ASSESSMENT OF SPATIO-TEMPORAL CHANGES IN WETLAND AREA IN RESPONSE TO CLIMATE CHANGE IN SALT RANGE WETLANDS COMPLEX, PAKISTAN

By

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DEDICATION

I dedicate this research to Almighty ALLAH, Who helped me in accomplishing this thesis and for giving me wisdom or giving me strength to overcome pressure while doing this thesis. This humble effort is also dedicated to my beloved parents who are the symbol of guidance in my life and motivated me to accomplish this research project and whose hands always rose in prayers for my success.

DECLARATION

I hereby declare that the work present in the following thesis titled as "**Assessment of Spatio-temporal Changes in Wetland Area in Response to Climate Change in Salt Range Wetlands Complex, Pakistan**" is my own effort, except where otherwise acknowledged and that the thesis is my own composition. No part of the thesis has been previously presented for any other degree.

Date 28-12-2016

Sehrish Aslam

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LIST OF ABBREVIATION

LULC	Land Use Land Cover
PWP	Pakistan Wetland Program
WWF-P	World Wide Fund for Nature Pakistan
RS	Remote Sensing
GIS	Geographic Information System
EVI	Enhanced Vegetation Index
NDVI	Normalized Difference Vegetation Index
MODIS	Moderate Resolution Imaging Spectroradiometer (NASA/EOS instrument)
SRWC	Salt Range Wetlands Complex
RCP	Representative Concentration Pathways
CRU	Climate Research Unit
NDWI	Normalized Difference Water Index
ILWIS	Integrated Land and Water Information System
LSMM	Linear Spectral Mixture Model
MNDWI	Modified Normalized Difference Water Index
TRH	Three-River Headwaters
GCM	Global Circulation Model
SRS	Satellite Remote Sensing
PMD	Pakistan Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
ERDAS	Earth Resources Data Analysis System
ISODATA	Iterative Self-Organizing Data Analysis Technique

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ABSTRACT

Wetlands are considered to be one of the most valuable naturally occurring habitats for wide variety of flora and fauna. They also support ground water recharge and monitor climate change. Their deterioration has been noticed due to economic development and population growth. Changes in wetlands are being affected directly by variability in climatic conditions viz., hydrological regime, precipitation patterns, and temperature/ humidity/ evaporation/evapotranspiration. Climate Research Unit (CRU) data was used to demonstrated yearly trends in rainfall, temperature and potential evapotranspiration from 1985-2014. Land Use Land Cover (LULC) change was detected in ERDAS 2014 and ENVI 5.1 from 1987-2014. Lake area was calculated by using Normalized Difference Water Index (NDWI), Normalized Difference Vegetation Index (NDVI) and threshold approach. Representative Concentration Pathways (RCPs) 4.5 and 8.5 data was used for predicted future changes in wetlands.

Increased average annual trend was observed for rainfall while temperature and potential evapotranspiration showed decreasing trend in a period of 30 years (1985-2014). Significant changes have been observed in Salt Range Wetlands Complex (SRWC) with reference to lake area from 1987 till 2014. Change detection showed reduction in, forest and scrub area while there has been an increase in agricultural, uncultivated, built-up areas and water bodies since 1987. Lake area increase was observed in Namal lake (26 ha), Jahlar lake (3 ha) and Kallar Kahar lake (162 ha) while shrinkage was seen in Uchalli lake (176 ha) and Khabbaki lake (120 ha) from 1987-2014. This behavior is direct indicator of bringing change in the level of small area lakes in association with increase in the rainfall pattern. Evaluation of RCPs data (2010-2050) predicted that changes in the rainfall, temperature and potential evapotranspiration pattern in future will put pressure on water resource to meet future demands. Change detection of wetlands will help in assessing the implications of the observed changes and decision making for the purpose of land development and management of these wetlands.

Chapter # 1

INTRODUCTION

1 INTRODUCTION

Wetlands are the important features of landscape for their economic, cultural and recreational values (Arshad *et al.*, 2014). Wetlands play a key role in climate regulation through regional and ecological balances and also sustain living environment for specific flora and fauna (Tong *et al.*, 2014). Wetlands cover about 6% of the land surface of the world (Ahmed and Erum, 2012). Ramsar convention (1971), defines wetlands as "the areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six meters". Historically, these valuable ecosystems were considered waste lands and breeding ground for insects. Despite of the wetland's services these areas are considered as the most endangered habitats worldwide (Papastergiadou *et al.*, 2008). Globally, these are threatened due to unsustainable development and population pressure (Qazi *et al.*, 2012).

Due to their role as sink and source for climate regulators (Carbon dioxide and methane), wetlands are susceptible to change in climate (Desta *et al.*, 2012). Climatic variation is attributed to anthropogenic greenhouse gas emissions and LULC changes that would rise global temperatures from 1.1 to 6.4°C by 2100 (IPCC, 2007). These projected changes will in return effect the climatic balances resulting in extreme climate events i.e., floods, droughts, and heatwaves (Yadessa, 2014). Climate change associated with alterations in climatic patterns is recognized as greater threat to wetlands. These ecosystems are susceptible to the changes in water quality and quantity. Alterations in hydrological regimes specifically related to the changes in hydro-period seem to have more pronounced effect on wetlands (Erwin, 2009). According to Bardecki (1991) and Carter (1986) impacts on wetlands will not likely to occur due to direct change in temperature but due to other parameters like precipitation, surface water inputs/ output, evapotranspiration and ground water inputs and output. Extreme precipitation can further cause change in wetland ecology due to increased sedimentation. Even in the absence of precipitation, wetlands are threatened to climatic changes such as rising temperature results into the rise of evaporation/ evapotranspiration (Desta *et al.*, 2012).

The wetlands are complex, ecologically sensitive and adaptive systems (Bassi *et al.*, 2014). The rate and magnitude of climate change could have major impacts on regional water resources due to changes in the hydrological cycle (IPCC, 2007). Developing countries undergo more variations in climate changes as compared to developed countries due to lack of economic and technological capacity. Pakistan is blessed with large amounts of rivers and streams. It also supports various inland and coastal wetlands due to the topographic and climatic variations. Pakistan has 225 wetlands of national importance out of which 19 are declared as the Ramsar sites that support an area of 780,000 ha (Ali and Akhtar, 2006). Pakistan's wetlands have also experienced deterioration due to changes in LULC, soil, water pollution and diversion (Yahya, 2008). Wetlands are under threats and depleting incessantly as the change in climatic variability is altering the hydrology of a specific wetland. The shifts in climatic parameters and climate change may pose greater challenge to wetland management, conservation and restoration (Erwin, 2009). The rate and extent of Pakistan's wetland loss and degradation is associated with the allocation and distribution of water, construction of dams, barrages, head works and flow regulation of rivers to meet the water demands for hydroelectricity and irrigation. These impacts result in salinity increase, retreating aquifers and habitat loss or degradation. Approximately, 60 percent of Pakistan's Inland wetlands have been lost or degraded since 1970's (Khan and Arshad, 2014).

Pakistan lacks the legislative framework for wetland's protection and preservation as it remains restricted to agriculture, water, pollution and forest sector (Arshad, 2011). Wetland's significance was the focus of attention for the first time in 1967 after that Pakistan became the signatory of Ramsar convention in 1976. At that time only nine sites were globally significant but later on the number increased to 16 in 2001 and then to 19 sites in 2002 which were designated as Game reserves, Wildlife sanctuaries, National parks and Ramsar sites (Khan and Arshad, 2014). In year 2000, Pakistan Wetlands Programme (PWP) was initiated by World Wide Fund for Nature, Pakistan (WWF-P) with main aim of conserving the wetlands and the associated biodiversity for 5 years till 2005. Later in 2009, wetlands policy of Pakistan was drafted for the protection of wetlands. Ministry of Climate Change also made changes in the climate change policy in year 2011 to protect, sustain and enhance the wetlands in Pakistan (Qamer *et al.*, 2009; Qazi *et al.*, 2012).

Monitoring of wetlands is required at present time for the assessment of climatic variations and impacts on wetlands (Erwin, 2009). It is critically important to study the expected future climate changes in order to predict the changes in wetlands. Previous studies depicted that Remote Sensing (RS) and Geographic Information System (GIS) are the appropriate tools for spatio-temporal wetland change studies. These are valuable tools for identification, monitoring, inventory making, delineation and spatial extent measurement of wetlands. Remote sensing provides the cost and time effective data to study wetland ecosystems (Sarkar and Jain, 2007). Several studies have been conducted to study the wetlands change detection by using GIS/RS worldwide (Ahmad and Erum, 2012). Time series remote sensing data has been widely used for LULC mapping, change detections and monitoring the essential ecosystems. Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) have been used for identification of different vegetation covers including the croplands using time series MODIS indices. But being complex dynamic ecosystems and limited access to inundation area it is difficult to perform detail analysis and long term monitoring of wetland covers. Besides the limitations, remote sensing data is appropriate for monitoring wetland hydrology and vegetation analysis (Chen, 2014).

Projecting future changes determine the future impacts in an area. Limited studies have been conducted in Pakistan for detecting wetland changes. The present study has been opted for this reason to detect impact of climate change on Salt Range Wetlands Complex (SRWC) located in Punjab province. The complex contains five wetlands Namal lake, Uchalli lake, Khabbaki lake, Jahlar lake and Kallar Kahar lake. The purpose of the study is to assess the climate conditions, LULC changes and the area of lakes in SRWC over a period of time in relation to climate variables (1987-2014). Study also provided the Predictive assessment of future changes due to changing climate scenarios (RCP 4.5 and 8.5).

1.1 Problem Statement

Wetlands are at risk from human activities within and surrounding the catchment area leading to the wetland degradation. Alterations in wetlands results in the loss of water quantity and quality, wildlife habitat, biodiversity, erosion and flooding in the area (Ghobadi *et al.*, 2015). Massive loss of the wetlands has been witnessed in past decades because of over exploitation (Kassaye, 2014). Salt Range Wetlands Complex (SRWC) is the largest habitat for migratory birds due to its suitable climatic conditions and environment (Arshad, 2011). Despite of its value the area is highly vulnerable to natural calamities like droughts and floods. Shrinkage along with deterioration of water quality and habitat loss in lakes dragging our attention to address this topic in response to climate change (Ali and Akhtar, 2006).

1.2 Significance of the Study

Climate change and wetland studies are underway to determine the impacts, relationship and the responses worldwide (Kim *et al.*, 2012). While a limited literature is available in Pakistan regarding wetland changes due to climate change. This drives our attention towards the assessment of wetland response to climate change. The Salt Range has the environmental significance and moreover prone to the extreme climate events like droughts and floods. Prevailing water shortage conditions in the area also drives our attention towards the protection of these wetlands. Scientific research is the need of time specifically in connection with wetlands and climate change in SRWC. Present study determined the relationship between climate variables and wetlands that drive the attention of policy makers for the adequate management and protection of wetlands complex. Study could also provide the valuable knowledge about the major consequences of change in the SRWC, to the environmentalists, planners and decisions makers for sustainable development and protection. Study will be helpful for other scholars to conduct further research.

1.3 Limitation of the Study

Limitations that are faced during the study area as follow;

1. Lesser density of observed meteorological stations in study area limits the usage of observed climate data; instead Climate Research Unit (CRU) data was used for climatic conditions.

1.4 Aim and Objectives

The main aim of the research, to assess the change in wetlands in response to climate change in Salt Range Wetlands Complex (SRWC) was achieved by executing following objectives;

1. Assessment of the climatic conditions in SRWC.
2. Spatiotemporal LULC change detection in study area.
3. Change in the area of lakes over a period of time (1987-2014).
4. Predictive assessment of future changes due to changing climate scenarios.

Chapter # 2

LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 LULC Mapping and Spatiotemporal Wetlands Change Detection

Several studies have been conducted worldwide using various methodologies for mapping and assessment of spatiotemporal wetland changes.

Kavyashree and Ramesh conducted a study on wetlands mapping and change detection in the west coast of Karnataka, India using GIS and RS in 2016. Thresholding technique and indices like NDWI and NDVI were used to extract the wetlands from Landsat images. Unsupervised classification was done using ERDAS for land use and wetland map generation. LULC changes in the study area were determined through change detection technique. Results indicated that for water body extraction NDWI gave good results as compared to the NDVI. Secondly water body showed a decrease in the area from 1998 to 2008-09 at a rate of 982 hectares yearly.

Mousazadeh *et al.*, have studied the costal wetland Anzali in 2015 for LULC change detection and assessment of the impacts due to these land use changes. Anzali is one of Ramsar site of international importance in Iran. Besides the high ecological diversity this wetland is under threat to pollutants, increased sedimentation, unsustainable development, land use changes and over- extraction and utilization of wetland resources. Most destructive factor of land use change and associated impacts on Anazil wetland was detected by using GIS and RS tools for the past 38 years (1975-2013). Land use changes were determined for the year 1975, 1989, 2007 and 2013 through supervised classification, zonal and object-oriented analysis. Study results indicted extensive land use change from 1975-2013. Rangelands have been degraded while the agriculture and urban area extended over the study period. These changes could degrade the wetland's water quality resulting in water shortage in the area.

According to Ghobadi *et al.*, 2015, wetlands are of prime importance due to their services provision. Al Hawizeh wetland changes were assessed by Ghobadi *et al.* for the period 1985-2013. Maximum likelihood classification method was used for identification and mapping of LULC using remote sensing satellite images. Accuracy assessment was done for 1985, 1998, 2002 and 2013. Post classification method was used for examining the classified images and wetland changes were observed. Post classification results revealed a drastic change in the size and extent of wetland. Decrease in the surface area of wetland was observed in 1985-2002. While almost 29% increase in surface area was observed in 2002.

Small area was converted to bare soil during the same period. After 2002, wetland area restored till 2013. Human interventions especially unsustainable development projects are the main cause of these wetland alterations. Mitigation measures and recommendations for the recovery of Al-Hawizeh wetland were also discussed in the study.

Another study was conducted by Shopan *et al.*, in Bangladesh in 2013 to estimate the wetland changes using satellite images. In past few years, the wetlands in the area have been declining and almost 2.1 million ha of wetlands have been lost only in Ganges-Brahmaputra floodplain. GIS, ILWIS and remote sensing tools were used for the analyzing Landsat images. Three Landsat images (1989, 2000 and 2010) of dry period were utilized. Results indicated that 25 % of wetlands area decreased from 1989-2000 and 4% decreased from 2000-2010. Overall decrease in wetland area was observed from 1989-2000 in most of the selected districts of Bangladesh.

According to Liu *et al.*, 2012 wetlands are sensitive ecosystems and are being deteriorated rapidly. Liu *et al.*, 2012 studied the wetland changes in Longfeng wetland of Daqing City in China using time series of remote sensing data. Landsat images were selected for the year 1979, 1990, 2001 and 2006. Wetland classification was done using a model "Linear Spectral Mixture Model (LSMM)". Study results indicated that Longfeng wetland have been effected by human interventions.

Mahmud *et al.*, 2011 have conducted a remote sensing and GIS based study to analyze the spatiotemporal change of wetlands in Dhaka city of Bangladesh. Dhaka is one of the mega cities of the world experiencing the unsustainable development and shrinkage of wetlands. The study was conducted for the analysis of wetland change in Dhaka metropolitan area during 1978 to 2009. Four Landsat images were used to measure the spatiotemporal dynamics of changes in wetland. Images were processed through supervised image classification algorithm and change was observed using post classification method in GIS environment. Accuracy assessment ranged from 87% to 92.5%. The analysis results showed that the wetlands and rivers area decreased over past 30 years ranging from 76.67% to 18.72%. Wetland changes could result in the water logging problems in Dhaka. Landfilling and human encroachments to these wetlands were the main causes for the reduction in wetlands.

Wetlands in Ghana city were studied by Aheto *et al.*, 2011. According to study lagoons and estuaries are one of the most critical habitats that support country's economy.

These ecosystems are under threat due to the climate changes. Vulnerability assessment to possible impacts of climate and land use changes on fish biodiversity was done for the period 1973 to 2010 using GIS. Study resulted that the Whin estuary is more productive system for the fisheries development, adaptation and management as compared to the Butuah lagoon. However, these productive systems could be affected by sea level rise due to climate change resulting into increase in the wetland's water with negative impacts on fisheries production and development. Land use changes could accelerate these climate impacts. This study provided the baseline information for protection and management of valuable ecosystems.

Another study on wetland change detection was done by Zhang *et al.*, 2010 in Yinchuan plain, China. Multi-temporal remote sensing datasets were used to determine the wetland change over a period of time. Study results indicated a decrease in the area of lake and river wetlands but paddy wetland area increased during 1978-2006. The causes of wetland changes were studied that human activities and natural climate forcing are the basis of wetland loss and degradation. Increased population pressure, large number of water resources and requirement of more farmlands caused the lakes to be drained and local area groundwater levels to fall.

Environmental monitoring of Mediterranean wetland changes was done by Papastergiadou *et al.*, in 2008. For spatiotemporal analysis of these wetlands remote sensing technique was used to generate land use land covers and to determine the change in lake. GIS was used for data analysis. Study aimed at assessing the spatial and temporal land use land cover changes and to determine the main causes effecting these changes. Study was conducted in Cheima ditida lake wetland using GIS. Classified images of 1945, 1969, 1982 and 1996 were compared. Data analysis results showed that Cheima Ditida lake has been influenced by anthropogenic activities for past few decades. There has been experienced a decline in open waters and peatlands by 74 and 99% while reed beeds increased.

Ruan *et al.*, 2008 have studied the change detection in Hongze lake wetland using time series of Landsat images between 1979 and 2002. The method was comprised of three parts. First process was the classification of the image of 2002 using Hybrid classification technique. Secondly, clustering was done using unsupervised classification technique ISODATA and third was the extraction of the "Emergent" class from thematic maps of the corresponding years. The change in "Emergent" class was considered as the indicator of change in wetland. Study resulted wetland loss and degradation for past twenty years.

Hui *et al.*, 2008 have studied the spatiotemporal change using Landsat imagery for Poyang Lake from 1999 to 2000. Yearly eight Landsat images were used in the study. Water body detection was done using Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) and area was derived using threshold approach. Annual spatiotemporal change based on water extent of Poyang Lake was determined in order to gain the extent of water accumulation of marshland. Results revealed that the accurate estimations of spatiotemporal water inundation over marshlands are insufficient to obtain by linear interpolation.

2.2 Wetland and Climate Change

Global changing climate is one of the recognized threats to the survival of the natural ecosystems. Global climate variations have distinct effects on the wetlands hydrology (Erwin, 2009). Climate variability and change could result in the alterations of wetlands (Finlayson *et al.*, 2006). Wetland change and response to climate change were studied by Tong *et al.*, 2014 in "Three-River Headwaters" district of China from 1990 to 2012. Changes were analyzed through Remote sensing (RS) study and climate change trend analysis. Correlation was done to determine the relationship between climatic factors and wetland changes from 1990-2012. Study results showed that changes in precipitation patterns and evaporation were significant dynamic forces for variations in wetland. Overall increased humidity index contributed to an increase in wetlands specifically in western TRH region.

The climate change impacts on wetlands of Brazilian amazon were studied by Barros and Albernaz, 2014. The possible impacts were determined considering scenario data. Rainfall and temperature (increased or decreased) scenarios were used. Results revealed that one of the major consequences of change was the hydrological disturbances due to increase or decrease in rainfall patterns. Moreover, long term exposure to climate disturbances would cause alterations in species composition that might result in the loss of these humid ecosystems.

Global warming is one of the climate change influence on the wetlands. Kim *et al.*, 2012 carried out the study in upo wetland of Korea which is designated as the Ramsar site, to determine the impacts of climate change on hydrologic and biogeochemical functions of these wetlands and also on habitat of flora and fauna. Emission scenario, Global Circulation Model (GCM) and analysis methods were used for the impact assessment. With the help of

Hydrogeomorphic method the functional assessment of wetland was performed. It is predicted that only 10% change will be experienced in upo wetland.

2.3 Lake Area Variations Due to Climate Change

Lakes are the vital resources for the flora, fauna and a livelihood for human beings. Alteration in the water quality, water level and renewal rate could affect these ecosystems. Historically, lakes have been encountered to the threats of climate change. Parameters like rainfall and temperature could alter the intake and removal of water from these lakes affecting the chemical, physical and biological features of these lakes (Vincent, 2009).

Study related to periodic and inter-annual variations in lake area have also been carried out by Kang and Hong in 2016. Lake surface area of Mongolia was determined using NDVI (15-day) from MODIS dataset. Overall seventy three lakes were selected out of which 28 were selected for error estimations. The decrease in lake area was observed during 2000-2011 for 73 lakes. Rapid area reduction was observed in arid region as compared to semi-arid regions of Mongolia.

The expansion and shrinkage of the lakes situated in Tibetan Plateau was observed by Liao *et al.*, 2013 in past 40 years (1970-2008). The surface area was extracted from the Landsat images of 1970-2008 and the topographic map of 1970. The relationship between climate variables and lake area variations was determined though multivariate correlation analysis. Initial results showed that area variations are in correlation with the precipitation and temperature. Particularly, warming climate is responsible for glacier melting and snow cover is decreased leading to the expansion of water in these lakes.

Ma *et al.*, 2007 have studied the variation in the lake area of Ebinur lake in china. SPOT or VEGETATION imagery was used for the mapping of the lake area. NDVI and NDWI were the selected indices for the identification and extraction of lake. It was observed that surface area of lake was lowest in 1998 while the large area change was observed in 2001-2002. Lake area peak was observed in 2003 and gradually it decreased in 2005. Remote sensing technique was also used in the study which showed similar fluctuations in the area.

2.4 Studies Carried Out on the Wetlands of Pakistan

Pakistan is blessed with the wide variety of the wetlands extended over the whole region and comprised of 200 identified wetlands or the protected wetlands complexes (Qamer *et al.*, 2009). Lack of information regarding wetlands resources in 1989 has led to wetland inventory making to fill the information gaps regarding wetlands. Only forty eight significant wetlands have been documented in past (Scot, 1989). Wetland inventory was developed under Pakistan wetlands programme for serving academic and scientific awareness (Qamer *et al.*, 2009). Several avifauna studies in different areas of Pakistan wetlands have been conducted. Avian counts have been studied in Uchalli lake in relation to the change in hydrology of lake in 2010 and 2011 (Arshad *et al.*, 2014). Similarly, a research has been conducted on determining the white headed duck counts and its status at sixteen selected sites (Kallar Kahar , Uchalli, Khabbaki, Namal, Jehlum bridge, Rangpur lake, Sulmanki headworks, Qadarabad headworks, Chilianwala, River Ravi, Chashma barrage and Marala headworks) in Punjab since 1880's (Ali and Akhtar, 2005). Bird counts were also studied at nine selected sites including Uchalli wetlands complex from 1993 to 2003. The loss of migratory birds has been experienced in salt range wetlands complex in 1993 (Ali and Akhtar, 2006). Akbar *et al.*, 2010 conducted the survey of waterfowl of Rasool Barrage Game reserves at Jhelum from 1996-2005. Bhinder *et al.*, 2015 reported the avifauna of Bajwat wetland located in Sialkot Pakistan. A baseline survey was conducted by Ali *et al.*, 2011 in Salt Range Wetlands Complex (SRWC) from 15 December to 22 December for the collection of bird's data at each wetland. Recently, Dauda *et al.*, 2016 carried out a study to evaluate bird diversity and abundance of species in Uchalli wetland in Punjab, Pakistan. From the above conducted studies the significant biodiversity was observed in some wetlands while a decline in bird count was experienced in others. Besides the avifauna studies Qureshi, 2008 conducted a floristic study in Chitori wetland complex (September 2006) to determine the plant biodiversity.

Study related to wetland change analysis was conducted by Ahmad and Erum in 2012 in Kallar Kahar. Object-based method was used to detect the changes in Kallar Kahar wetland using ENVI. High resolution Quick bird imagery and Corona imagery was used to detect the change over a period of time. Study results showed a reduction in agricultural and shrub area while percentage increase was observed in built-up area, water-body, orchard and uncultivated/soiled area. Anthropogenic activities and unsustainable development were the main causes of changes in Kallar Kahar wetland. Similarly, research done by Qazi *et al.*, 2012 in Kallar Kahar showed that population expansion, industrial development, pollution and natural hazards were the main cause of wetland changes.

According to the research conducted by Kazmi *et al.*, 2006, Pakistan's wetlands of Sindh are facing tremendous environmental degradation. GIS based wetland inventory development for Sindh wetlands was the main aim of the study. For this purpose medium and high resolution imageries were processed using GIS and Satellite Remote Sensing (SRS) for the identification and monitoring of spatiotemporal changes in wetlands from 1990-2000. Results indicated the decrease in wetland area in Sindh region of Pakistan.

Chapter # 3

MATERIAL AND METHODS

3 MARTIAL AND METHODS

3.1 Study Area Description

The study area is located in the central north region of the Punjab province, Pakistan designated as the Salt Range Wetlands Complex (SRWC). It is a 175 km thrust between the foot hills of Himalayan Mountains and Indus plains extending from Jehlum in the east and Kala Bagh in the west (Ahmad *et al.*, 2008). Geographically it is located between 71° and 74° E longitudes and 32°10 and 33°15 N latitudes, covering an area of 10,529 km^2 (Afzal *et al.*, 1999). It is constituted of five independent wetlands i.e. Kallar Kahar Lake (32°46' N, 72°42' E) Khabbaki Lake (32°37' N, 72°14' E), Uchalli Lake (32°31' N and 72°1' E), Jahlar Lake (32°29' N, 72°07' E) and Namal Lake (32°41' N, 71°47' E) (Figure 1). Uchalli, Khabbaki and Jahlar Lake are situated in catchment area called Soan valley while Kallar Kahar and Namal Lake are at the periphery (PWP, 2002). These wetlands have been notified as the wetlands of international importance in 1976 and designated as wildlife sanctuaries and game reserves under "Punjab wildlife (Protection, preservation, conservation and management) Act 1974". Two lakes of Uchalli wetlands Complex (i.e., Khabbaki and Jahlar Lake) has been designated as the wildlife sanctuaries while Uchalli Lake is a game reserve. Namal lake was first declared as the wildlife sanctuary in 1964 than its status changed to game reserve due to reduction in the migratory birds in 1991. Kallar kahar has been declared as the game reserves and it is one of the famous wetlands supporting the wintering waterfowl species (Arshad, 2011).

Salt Range vegetation is covered with coarse grasses, scrub plants and (Ahmad *et al.*, 2008) subtropical dry evergreen scrub forests (Nawaz *et al.*, 2010) which vary with elevation, soil type and precipitation. The main species in an area are *Dodonea viscosa, Tecoma undulata, Acacia modesta, Capparis aphylla, Xizyphus nummularia and Gymnospora rolyeana* (Ahmad, 2001). Major crops are wheat and lentils (Nawaz *et al.*, 2012). SRWC is well-known for breeding habitats of some threatened and vulnerable waterfowl species, e.g., white-headed ducks (Nawaz *et al.*, 2012) and a core habitat for endemic Punjabi Urial *(Ovis vignei punjabiensis)*. Entire Salt Range is a hilly area comprised of sandstone and limestone rocks, minerals like salt, coal, lime, and different kinds of clay and gypsum (Arshad, 2011).

The socioeconomic conditions of the area depict the population pressure along with the excessive use of natural resources for livelihood (Arshad, 2011). The climatic conditions of the area consist of the moderate summer and harsh winters. The rainy season includes the monsoon rains, starting from July to September with frequent rainfall in month of July and August while winter rains starts from January and persist upto the month of March. The wetlands of salt range are the source of water for domestic use and also for the irrigation. Area around the lakes is privately owned and has been used for the agricultural purposes (Ali *et al*, 2011). The lakes of salt range are the inland permanent saline/ brackish or shallow lakes. These lakes are fed by the local rainfall, hill torrents, several intermittent streams and runoff from the catchment areas (Arshad, 2011). During rainfall drainage from surrounding area results in the water accumulation of approx. 800 ha in Uchalli, 282 ha in Khabbaki and approx. 100 ha. in Jahlar and Kallar Kahar lakes (Nawaz *et al.*, 2012).

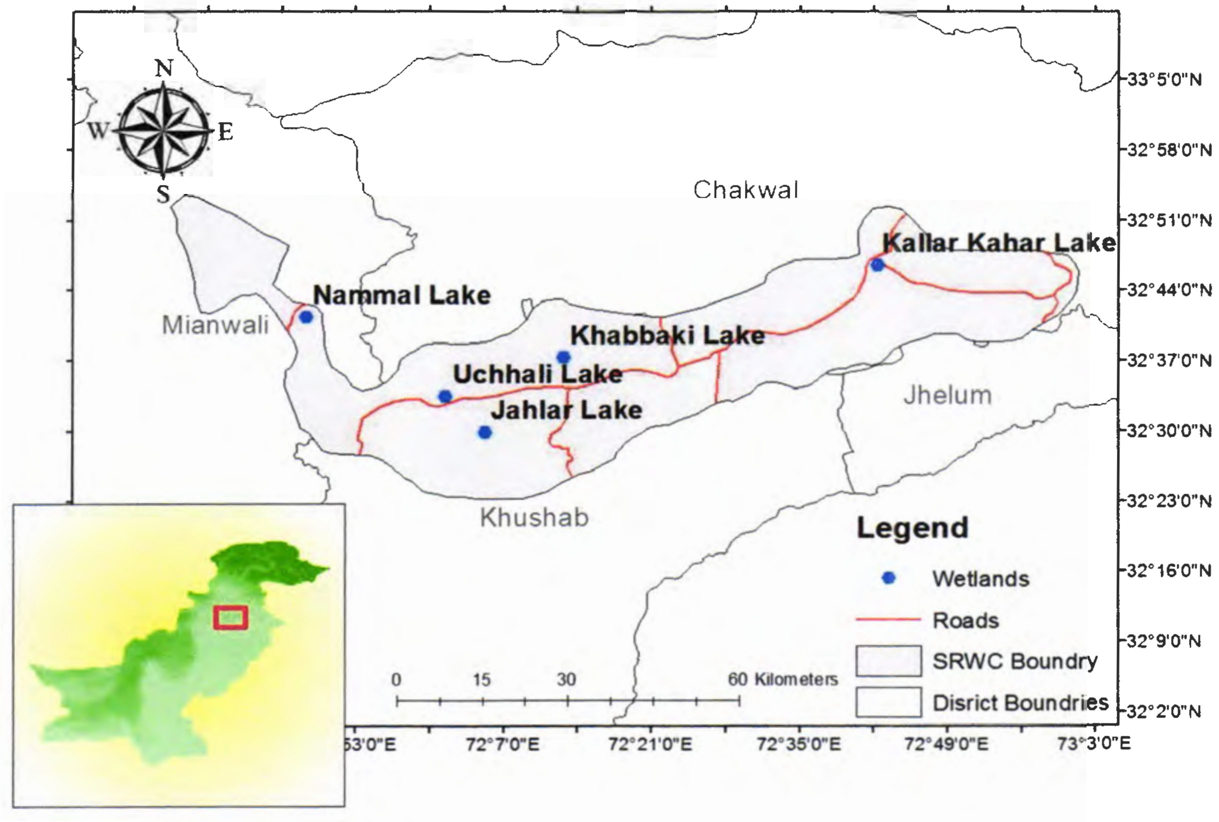

Figure 3. 1 Map of Study Area

3.2 Data Acquisition and Analysis

The gauge based Climate Research Unit (CRU) data generated by Pakistan Metrological Department (PMD) was used for the study. CRU datasets consists of monthly grids of observed climate, covering an area of all land surfaces except Antarctica at 0.5 degree resolution (Chaudhry *et al.*, 2009). The Climate Research Unit Data (CRU) of annual average precipitation (mm), temperature (°C) and potential evapotranspiration (mm) from the year 1985 till 2014 were presented graphically for yearly trends in rainfall, temperature and potential evapotranspiration.

Nighty one Landsat 4-5, ETM+ and OLI8 imageries (path/row 150/37) of SRWC from 1987 till 2014 were acquired. Landsat imagery for the months of October and November for the years 1987, 1991, 2000 and 2014 were selected to analyze spatiotemporal Land Use Land Cover (LULC) change. Pre-processing was done by layer stacking and radiometric calibration and were then processed using supervised classification technique in ERDAS-14. Supervised classification was executed by making the subset of Landsat image on the basis of Area of Interest (AOI). Land use land cover information was generated through classification of image by assigning per pixel signatures and differentiating the study area into seven classes. The delineated classes were barren/uncultivated, scrub/grasses, water body, built up area, forests and croplands. Band combination of RGB (7,5,3 and 5,4,2) was used during training stage. Pixels within the training sites were analyzed and spectral signatures were created for each cover type. At the end maximum likelihood supervised classification was run using ERDAS 2014. The accuracy assessment of the classified imageries was executed by generating series of reference points in ERDAS-14 (Butt *et al.*, 2015). Post-processing classified the amount, location, and nature of change and change detection maps were generated. Indexes selected for the identification and the extractions of wetted vegetation and water body from each temporal image were NDVI and NDWI individually. NDVI and NDWI were calculated using the equations in ArcGIS 10.1 (eq.1 and 2) (Kavyashree and Ramesh, 2016; Singh *et al.*, 2016).

$$NDVI = NIR - Red / NIR + Red \quad \ldots\ldots\ldots\ldots (1)$$

$$NDWI = Green - NIR / Green + NIR \quad \ldots\ldots\ldots\ldots (2)$$

Threshold values were applied to the range of NDWI for delineating the surface water extent (Singh *et al.*, 2016). Lake area for five wetlands in SRWC was calculated after threshold estimations by pixel counts using field calculator. Trend analysis demonstrated the response of wetland area change to climate change on yearly basis.

The changes in atmospheric composition and greenhouse gas emissions are associated to specific radiative forcing. IPCC adopted a new scenario based approach for future radiative forcing of climate change as representative concentrations pathways (RCPs) (Emanuel and Janetos, 2013). RCPs viz., RCP 4.5 and 8.5 are climate scenarios that predict future scenarios with reference to probable greenhouse gas emission rates and mitigation efforts. RCP 4.5 represents an optimistic future pathway to stabilized radiative forcing of 4.5 W/m2 with limited greenhouse gas emissions while RCP 8.5 is high emission scenario with no policy changes to reduce greenhouse emissions (Records *et al.*, 2014). Downscaled monthly data of RCPs 4.5 and 8.5 was acquired from Pakistan Meteorological Department (PMD) for the prediction of future changes in wetlands of salt range. The baseline and GCMs were used in generating RCPs data using CCSM4 (Community Climate System Model) and downscaled at regional level. CCSM is a coupled climate model for simulating Earth's Climate, composed of five different models simultaneously simulating the earth atmosphere, ocean, land and sea ice, plus one coupler component. CCSM is beneficial for the researchers in order to conduct fundamental research in earth's past, present and future climate states (Vertenstein *et al.*, 2004). Downscaling is the method of generating the local or regional climate data by taking information at large scale (Hewitson and Crane, 1996). Decadal average rainfall values along with the temperature and potential evapotranspiration were arranged from 2010-2050 for both RCP 4.5 and RCP 8.5. Trend analysis predicted the future changes in wetlands of Salt Range.

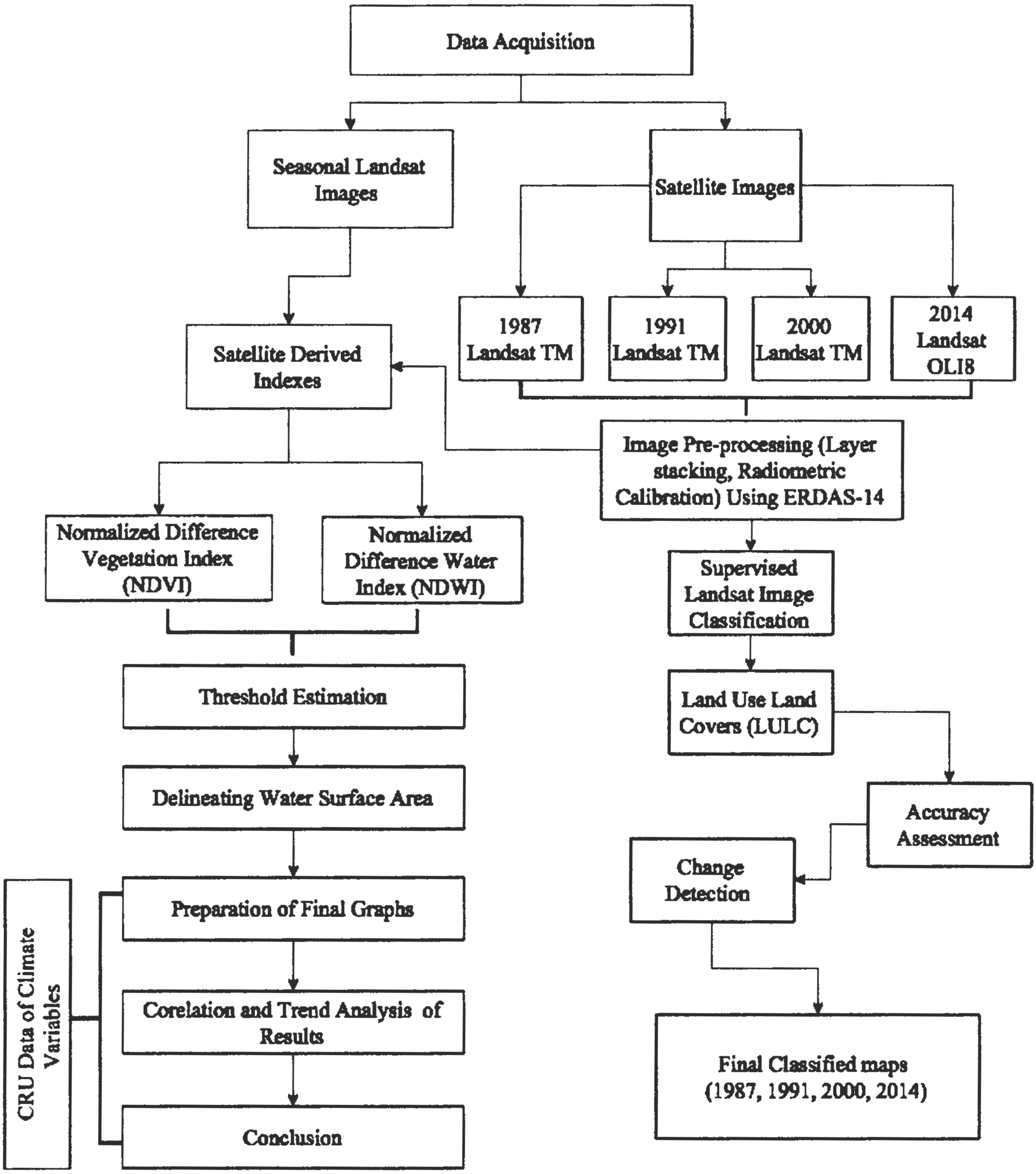

Figure 3. 2 Methodology for LULC Change Detection and Lake Area Assessment

Chapter # 4
RESULTS

4 RESULTS

4.1 Climatic Conditions in SRWC

Climatic conditions of Salt Range Wetlands Complex (SRWC) consisting of five independent wetlands viz., Kallar Kahar, Khabbaki, Uchalli, Jahlar and Namal Lakes were studied to see the fluctuations in rainfall, temperature and potential evapotranspiration for a time series of 30 years (1985-2014). Average annual rainfall for 2000-2014 showed an increase (long term average of 54.43mm) in comparison to the average annual rainfall during 1985-1999 (i.e. 51.54mm) (Table 4.1). The year which observed high average annual rainfall values of 67.10mm, 70.82mm, 65.80mm, 69.84mm and 77.81mm were 1992, 1994, 2005, 2008 and 2010 (Figure 4.1a) while low average annual rainfall values of 31.83mm, 31.36mm and 33.32mm were recorded in 1985, 1987 and 2002 (Figure 4.1a). The overall trend line of rainfall indicated the increasing average annual rainfall trend between 1985 and 2014 (Figure 4.1a).

Average annual minimum temperature during 2000-2014 exhibited an increase in comparison to 1985-1999 (Table 4.1). Temperature showed an inverse relationship with average annual rainfall. The maximum value of 24.6°C was recorded in year 1999 while minimum value was 22.4°C in year 1997 (Figure 4.1b). The overall trend line of average annual temperature showed no significant increasing trend from 1985-2014 (Figure 4.1b).

Evaporation is also an important climate variable regarding the natural loss of water from water bodies or soil. Decrease in average annual potential evapotranspiration was observed during 2000-2014 (3.68mm) in comparison to previous years (Table 4.1). The maximum potential evapotranspiration rate of 3.90mm was observed in 1999 (Figure 4.1c). The overall trend line showed decreasing average annual potential evapotranspiration trend from 1985 till 2014 (Figure 4.1c).

Table 4. 1 Basic Statistics for Climate Variables from Year 1985 till 2014

	Rainfall	Temperature	Potential evapotranspiration
Min--Max			
1985-2014 (30)	31.36- 77.81	22.47- 24.60	3.56- 3.90
1985-1999 (15)	31.36- 70.81	22.47- 24.60	3.61- 3.90
2000-2014 (15)	33.32- 77.81	23.14- 24.29	3.56- 3.88
Mean ± S.D			
1985-2014 (30)	52.97±11.99	23.68±0.47	3.71±0.09
1985-1999 (15)	51.51±13.21	23.53±0.52	3.73±0.06
2000-2014 (15)	54.43±10.90	23.83±0.38	3.68±0.11

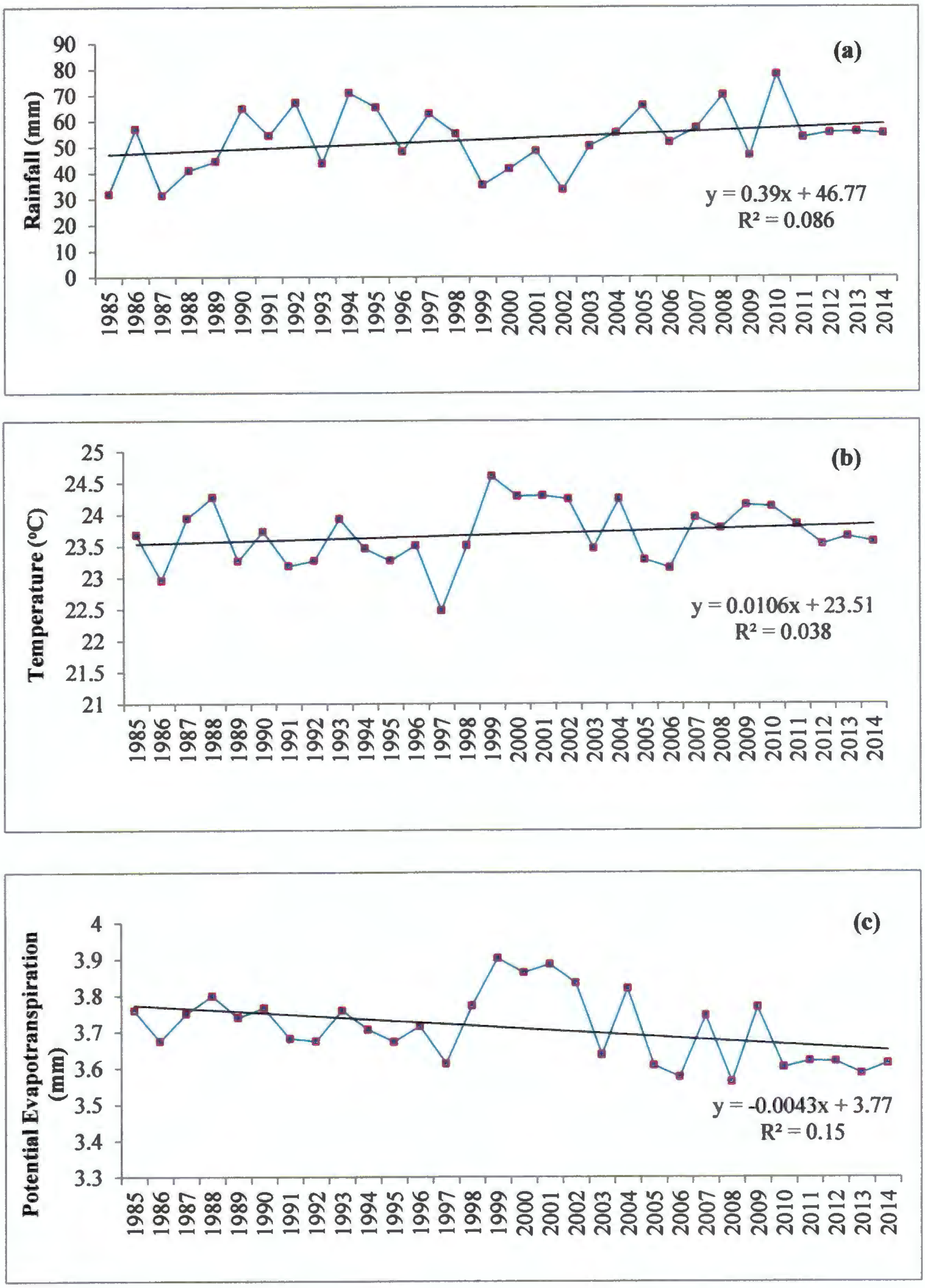

Figure 4. 1 Average Annual Rainfall (4.1a), Temperature (4.1b) and Potential evapotranspiration (4.1c) Patterns

4.2 Land Use Land Cover (LULC) Change Detection in SRWC

4.2.1 Land Use Land Cover Classification

Determining and mitigating the problems related to loss of agricultural lands, wetlands and wildlife habitats is important in current scenario of increased anthropogenic activity and population growth (Mallupattu and Reddy, 2013). Change detection through supervised classification has been done for years 1987, 1991, 2000 and 2014 (Figure 4.2-4.5). Change detection analysis exhibited significant changes in land use land covers of 1987, 1991, 2000 and 2014 (Table 4.2).

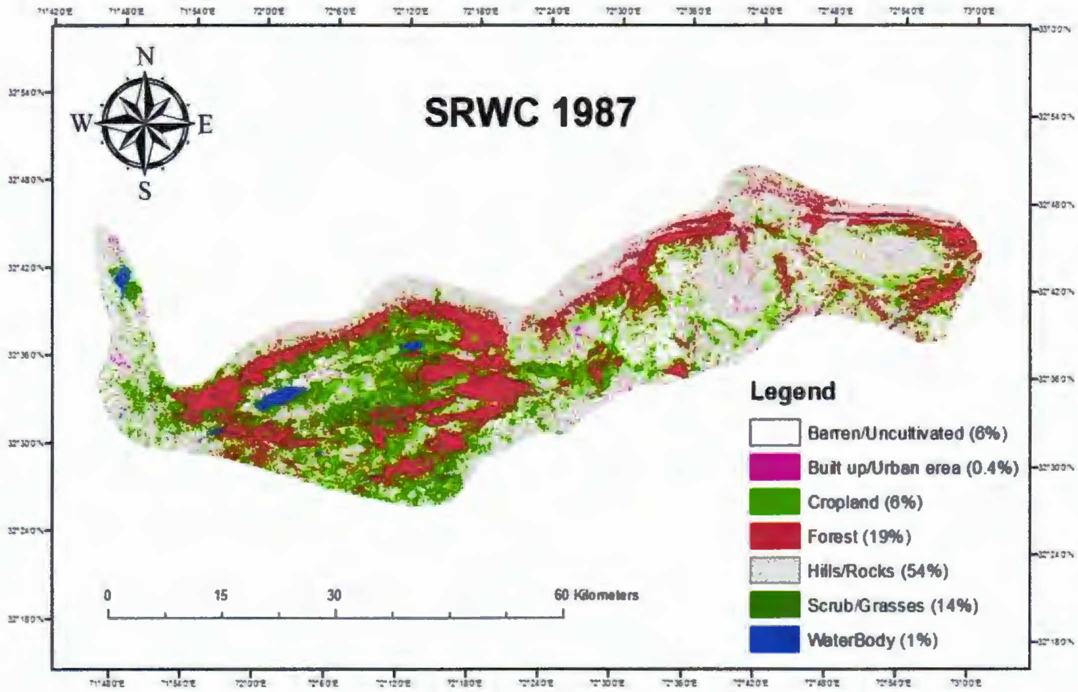

Figure 4. 2 Changes in Land Use Land Cover Classification in Year 1987

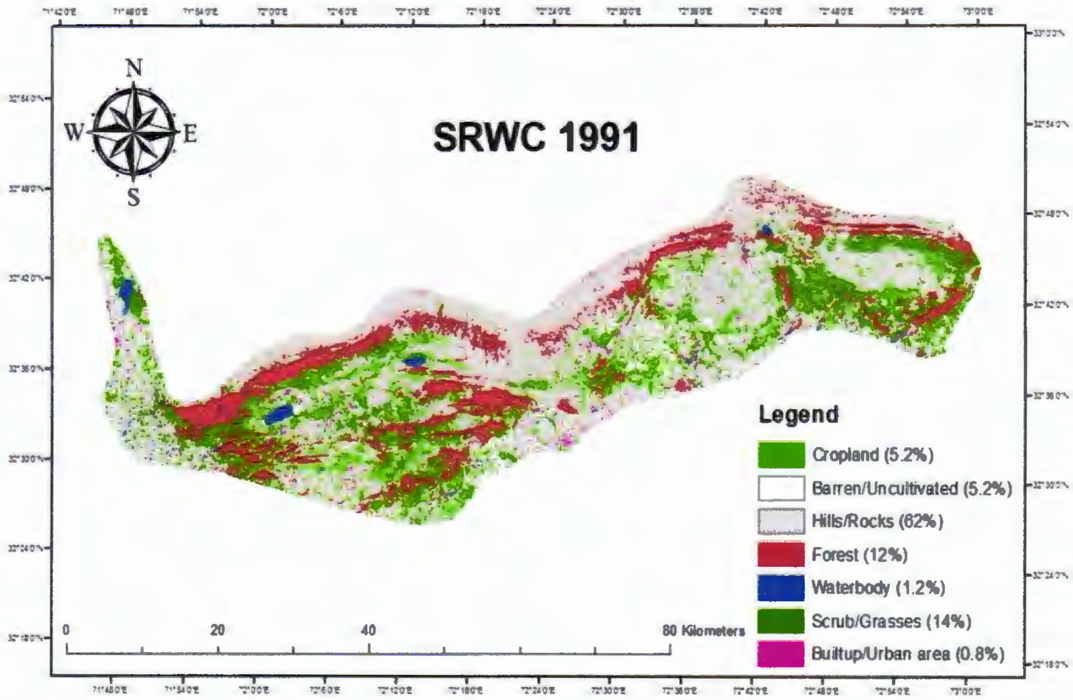

Figure 4. 3 Changes in Land Use Land Cover Classification in Year 1991

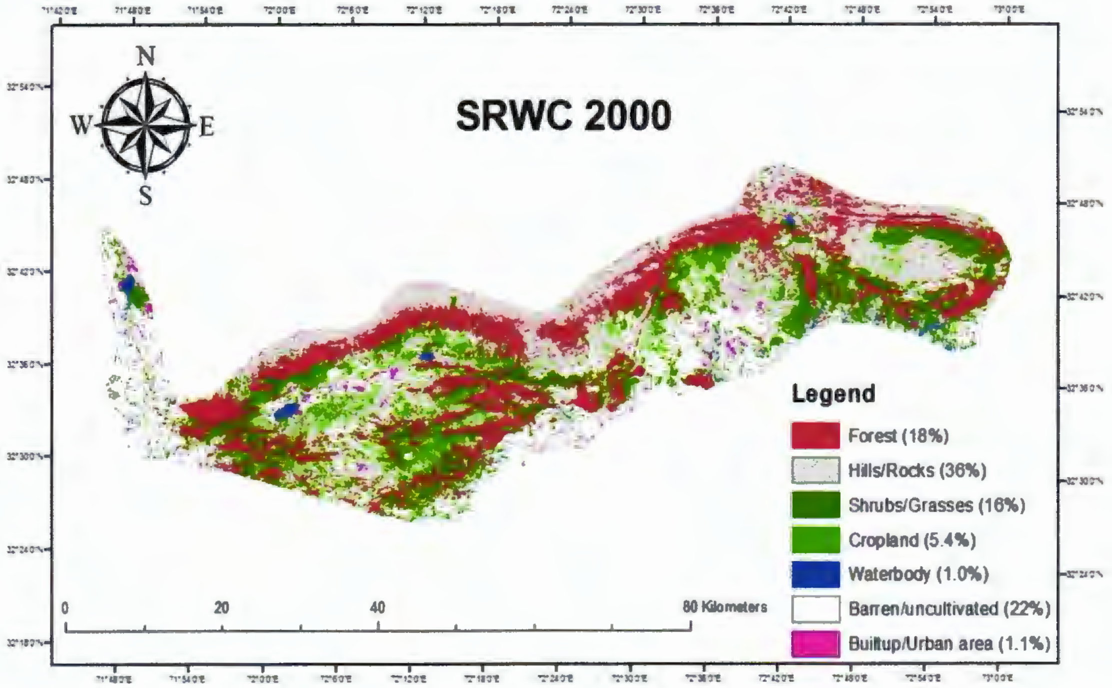

Figure 4. 4 Changes in Land Use Land Cover Classification in Year 2000

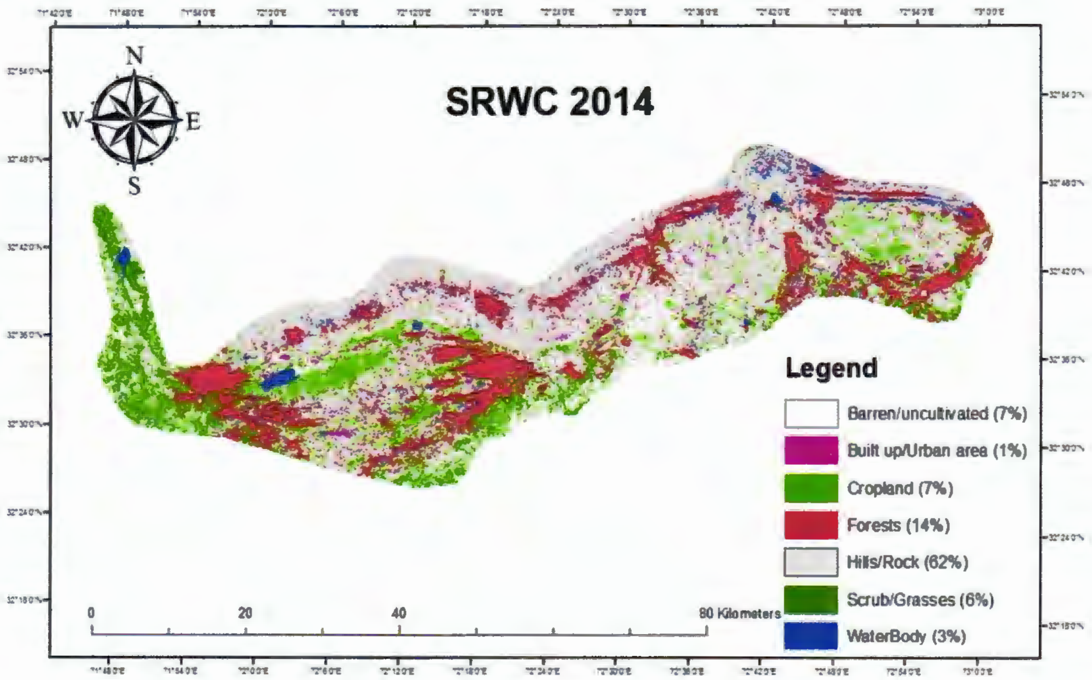

Figure 4. 5 Changes in Land Use Land Cover Classification in Year 2014

Table 4. 2 LULC Classes and Area in Hectares

LULC classes	Area (ha) 1987	%	Area(ha) 1991	%	Area(ha) 2000	%	Area (ha) 2014	%
Barren/ Uncultivated	12707.85	6	11398.05	5.2	48135.86	22	14413.85	7
Built up/ Urban area	1039.60	0.4	1781.18	0.8	2484.19	1.1	2591.90	1
Cropland	13554.92	6	11646.58	5.2	11920.95	5.4	15760.07	7
Forests	41113.32	19	26231.71	12	39993.06	18	30551.77	14
Scrub/Grasses	30324.26	14	30910.41	14	35133.29	16	13843.60	6
Waterbody	2650.84	1.2	2542.50	1.2	2221.29	1.0	6569.65	3
Hills/Rocks	118353.11	54	135254.09	62	79857.77	36	135968.67	62

Results showed that during 1987, most of the area in Salt Range Wetlands Complex (SRWC) was undeveloped. Forests were 19% of the total area covering an area of 41113ha, 1.2% was water body with 2651ha area covered, 14.5% (30324ha) was covered with scrubs/grasses and about 6% of the total land area was barren/ uncultivated. The built-up/urban area and cropland were nearly 6.4% covering an area of 14594ha (Figure 4.2). During 1991 a decline in the forest cover, barren land and cropland was observed. Approximately 12% (26232ha) of the total area was covered with forest. Barren land/ uncultivated area and cropland decreased from 6% (12708ha) to 5.2% (11398ha) of total area. Built-up area barely increased from 0.4% (1040ha) to 0.8% (1781ha) of the total area. While the waterbody and scrub/grasses remained the same as in previous period (Figure 4.3). During 2000 decrease in waterbody was observed while there was a significant increase of 22% (48136ha) in the barren /uncultivated area, 18% (39993ha) in forest area and 16% (35133ha) in scrubs/grasses (Figure 4.4). Slight increase in built-up and urban area was observed (almost 1% of the total area). During 2014 the forest cover decreased to almost 14% (30551ha) of the total area while there was an increased in the waterbody (3% of total area). Only 6% (13844ha) of the total area was covered with scrubs/grasses whereas built-up and cropland area was 8% covering 18351ha of total land area. There was a significant decrease in barren/ uncultivated area relative to earlier data (Figure 4.5).

4.2.2 Accuracy Assessment

Accuracy Assessment is essential for improving classification and for misclassification reduction. Using medium resolution Landsat images create a problem of pixel mixture of land cover features (Butt *et al.*, 2015). Visual interpretation and analysis was done to avoid pixel mixture and for improving the quality of LULC maps. According to Pareta, (2014) LULC classification is incomplete without accuracy assessment. Therefore, observed due to increased rainfall during the same periods (Figure 4.6a). After that lake area reduced to 89.79 ha in 2000 due to increased temperature (upto 24.28°C) and again started to increase till 2014.

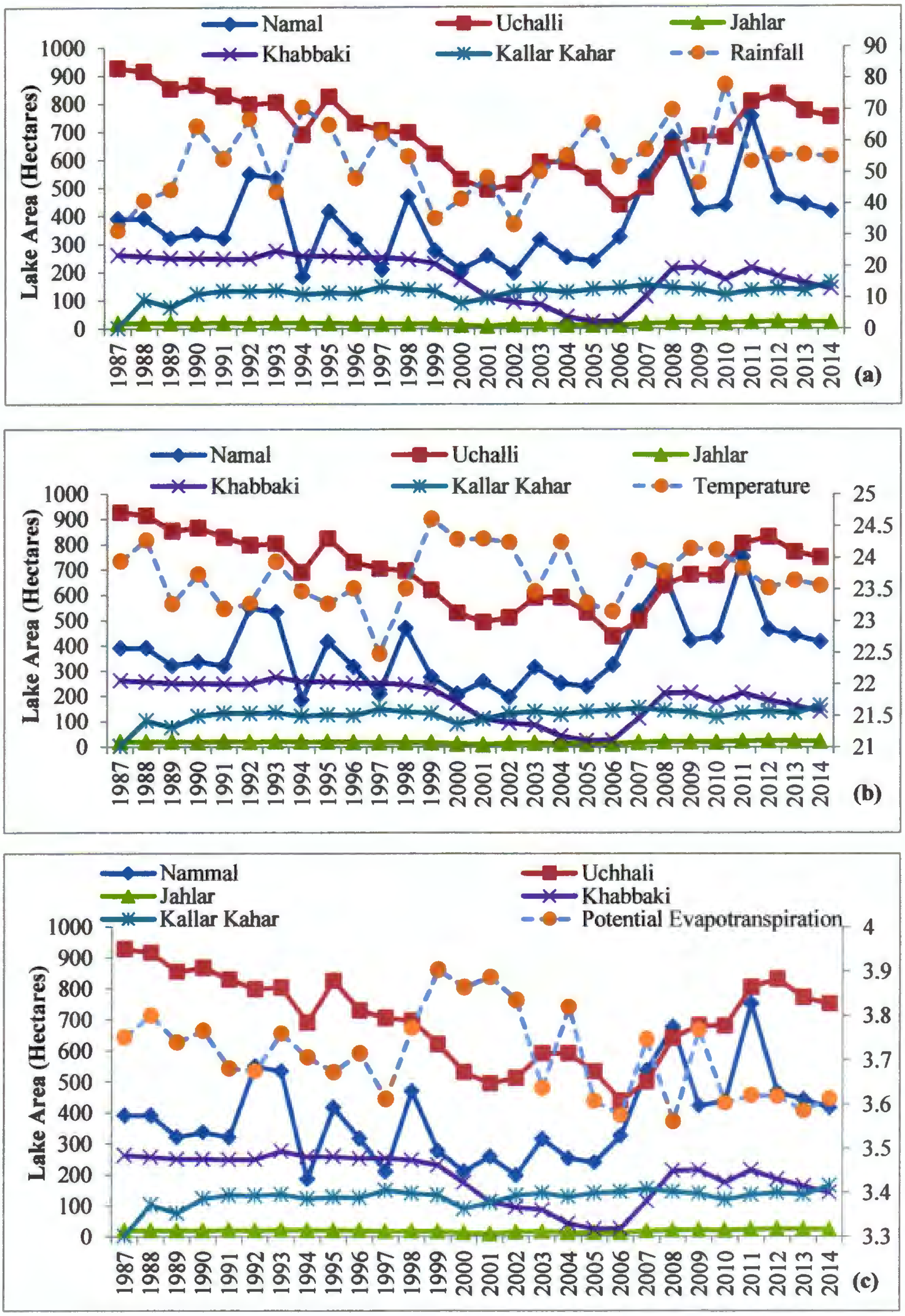

Figure 4. 6 Lake Area Change Detection in Relation to (a) Rainfall (b) Temperature and (c) Potential Evapotranspiration in SRWC

4.3 Predictive Future Changes Using Climate Scenarios (RCP 4.5 and 8.5)

Climate projections are useful for studying the future rate, magnitude and direction of possible changes. Scenarios selection, to identify and examine future climate impacts is based on the natural resources and their sensitivity to climate change (Daniels *et al.*, 2012). Downscaled future projections on rainfall, temperature and potential evapotranspiration were used at different time intervals to predict the expected magnitude of climate response on wetlands. Climate scenarios RCP 4.5 and 8.5 were selected for intervals 2011-2020, 2021-2030, 2031-2040 and 2041-2050 (Figure 4.7).

During 2011-2020 the rise in temperature and decrease in rainfall is expected based on RCP 4.5 while RCP 8.5 temperature and rainfall scenario is likely to increase. The potential evapotranspiration data showed less fluctuation for both scenarios RCP 4.5 and 8.5 (Figure 4.7 a, b, c).

Maximum rainfall is expected to occur with increase in temperature and Potential evapotranspiration based on RCP 8.5 as compared to RCP 4.5 between 2021 and 2030. Rainfall and potential evapotranspiration probably will decrease and temperature is likely to further increase based on RCP 4.5 in corresponding years. There will be a slight decrease in the potential evapotranspiration as compared to previous decade in case of RCP 4.5 (Figure 4.7 a, b, c)

During 2031-2040 rainfall trend showed a decrease with expected minimum fluctuations in both scenarios RCP 4.5 and 8.5. Maximum increase in temperature is likely to occur between 2031 and 2040 based on RCP 8.5 as compared to RCP 4.5. Minimum fluctuations with increase in potential evapotranspiration are expected for both RCP 4.5 and RCP 8.5 (Figure 4.7 a, b, c).

Maximum potential evapotranspiration is expected during 2041-2050 based on RCP 8.5 while it is expected to decrease based on RCP 4.5 from past decades. Minimum rainfall and maximum temperature is likely to occur in 2041-2050 based on RCP 4.5 as compared to RCP 8.5 (Figure 4.7 a, b, c).

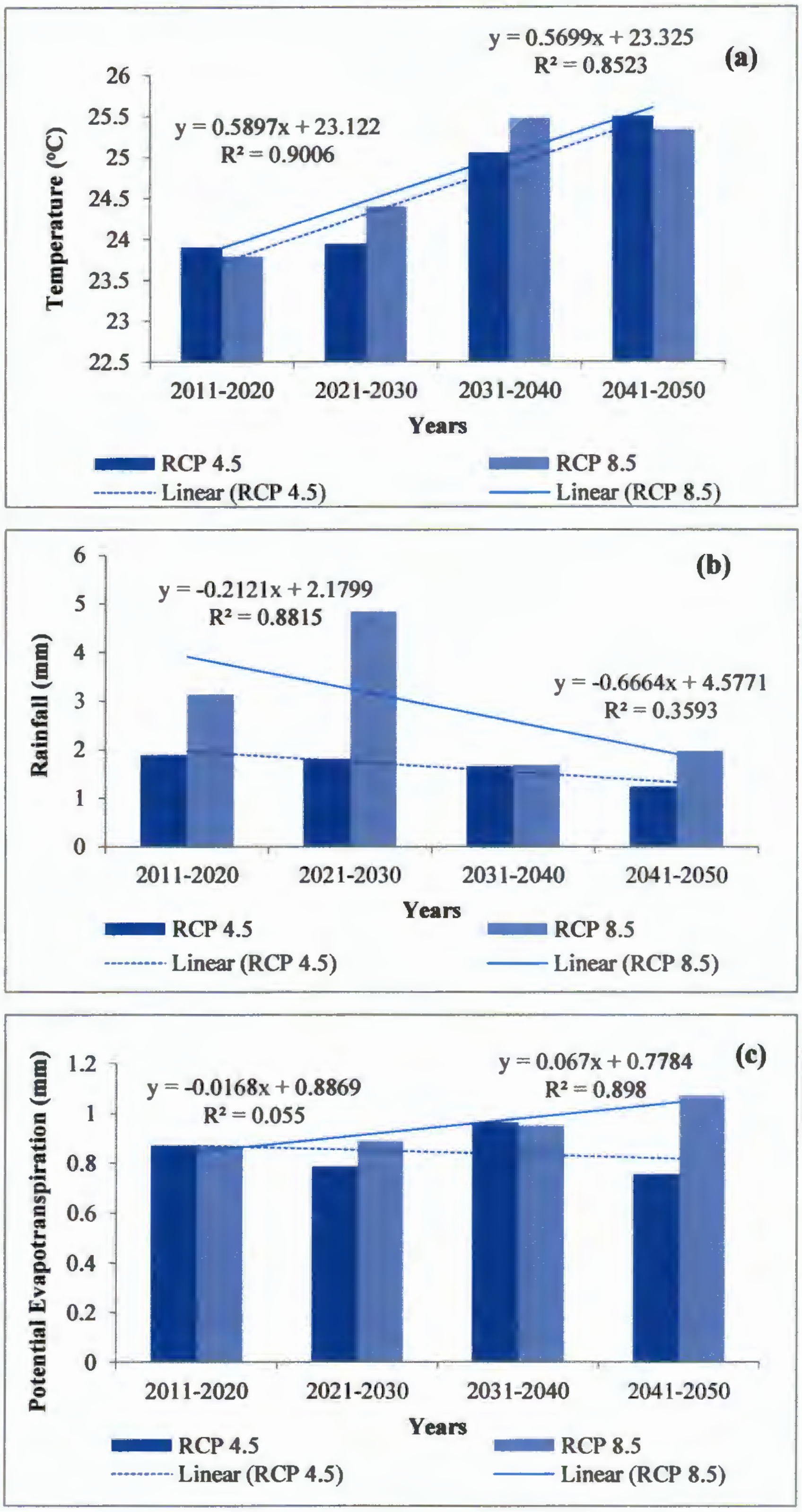

Figure 4. 7 Future Impacts of Climate Change Based on RCP 4.5 and RCP 8.5 in SRWC

Chapter# 5

DISCUSSION

5 DISCUSSION

Climate variability and change has been experienced in past decades. But most significant changes are human-induced, playing major role in changing climate. Recently, increased in carbon dioxide (CO_2) concentrations and rise in global temperatures on land and water surfaces are the evidences to change in climate (Chaudhry *et al.*, 2009). Recent study also demonstrated the climatic conditions of the area which determined an increase in average annual precipitation and decrease in average annual temperature and potential evapotranspiration from 2000-2014 in comparison to previous years (1985-1999). According to the survey conducted in 2010 the average yearly rainfall is 70-80 mm for salt range (Jawad, 2011) which is in accordance with the study results of 2010 (77.81mm rainfall). The climate of the area is dry subtropical with hot summers and cool winters (Dauda *et al.*, 2016). Results were evident by the rainfall variability that has increased in Asia in past few decades while coastal areas are experiencing the decreasing trend (IPCC, 2007).

Globally, many studies have been conducted on the sensitivity of lakes to climate variables at decadal or inter-annual scales. Studies determined that causes of lake area changes involve several climatic factors like precipitation, evaporation/evapotranspiration, and glacier melting due to increased temperatures (Song *et al.*, 2014). Salt range wetland complex is a hilly area consists of five different wetlands Namal, Uchalli, Khabbaki, Jahlar and kallar kahar. Crop production is the main occupation in SRWC and mostly wheat and vegetable crops are grown in the area. Overall classification results indicated a decline in forest area and scrub/ grass vegetation while the area of cropland, settlements, barren/uncultivated and waterbody classes increased in 2014 (Figure 3). Decrease in the forest cover has been observed due to increasing temperature and decreasing rainfall and it is evident that rainfall and temperature extremes are most tragic impacts of climate change that caused the decline in forest cover of Pakistan (Siddiqui *et al.*, 1999). Decline in forest area during 2000-2014 in current study is evident with the study conducted in district Chakwal. There was observed a decline in the forest area due to reduction in rainfall and increase in temperature for the period of 2005 to 2010. Beside this, forest landscape alterations could affect the topography resulting into degradation of forest (Ahmad *et al.*, 2010). Settlements increased from 6.4% to 8% of total covered area from 1987 till 2014. Prevailing socioeconomic conditions in area showed excessive population growth that depicts the increase in settlement area. One of the major threats in SRWC is an increased population, posing threats to the natural resources due to unsustainable utilization. The high population pressure and its demands have put the natural resources at risk (Hussain, 2002). The Barren land showed an increment in the total area because of the soil erosion that has been encountered in SRWC due to overgrazing and illegal deforestation (Arshad, 2011). In past years the rainfall frequency has been reduced resulting in the drop down of the water table from which not only the water bodies are severely affected but also the vegetation of the area. Deforestation in the area along with the increased temperature has converted the green lush slops into barren land (Ahmad *et al.*, 2002).

The total area covered with waterbody continued to decrease from 1987-2000 while an increase in total share from 1% to 3% was observed from 2000-2014. The increase in the waterbody in the area could be due to the contractions of dams and reservoirs along with the expansion in wetlands area and new water body was also observed in the area which was not present in the imagery of 1987. If we talk about the wetlands the overall decrease in wetland area of Uchalli and Khabbaki was observed since 1987 while Namal, Jahlar and Kallar kahar showed an increase. The wetland area observed in 1987 was 927 ha in Uchalli and 262 ha in Khabbaki which reduced to 750 ha and 142 ha respectively. Whereas, 417ha, 23ha and 164ha area was observed in Namal, Jahlar and kallar kahar in 2014 that was an increase with lake area inter-annual variations. So, results showed that lake area variations are closely related to the climatic factors as shown in figure 4 (a, b and c).

The water surface area of Namal, Jahlar and Kallar Kahar and their corresponding average annual precipitations showed similar fluctuation patterns that depict these area variations are driven by local rainfall. As, these lakes are brackish to saline inland wetlands that supports marshy and aquatic vegetation and are mostly fed by the rainfall and by small springs in a small quantity from hills (WWF, 1994). The increase in surface area of Namal lake was compatible with the rainfall pattern in years 1992, 1993, 2007, 2008 and 2011. While, decrease in surface area has been observed when rainfall pattern has decreased (Figure 4.6a). Uchalli and Khabbaki lake were more influenced by the drought conditions, this is evident by study conducted by Ahmed *et al.*, 2012. According to him rise in temperature and decrease in rainfall has lowered the water level in Uchalli, Khabbaki and Jahlar causing several impacts. Runoff is the main source of water for Kallar Kahar Lake. It is mostly fed by the surrounding mountain streams and has much deeper water table because of potohar plateau. The volume of water increases depending upon the received rainfall and can increase especially during monsoon season (Rais *et al.*, 2011).

Abrupt climate change events like floods and droughts have encountered the change in surface area (IPCC, 2007). Extreme climate events have been experienced in SRWC in past years. The drought in 2000 and floods of 2010 are the evidences of extreme climate events in Punjab, Pakistan (Salma *et al.*, 2012). In response to these extreme climate events the area expansion and reduction behavior was in accordance with extreme rainfall and temperature trend. Extreme rainfall resulted in filling of the lakes while extreme temperature resulted in the rise of potential evapotranspiration, which caused shrinkage in corresponding wetlands area. According to IPCC, 2007 large surface warming and decreased in land precipitation in past few decades have contributed towards the drying trend. The decrease in the size of lakes in SRWC along with the water bird counts were also evident by Ali and Akhtar in 2006 when several wetlands sites were studied to determine the avian diversity at these sites. It was determined that these wetlands are not only facing the area reduction but the quality of water is also being degraded due to anthropogenic activities.

Climate change impacts on salt range wetlands area were predicted based on projected changes in rainfall, temperature and potential evapotranspiration rate from RCP 4.5 and RCP 8.5 scenarios. Climate change have potential impacts on future hydrological and climate variables due to increased greenhouse gas emissions associated to increasing temperature globally (Gebre and Ludwig, 2014). Previous results regarding area variations due to climate change indicated a positive correlation between the wetland area and precipitation. Hence, any change in precipitation could alter changes in wetland area leading to the degradation of wetlands in salt range. Variability in climate parameters could play a vital role in hydrological disturbances which in turn could result in the loss of dynamic ecosystems. As for RCP 8.5 mean annual rainfall increases between 2011 and 2030, then decreases for 2031-2040 and then again increases (by small amount) for 2041-2050. While mean annual temperature increases from 2011 till 2040 and then slightly decreases for 2041-2050. As compared to RCP 8.5, mean annual rainfall probably will decrease gradually from 2011-2050 under RCP 4.5 while temperature is expected to be increased in corresponding years. It would have profound effects on wetlands. Generally, the expected temperature under RCP 4.5 and 8.5 scenarios indicate an overall warmer climate. Climatic warming could start a drying trend in wetlands ecosystems due to increased temperatures along with greater changes in precipitation and potential evaporation/ evapotranspiration over a century. The impact of climate change in precipitation and temperature will create disturbances in the runoff which could alter the area of wetlands.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on study results it is concluded that significant LULC changes were evident by decline in scrub/grass vegetation and forest area (6% and 14% respectively) and increase in the area covered by cropland (7%), settlements (1%) and barren/ uncultivated land (7%). The overall increase in the water body was observed upto 3% of total area. Climate changes were also observed during 1985-2014. Changes in lakes surface area due to climate change were evident by increase in the surface area of lakes when rainfall is observed at its maximum. Moreover, temperature rise resulted in surface area shrinkage. Future climatic predictions have resulted in the hydrological alteration due to disturbances in climate patterns and drying trend is expected to be encountered by these wetlands.

Recommendations

In the light of present study and its findings following recommendations area made in order to bring awareness about the current issues and its problems. Also recommendations could be taken up by scientific community in future to do extensive research in the subject area.

- ✓ Increasing awareness among local community can play its vital role in reducing the damages to wetlands.
- ✓ Involvement of stakeholders at provincial level can improve the collaborative management of the natural resources.
- ✓ Alternative livelihood opportunities (i.e., ecotourism and skills development) should be provided for living community in order to alleviate poverty and over exploitation of resources.
- ✓ Enforcement and implementation of rules, regulations, policies and the management plans should be promoted for wetlands protection and preservation.
- ✓ Catchment area of Uchalli Lake, Khabbaki Lake, Jahlar Lake, Kallar Kahar Lake and Namal lake should be protected by proper planning and development of defined boundary in the natural area.
- ✓ Environmental impact assessment should be conducted in the area before executing any development project.

- ✓ Water quality monitoring and management plans should be developed and implemented.
- ✓ Studies regarding the climate impacts on wetlands should be promoted to determine the wetlands responses.
- ✓ Policy makers and researchers should take appropriate measures for wetland restoration before it goes under a complete change due to extreme climate events.

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