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Hydrological Aspects of Climate Change

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Hydrological Aspects of Climate Change

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Foreword

Climate change is one of the most critical global challenges likely to cause considerable changes in the spatial and temporal distribution of water resources in the coming decades. Unfortunately, these changes are likely to be unfavorable in many countries which already suffer from pressures on water resources and water scarcity. This may prove to be the case in India which is still largely dependent upon rain-fed agriculture. In the context of anticipated global warming due to increasing atmospheric greenhouse gases, it is necessary to evaluate the possible impact on freshwater resources of the country as climate change can have important implications for freshwater supply for drinking water, rain-fed agriculture, groundwater supply, forestry, biodiversity, and sea level. Climate change affects the hydrologic cycle by directly increasing the evaporation of available surface water and vegetation transpiration and snow and glacier melts. Consequently, these changes can influence precipitation amounts, timings, and intensity rates and indirectly impact the flux and storage of water in surface and subsurface reservoirs (i.e., lakes, soil moisture, and groundwater). In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration, and potable water shortage. The impact of future climatic change is expected to be more severe in developing countries such as India whose majority of the rural population is dependent on agriculture. Water sector in India is under stress due to many reasons including population increase and rising demands for energy, fresh water, and food.

In order to minimize the adverse impacts of climate change on country's water resources and attaining its sustainable development and management, there is a need for developing the rational adaptation strategies and enhancing the capacity to adapt those strategies after carrying out the risk, reliability, and uncertainty analysis. Accordingly, the present practices being followed in the water resources sector are required to be reviewed and revised considering climate change, which would provide the means for alleviating the negative impacts of climate change.

The Roorkee Water Conclave 2020, broadly focusing on "Hydrological Aspects of Climate Change," provided an opportunity to policy-makers, academicians, researchers, students, and practitioners to share their experiences and knowledge by presenting the fundamental/applied scientific advancements made in the field of water resources development and management under changing climate for sustainable development. This volume includes full-length papers of 19 keynote papers from India and abroad.

I hope that this book will become useful to researchers and practitioners.

Roorkee, India

Ajit K. Chaturvedi
Director, IIT Roorkee

Preface

This book comprises 16 chapters focusing on the hydrological aspects of climate change. It includes climate change and water–food security and policy issues within water–energy–food nexus and climate risks to water security in Canada's western interior. Moreover, forcing global hydrological changes in the twentieth and twenty-first centuries, Indian summer monsoon system, observed climate change over India and its impact on hydrological sectors, the importance of data in mitigating climate change and real-time monitoring of small reservoir hydrology using ICT and application of deep learning for prediction of water level have been demonstrated.

The book has covered the hydrology problems, challenges and opportunities to provide timeline of significant hydrology developments over the past century and a half; flood modelling, mapping and monitoring of sparsely gauged catchments using remote sensing product study have been presented. A chapter on "Ground and Satellite Observations to Predict Flooding Phenomena" focuses on some crucial questions that may be considered a challenge for the scientific community, Indices for Meteorological and Hydrological Drought.

It broadens an Indian perspective to highlight the various initiatives/steps taken by the Government of India to efficiently manage water to reduce the country's agricultural water footprint, an overview highlighting the importance of water resources management in the Indian context. Adaptation to Climate Change in Agriculture, Improved Agricultural Water Management and Protected Cultivation Technologies and Use of Oxygen-18 and Deuterium to Delineate Groundwater Recharge have also been included.

This book is useful for academicians, water practitioners, scientists, water managers, environmentalists, administrators, NGOs, researchers and students involved in hydrological studies focusing on climate change, etc.

Roorkee, India

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About the Editors

Dr. Ashish Pandey is currently a Professor at the Department of Water Resources Development & Management, IIT Roorkee. He received Ph.D. from IIT Kharagpur. He pursued his B.Tech. in Agricultural Engineering and M.Tech. in Soil and Water Engineering from JNKVV, Jabalpur. He is a Fellow member of Institution of Engineers, the Indian Association of Hydrologists, and Indian Water Resources Society. He published 165 research papers in peer-reviewed and high impact international/national journals/seminars/conferences/ symposia. Prof. Pandey has over 20 years of experience in the field of Irrigation Water Management, Soil and Water Conservation Engineering, Hydrological Modeling of Watershed, Remote sensing and GIS Applications in Water Resources.

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Prof. Arun Kumar is currently working as Professor of HRED, IIT Roorkee. He pursued his Bachelor's in Civil Engineering from IIT Roorkee, Master's in Civil Engineering from IISc Bengaluru and Ph.D. from IIT Roorkee. He did Hydropower Diploma studies at NTH, Trondheim. His research areas are hydropower development, environmental management of water bodies, energy economics and policy. He was the coordinating lead author for IPCC special report on renewable energy for hydropower. Prof. Kumar has over 39 years of experience in the field of hydropower and environmental management of rivers and lakes.

Chapter 1
Climate Change, and Water and Food Security: Policies Within Water–Food–Energy Nexus

R. S. Kanwar, S. S. Kukal, and P. Kanwar

1.1 Introduction

Climate change is one of the most important challenges facing humanity on the planet, especially water and food security which is affecting almost all continents of the world. Industrialization and population growth in twenty-first century are considered to be the primary reasons for increased annual air temperatures, and highly variable and intense rainstorms around the globe. As a result, enhanced greenhouse effect has exposed us to the adverse effects of global warming (Haris et al. 2013; Hundal and Kaur 2007). The mean surface temperature on the planet has increased by 0.85 °C since 1880 and is likely to increase by another 3.7–4.8 °C by 2100 (IPCC 2014). Climatic change is causing global warming which is affecting every aspect of life. Tropical and sub-tropical regions of the world are facing high temperatures at abnormal scales resulting in huge impacts on agricultural productivity. Some studies have reported that 10–40% loss in Indian food grain production could occur due to increase in temperature by 2080–2100 (Parry et al. 2004; IPCC 2007).

In order to achieve UN's Sustainable Development Goals for 2030 to make the world free of hunger and malnutrition, we must take actions now to develop, strengthen and sustain resilience in water and food production and distribution systems to meet the future demand that will increase demands on water for irrigation,

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particularly in water scarcity areas of the world. An increase in water scarcity under changing climate presents its own challenges, including cross-border water conflicts as well as competing demands for water for agriculture, industry and domestic use.

Groundwater is the primary source of irrigation and drinking water for about 2 billion people in the world, and the impact of climate change on the quantity and quality of groundwater resources is huge. Groundwater has been withdrawn at unsustainable rates in almost every country in the world to meet the drinking water needs of growing population and irrigation demands to grow more food in arid and semi-arid climates of the world.

At the same time, little research has been done to determine the impact of climate change on groundwater recharge rates and quality. Changing weather patterns and more frequent intense rain storms, observed within last 10–15 years, are causing flooding, soil erosion and water pollution. Unless we develop science-driven management systems and incentive-based policies, water quality could become one of the major challenges for the society. Everts and Kanwar (1993) installed 50 piezometers (vertical and angled) at depths of 3–120 m in glacial till shallow and artesian aquifers of Central Iowa and measured groundwater recharge rates. Ella et al. (2002) used the field data on hydraulic conductivities for different soil and aquitard layers to develop hydrologic models to determine groundwater recharge rates to artesian, glacial till aquifers in Iowa. Rekha et al. (2011) and Olson et al (1997) reported that macropore flow was primarily responsible for carrying nitrate from manure and agricultural fertilizers to shallow and deeper groundwater systems in Iowa. Several other studies have been conducted to investigate the long-term effects of climate and agricultural production practices on the leaching of nitrate, phosphorus, bacteria, and pesticides to shallow and deeper groundwater systems (Hruby et al. 2016, 2018; Hoover et al. 2015; Huy et al. 2013; Pappas et al. 2008; Kalita et al. 1997; Kanwar et al. 2005, 1997; and Karlen et al. 1998). These studies have shown clearly that land-applied chemicals and animal waste can pollute groundwater systems of the Midwest in the USA but farmers and producers have become willing partners to adopt innovative best chemical and crop production practices to minimize impacts on water quality, improve soil health and helping mitigate climate change impacts on agriculture.

In certain parts of the world, the availability of good quality groundwater for drinking and irrigation is going to be the greatest threat to humanity in twenty-first century. Therefore, we must invent new governance using innovative incentive-based policies and technological innovations to mitigate the threat of climate change on water and food security for the growing population. For example, 85% of groundwater is used for irrigation in India and farmers have been pumping groundwater at unsustainable rates since the green revolution started in 1960s, resulting in lowering of groundwater tables in many aquifers from about 6 m in 1970 to more than 100 m in 2019 in less than 50 years. In USA, compared to an average year, only 55% of Colorado River water is flowing to Lake Powell due to below-average rainfall and runoff. Reservoirs in the Colorado River Basin are 12% more likely to fall to below the critical low levels by 2025.

The impact of climate change on the faster depletion of groundwater for irrigation and its impact on declining agricultural production in certain parts of the world has escalated food inflation. Also, acute food shortages in many African and Asian countries, where people cannot afford expensive food, are dying of starvation (Misra 2014). There are water crises all over the world including western USA, India, Africa and Middle East due to depletion of surface and groundwater resources.

The earlier described studies/panel reports are clear evidence that climate change is making huge impact on accelerated loss of biodiversity with major long-term consequences on the global economy. In order to ensure an environmentally and economically sound sustainable future for the growing population of the world, we as a global society must recognize that the climate change is real; and environmental quality and economic development are not mutually exclusive. Therefore, the key question for the global society is "what can be done to reduce the emission of greenhouse gases (carbon dioxide, nitrous oxide and methane)? Greenhouse gases trap heat in the atmosphere and make the planet warmer. To be very honest, the major cause of increased greenhouse gas emissions to atmosphere is the human activities for the past 150 years (IPCC 2007). The largest source of greenhouse gas emissions in the USA is from burning fossil fuels for electricity, residential and commercial buildings, industry and transportation (Fig. 1.1).

Fossil Fuels and Climate Change: Developed countries are the largest consumers of fossil fuels and producing larger share of greenhouse gas emissions. The USA, for example, is just 5% of world population, but contributes 25% of total CO_2 output in the world. Currently, a child born in the USA is likely to produce seven times the carbon emissions of a child born in China and 168 times the child born in Bangladesh. The USA has the largest population in the developed world, and its population may double before the end of the century. Currently, US's 350 M people produce more than double the greenhouse gases than that of Europe, five times the global average

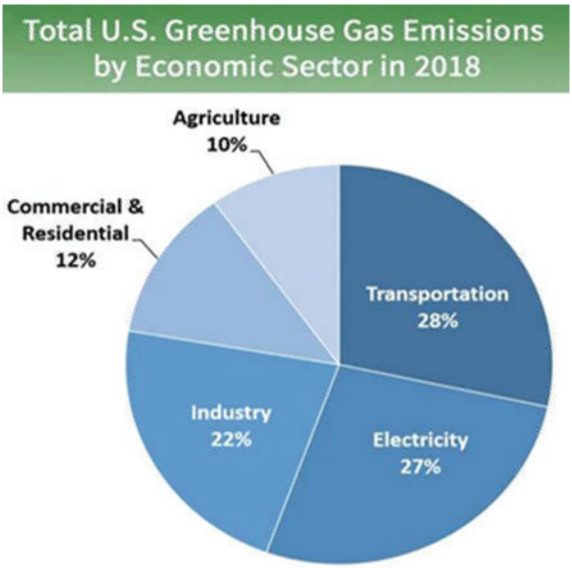

Fig. 1.1 Sources of greenhouse gas emissions in the USA as affected by population growth

and more than 10 times the average of developing nations. The increased greenhouse gas emissions are the result of massive consumption of natural resources and fossil fuels to maintain higher standard of living and lack of political will to end fossil fuel economy. Transportation sector accounts for 28% of all US carbon emissions (Fig. 1.1). About 12% of US carbon emissions come from the residential sector. Due to a dramatic decrease in household size, from 3.1 persons per home in 1970 to 2.6 in 2000, homebuilding is outpacing the population growth. More Americans are driving farther to reach bigger homes with higher heating and cooling bills. These trends are carbon footprint inherent of a burgeoning US population.

Population Growth and Climate Change: Whether we agree or not, there is a direct relationship between population growth and climate change which is one of the focus areas of this chapter. Climate change is affecting the entire world, and different regions are experiencing varying degrees of effects due to faster population growth. Some researchers in the world are making it very clear that one of the best options for the world is to consider controlling population to reduce the burden on earth. The largest single threat to the ecology and biodiversity of the planet is the climate change due to the build-up of human-generated greenhouse gases in the atmosphere.

In just 50 years (1970–2020), the world's population has more than doubled to over 7.5 billion people. That means more than 7.5B bodies that need to be fed, clothed and kept warm, all requiring a large amount of energy, which is largely coming from fossil fuels. Along with this consumption, these 7.5B people are also producing large quantities of waste requiring more energy to treat the waste to keep soil, water and air clean. The demand for energy and the production of waste are among significant producers of greenhouse gas emissions that contribute to climate change.

At the 2015 UN Climate Change Conference in Paris, 196 counties have agreed to limit global warming to 1.5 °C. Several countries around the world are beginning to address the problem by reducing their carbon footprint through less consumption of natural resources and use of better technologies. But unsustainable population growth can overwhelm these efforts, leading us to conclude that we not only need smaller footprints, but fewer feet on the planet. A successful example is from the city of Portland, Oregon, in the USA where city decreased its combined per-capita residential energy and car driving carbon footprint by 5% between 2000 and 2005. During this period, however, its population grew by 8%. Second successful example is from the city of Stockholm in Sweden which has become the first fossil-fuel free city in the world. Stockholm uses nearly 100% energy from clean energy sources such as biofuels produced from city's food waste and municipality wastewater. Sweden has also decided to become the world's first fossil-fuel free nation as part of their commitment under Roadmap 2050. To do this, Sweden must reduce greenhouse gas emissions by 40% by the year 2020 compared with 1990 levels, and completely rid of vehicles using fossil fuels by 2030.

Global human population is growing by 83 million or 1.1% annually, although growth rates among countries vary from 0.1% to more than 3%. The global population has grown from one billion in 1800 to 7.8 billion in 2020. It is expected to keep growing, and estimates have put the total population at 8.6 billion by mid-2030,

Table 1.1 Global population growth rate from 1800 to 2050

Year	Population (10^9)
A&E → Malthus	0.9
1800	1
1900	1.6
2000	6
2010	6.9
2020	7.5
2030	8.2
2050	9.2
2100	11.2

9.8 billion by mid-2050 and 11.2 billion by 2100 (Table 1.1). Many nations with rapid population growth have low standards of living, whereas many nations with low population growth rates have higher standards of living. Table 1.1 gives data on population growth in the world in recent history (1800–2020) and projected growth in 2030, 2050 and 2100. Table 1.1 shows that population grew from 1 billion to 1.6 billion (1.6 times) in 100 years from 1800 to 1900, whereas population grew from 1.6 billion to 6 billion (3.75 times) in next 100 years. Other way to look at the population data in Table 1.1 is that in 100 years between 1800 and 1900, world population grew by only 600 million, whereas in next 100 years (1900–2000), the world population grew by 4400 million and the world added another billion people on earth in just 10 years (from 2000 to 2010) on the planet. Therefore, the question for the global community would be to see if we can sustain this level of population growth without deteriorating biodiversity and the environment around us where we live and our children will thrive for years to come. Haris et al. (2013) have clearly shown that increased population growth on the planet is resulting in deforestation, industrialization, urbanization and consumption of natural resources at alarming rates.

Climate change researchers have warned that we must reduce atmospheric CO_2 to 350 ppm in order to avoid global catastrophe (Solomon et al. 2007). A 2009 study of the relationship between population growth and global warming determined that the "carbon legacy" of just one child can produce 20 times more greenhouse gas than a person will save by driving a high-mileage car, recycling, using energy-efficient appliances and light bulbs, etc. Each child born in the USA will add about 9441 metric tons of carbon dioxide to the carbon legacy of an average parent. The study concludes that the potential for savings from reduced population growth are huge compared to the savings that can be achieved by changes in lifestyle.

The year 2020 is likely to be one of the five hottest years in the USA. Climate disasters are devastating the USA with record forest fires on the Pacific coast and Brazil with forest fires engulfing the Amazon; repeated floods and storms hitting the Atlantic and Gulf states in the USA; unknown earlier derecho-type rain storms with 80 plus miles an hour wind speeds in Iowa; frequent tornadoes in Midwest; the precipitous decline in Arctic sea ice; and the accelerating threats to Greenland's and Antarctica's ice sheets that could trigger a catastrophic rise in the sea level. Therefore, countries like USA and Canada and rest of the western world need to do its part to achieve global climate safety. The entire world needs a massive shift in industry from fossil fuels to renewable energy; from internal combustion engines to electric vehicles powered by the renewable energy; and from heating oil and natural gas to electric heat pumps in homes and commercial buildings. Oil-producing countries and the vested interests of the fossil-fuel industry will fight these changes but global society needs to develop legal framework and incentive-based policies to move away from fossil-fuel economy to bio- and clean energy economy for climate safety and enhancing biodiversity on the planet.

Other environmental consequences of global warming are the rise in seas water levels. There is plenty of evidence that the sea water levels are rising with temperature rise, threatening low-lying areas, coastal populations and ecosystems around the world. With rising sea levels, water is encroaching on agricultural lands resulting in soil salinity and other environmental hazards by making freshwater polluted that people may rely on for their drinking purposes. Many plants and animals live in areas with specific climate conditions, enabling them to survive and flourish. Extreme weather events, increase in temperature and rising seas are beginning to affect plants and animals, altering their habitat and bringing life-threatening stresses and diseases. Temperature increase of 2–3 °C would increase the number of people living in malarial climates by 3–5%, putting hundreds of millions of people at risk. Tremendous progress has been made in eradicating the mosquito and reducing malarial cases and deaths. Nonetheless, low rates of agricultural productivity growth and high rates of malaria infection often coincide, particularly in sub-Saharan Africa. For poor countries with limited resources, treating malaria can seem out of reach economically, especially in rural areas. Changes in land-use patterns, specifically the control of water pollution and deforestation can reduce malarial transmission. Reduction of greenhouse gas emissions to a level that brings atmospheric CO_2 back from 386 parts per million to 350 or less, lesser consumption of natural resources and long-term population reduction to ecologically sustainable levels will help solve the global warming crisis and move us towards a healthier and sustainable society.

Agriculture and Climate Change: Farmers are impacted by extreme weather conditions, which include drought, severe heat, flooding and shifting climatic trends. To meet the food security needs of the global society, we must increase food production by about 50% by 2030 and reduce greenhouse gas emissions by 30%. Nitrous oxide from agriculture is one of the primary source of greenhouse gas emissions (IPCC 2007). Agriculture has contributed about 70% of gas emissions from 2007 to 2016 from fertilizers in China, India and the USA (IPCC 2007). Agriculture uses about 100 million tons of nitrogen fertilizers in croplands around the world and about 100 million tons of nitrogen from animal manure cycles through pasturelands. The highest growth rates in gas emissions are found in emerging economies, particularly Brazil, China and India, where acres under crops and livestock numbers have increased significantly. Though agriculture is a contributor to climate change, the industry is playing a positive role in curbing greenhouse gas emissions like carbon dioxide, methane and nitrogen oxide. Farmers too are adopting carbon sequestration farming practices and cutting-edge tools to reduce greenhouse gases to atmosphere. The development of climate-smart solutions like digital farming, improved plant breeding technologies, innovative irrigation methods like drip irrigation, reduced tillage and good nutrient management practices for crop production will reduce agriculture's impact on climate change. Digital tools and new agriculture techniques have enabled farmers to make on-site decisions to grow more food on less acreage, offering to feed a growing population. In addition, effective crop protection solutions are helping farmers to manage their crops in response to threats of weeds, insects or disease.

Another area where the global agricultural community needs to pay attention is area of food waste. An estimated 1/3 of all food produced is wasted or damaged in storage or lack of storage. Food wastage, a food security issue, apart from releasing about 6% of global greenhouse gas emissions from agriculture is also a serious issue to address for the agricultural community.

1.2 US Midwest Case Studies on Climate Change Effects on Water and Food Security

Iowa, USA Case Study: Iowa's climate is typically cold in winter and hot and humid in summer. More recently, Iowa has been experiencing extreme weather patterns, more frequent rains and warmer winters. Although several studies have been conducted in Iowa to observe the long-term effects of climate change on crop production and water quality, we have decided to include the following study in this chapter to make a point on how weather patterns are affecting Iowa agriculture. Impacts of agriculture on water quality is the major issue facing Iowa's water security, and most of the research efforts are designed to develop innovative technologies, cropping systems and policies to minimize the impact of agriculture on water quality. Two field hydrology laboratories were established in 1980s to collect long-term data on Iowa's tillage and crop rotation systems to investigate the impact of different farming systems on production, soil health and water quality. This allowed us to collect weather data on rainfall patterns and its impact on groundwater recharge rates and chemical leaching into groundwater (Ella et al. 2002; Everts and Kanwar 1993; Rekha et al. 2011; and Olson et al. 1997; Hruby et al. 2016, 2018; Huy et al. 2013; Pappas et al. 2008; Kalita et al. 1997; Kanwar et al. 2005, 1997).

Experiments and Data Analysis: Experiments were collected at the Glacial-Till Field Hydrology Laboratory near Ames, Iowa. Eleven field plots were used in this experiment with corn and soybeans on half of each plot (Huy et al. 2013). Data on weather, crop production, and shallow groundwater quality was collected for 12 years (1998–2009) using state-of-the-art instrumentation to monitor subsurface drain flows and collect water samples for water quality analyses. The experimental treatments were arranged in a completely randomized design with three replications of each treatment.

Daily rainfall data was collected at the Iowa State University Agricultural Engineering Farm weather station, and the monthly precipitation values are presented in Table 1.2. The long-term average precipitation for Ames, Iowa (1961–1990), was 740 mm during the major rainy season and most of growing season (between March and October). During the 12-year study period (1998–2009), the average precipitation at the experimental site was 798 mm, which was about 8% above the long-term average. For four years (1999, 2007, 2008 and 2009), the average precipitation measurements of 949, 915, 1145 and 829 mm, respectively, were higher than the normal precipitation. Seven of the 12 years had precipitation within 10% of the normal precipitation. Comparison of monthly average precipitation data revealed that in the months of April, May and August, the monthly precipitation amounts were higher than the long-term average. The higher than normal amounts of rainfall measured in April and May likely resulted in higher tile flow volumes and nitrate losses with tile drain water, which may require innovative crop and nutrient management practices to protect the quality of surface and groundwater resources. In addition, data in Table 1.2 also indicates that almost every three years, Iowa is facing either flooding conditions due to more than normal rainfalls or drought conditions due to less than normal rainfall. This weather phenomenon in Iowa is more recent, and Iowa is seeing more extreme events of flooding causing several economic losses in agriculture and other property.

Table 1.2 Precipitation (mm) at Ames, Iowa during the study period, 1998–2009 (Huy et al. 2013)

	Month								Growing season	Drainage season
Year	March	April	May	June	July	August	Sept	Oct	(May–Sept)	(March–Oct)
1998	71	81	92	274	68	94	24	102	552	806
1999	25	207	150	185	162	151	61	9	709	949
2000	11	21	120	104	72	34	26	50	356	437
2001	28	96	190	50	48	74	149	65	511	700
2002	10	95	130	81	150	209	38	79	606	790
2003	29	112	122	150	168	25	100	24	565	730
2004	96	61	208	91	50	132	34	45	515	717
2005	35	82	111	124	104	172	111	9	622	748
2006	74	109	55	21	141	156	191	63	564	811
2007	81	153	169	52	75	200	48	137	545	915
2008	71	130	216	271	234	53	78	92	852	1145
2009	103	116	102	104	70	123	24	186	424	829
Average	**53**	**105**	**139**	**125**	**112**	**119**	**74**	**72**	**568**	**798**
Normal	54	89	108	129	106	102	87	65	532	740

Table 1.3 gives data subsurface drainage volumes from shallow groundwater from the field plots. As expected, the variation in precipitation patterns considerably affected the variation in subsurface drain flows at both yearly and monthly levels (Table 1.3). Figure 1.2 presents the effects of precipitation on subsurface drain

Table 1.3 Average monthly and yearly subsurface drainage flow volumes (mm) (Huy et al. 2013)

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1998	2	33	31	96	41	0	0	0	203
1999	0	44	46	55	6	3	0	0	154
2000	0	0	1	4	0	0	0	0	5
2001	0	3	41	22	2	0	0	0	69
2002	0	0	46	19	10	6	0	0	81
2003	0	0	84	10	46	0	0	0	141
2004	15	47	39	52	1	0	0	0	153
2005	0	24	42	10	7	9	0	0	93
2006	0	23	52	3	1	0	72	75	226
2007	0	0	14	59	10	0	0	0	83
2008	0	63	77	167	50	48	0	0	405
2009	0	51	83	27	3	0	0	10	174
Average	1	24	46	44	15	6	6	7	149

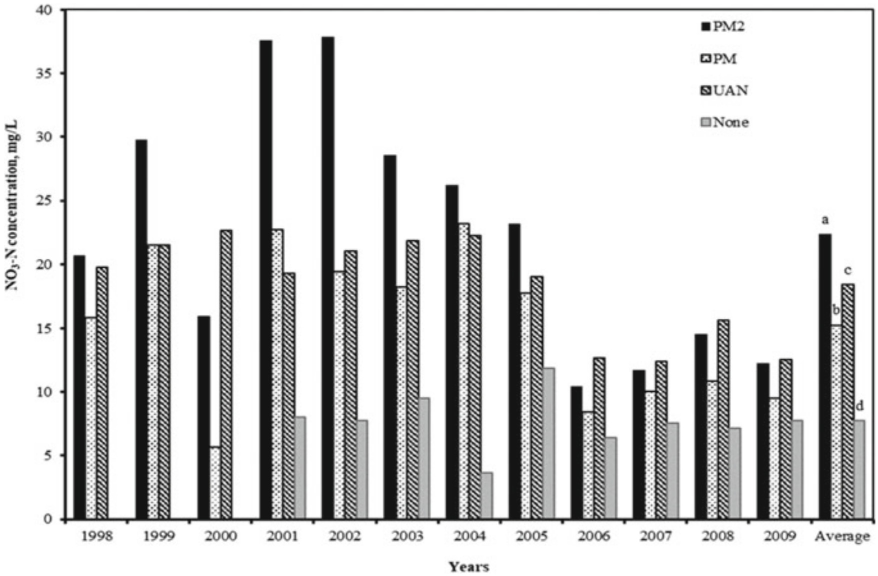

Fig. 1.2 Subsurface drainage (mm) as response to annual precipitation by different N treatments and years (Huy et al. 2013)

flow over the 12-year study period. Subsurface drain flows were lowest in 2000, the driest rainfall year and highest in 2008, the wettest year. The control treatment yielded the highest annual average tile flow (13.3 cm year^{-1}), which is likely due to reduced evapotranspiration caused by reduced crop development and yields from reduced nutrient application.

High monthly subsurface drain flow variability was observed for all treatments. Similar spatial variability in subsurface drain flow was observed in previous studies, with this variability attributed to changes in soil characteristics following long-term cultivation with different crop rotations and N sources. This study found that there was no difference in subsurface drain flow volumes between corn and soybean years during a six-year study period because each year had a different combination of rainfall timing, intensity and amounts. The timing of precipitation had a larger impact on subsurface drainage volume and NO_3–N export in subsurface drainage, especially due to the cycle of wet–dry–normal weather conditions in the Midwestern US. This study and several other studies conducted at this research site on nitrate leaching concluded that variation in NO_3–N concentration and losses may not be closely associated with daily subsurface drain flows but rather with seasonal variation in rainfall patterns due to climate change. Rainfall patterns during the growing season were the main factors contributing to NO_3–N export to subsurface drainage and eventually to Iowa's rivers and deeper groundwater systems.

Wet and dry cycles of weather conditions, and the seasonal effects of rainfall distribution during the growing season, resulted in significant effects on subsurface drain flows, groundwater recharge and the NO_3–N concentration and NO_3–N losses with subsurface drain water. Currently, approximately 9.5 million ha of Iowa farmland were planted to corn and soybean, with 5.7 million ha designated to corn only. This study results suggest that with nitrogen application at a rate of 168 kg N ha^{-1} to corn fields, significant amounts of nitrogen could be transported to Iowa's water bodies resulting in water quality impairments. Therefore, it can be concluded that the land application of N-fertilizers may be an environmentally sound option if timings of fertilizer application in response to weather patterns can be managed well using concepts of precision farming to maintain NO_3–N concentrations measured in subsurface drain water not exceeding the EPA standard of 10 mg/l for safe drinking water. Additional research on agricultural production systems and climate change needs to be continued so that farmers can be educated on how to keep their farm economically viable in meeting food security needs of growing world population.

Minnesota, USA Study: Just like Iowa, Minnesota is accustomed to cold and snowy winters, along with warm and humid summers. In addition, Minnesota's agriculture is very similar to Iowa growing corn and soybeans as primary two crops. It is relatively common for any season to be far warmer, colder, wetter or drier than normal. This variability in climate can make it difficult to notice where, when and how climatic conditions change in the state; however, over 125 years of consistent climate data makes it clear that widespread changes outside the normal variations are clearly underway in Minnesota. Minnesota has experienced wetter and warmer weather in the past several decades. All but two years since 1970 have been some combination of wetter and/or warmer than historic averages, and compared to twentieth-century

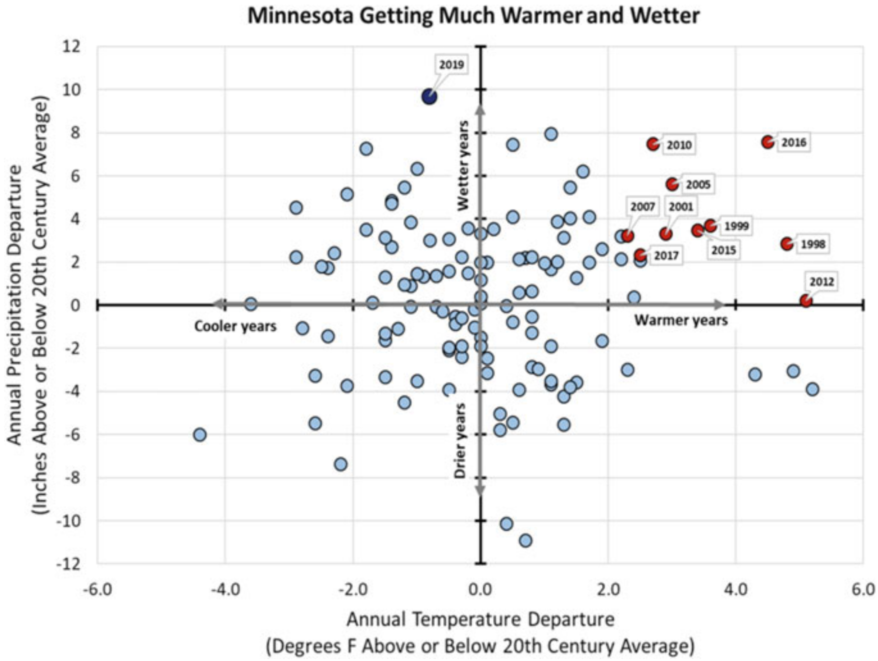

Fig. 1.3 Plot of annual temperature and precipitation in Minnesota (Kanwar et al. 2020)

averages, all of the ten wettest and warmest years on record occurred after 1998 (Kanwar et al. 2020), see Fig. 1.3. Just recently, in 2019, Minnesota experienced the wettest year on record, see Fig. 1.3.

Minnesota's climate swings naturally from relatively dry to relatively wet periods; however, the wetter conditions have dominated recent decades. Precipitation above historical averages have become increasingly frequent, and departures from those averages have grown as well, leading to sustained precipitation surpluses never before documented in the state (Kanwar et al. 2020), see Fig. 1.4.

Minnesota is also becoming warmer during nights and winter. Annual temperatures have climbed nearly 3° since 1895, but 80% of that warming has only been since 1970. During those five decades, winters have warmed by 5 °F, winter nights have warmed by 6 °F, but summers have warmed by just a half a degree F, and summer daytime high temperatures have decreased slightly in southern Minnesota (Kanwar et al. 2020), see Fig. 1.5. Water is a defining resource for Minnesota, central to our economy, communities and identity; and the state will always be sensitive to dry conditions and drought. While Minnesota continues to experience periodic drought in specific regions, those periods have not increased in severity or length. Recent surges in precipitation have meant the state has not seen any increases in drought severity, duration or areal coverage over the past few decades. However, the extremely wet cycle the state is in will end eventually. A shift towards a dry regime should be expected, as climate change will not eliminate wet and dry periods in Minnesota.

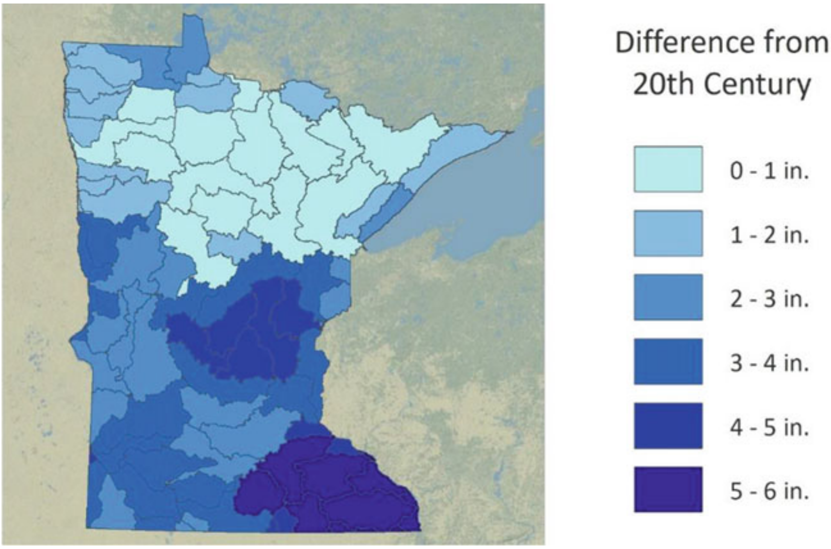

Fig. 1.4 Annual precipitation increase since the twentieth century (Kanwar et al. 2020)

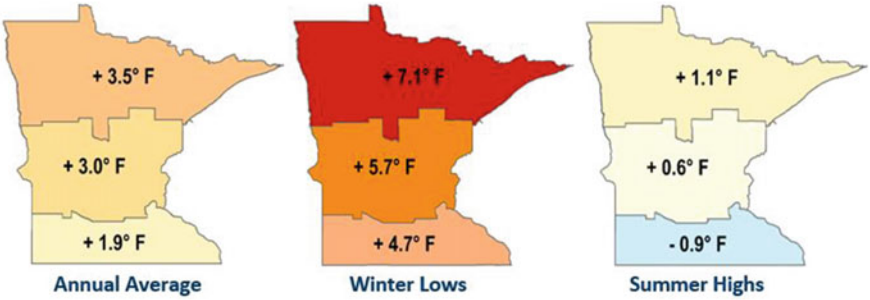

Fig. 1.5 Temperature change by region (Kanwar et al. 2020)

Even with a generally wetter climate, climatologists predict that Minnesota should expect occasional episodes of severe drought, and these drought events could happen immediately following, or may even occur in specific areas of the state during, a wet period affecting agricultural productivity of the state of Minnesota severely (Kanwar et al. 2020).

1.3 India Case Study on Climate Change Effects on Food and Water Security in South Asia

India Case Study at PAU Ludhiana: The state of Punjab in India is the largest irrigated, wheat and rice growing, area of India. The average crop yields in Punjab are close to some of the most advanced agricultural economies of the world such as USA, Canada and Australia. This is due to the contributions of Punjab Agricultural University at Ludhiana, Punjab (PAU), in educating the farmers of Punjab on the use of best agricultural and water management practices. This university was established in 1961 by the Ohio State University on the Land Grant pattern under a USAID grant of $70 million. The PAU recruited some of the best trained faculty in the world in 1960s who developed new plant varieties and helped Punjab farmers to adopt best agricultural practices to fully mechanize crop production methods. Climate change is now affecting India's agriculture. Therefore, it was decided to include the climate data collected from a weather station in Ludhiana in this chapter to provide evidence of climate change in South Asia. The city of Ludhiana in Punjab, India, is situated at 30°54′33″ N latitude, 75°48′22″ E longitude and 247 m altitude above mean sea level. This part of South Asia experiences semi-arid type of climatic conditions resulting in distinct spring, winter and summer seasons. The climatic data on maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (RH), wind speed (WS), sunshine hours (SSH) and open-pan evaporation (PE) was collected from the Agrometeorological Center at PAU for 47 years from 1970 to 2016 and are given in Figs. 1.6, 1.7, 1.8, 1.9, 1.10 and 1.11 (Kingra 2017). Temporal variability depicted increase in minimum temperature at 0.05 °C analysis using Mann–Kendall and Sen's slope per year both during rabi and kharif seasons (Kingra et al. 2017) as well as annually (Kingra et al. 2018a; b, c). In this chapter, we are using these data to show the impacts of climatic change on crop yields of Punjab and future directions for research at PAU to make sure that farming systems in South Asia stay sustainable and farmers' incomes are protected.

Climate change is posing a serious threat to the food security for the growing population growth of India. This has attracted the attention of scientists and policy-makers in the recent decades to focus their energies in addressing this serious global issue. Under the present environmental conditions and circumstances, there is an urgent need to manage climate variability and its adverse effects to attain food security and agricultural sustainability in future. Keeping this in view, the climatic records of central Punjab (Ludhiana) have been analysed to quantify the climatic changes and their likely impacts on agricultural productivity. Lower minimum temperature, relative humidity, rainfall and number of rainy days during the reproductive growth period of wheat covering the months of February and March have been found favourable for higher grain yield (Kingra 2016a). Minimum temperature explained 44% variability in wheat yield (Kingra et al. 2018a). Higher daytime temperature, sunshine hours and lower afternoon relative humidity during vegetative growth and lower daytime temperature, sunshine hours and higher afternoon relative humidity are favourable

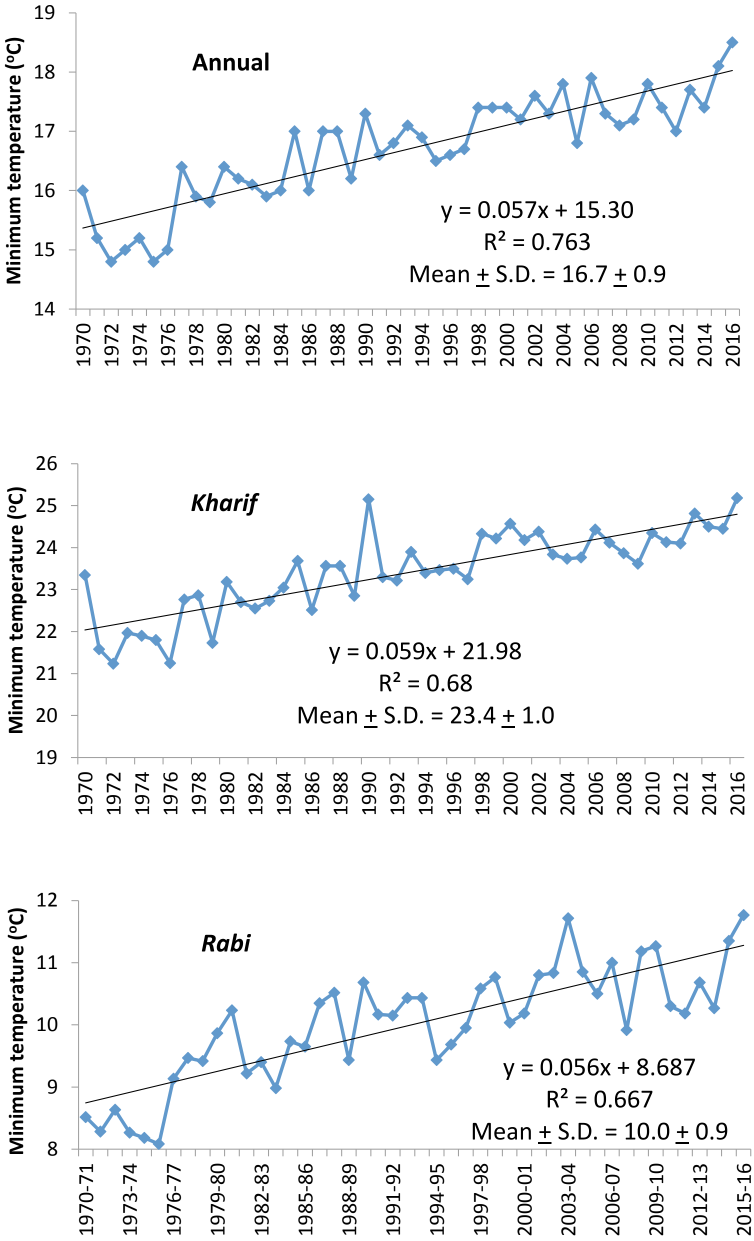

Fig. 1.6 Temporal variability in annual and seasonal (during rabi and kharif seasons) average minimum temperature in central Punjab (Kingra 2017)

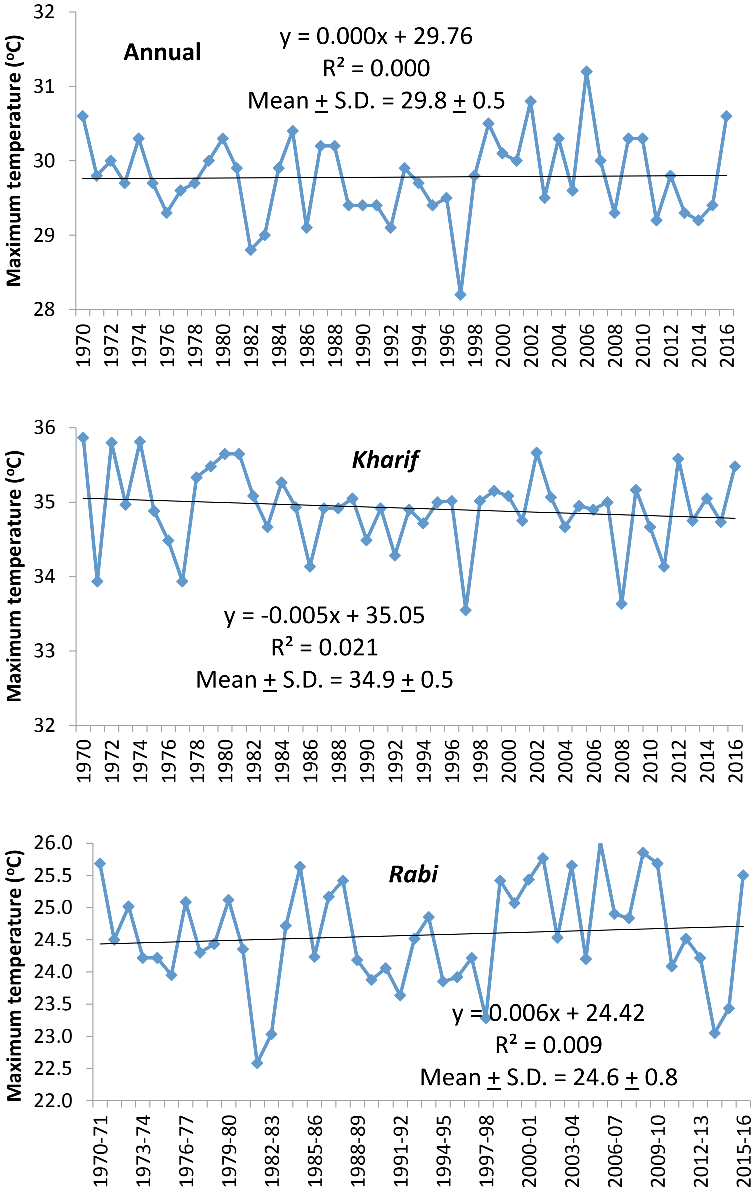

Fig. 1.7 Temporal variability in annual and seasonal average maximum temperature in central Punjab (Kingra 2017)

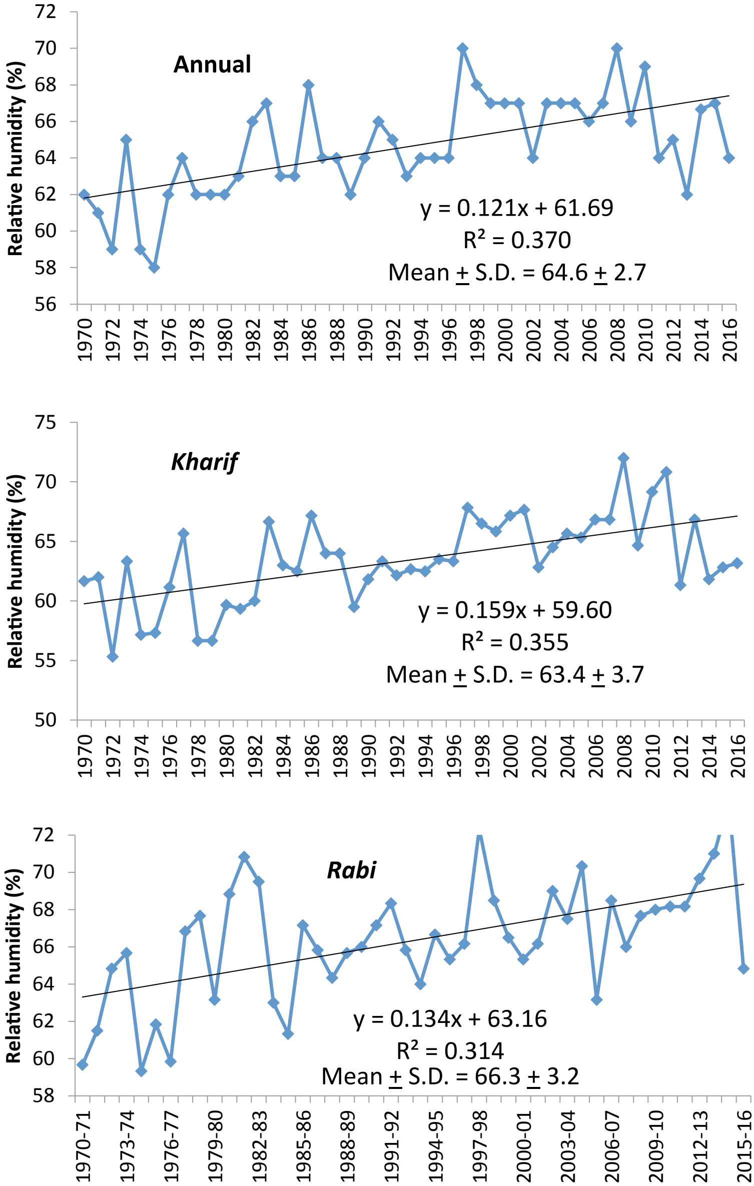

Fig. 1.8 Temporal variability in annual and seasonal average relative humidity in central Punjab (Kingra 2017)

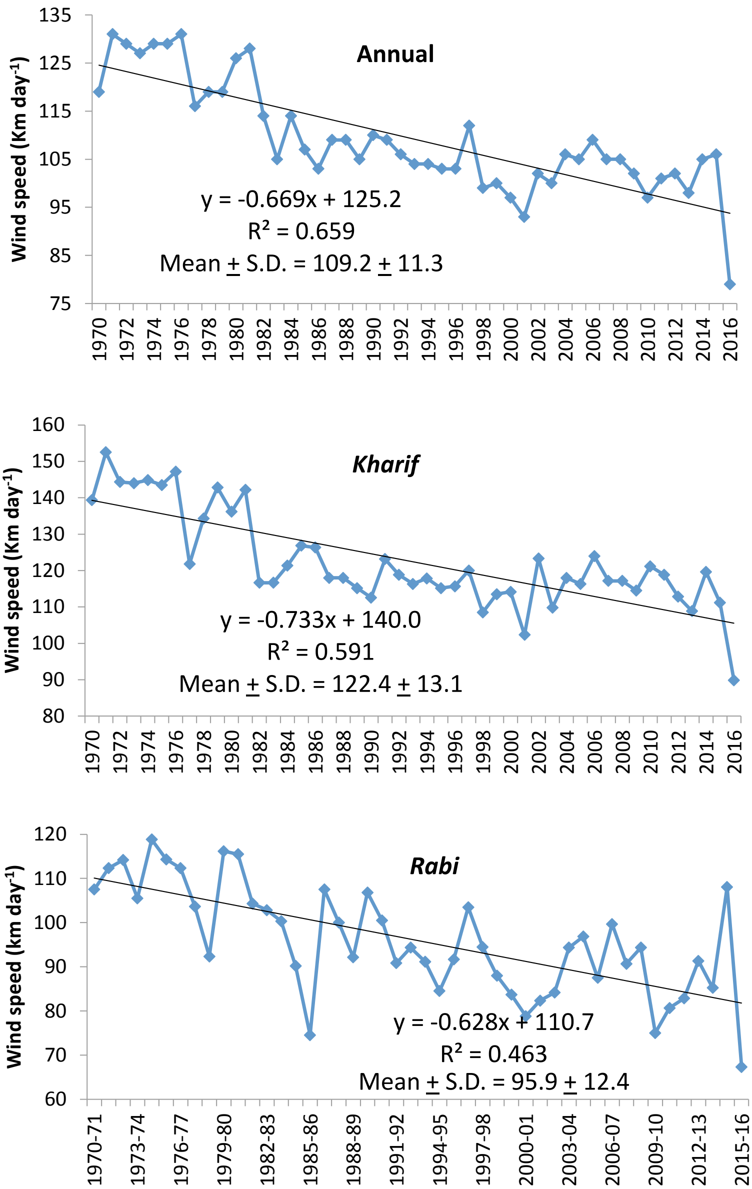

Fig. 1.9 Temporal variability in annual and seasonal average wind speed in central Punjab (Kingra 2017)

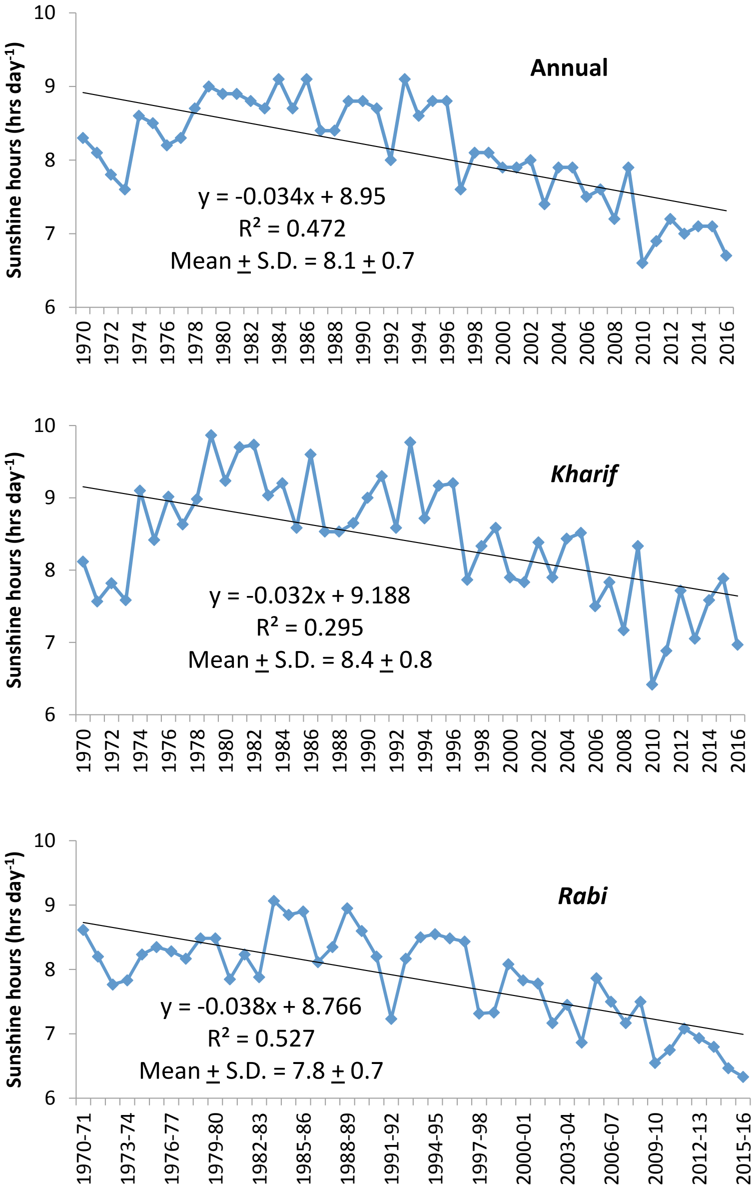

Fig. 1.10 Variability in annual/seasonal average sunshine hours in central Punjab (Kingra 2017)

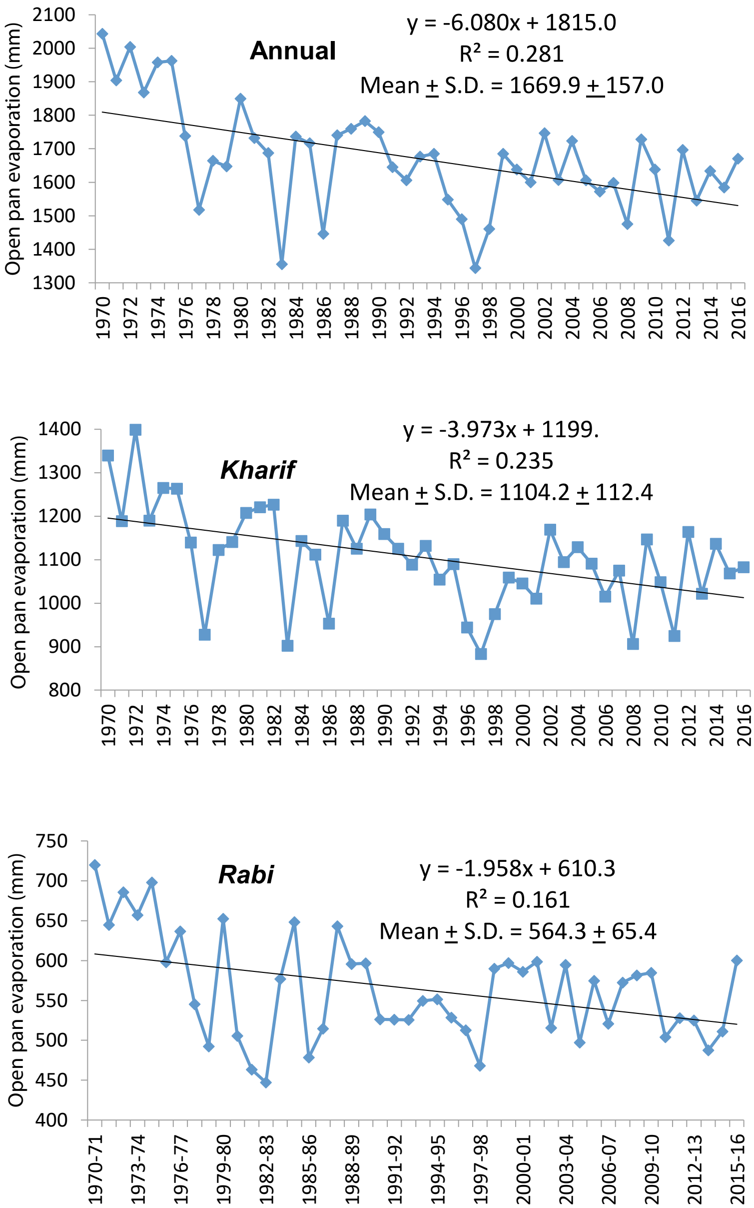

Fig. 1.11 Temporal variability in annual and seasonal open pan evaporation in central Punjab (Kingra 2017)