unavailability of food for about one billion people globally (Pongratz *et al.,* 2008; Engstrom *et al.,* 2016; Qin *et al.,* 2015). Land cover change can be detected by studying vegetation phenology. Phenology is the study of periodic events in the life cycle of living species (Vina *et al.,* 2004; Sakamoto *et al.,* 2010). An efficient method for assessment of vegetation phenology is the use of satellite derived vegetation indices including Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) (Gong *et al.,* 2015). Landsat 8 provides an efficient source of phenology assessment in the area like Pakistan having diverse crops. Sensors of the satellite i.e., Operational Land Imager (OLI) with nine bands and Thermal Infrared Sensor (TIRS) with two thermal bands provide the resolution of about 30 m (Jia *et al.,* 2014) which is an accurate resolution for phenological assessment of large as well as small crop lands like that of Potohar region.

The geographic area of Pakistan is about 80 million hectares (Mha), of which 18 Mha is irrigated and dry land farming is practiced on 12 Mha. The *barani* (rainfed) areas of Punjab cover about 7 Mha and are home to over 19 million people. This is equivalent to about 40% of the total area of the Pakistan Punjab (Oweis and Ashraf, 2012). These areas, however, contribute less than 10% to total agricultural production and depend solely on the rainfall. In addition to a food source for the citizens of the country, agriculture is also a very important economic sector of Pakistan contributing about 21% in GDP. An important subsector of agriculture is cropland constituting 39.6% of agriculture and which has a share of about 8.3% in GDP (Khan *et al.*, 2016). The major share (76%) is contributed by Punjab (Rashid *et al.*, 2014). Kazmi and Rasul (2009) hypothesised that the underestimated *barani* land (rainfed area) of Potohar plateau is capable to significantly contribute in the economy of Pakistan because more than 1200 kg/acre wheat is grown in the area which shows its potential to lower import load.

Productivity of Potohar is reported to be decreased about 2.5 to 7 times due to over grazing and removal of vegetation for purpose of obtaining fuel wood. Habitat degradation is the obvious consequence of this event as water erosion effects the agro ecosystems. The vegetation cover can be recovered by increase in precipitation (Gong *et al.*, 2015).

Land cover mapping of a region is an important task in order to determine the ongoing changes in LULC over time. Land cover mapping helps us determine whether a certain sector either agriculture or urban requires proper planning and management. The study of crop phenology help us to determine changes in the climate of the area as the climate of the region directly affects the agricultural lands. Data about crop phenology relate to food security of an area.

The main objectives of the present study were to develop land cover maps for determining area under agricultural land cover, analyze the seasonal trend of Potohar region from 2012-2016 and to find out correlation between precipitation and NDVI.

MATERIALS AND METHODS

Study area: The study area chosen for the present study was Potohar plateau, Pakistan and includes major portion of districts Attock, Chakwal, Islamabad, Jhelum and Rawalpindi (Fig. 1). The region lies between Indus River and the Jhelum River and stretches from the salt range northward to the foot hills of Himalayas (approximately 32.5°N to 34.0°N Latitude and 72°E to 74°E Longitude). The total area of this region is approximately 13,000 km^2 with elevation from sea level fluctuating between 305 - 610 m. It has highly undulating topography and erratic rainfall pattern. The climate of the area is semi-arid to humid. Out of total, about 80% rain falls during July to October (Sarwar *et al.*, 2014). The summer temperature ranges between 15°C and 40°C while the range of winter temperature is generally between 4 and 25°C but it can occasionally drop. Around 994 thousand hectares area of Potohar plateau is being cultivated (GoP, 2016). About 4% of the cultivated land is irrigated while 96% is dependent on rain (Majeed *et al.*, 2010). The major crops grown in the area include wheat (*Triticum vulgare*), maize (*Zea mays*), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), millets (*Panicum miliaceum*), lentils (*Lens culinary*), gram (*Cicer arietinum*), groundnut (*Arachis hypogaea*) and brassica (*Brassica rapa*).

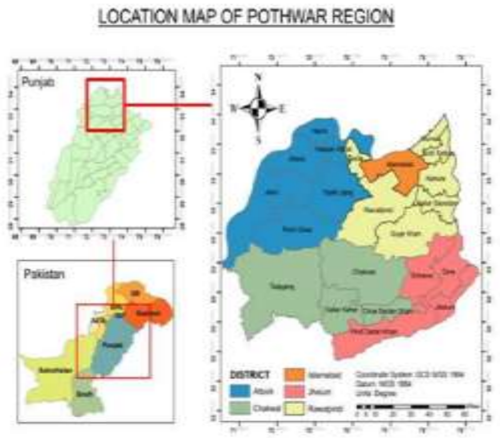


Figure 1. Location map of the study area.

Land cover mapping and phenology: In order to map land cover and trends in land surface phenology of the croplands, Landsat 8 satellite data was used. All the data analyses were carried out in Google Earth Engine (GEE) platform. The dataset used was calibrated top-of-atmosphere (TOA) reflectance (Collection 1 Tier 1) from Landsat 8 imagery. The reflectance is calculated on the calibration coefficients defined by Chander *et al.* (2009). The study area is covered by World Referencing System (WRS) path 150 and row 37. For developing land cover an image acquired 17th March 2017 was used (landsat ID: LC08_L1TP_150037_20170317_20170328_01_T1) that contained <1% cloud cover. All the available imagery (n=77) was used for the analysis of land surface phenology trends. The selected images from year 2012 to 2016 were processed using Earth Engine API.

Cloud removal: Some of the acquired data becomes inaccurate due to presence of cloud cover over the study area which hinders the satellite assessment of the region. It is termed as noise in the data. Such regions were masked by removing clouds. In this study, all these bad observations were masked using Landsat 8 quality assessment band

(Scaramuzza *et al.*, 2012; Roy *et al.*, 2014). The masked correction of bad observations is classified in four levels including "not determined" (Algorithm did not determine the status of this condition), "no" (0–33% confidence), "maybe" (34–66% confidence), and "yes" (67–100% confidence) (Dong *et al.*, 2016). We used the 67–100% confidence level to exclude all the potential bad observation effects from clouds and cirrus. It helped to obtain 97.8% accuracy of results.

Spectral indices: The time series of Landsat TOA image collection was used to calculate three vegetation indices, including NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index) and MNDWI (Modification of Normalized Difference Water Index). The spectral indices were calculated using following equations:

$$\mathrm{NDVI}\left(\frac{B5-B4}{B5+B4}\right);\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq (1)}$$

$$\mathrm{NDWI}\left(\frac{B3-B5}{B3+B5}\right);\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq (2)}$$

$$\mathrm{MNDWI}\left(\frac{B5-B4}{B5+B4}\right),\ \mathrm{MNDWI}\left(\frac{B3-B7}{B3+B7}\right)\ldots\ldots\text{eq (3)}$$

Gaps in the original NDVI were filled using linear and harmonic regression models.

Linear regression: Google Earth Engine contains a variety of methods for performing linear regression. Linear regression model gives the fitted values out of original NDVI values in a linear trend. Linear model only describes the trend on the values being increasing or decreasing over a certain period of time. The linear trend was calculated in Earth Engine using the following equation:

$$pt = \beta 0 + \beta 1t + et\ldots\ldots\ldots\ldots\text{eq (4)}$$

Where, pt is NDVI at time, t is time and et is random error. The missing data in the original NDVI were filled using this model. This was shown as the fitted value in the graph. Linear regression equation was used in the script in order to show the increasing and decreasing trend for NDVI value.

Harmonic regression: In order to extract the phase and amplitude using windowed fourier analysis for seasonal trend analysis, a script was developed in Earth Engine Code editor whereby the equation of harmonic regression was incorporated along with linear regression trend. The number of harmonic cycle taken was two. This equation of harmonic regression is as follows;

$$Y=\beta_0+cT+\sum_{i=1}^{n} A_i \mathrm{Sin}\left(\frac{2\pi i}{s}T\right)+\varphi_i \quad \ldots\text{eq (5)}$$

Where Y is the NDVI, β0 is an offset, c is the trend, Ai is the amplitude of the *i*th oscillation, φi is the phase component of the *i*th oscillation, s is the fundamental frequency and T is the time-dependent variable. The peak of annual greenness was represented by the amplitude while the timing of the peak NDVI value was represented by phase.

Seasonal trend analysis: Seasonal trend analysis is a two stage process to describe seasonal NDVI cycle. First stage dealt with obtaining amplitude 0 (mean annual greenness) and amplitude 1 (peak of annual greenness) by performing harmonic regression on each pixel of 5- year NDVI time series with temporal window of one year. Phase 0 and phase 1 were obtained in the second stage relevant to amplitude 0 and amplitude 1. Values for phase image ranges from 0 to 359 degrees and after every 30 degrees a change of one calendar month is represented (Eastman *et al.*, 2009). The equation utilized in script for seasonal trend analysis is expressed as follows;

$$y = \alpha_0 \sum_n \left\{a_n \sin\left(\frac{2\pi nt}{T}\right) + b_n \cos\left(\frac{2\pi nt}{T}\right)\right\} + e \quad \text{eq (6)}$$

Where, t is time, T is the interval of time-series, n is a harmonic multiplier, e is an error term, α_0 is the series mean and a_n and b_n are regression parameters.

Digital image classification: To classify the land cover of Potohar, complex pixels of satellite image containing multiple spectral bands and range of millions of colours, were classified into definite number of classes. Earth engine classifier package handled the pixels using CART classifier to generate land cover maps. It fundamentally separated the forest and non-forest areas.

Figure 2. Schematic flow of the methodology.

RESULTS AND DISCUSSION

Land cover classification: The supervised classification of satellite images of Potohar distinguished seven types of land cover. Figure 3 illustrates these types along with the area covered by each land cover type. Land cover types identified included agriculture, grasses, tree/forest, shrubs/tall herbs, bare soil/rocks, built-up and water bodies. Some of the area remained unclassified due to research time and resource constraints.

189

Area that each of the land type covered was calculated separately for five districts of Potohar namely Chakwal, Attock, Rawalpindi, Jhelum and Islamabad. Percentage of the area covered in each district is mentioned in Table 1 while Figure 4 shows the same in kilometre square (km²).

Table 1. List of land cover distribution (in percentage) in districts of Potohar in year 2017.

Land cover types	Islam-abad	Attock	Chak-wal	Jhelum	Rawal-pindi
Agriculture	37.32%	69.17%	68.65%	37.35%	38.52%
Grasses	16.42%	7.88%	7.46%	14.38%	16.13%
Trees/Forests	19.85%	16.11%	17.03%	30.78%	29.45%
Shrubs/Tall herbs	13.81%	2.69%	3.10%	5.69%	10.94%
Bare soil/Rocks	3.01%	1.05%	1.35%	5.79%	1.58%
Built-up	8.94%	2.76%	2.25%	5.55%	3.29%
Water	0.66%	0.35%	0.17%	0.45%	0.09%

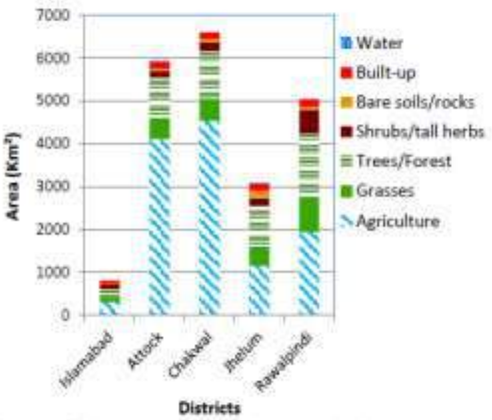


Figure 4. Illustration of Land cover distribution in each district of Potohar Region in kilometre square (Km²) in year 2017.

Accuracy assessment: The overall accuracy of the land cover map was 97.81% with value 0.971 for Kappa quotient, and 0.9903 was the maximum possible un-weighted Kappa given the observed marginal frequencies. At 0.95 confidence interval upper values in both methods 1 and 2 were 0.9832 and lower values were 0.9586. Both the accuracies, 'Producer and User', were greater than 94% for all the land cover classes except for class 'grasses' that have producer accuracy 91.61% as shown in Table 2.

Seasonal trend analysis: The first harmonic cycle indicates the first half of the year (from January to June) in terms of phase 1 and the second harmonic cycle indicates the latter half of the year (from July to August) in terms of phase 2. Figure 5 visualizes phase 1 trend analysis while Figure 6 illustrates this trend over agricultural land.

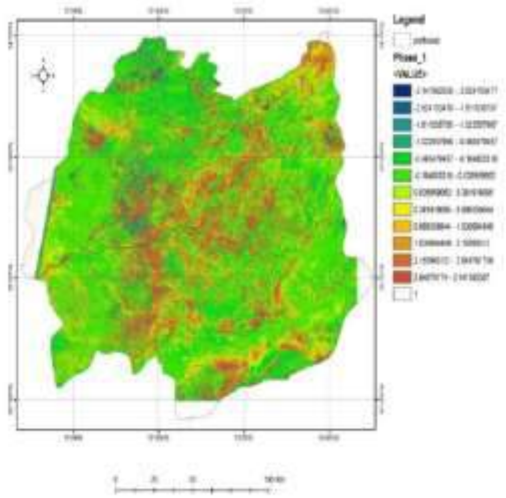


Figure 5. Map of Potohar region illustrating phase 1 trend analysis (2012 - 2016).

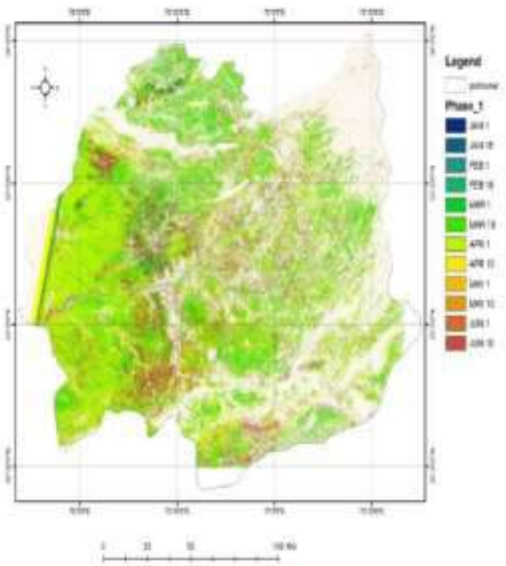


Figure 6. Map of Potohar region illustrating phase 1 trend over agricultural land cover (2012 - 2016).

Phase 2 trend is shown in Figure 7 & 8. The shades of the resulted phase maps illustrate months of the year. The colour codes for each month of phase 1 and phase 2 are mentioned in Tables 3 & 4.

Table 2. Error matrix for land cover classification showing accuracy assessment of the results in terms of user accuracy, producer accuracy and overall accuracy with Kappa=0.971.

Land cover	1	2	3	4	5	6	7	Total	Useraccuracy
1. Agriculture	340	8	0	0	1	0	0	349	97.42%
2. Grasses	6	142	1	0	0	0	0	149	95.30%
3. Trees/Forest	0	5	264	0	0	0	0	269	98.14%
4. Shrubs/Tall Herbs	0	0	0	88	0	0	0	88	100.00%
5. Bare Soil/Rocks	0	0	0	0	19	0	0	19	100.00%
6. Built-up	0	0	0	0	0	47	0	47	100.00%
7. Water	0	0	0	0	0	0	38	38	100.00%
Total possible	346	155	265	88	20	47	38		
Omissions	6	13	1	0	1	0	0		
Commissions	9	7	5	0	0	0	0		
Correctly Classified	340	142	264	88	19	47	38		
Producer Accuracy	98.27%	91.61%	99.62%	100.00%	95.00%	100.00%	100.00%		Overall Accuracy = 97.81%

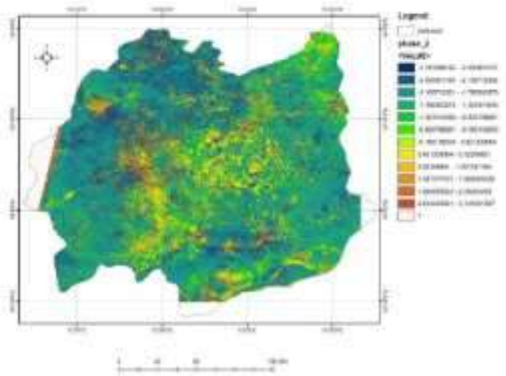


Figure 7. Map of Potohar region illustrating phase 2 trend analysis (2012 - 2016).

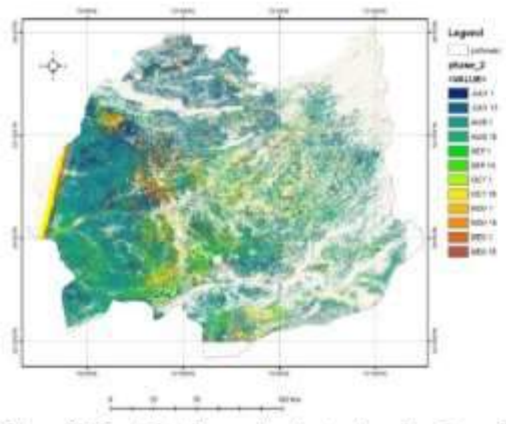


Figure 8. Map of Potohar region illustrating phase 2 trend over agricultural land cover (2012 - 2016).

Table 3. List of colour codes with their identical description for phase 1.

Colour Identity	Description
Dark Blue	peak beginning of January
Moderate Blue	Middle of January
Light Blue	peak beginning of February
Sea Green	Middle of February
Dark Green	peak beginning of March
light green	Middle of March
Lime Green	peak beginning of April
Bright Yellow	Middle of April
Orange	peak beginning of May
Dark Orange	Middle of May
moderate Brown	peak beginning of June
Maroon	Middle of June

Table 4. List of colour codes with their identical description for phase 2.

Colour Identity	Description
Dark Blue	peak beginning of July
Moderate Blue	Middle of July
Light Blue	peak beginning of August
Sea Green	Middle of August
Dark Green	peak beginning of September
light green	Middle of September
Lime Green	peak beginning of October
Bright Yellow	Middle of October
Orange	peak beginning of November
Dark Orange	Middle of November
moderate Brown	peak beginning of December
Maroon	Middle of December

Overall seasonality of the area is shown in Figure 9. In simple RGB model crop phenology of different land covers in the study area is displayed. This phenological trend is shown via

191

graphs in Figures 10-15 using random points throughout the study area.

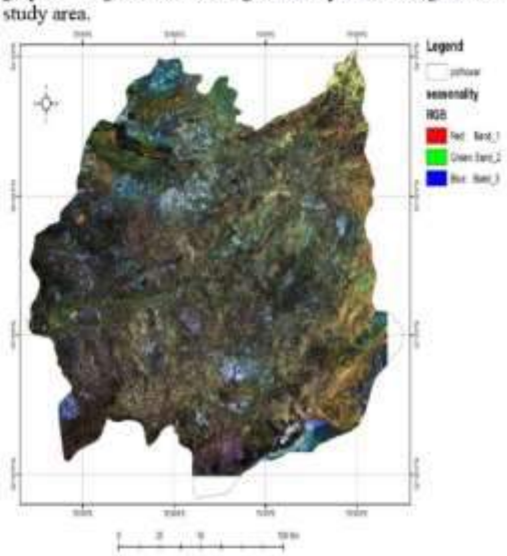


Figure 9. Map of Potohar region illustrating seasonality trend analysis (2012 - 2016).

Precipitation correlation: The productivity of Potohar region was correlated with precipitation as it is a *barani* area. Figure 16 displays the change in productivity immediately after precipitation. In Figure 17, map of correlation lag 17 is displayed which shows the change in NDVI 17 days after the precipitation. Similarly in Figure 18, lag 30 map shows the change 30 days later.

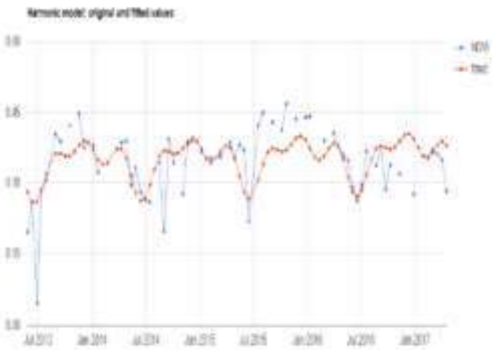


Figure 10. Illustration of phenological trend in forest cover near Attock district.

Figure 11. Illustration of phenological trend in agricultural field in Chakwal district.

Figure 12. Illustration of phenological trend in crop field of Jhelum district.

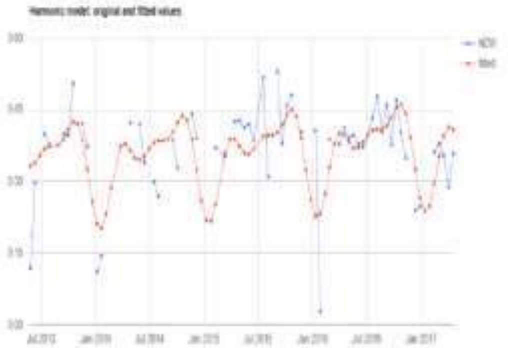


Figure 13. Illustration of phenological trend in evergreen forest at foothills of Himalayas.

192

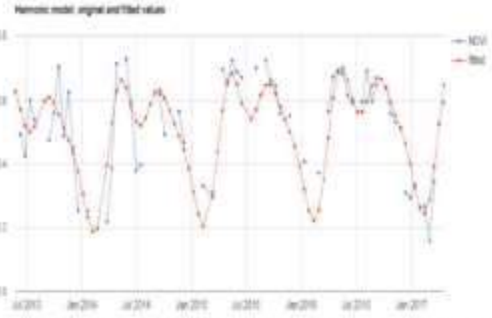


Figure 14. Illustration of phenological trend in forest near Rawal Lake, Islamabad.

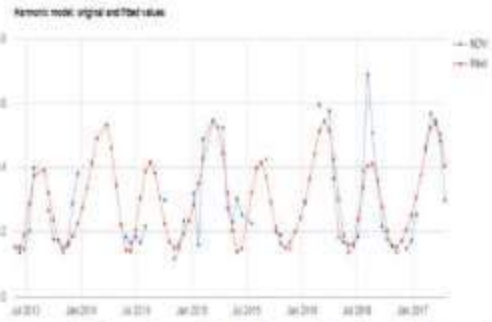


Figure 15. Illustration of NDVI trend in urban built-up of Rawalpindi district.

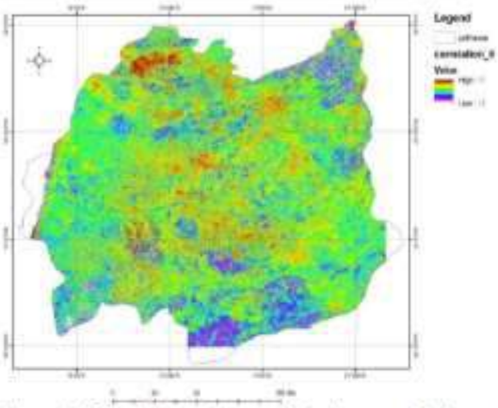


Figure 16. Map illustrating precipitation correlation at lag 0 with changing NDVI.

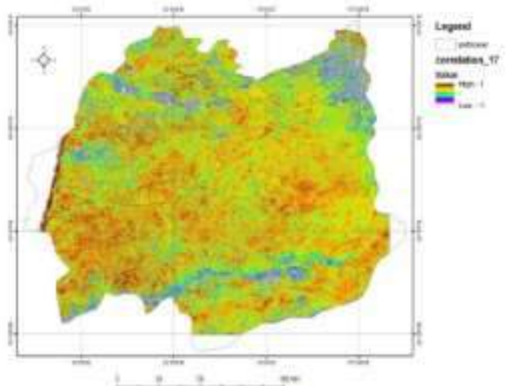


Figure 17. Map illustrating precipitation correlation at lag 17 with changing NDVI.

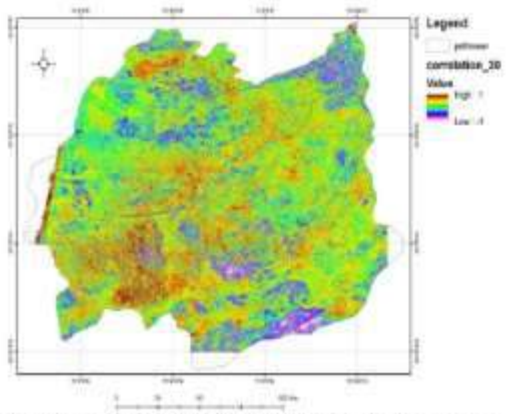


Figure 18. Map illustrating precipitation correlation at lag 30 with changing NDVI.

To characterize seasonal trend and crop phenology of Potohar region, satellite-derived time-series data was utilized. A very interesting crop phenology trend was found to be obtained in Figures 5 & 6. A negative NDVI value describes an early season of the year indicated by blue colour, while, red colour in the map having positive NDVI values indicate the peak of the season (Fig. 5). In Figure 6, first harmonic cycle completing in June shows the phenology of a crop which possibly has a harvest time period in March or April as most of the study area was represented in green which shows a mean NDVI value. Wheat crop is an abundant crop in Potohar which possibly describes the obtained NDVI value for March and April (Kazmi and Rasul, 2006). The similar trend is followed in Figures 7 & 8, whereas, in July the early season

Annexure 1. Showing the codes (JAVA Script) and procedural measures adopted for data acquisition and processing.

Processing	Code

Image processing
Satellite data Acquisition
Year: 2012-2016
Bands Used: 1, 2, 3, 4, 5 & 7
Worldwide Reference System: WRS 2: 150/37
	//Landsat Data
	VarNAME=ee.imageCollection('LANDSAT/LC8_L1T_TOA')
	.filterData('2012-01-01');
	.filter(ee.Filter.eq('WRS_PATH', 150));
	.filter(ee.Filter.eq('WRS_ROW', 37y));
	//Band Selection
	var bands = ['B1','B2','B3','B4','B5','B7];

Cloud Removal	var image = ee.ImageCollection('LANDSAT/LC8_L1T_TOA')
	//selected year cloud remove
	.sort('CLOUD_COVER')
	.map(maskClouds)

Spectral Indices	
NDVI $\left(\frac{B_5-B_4}{B_5+B_4}\right)$:............eq (1)	var ndvi = image.normalizedDifference(['B4','B5']);
NDWI $\left(\frac{B_3-B_5}{B_3+B_5}\right)$:............eq (2)	var ndwi = image.normalizedDifference(['B3','B5']);
MNDWI $\left(\frac{B_3-B_7}{B_3+B_7}\right)$............eq (3)	var mndwi = image.normalizedDifference(['B3','B7']);

Land Cover Classification	var trainingImage = ee.Image([image.select('B1'),
	image.select('B2'),
	image.select('B3'),
	image.select('B4'),
	image.select('B5'),
	image.select('B7'),
	ndbi.rename('ndbi'),
	ndvi.rename('ndvi'),
	mndwi.rename('mndwi'),
	Map.centerObject(roi);
	Map.addLayer(trainingImage,vizParams,'True-color composite',false);
	Map.addLayer(trainingImage,{'bands':['ndvi','ndbi','mndwi'],
	'min':-1,'max':1},'NDXI composite',false);
	/*
	//Classification starts Here
	print(trainingImage);
	// Image classification
	var predictionBands = trainingImage.bandNames();
	print(predictionBands);
	var trainingFeatures = agriculture //1
	.merge(grasses) //2
	.merge(trees) //3
	.merge(shrubs) //4
	.merge(bare) //5
	.merge(builtup) //6
	.merge(water); //8
	var classifierTraining = trainingImage
	.select(predictionBands)
	.sampleRegions({collection: trainingFeatures,
	properties: ['landcover'],
	scale: 30
	});
	// train the classifier
	var classifier = ee.Classifier.cart().train({
	features: classifierTraining,
	classProperty: 'landcover',
	inputProperties: predictionBands
	});

Accuracy Assessment on the basis of classification	print(classifier.explain());
	var confusionMatrix = classifier.confusionMatrix()
	var accuracy = confusionMatrix.accuracy()
	print(confusionMatrix.accuracy);

Linear regression formulation	ee.Reducer.linearFit()
Export result for further image processing	Export.image.toDrive({ image: classified, description: 'classified_image', scale: 30, region: roi });

shows negative NDVI trends indicating the sowing of a crop. The other intermediate shades between blue and red indicate the presence of other minor crops.

Crop phenology study was conducted to determine the start and end of seasons of various crops in Potohar and their relation with the land cover and precipitation. Random points

194

taken from the study area revealed the patterns of vegetation in various land cover types. A sub-tropical deciduous forest in Attock sheds its leaves in the start of dry season so as to retain water to survive in harsh weather conditions and drought. The seasonal trend didn't show a very high change in NDVI showing the stable nature of the forest cover. The agricultural field in Chakwal shows crop phenology by exhibiting changes in NDVI. Wheat has the harvesting period from March to May during which it shows decrease in NDVI value and then in sowing period from October to November, it shows high increase in NDVI. The other minor fluctuations show the presence of grasses in the field. The crop field of Jhelum displays the phenologies of wheat and maize in the area indicating high increase in NDVI in November till March for wheat and from July till October or November for maize crop. An evergreen forest on the foothills of Himalaya was taken as the comparison between NDVI of deciduous and evergreen forest. Evergreen forest indicated a very minor fluctuation in NDVI throughout the year with decreasing trend in winters due to snow cover. Forest vegetation near Rawal Lake was taken to determine the relation of water body with the changing NDVI. The trends in NDVI show increase, only minor, in value during monsoon and winter rains when lake is filled by the precipitation and decrease in values in dry seasons. Near urban areas of Rawalpindi, the vegetation either consists of grasses or they may be small private crop fields showing negligible change in NDVI.

In Figures 16, 17 and 18, the productivity of the crops is correlated with precipitation. The areas having positive values indicate that the increase in precipitation increases the productivity. Such areas are arid having water scarcity and dependant on precipitation as water source. Those having negative correlation show that the productivity decreases as the precipitation increases while those having zero values for correlation mean, it is not dependant on precipitation. In Figure 17, map of correlation lag 17 is displayed, which shows the change in NDVI 17 days after the precipitation. Similarly in Figure 18, lag 30 map shows the change 30 days later. Lag 17 maps indicated high correlation in dense agricultural lands and forest covers near urban settings showing human induced changes in the area. Lag 30 maps indicated the high values of correlation for agricultural lands and moderate for urban settings. Correlation values for forest covers in moist environments remained low while for arid and dry climatic regions like Attock, precipitation seemed to have high impact. Mishra and Chauhdary (2014) also discussed in their study about the precipitation correlation with seasonality analysis showing increase in brownness due to changing precipitation patterns due to anthropogenic activities.

Conclusion: The underlying goal of this research was to evaluate the seasonality shift and land cover classes in Potohar. Using the refined resolution of Landsat 8 (30m), the vegetation indices were studied for an assessment of land cover activity based on time series trend analysis. The long term seasonality trend helped to monitor and identify the factors which are responsible for land cover changes in Potohar. The results have shown the seasonality shift based on land cover change with the accuracy of Kappa= 0.9781. The vegetation alongwith the urban setting had shown shift in the values of NDVI, while the forest cover away from urban area had quite stable seasonality trend. The agricultural land, however, showed different NDVI trends for different crops depending upon their start of season. On the basis of these results, it is incurred that, vegetation in different land cover types is dependent upon the prevailing environment in the particular land cover type. Land use and land change is highly associated with the changing environment especially in the context of climate change.

REFERENCES

Chander, G., B.L. Makhram and D.N. Helder. 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sense Environ. 113:893-903.

Dong, J., X. Xiao, M.A. Menarguez, G. Zhang, Y. Qin, D. Thau, C. Biradar and B. Moore. 2016. Mapping paddy rice planting area in north-eastern Asia with Landsat 8 images, phenology-based algorithm and Google Earth Engine. Remote Sense Environ. 185:142-154.

Eastman, J.R., S. Florencia, G. Bardan, Z. Honglei, C. Hao, N. Neeti, C. Yongming, A.M. Elia and C.C. Crema. 2009. Seasonal trend analysis of image time series. Int. J. Remote Sense 30:2721-2726.

Engstrom, K., M.D.A. Rounsevell, D.M. Rust, C. Hardacre, P. Alexander, X. Cui, P.I. Palmer and A. Arneth. 2016. Applying Occam's razor to global agricultural land use change. Environ. Modell. Soft. 75:212-229.

Gong, Z., K. Kawamura, N. Ishikawa, M. Goto, T. Wulan, D. Alateng, T. Yin and Y. Ito. 2015. MODIS normalized difference vegetation index (NDVI) and vegetation phenology dynamics in the Inner Mongolia grassland. Solid Earth 6:1185-1194.

GoP. 2016. Punjab Development Statistics. 2016. Bureau of Statistics, Planning and Development Department, Government of the Punjab, Pakistan.

Hegazy, I.R. and M.R. Kaloop. 2015. Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. Int. J. Sustain. Built. Environ. 4:117-124.

Jia, K., S. Liang, X. Wei, Y. Yao, Y. Su, B. Jiang and X. Wrang. 2014. Land cover classification of landsat data with phenological features extracted from Time Series MODIS NDVI Data. Int. J. Remote Sense 6:11518-11532.

Kazmi, D.H. and G. Rasul. 2009. Early yield assessment of wheat on meteorological basis for Potowar region. Pak. J. Meteorol. 6:73-87.

Khan, A., M.C. Hansen, P. Potapov, S.V. Stehman and A.A Chatta. 2016. Landsat based wheat mapping in the heterogeneous cropping system of Punjab, Pakistan. Int. J. Remote Sense 37:1391-1410.
Majeed, S., I. Ali, B.S. Zaman and S. Ahmad. 2010. Productivity of mini dams in Pothwar Plateau: A diagnostic analysis. Research briefings Vol (2), No (13), Natural Resource Division, Pakistan Agricultural Research Council, Islamabad, Pakistan.
Misha, N.B. and G. Chaudhary. 2015. Spatio-temporal analysis of trends in seasonal vegetation productivity across Uttarakhand, Indian Himalayas, 2000-2014. Appl. Geogr. 56:29-41.
Oweis, T., M. Ashraf (eds). 2012. Assessment and options for improved productivity and sustainability of natural resources in Dharabi Watershed Pakistan. ICARDA, Aleppo, Syria.
Pongratz, J., C. Reick, T. Raddatz and M. Claussen. 2008. A reconstruction of global agricultural areas and land cover for the last millennium. Global Biochem. Cycles 22:1-16.
Qin, Y., X. Xiao, J. Dong, Y. Zhou, Z. Zhu, G. Zhang, G. Du, C. Jin, W. Kou, J. Wang and X. Li. 2015. Mapping paddy rice planting area in cold temperate climate region through analysis of time series Landsat 8 (OLI), Landsat7 (ETM+) and MODIS imagery. Int. J. Remote Sense 105:220-233.
Rashid, K., M. Ayaz and K. Noureen. 2014. Weather and maize crop development in Potowar Region Punjab (Rawalpindi). Pakistan Meteorological Department, Islamabad. Pakistan.
Rawat, J.S. and M. Kumar. 2015. Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. Egypt. J. Remote Sense 18:77-84.
Roy, D.P., M.A. Wulder, T.R. Loveland, C.E. Woodcock, R.G. Allen, M.C. Anderson, D. Helder, J.R. Irons, D.M. Johnson and R.Kennedy. 2014. Landsat-8: Science and product vision for terrestrial global change research. Remote Sense Environ. 145:154-172.
Sakamoto, T., M. Yokozawa, H. Toritani, M. Shibayama, N. Ishitsuka and H. Ohno. 2010. A crop phenology detection method using time-series MODIS data. Remote Sense Environ. 96:366-374.
Sarwar, M., I. Hussain, M. Anwar and S.N. Mirza. 2014. Baseline data on anthropogenic practices in the agro-ecosystem of Potowar plateau, Pakistan. J. Anim. Plant Sci. 26:850-857.
Scaramuzza, P.L., M.A. Bouchard and J.L. Dwyer. 2012. Development of the landsat data continuity mission cloud-cover assessment algorithms. IEEE. T. Geosci. Remote 50:1140-1154.
Vina, A., A.A. Gitelson, D.C. Rundquist, G. Keydan, B. Leavitt and J. Schepers. 2004. Monitoring maize (*Zea mays* L.) phenology with remote sensing. J. Agron. 96:1139-1147.

Pak. J. Agri. Sci., Vol. 57 (2), 465-475 : 2020
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/19.9030
http://www.pakjas.com.pk

FARMERS' PERCEPTIONS AND ADAPTATION PRACTICES TO CLIMATE CHANGE IN RAIN-FED AREA: A CASE STUDY FROM DISTRICT CHAKWAL, PAKISTAN

Sarah Amir[1,*], Zafeer Saqib[1], Muhammad Irfan Khan[1], Muhammad Azeem Khan[2], Syed Atif Bokhari[3], Muhammad Zaman-ul-Haq[1] and Abdul Majid[4]

[1]Department of Environmental Science, Faculty of Basic & Applied Sciences, International Islamic University, H-10, Islamabad, Pakistan;[2]Pakistan Agricultural Research Council (PARC), Islamabad, Pakistan;[3]Department of Geography, Government Postgraduate College, Asghar Mall, Rawalpindi, Pakistan;[4]Country Head, ICARDA-Pakistan, NARC, Park Road, Chakshahzad, Pakistan
[*]Corresponding author's email: sarahamir_2001@yahoo.com

Farmers in the rain-fed regions are becoming more exposed to extreme weather adversities and hence, suffer significant losses. The present study was designed to decipher the impacts of the climate change on the farming communities residing in the rain-fed areas of Pakistan. For this purpose, 475 households were surveyed through a pre-tested structured questionnaire to know farmers' perceptions about climate change and its impacts; available sources of information and strategies adopted to cope with climate-related events. The results indicated that 96% of the respondents perceive that the climate in their surroundings is not only changing rather aggressively denting on crop productivity, livestock sustenance and human health. These climatic variations are being realized in the form of rising temperature (61%), irregular pattern of precipitation (86%) hailstorm (73%), delay in the start of winter season (71%), incidents of the cold breeze (67%) and heat waves (65%), storms (64%), frost (59%) and an increase in the occurrences of drought conditions (39%). This factor by and large tantamount the overall depression in the rain-fed farming community pressing them to look for the alternative avenues for their livelihood. Nevertheless, the farmers rely on different adaptation strategies (changing planting decisions: 76%, changing cropping pattern: 46%, left land fallow: 24% etc.), but these are insufficient and less effective. In conclusion, only few farmers could adapted their agricultural strategies to changing climate due to limited resources and capacities and majority is vulnerable Therefore, the scenario demands for integrated technical, financial and institutional support to the farmers. This upcoming alarming situation requires potential measures be taken to ensure resilience of agriculture sector that may ultimate poverty reduction.
Keywords: Climate change, perception, farmers, adaptation strategies, rain-fed agriculture.

INTRODUCTION

Climate change is becoming a daunting and challenging threat for the global food security. The phenomena is proving burdensome for the natural and human resources and, thus, a real challenge for the social, economic and ecological sustainability of the resource-stricken developing regions such as South Asia (IPCC, 2014; Bokhari *et al*., 2018; IPCC, 2018). The researchers such as Abid *et al*. (2016), Atif *et al*. (2018a) and Wu *et al*. (2017) opined that the consequential impacts of these weather and climatic fluctuations are adversely impacting the environmental resources of these regions. Whereas, the economic and social viabilities of these contextual settings are dependent on the agricultural productivities, therefore, integrated efforts are incumbent for ensuring the resilience of their agro-based economies.

The scientific postulations regarding the likely upsurge in the global surface temperature (Easterling *et al*., 2000; McCarthy *et al*., 2001) and findings of the similar investigations (IPCC, 2014; Wu *et al*., 2017) corroborating the notions of Pachauri *et al*. (2014) that the climate-induced anomalies are exasperating the socio-economic stabilities and affecting food-insecurities in the South Asian region. Food and Agriculture Organization (FAO, 2015) reported that approximately 50% of the total land area in the South Asian region is being utilized for agricultural activities, thus, integrated efforts for the resilience of the agricultural sector are obligatory.

The growing population density, technological innovations and concomitant lifestyle changes are exerting their own pressures on Land Use Land Cover (LULC) changes. These LULC modifications are incumbent to fulfilling the growing demands for food and abode in this densely populated region (Vadrevu *et al*., 2015). The resultant LULC transformations are taking place at the cost of shrinkages in the forested and pastoral lands (Mitra and Sharma, 2012). These planned and unplanned intrusions in the natural equilibrium are exacerbating the impacts of the weather and climatic anomalies. Thus, the consequential imbalances in the natural environment are proving more stressful for the life and livelihood strategies in this part of the globe.

The conjectures, based upon simulation modelling techniques, indicate that the slightest surge in the surface temperature of the earth will negatively affect the yield and quality of the cereal crops such as wheat, rice and maize etc. (Morton, 2007). The ultimate victim of these corollaries will be the small landholding farmers (Harvey *et al.*, 2014). Their poor economic base, lack of awareness and preparedness further compromises their capacities to address these mounting challenges. Atif *et al.* (2018b) opined that the contemporary environmental degradation necessitates for corrective and remedial measures through identifying context-based strategies. These measures are obligatory to moderate the looming impacts of climate induced vulnerabilities for the farming communities (Bryan *et al.*, 2013; Abid *et al.*, 2016; Jin *et al.*, 2016).

Pakistan is located in the region, which is vulnerable to natural disasters such as the earthquakes, floods, droughts, cyclones, land and soil erosion (GoP, 2017-18). In this connection, Global Climate Risk Index (2017), ranked Pakistan at the 7th position among the most adversely affected countries by the phenomena of climate change. The National Disaster Management Authority (NDMA) of Pakistan estimated an approximate loss of 4 billion US dollars, to national economy in the past twenty years (1994-2013) due to such unwarranted events. The reported rise in the temperature (Aggarwal and Sivakumar, 2010; Ahmad *et al.*, 2013) and unpredictable patterns of precipitation (Abid *et al.*, 2015; Pak-INDC, 2016; Ali and Erenstein, 2017) in Pakistan are badly impacting the per acreage yields of the food crops (Prikhodko and Zrilyi, 2013; Abid *et al.*, 2015; FAO, 2015). Resultantly, the supply-demand gap for the food crops is broadening (Zulfiqar and Hussain, 2014). Whereas, the focus towards this pressing issue is far from satisfactory in Pakistan and, thus, stresses for immediate attention (Smadja *et al.*, 2015).

Pakistan is classified among those countries which are more vulnerable to abrupt climatic oscillations. The lack of orientations towards the above catalogued critical issues allied with low adaptive capacity and compromised financial resource base are further aggravating the situation (Stocker *et al.*, 2013; Atif *et al.*, 2018a). Therefore, the country is in the dire need of approximately 07 to 14 billion US $ to address the looming challenges linked with the climate change (Pak-INDC, 2016).

In this connection, the knowledge about contextual agricultural practices and an assessment of the perception about climate change are the prerequisites for postulating doable adaptation strategies (Bryan *et al.*, 2009; Abid *et al.*, 2018). The analysis of socio-economic factors and the identification of sources through which the information disseminates among the stakeholders are also mandatory for devising pragmatic strategies.

Apropos to this, the present study was conducted to know farmers' perceptions about climate change and its impacts on their lives and livelihoods. The current study tried to decipher the socio-economic conditions of the farming communities and their perception about the fluctuations in the climatic patterns such as droughts, untimely rains, temperature rise etc. It also focuses the on-farm and off-farm adaptive practices/ strategies deployed by the farmers to cope with the climate-related events in the rain-fed rural settings.

MATERIALS AND METHODS

Study area: Pakistan Agricultural Research Council (PARC) sub-divides the Province of Punjab into four agro-ecological zones i.e. Irrigated plains, *Barani* (rain-fed) regions, *Thal region* and the Marginal lands (Abid *et al.*, 2016).The current study was carried out in the contextual settings of the *Barani* (rain-fed) region of the Northern Punjab, known as the Potohar Plateau. This geographical region is located in the *Sind-Saghar doab* (river-interfluve) and comprises over five districts Attock, Chakwal, Islamabad, Jhelum and Rawalpindi. The field investigations for the current study were made in five tehsils (sub-divisions) of Chakwal district i.e. Chakwal, Choa Saiden Shah, Kallar Kahar, Lawa and Talagang. The study area approximately lies across 32°55'29.39" N and 72°51'11.99" E (Fig. 1). The total area of Chakwal District is 6690 km^2. The total population of the district is 1.49 million people of which 81% are residing in the rural areas (PBS, 2017).

The rain-fed agriculture of the Chakwal district is dependent upon the *summer monsoons* and the precipitation from the *western depressions* during the winter season. Therefore, the agricultural productivity is subject to extreme weather and climatic fluctuations (NDMA, 2017). The uncertainties about the crop yields/outcomes are making the livelihood of the people more fragile and vulnerable. Thus, the selected geographical location is an appropriate contextual setting for assessing the farmers' perceptions regarding climate-related impacts.

Data collection: The data for this study were collected with the help of a structured questionnaire. This mechanism for the data collection was prepared on the basis of the contextual information obtained through a pilot survey. The questionnaire used for this study was compartmentalized in different sections. The first part of the questionnaire deals with the demographic and socio-economic characteristics of the respondents. While, the remaining sections of the questionnaire were conceived to acquire information regarding: the availability of basic civic facilities, land- use patterns, agricultural production, perception about climate change, adaptation strategies and access to institutional support etc. The questionnaire was initially developed in the

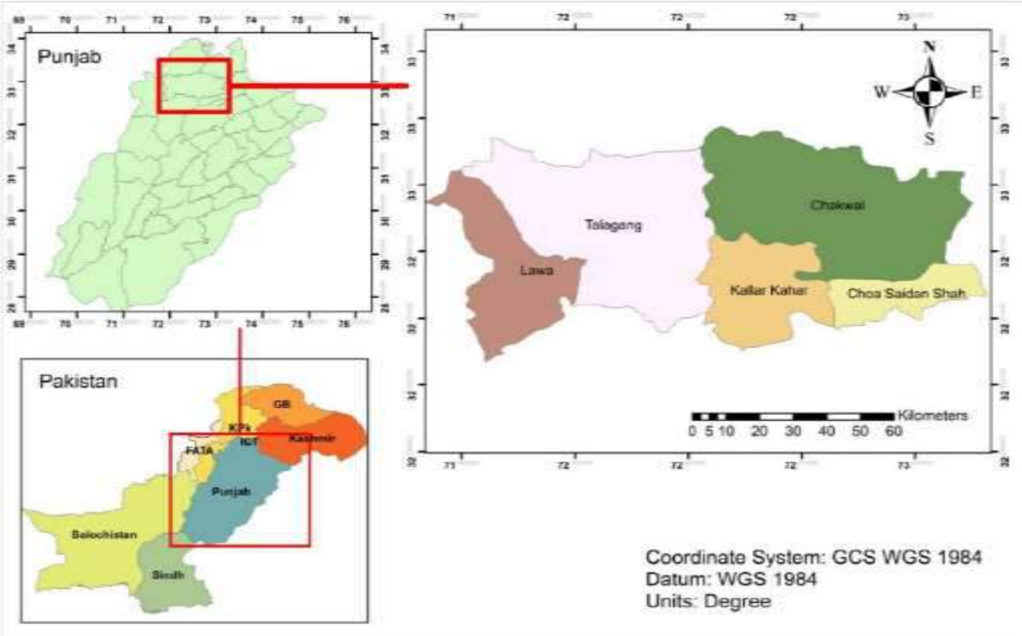


Figure 1. Location map of the study area

English language and was subsequently translated into Urdu for the convenience of the respondents.

However, vernacular was used during the course of interviewing. The field investigations and interviews of 475 respondents were conducted during the months from April to August, 2017. The respondents were selected from 183 villages of the study area through cluster-sampling technique (Fig. 2). The individual respondent was approached with the help of snowballing technique on the principle of convenience sampling method.

***Data analysis*:** Data were condensed in spreadsheet for further processing and subsequent analysis in the Statistical Software 'R' (version 3.4.3). The descriptive statistical methods and techniques such as those dealing with the frequency distribution, median etc. were deployed for the initial probes. In the subsequent stage, the non-parametric Spearman correlation test was relied upon to explore the nature of relationships between the socio-economic status of the household and their farming characteristics. The assessments were also made to evaluate the nature and orientation of adaptation strategies deployed by the farming communities in the study area.

Figure 2. Sampling framework of the study

RESULTS

Socio-economic and demographic characteristics: The demographic and socio-economic profile of the respondents (Fig. 3) portrays the characteristics of a patriarchic rural society. It is quite evident from the fact that all of the respondents were farmers, mature and experienced with a mean age of 52.9 ± 12 years and the mean household size being 7.5 ± 3.3 members. The preliminary investigations reflected the state of compromised economic base of the respondents. The subsequent dependency ratio for the sampled population was found 1.3. The proportionate share of "nucleated families" was larger (65%) than the "combined families" (35%) indicating socio-economic restructuring of the rural society. Regrettably, the low literacy rate and education level of the respondents is discouraging. The majority of them (93%) rely on firewood for domestic energy needs. However, the modern gadgetries such as television, refrigerator and computers etc. are rapidly gaining acceptance among the study population (Fig. 3).

Characteristics of farming systems: The salient characteristics of the farming practices show a consistent biannual cropping pattern of *Kharif* (summer) and *Rabi* (winter) crops. The *Kharif* crops such as groundnut, maize, Green Gram (Moong), Black Gram (Mash) and vegetables etc. and *Rabi* crops like wheat, oilseed, fodder crops, lentils, vegetables etc. complete their production cycle from May to September and October to April, respectively.

The size of agricultural tract used for cultivation is small as 53% of the respondents cultivate on less than 2.5ha of land. In addition to crop production, the majority of respondents also keep livestock for personal use or for supplementary income. In terms of Total Livestock Units (TLUs), it was found that 71% of households had up to 10 TLU. Most small farmers get rental support from service providers as they don't own their machinery. It's evident from the table that only few farmers own tractor (41%) and threshers (19%). However, the majority (90%) of the respondent conveyed that they could not purchase any new asset for farming purposes during the last five years. It was also observed that the use of chemical fertilizers is gaining acceptance as (87%) of the respondents rely on these additional inputs for improving their agricultural yields.

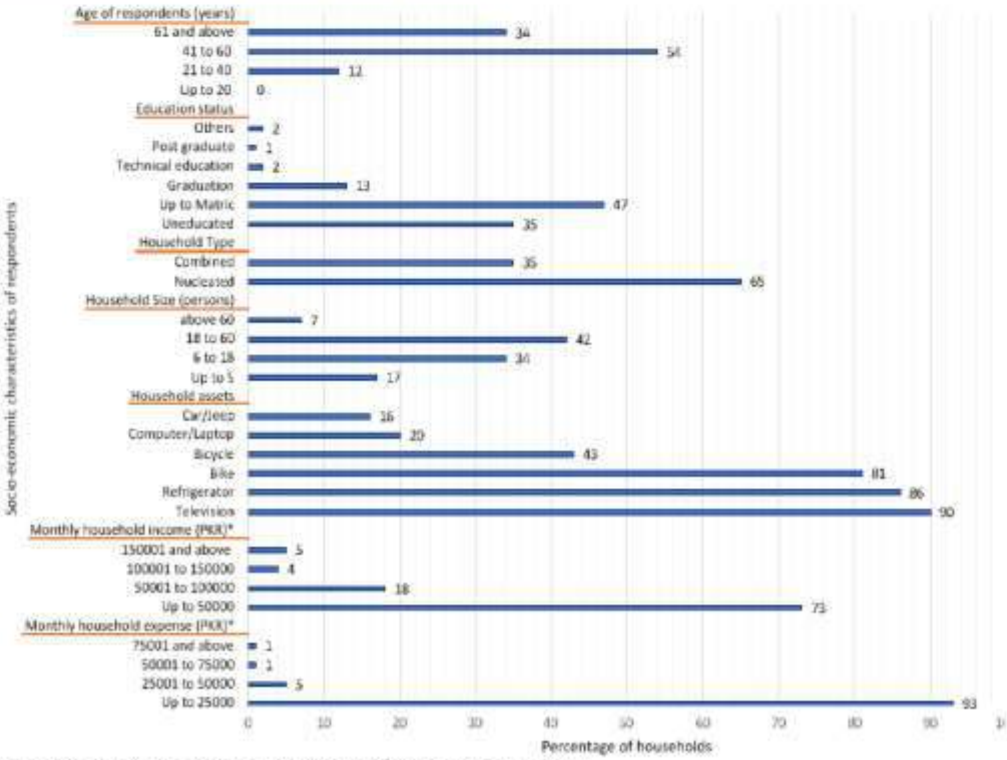


Figure 3. Demographic and socio-economic statistics of the sample
(One hundred and forty one Pak rupees are equal to 1$ (United States Dollar) on May, 02, 2019)

468

Table 1. Characteristics of the farming systems of the surveyed households.

Variables		
Farm assets	**N=475**	**% of households**
Tractor	475	41
Thresher	475	19
Tube well (electric)	475	35
Fodder chopper (electric)	475	78
Fodder chopper (manual)	475	06
Land ownership (ha)	**N=475 (% Total)**	**Cultivated (%)**
up to 2.5	206 (43)	53
> 2.5 to 5	142 (30)	28
> 5 to 7.5	54 (11)	09
> 7.5 and above	73 (15)	10
Household Crop diversification	**N**	**Mean**
No. of crops grown per household	475	4.7
Total Livestock Units (TLU)	**N=475**	**% of households**
Up to 10	335	71
> 10 to 20	89	19
> 20 to 30	35	07
> 30 to 40	12	03
> 40 to 50	02	0.4
> 50 and above	07	1.4

***Limitations and impediments for the farmers*:** The study also tried to evaluate the impacts of climatic uncertainties in conjunction with contextual impediments on the perception and performance of agricultural sector in the rain-fed areas. The study tried to decipher the causes and consequences of the financial limitations on the produce and perception of the farming communities. The findings revealed that water scarcity and drought conditions (98%), land degradation (64%) and soil erosion (32%) are being reported as the potent threats for the agricultural sector (Fig. 4). Besides, a substantial proportion (76%) of respondents also complained against man-made impediments such as the lack of access to agricultural inputs, absence of a coherent mechanism for financial assistance (49%) and non-availability of technical guidance (39%) for sustained agronomic practices. The findings portray that more than half of the respondents (54%) do not have any access to such vital information. Whereas, the information disseminating through mass media receives due attention in the study area (Fig. 4). While, the role and effort of the agriculture extension department was observed insignificant/unimpressive. The field visits meant to stimulate awareness for promoting increased use of technology are gradually decreasing. The active presence of community based farmer research groups is discouraging as only 11% of the respondents reported the presence of such entities in the area (Fig. 4).

Livelihood strategies and food security: Rain-fed agriculture is the primary economic activity in the study area. The crop yields and livestock improvement are important for the

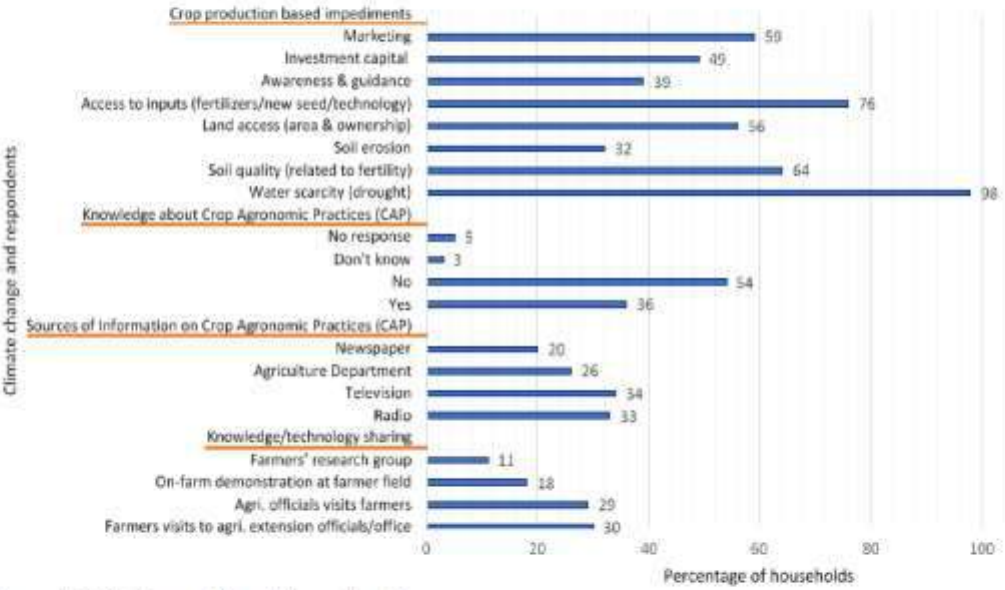


Figure 4. Limitations and impediments in study area

469

domestic food needs and contribute significantly to the household income. However, additional income generated through raising animal heard, government vs private jobs by some family members and obtaining part time farm labor jobs by other members, are key elements that help sustain livelihood of such small farming communities. (Fig.5). The majority of respondents (66%) claimed their self-sufficiency regarding food availability, while, a sizeable minority (34%) is vulnerable in case of crop failure or food shortage. Loans from acquaintances (14%), selling of livestock (27%) or nonagricultural belongings (6%) and government subsidies (8%) are the most preferred strategies to cope with the scenario. Factors positively related to household food security included livestock ownership (r=0.11, p=0.01), crop diversification (r=0.16, p<0.001) and education level of respondents (r =0.04, p< 0.0001).

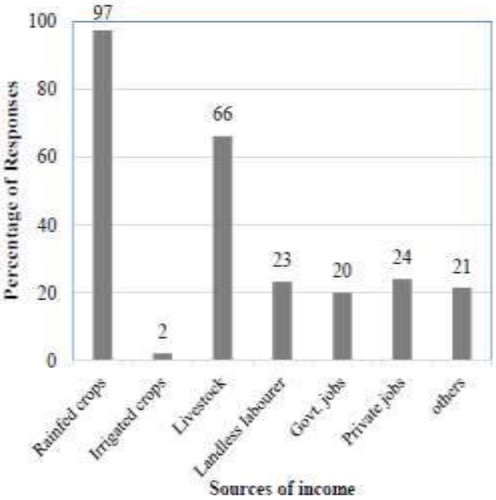


Figure 5. Livelihood strategies of respondents

Perception about Climate change: The majority (96%) of the respondents perceive that the weather and climatic conditions are changing in their surroundings. The findings also revealed that the majority (57%) of these respondents rely on their sensory perception, conventional wisdom and traditional knowledge for such atmospheric assessments. The farming community was more apprehensive about fluctuations in the pattern of precipitation and drought conditions. The respondents also opined that the frequencies and intensities of these unwanted phenomenon have become more recurrent.

***Climatic hazards and their impacts*:** The farmers were inquired about the nature and consequential impacts of climate-induced hazards for their lives and livelihoods. The majority of respondents were apprehensive about the occurrences of incidents such as the untimely rains, hailstorms, delay in the start of winter season, unpredictable incidents of the cold and heat waves etc.

The consequential outcomes of these extreme events directly and indirectly influence the socio-economic conditions in such rural environments. The respondents overwhelmingly reflected concerns over their suffering further added by unpredictable climatic adversities posing dire impact on the overall crop husbandry, livestock maintenance and ultimate human health (Table 2). However, the ramifications were adjudged asymmetrical and heterogeneous across the study area.

Adaptation strategies and farmers: The findings divulged that farm and non-farm based coping strategies are deployed to alleviate the effects of climatic instabilities (Fig. 6). The farm-based strategies such as the temporal re-adjustments in the cultivation (76%), changes in the cropping patterns (46%), more reliance on the techniques for improved production (28%) and irrigation (27%) etc. are the preferred choices. The farmers also sell their livestock (55%), land resources (25%) and consult expert opinions (25%) to cope with the situation. In addition to that, the non-farm based strategies such as

Table 2. Climatic fluctuations and their impacts on farmers over the last 20 years or so (1997-2017)

Climate-related events	Responses			Rate of Change		Impacts on human health (Disease/Illness)			Impacts on crop yield/productivity (Uncertainty/Decline)			Impacts on livestock (Disease/Death)		
	Yes (%)	No (%)	Don't know (%)	Inc-rease (%)	Dec-rease (%)	Inc-rease (%)	Dec-rease (%)	No change (%)	Inc-rease (%)	Dec-rease (%)	No change (%)	Inc-rease (%)	Dec-rease (%)	No change (%)
Drought	39	32	29	30	1	24	0	2	15	15	1	15	13	1
Hailstorm	73	8	18	54	8	48	0	2	38	15	2	35	12	12
Untimely rains	86	3	11	64	2	21	1	2	15	12	0	14	8	8
Winter arrival (late)	71	8	21	42	18	18	0	0	13	8	1	13	6	6
Cold breeze	67	9	24	15	42	18	0	0	14	5	1	14	5	0
Summer arrival (early)	72	7	21	55	4	16	0	0	13	6	2	12	5	5
Heat waves	65	10	25	55	2	16	0	0	13	7	1	12	5	5
Storm	64	11	25	46	3	12	0	1	9	6	0	8	4	4
Frost	59	17	23	41	5	5	0	1	1	6	1	1	4	4
Temperature Change	61	7	31	59	2	32	0	1	17	2	1	16	1	1

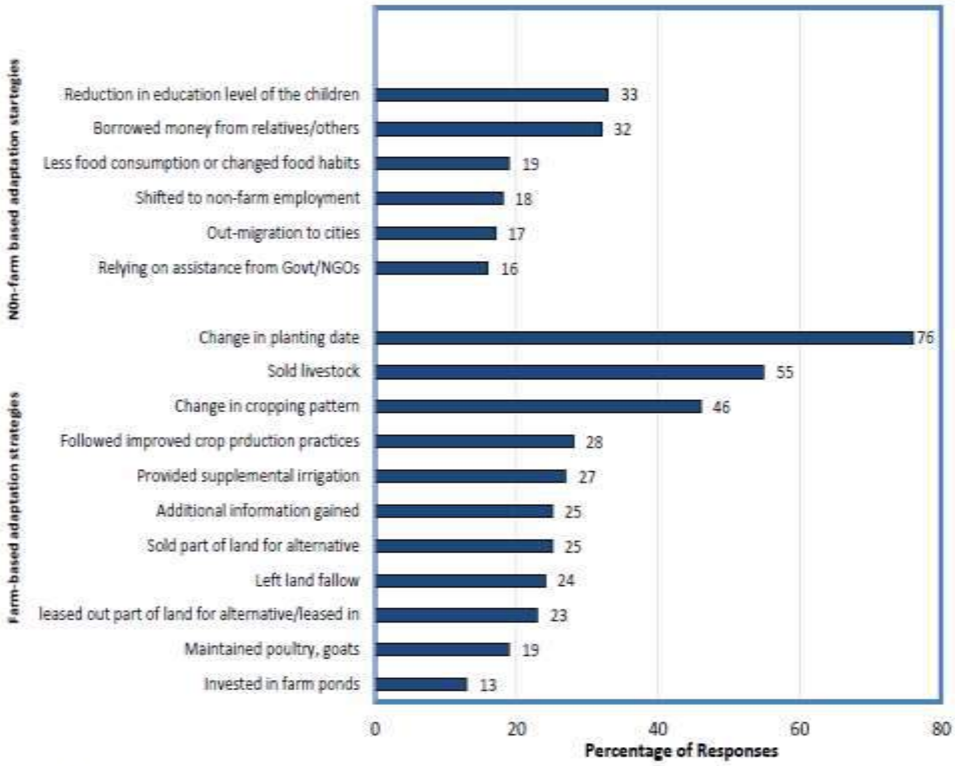


Figure 6. Respondents and their adaptation strategies

migration to cities, borrowing of money, compromises over the dietary requirements, health and educational needs are also relied upon for ensuring socio-economic resilience (Fig.6). However, a small proportion of (16%) the respondents also acknowledged the availability of financial assistance from government/NGOs (Non-governmental organizations) in case of acute shortages. The results of the Spearman correlation test indicated that there is a positive correlation between the number of adaptation measures adopted per household with sources of income ($r = 0.24$, $p<0.001$), farmer education levels ($r = 0.17$, $p< 0.001$), food security ($r = 0.28$, $p< 0.001$) and livestock ownership ($r = 0.19$, $p<0.001$). Whereas, it was found negatively correlated in case of crop diversification ($r= -0.01$, $p = 0.69$).

DISCUSSION

Farmer vulnerability to climate-related hazards: The current rain-fed agricultural practices are more susceptible to climate and weather related unpredictable changes. Therefore, the situation warrants for the assessment of preventive and curative strategies deployed by the farming communities. The research based initiatives are incumbent (Bryan et al., 2013; Harvey et al., 2014; Abid et al., 2015; Abid et al., 2016; Tran et al., 2017; Akhtar et al., 2019) for addressing the looming threats from climate change. The reported findings such as Ali and Erenstein (2017) and Abid et al. (2018) divulge that the phenomena of climate change is seriously threatening the socio-ecological landscape of Pakistan. The reported weather and climatic abnormalities are jeopardizing the objectives such as the food security and poverty reduction in this country (Ali and Erenstein, 2017). The present study was carried out for evaluating the orientations of farming communities regarding the phenomena of climate change in the rain-fed rural settings of the Punjab.

The findings of the present study divulge that the socio-economic conditions in the rural settings of the district Chakwal are dependent on the rain-fed agriculture (Fig. 5). These outcomes conformity with the earlier assertions such as Harvey *et al.* (2014) and Abid *et al.* (2016) that agro-based economic activities are the primary source for food and income generation in the rural landscape of Pakistan. The results substantiate the conclusions of Field *et al.* (2012), IPCC (2007), IPCC (2014), Dong *et al.* (2015), Wu *et al.* (2017), and Tesfahunegn *et al.* (2016) that fragile socio-economic sustainability of such rural settings are dependent upon the agricultural outputs. Whereas, the low agricultural yields in these areas (Morton, 2007; Tesfahunegn *et al.*, 2016; Oweis, 2018) are, still, far from the global standards (Prikhodko and Zrilyi, 2013; Abid *et al.*, 2015; FAO, 2015). The compromised performance of the agricultural sector, thus, further aggravates the socio-economic vulnerabilities of farming communities (Abid *et al.*, 2015; Li *et al.*, 2016). The findings substantiate the notions of Lobell *et al.* (2008) and Li *et al.* (2016) that the inadequate resource base, ineffective adaptation strategies and absence/or compromises over the policies are also culpable for the exacerbation. Therefore, making these locations, intrinsically, more prone to the impacts of climatic oscillations and, hence, demand coordinated efforts to ensure their socio-economic resilience (Bryan *et al.*, 2013; Harvey *et al.*, 2014; Abid *et al.*, 2015; Abid *et al.*, 2016; Tran *et al.*, 2017).

The findings of the study in (Table 1) portrayed that a significant proportion of respondents is susceptible and unprepared to absorb the impacts of abnormal climatic fluctuations or non-climatic shocks. The corollary affects further reduce their agricultural outputs and adversely impact the food availability. The repercussions manifest themselves in the form of malnutrition, compromises over socio-cultural spending and child mortality etc. (Pachauri *et al.*, 2014; FAO, 2015). The small size of fields, inadequate use of agricultural inputs (fertilizers, pesticides, improved seed varieties etc.), less/low reliance on technology and soil /land degradation are the perceptible explanations for the reported low agricultural productivity in the study area. Besides this, the less organized and poorly integrated mechanisms of connectivity between the farms and markets are the other noticeable impediments in the study area. The farmers have to bear extra financial burden on transporting their produce and agricultural inputs. The resultant reduction in the profit margin, ultimately, retards the capacity and will of the farmer for innovative measures to address the looming challenges associated with the climate change (Harvey *et al.*, 2014; Abid *et al.*, 2015; Abid *et al.*, 2016; Ali and Erenstein, 2017; Arshad *et al.*, 2017).

The lack of access to formal safety nets such as the absence of coordinated mechanism for crop/livestock insurance is another critical factor that is also responsible for the socio-economic exacerbation in the study context. The absence of an integrated mechanism forced the agrarian communities to rely on informal support systems i.e. borrowing money/ food from family or friends. Farmers are also further constrained by the limited access to agro-meteorological and market related information (Fig. 4). Though, the local NGOs and an agricultural extension department are operating in the study area, yet, a significant proportion (40%) of the respondents reported that they didn't receive any technical guidance. The technical assistance is a prerequisite for informed decision making concerning the choice of crops, planting dates and devising strategies to overcome/minimize the impacts of droughts and climate-related hazards (Maddison, 2007; Woods *et al.*, 2017).

The findings of the study helped to cognize about the multiple challenges the farmers are facing in the rain-fed rural surroundings, ranging from socio-economic impediments to abrupt atmospheric anomalies. The consequential outcomes are complex, manifold and far-reaching for the agricultural productivity and livelihood. It also transpires that these challenges have an acknowledgment in the study area. The consequential impacts are becoming more detectable and proving detrimental for the small farmers. These marginalized sections of rural landscape are economically more vulnerable, thus, are the apparent victims. Therefore, the growing incidents of crop failures/ yield reductions are proving counter-productive for initiatives to reduce poverty in rural areas. Thus, the emerging scenario demands for coordinated efforts for ensuring socio-economic sustainability in the rain-fed rural areas of Pakistan (Mertz *et al.*, 2011; Mougou *et al.*, 2011; Choudri *et al.*, 2013; Harvey *et al.*, 2014; Abid *et al.*, 2016; Arshad *et al.*, 2017; Barrucand *et al.*, 2017).

***Climate change and adaptation needs*:** Farmers in the study area rely on different coping strategies for ameliorating the impacts of climate change. The farm-based and non-farm based approaches (Fig. 6) are deployed for optimal agricultural production and ensuring food security. Though, these coping strategies significantly contribute to the wellbeing of the farmer, yet, the effectiveness of such measures are dependent on the socio-economic status of the individual and temporal settings of the phenomena. Besides this, there are certain limitations of such individualistic efforts. Therefore, the situation requires an integrated initiative for the socio-ecological and economic sustainability of the rural life.

The projections regarding escalating temperature (IPCC, 2014; Janjua *et al.*, 2014; Abas *et al.*, 2017) and predictions about fluctuations in the patterns of precipitation in Pakistan (Abid *et al.*, 2015; Pak-INDC, 2016; Ali and Erenstein, 2017) necessitate on postulating measures for the protection of small farmers. There is an urgent need to chalk out the contours of pragmatic strategies based upon the indigenous resources. The outcomes of such an endeavor will help to convert such looming challenges into opportunities.

However, the farmers, particularly the small landholders in the study area are reluctant to experiment with the innovative measures/methods due to the lack of financial support and awareness. The limited exposure and compromised resource base of the farmers makes it difficult and risky for them to improvise. Therefore, proactive engagements from the private sector such as agriculture service providers backed by the public sector are imperative for the desired objectives.

***Conclusions*:** The findings of the study revealed that the farming communities have awareness about the weather and climatic abnormalities. The respondents are mindful about the repercussions for their crops, livestock and health. The reported decline in the agricultural production is adversely impacting their livelihoods and making them more vulnerable. The farmers also have a realization that they can adjust with the phenomena through technical and financial support. Therefore, it requires the capacity-building and financial support of the stakeholders to adapt climatic changes. Although, the agricultural departments are operating but its imprints are less visible due to lack of clarity and consistency in policies. Whereas, the Sustainable Development Goals stresses on "taking urgent actions to combat climate change and its impacts" (SDG 3). Therefore, further research initiatives and transferring the technological outputs of the similar orientations are required for ensuring the socio-economic uplift and resilience of the farmers residing in the study area. Further, it is also recommended that similar or location based modified surveys be conducted in the other agro-ecological rain-fed zones as per description of the PARC agro-ecological zones of Pakistan.

REFERENCES

Abas, N., A. Kalair, N. Khanb and A.R. Kalair. 2017. Review of GHG emissions in Pakistan compared to SAARC countries. Renew. Sust. Energ. Rev. 80:990-1016.

Abid, M., U.A. Schneider and J. Scheffran. 2016. Adaptation to climate change and its impacts on food productivity and crop income: perspectives of farmers in rural Pakistan. J. Rural Stud. 47:254-266.

Abid, M., U.A. Schneider, J. Scheffran and E. Ehsan. 2018. Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. J. Environ Manag. 62:1-14.

Abid, M., U.A. Schneider, J. Scheffran and M. Ashfaq. 2015. Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab Province, Pakistan. Earth Syst. Dyn. 6:225-243.

Aggarwal, P. and M.V. Sivakumar. 2011. Global climate change and food security in South Asia: An adaptation and mitigation framework. Climate change and food security in South Asia, Springer. pp. 253-275.

Ahmad, M., M. Iqbal and M. Khan. 2013. Climate Change, Agriculture and Food Security in Pakistan: Adaptation Options and Strategies (Climate Change Brief).Pakistan Institute of Development Economics (PIDE), Islamabad.

Akhtar, N., Z. Saqib, M.I. Khan, M. Martin, S. Atif and Z. Rai. 2019. A bibliometric analysis of contemporary research regarding industrial symbiosis: A path towards urban environmental resilience. Appl. Ecol. Env. Res. 17:1159-1221.

Ali, A. and O. Erenstein. 2017. Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. Clim Risk Manag. 16:183-194.

Arshad, M., H.K. Timothy, J. Krupnik, T. S. Amjath-Babu, S. Aravindakshan, A. Abbas, Y. Mehmood and K. Müller. 2017. Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. Int. J. Sust. Dev. World. 24:532-544.

Atif, S., Z. Saqib,A. Ali and M. Zaman.2018a. The impacts of socio-economic factors on the perception of residents about urban vegetation: a comparative study of planned versus semi-planned cities of Islamabad and Rawalpindi. Appl. Ecol. Env. Res. 16: 4265-4287.

Atif, S., Z. Saqib,A. Ali, M. Zaman,N.Akhtar, H.Fatima,M. Atif and S. Farooqi. 2018b. Identification of key-trends and evaluation of contemporary research regarding urban ecosystem services: a path towards socio-ecological sustainability of urban areas. – Appl. Ecol. Env. Res. 16: 3545-3581.

Barrucand, M.G., C.G. Vieira and P.O. Canziani. 2017. Climate change and its impacts: Perception and adaptation in rural areas of Manizales, Colombia. J. Clim. Dev. 9:415-427.

Bokhari, S., Z. Saqib, , A. Ali, and M.Zaman-Ul-Haq. 2018: Perception of Residents about Urban Vegetation: A Comparative Study of Planned Versus Semi-Planned Cities of Islamabad and Rawalpindi. J. E. E. 8: 251.

Bryan, E., C. Ringler, B. Okoba, C. Roncoli, S. Silvestri and M. Herrero. 2013. Adapting agriculture to climate change in Kenya: household strategies and determinants. J. Environ. Manag. 114:26-35.

Bryan, E., T.T. Deressa, G.A. Gbetibouo and C. Ringler. 2009. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. Environ. Sci. Policy. 12:413-426.

Choudri, B.S., A. Al-Busaidi and M. Ahmed. 2013. Climate change, vulnerability and adaptation experiences of farmers in Al-SuwayqWilayat, Sultanate of Oman. Int. J. Clim. Chang. Str. 5:445-454.

Dong, Z., Z. Pan, P. An, L. Wang, J. Zhang, D. He, H. Han and X. Pan. 2015. A novel method for quantitatively evaluating agricultural vulnerability to climate change. Ecol. Indic. 48:49-54.

Easterling, D.R., J. Evans, P.Y. Groisman, T. Karl, K.E. Kunkel and P. Ambenje. 2000. Observed variability and trends in extreme climate events: A brief review. Bull. Am. Meteorol. Soc. 81:417-425.

FAO. 2015. FAOSTAT 2015, Database for Wheat Crop, Pakistan. Food and Agriculture Organization of the United Nations (FAO), Statistics Division, Rome, Italy.

Field, C., V. Barros, T. Stocker, Q. Dahe, D. Dokken, K. Ebi, M. Mastrandrea, K. Mach, G. Plattner and S. Allen. 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. Special report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. Cambridge University Press, New York, United States.

GoP. 2017–18. Economic Survey of Pakistan 2017–2018, Cabinet Division, Ministry of Finance, Government of Pakistan, Islamabad, Pakistan.

Harvey, C.A., Z.L. Rakotobe, N.S. Rao, R. Dave, H. Razafimahatratra, R.H. Rabarijohn, H. Rajaofara and J.L. MacKinnon. 2014. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. Phil. Trans. R. Soc. B. 369: 20130089.

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.New York, United States.

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: R.K. Pachauri and L.A. Meyer (eds.). IPCC, Geneva, Switzerland.p.151.

IPCC. 2018. Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In: V. Masson-Delmotte, P. Zhai, H.O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor and T. Waterfield (eds.). World Meteorological Organization, Geneva, Switzerland. p.32.

Janjua, P.Z., S. Ghulam and K. Nazakatullah. 2014. Climate change and wheat production in Pakistan: An autoregressive distributed lag approach. NJAS - Wageningen J. Life Sciences. 68:13-19.

JianJun, W., G. GuangPo, Z. HongKui, L. JingHu, W. QianFeng, Y. JianHua, J.J. Wu, G.P. Geng, H.K. Zhou, J.H. Liu, Q.F. Wang and J.H. Yang. 2017. Global vulnerability to agricultural drought and its spatial characteristics. Sci. China. Earth. Sci. 60: 910-920.

Jin, J., W. Wang and X. Wang. 2016. Adapting agriculture to the drought hazard in rural China: Household strategies and determinants. Nat. Hazards. 82:1609-1619.

Li, Xueling, J. Philp, R. Cremades, A. Roberts, L. He, L. Li and Q. Yu. 2016. Agricultural vulnerability over the Chinese Loess Plateau in response to climate change: Exposure, sensitivity, and adaptive capacity. Ambio. 45:350-360.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon and R.L. Naylor. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science. 319: 607-610.

Madison, D. 2007. The perception of and adaptation to climate change in Africa. World Bank Policy Research Working Paper 4308. Washington, DC: The World Bank.

McCarthy, J., O.F. Canziani, N.A. Leary, D.J. Dokken and C. White. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. New York, USA.

Mertz, O., C. Mbow, A. Reenberg, L. Genesio, E.F. Lambin, S. D'haen, M. Zorom, K. Rasmussen, D. Diallo, B. Barbier, I.B. Moussa, A. Diouf, J.Ø. Nielsen and I. Sandholt. 2011. Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa. Atmos. Sci. Let.12:104-108.

Mitra, A.P. and C. Sharma (eds.). 2010. Global Environmental Changes in South Asia: A Regional Perspective. Springer, Dordrecht, New Delhi.

Morton, J.F. 2007. The impacts of climate change on smallholder and subsistence agriculture. Proc. Natl Acad. Sci. USA. 104:19680-19685.

Mougou, R., M.Mansour, A. Iglesias, R. Z. Chebbi and A. Battaglini. 2011. Climate change and agricultural vulnerability: A case study of rain-fed wheat in Kairouan, Central Tunisia. Reg. Environ. Change. 11:137-142.

NDMA (National Disaster Management Authority), Pakistan. 2017. Integrated Context Analysis (ICA) on Vulnerability to Food Insecurity and Natural Hazards. Government of Pakistan.

Oweis, T. and M. Ashraf (eds). 2012. Assessment and options for improved productivity and sustainability of natural resources in Dharabi Watershed Pakistan. ICARDA, Aleppo, Syria.

Pachauri, R.K., M.R. Allen, V.R. Barros, J. Broome, W. Cramer, R. Christ, J.A. Church, L. Clarke, Q. Dahe and P. Dasgupta. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: R. Pachauri and L. Meyer (eds). Geneva, Switzerland. p.151.

Pak-INDC, Pakistan's Intended Nationally Determined Contribution. 2016. INDC Submission: UNFCCC Secretariat.

PBS (Pakistan Bureau of Statistics). 2017. Population census. Government of Pakistan, Islamabad.

PDMA (Provincial Disaster Management Authority). 2008. Disaster Risk Management Plan, Punjab. Government of Pakistan.

Prikhodko, D. and O. Zrilyi. 2013. Pakistan: Review of the Wheat Sector and Grain Storage Issues Country Highlights. Food and Agriculture Organization, Rome.

Smadja, J., O. Aubriot, O. Puschiasis, T. Duplan, J. Grimaldi, M. Hugonnet and P. Buchheit. 2015. Climate change and water resources in the Himalayas: Field study in four

geographic units of the Koshi basin, Nepal. J. Alpine Res. 103-2.
Stocker, T.F., Q. Dahe and G. Plattne, 2013. Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers (IPCC, 2013).Geneva, Switzerland.
Tesfahunegn, G.B., K. Mekonen and A. Tekle. 2016. Farmers' perception on causes, indicators and determinants of climate change in northern Ethiopia: Implication for developing adaptation strategies. ApplGeogr. 73:1-12.
Tran, H., Q. Nguyen and M. Kervyn. 2017. Household social vulnerability to natural hazards in the coastal Tran Van Thoi District, Ca Mau Province, Mekong Delta, Vietnam. J Coast Conserv. 21:489-503.
Vadrevu, K.P., C. Justice, T. Prasad, N. Prasad and G. Gutman. 2015. Land cover/land use change and impacts on environment in South Asia. J. Environ. Manage. 148:1-3.
Wood, B.A., H.Ø. Nielsenb, A.B. Pedersenb and D. Kristoferssonc. 2017. Farmers' perceptions of climate change and their likely responses in Danish agriculture. J. Land. Use. Policy. 65:109-120
Zulfiqar, F. and A. Hussain. 2014. Forecasting wheat production gaps to assess the state future food security in Pakistan. J. Food Nutr. Disord. 3:1-6.

[Received 09 May 2019: Accepted 09 Dec- 2019 Published 8 Feb. 2020