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CHANGING CLIMATE AND ITS IMPACT ON WATER AND AGRICULTURAL RESOURCES: AN INSIGHT INTO LITERATURE

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Abstract

Climate is continuously changing due to enhanced level of greenhouse gases. Fossil fuel burning is the main culprit behind the increasing GHGs. Climate change affects our planet in several different ways. It affects the water resources, agriculture, and ecosystems in many aspects. This review particularly discussed the impact of climate fluctuations on water and agriculture. With the alterations in weather regimes, changes in pattern of runoff, snow melt, temperature, precipitations and droughts are evident. It is being expected that these patterns will change further in future. These variations also affect agricultural sector in a bad manner. Due to change in temperature and precipitation, water abundance as well as the water scarcity can be expected. It can badly affect the crop yield and lead towards food insecurity. In different countries of world, adaptation strategies including technical, financial, and research-based strategies are being implemented. Further research is needed according to different areas and their climatic alterations.

Keywords
Climate Change, Water Resources, Agriculture Sector, Water Scarcity

1. Introduction

It has been observed over last few centuries that greenhouse gases are increasing continuously in atmosphere. The reason lies in the fact that humans are using fossil fuels to gain energy globally. Forest cover reduction also played a key role in climate shift. As a result of climate change, temperature of our planet has increased. Global average temperature has increased by 1.41C and this change in temperature is quite evident if we consider from pre-industrial period to the present. Due to this enhanced temperature, number of hot days and nights also increased along with a reduction in cold days and nights. The number of extreme events like droughts and floods also increased. They were severe as compare to previous events. As it is evident that population is increasing at an exponential rate, they need more land as well as industrial products. Rapidly increasing number of industries triggered cutting of forests. These heat trapping (GHGs) gases have altered our natural ecosystems to a greater extent (Anderson *et al.*, 2020)

Water is important for all organisms for their survival. As we have finite sources of fresh water, they should be conserved and administered properly. For the sustainable management of water resources, it is important to consider impacts of climate on water resources and how they are interconnected. The consumption of water has increased many times over recent decades due to increased number of people, industries and economic growth. Along with all these, irrigation water demand also increased as more people need more crops to fed themselves. Therefore, more water is required to irrigate the fields. On a global scale, basins are commonly called water-stressed if they have a per-capita water availability below 1,000 m3/year (Singh *et al.*, 2014).

It is a known fact that water resources are critical to human development and crop yield. The world's agriculture, hydroelectric power and water supplies depend on different components of the hydrological cycle, including the natural renewal of surface and groundwater resources. Climate change is one of the extreme pressures on the hydrological cycle along with population explosion, pollution, changes in land use, and other factors. In this context, water may be scarce in near future due to the possible reduction in rain fall in some parts of world.. Agriculture and food security are projected to be significantly affected by climate change. The impact will vary by crop variation as well as region variation. There is an urgent need for agricultural sector to go towards adaptive strategies in order to prevent food insecurity. By taking adaptive actions, food security can be ensured for an ever increasing population (Anderson *et al.*, 2020).

2. Major Impacts on Water Resources

Water resources are often prone to variations in climatic patterns. It is also believed that there will be changes in the water resources in near future due to climate change. Some of the major impacts are discussed.

2.1 Runoff

Runoff is the water which flows over surface of earth due to over flow of a water resource or it can be excessive rain water which does not infiltrate into soil. Recent observations and predictions made for future propose that one of the most evident impacts of climate change will likely be on the hydrological system and, thus, on river flow and regional water resources (Bates *et al.*, 2008; McCluskey & Strzepek, 2007).

When climate varies, it also causes changes in flood patterns. In the twentieth century, many studies investigated possible drifts in measures of river discharge at different spatial scales. Human intrusions have affected flow regimes in many catchments at the global scale. It is evident that there is coherence in patterns of change in runoff, some of the regions (e.g., high latitudes and large parts of the USA) experienced enhanced runoff. While other regions like Europe and west Africa encountered decrease in runoff. Increase in runoff caused by increased CO2 concentration and hence less transpiration triggered this phenomenon (Gedney *et al.*, 2006).

Moreover, it was observed that stream flow was continuously increasing in south America in four rivers after 1960s. This observation was made after considering thirty years data, although it was not true for all rivers. The increase in flow had been seen in America since 1940. By use of several approaches, USGS told that the increase in flow was different according to the seasons as well as regions. The areas which have undergone the most prevalent increases are the Upper Mississippi, Ohio Valley, and the Mid-Atlantic. As compare to these regions very few trends had been seen in the South Atlantic Gulf region, Missouri, and regions of the far West.

On the other side there are also some regions in which flow reduction was observed like the Pacific Northwest and the South Atlantic Gulf. Long-term shifts in the timing of stream flow have been observed for snowmelt-dominated basins throughout western North America since the late 1940s (Mote, 2003; Regonda *et al.*, 2005). These shifts indicate that snow gets melted earlier in recent decades while it was not so fast in previous decades. Many of the researchers have emphasised an increasing runoff trend, especially in winter and spring seasons. This is especially prominent in northern rivers like arctic rivers in Siberia. Climate warming in Siberian areas cause snow melt earlier than usual leading towards longer spring season. Other reasons include the reduction in permafrost area extent and an increase in active layer width under heating climatic circumstances (Singh *et al.*, 2014)

2.2 Floods

Another natural threat occurring due to climate variation is flood. And this threat is prevalent all over the world. Damages caused by floods are quite evident and badly affect the economic sector of the areas affected by them. (McCarthy *et al.*, 2001). As far as reasons behind the flooding are concerned, they are unusual rain and early snow melting due to the warmth temperature. Most devastating floods initiated by high rain fall are seen mostly in the humid parts of world along with some of the semiarid areas.

Rains in the monsoon season become the immediate cause of floods in India. And it is considered the most significant reason of floods in the country. In 2002, extreme floods with high intensity and longer periods were observed in the central and Eastern Europe. (Caspary, 2004). It seems very tough to identify the human induced changes in natural climate leading towards floods because of the natural changes taking place with time. The problem is more complicated with the flow patterns affected by land use change (Milly *et al.*, 2002). If we consider flood catastrophes globally, it is obvious that the floods were more severe in the time period (between 1996 and 2005) as compare to the floods between 1950 and 1980. Along with the intensity of floods, economic damage was also increased many times. On the basis of the data, it is predicted that climatic changes (warm climate) will lead to increase in flooding events (Singh *et al.*, 2014).

2.3 Drought

Among the natural hazards happened during 20th century, droughts are considered most fatal and devastating (Mishra & Singh, 2010; Obasi, 1994). More severe and widespread droughts affected all parts of world in recent decades including Europe, Africa, Asia, Australia, South America, Central America, and North America. Long duration droughts were experienced by Canada in previous two centuries. Minimum number of droughts was forty (Wheaton, 2000). The situation of droughts is worse in many parts of Europe. During last thirty years, Europe has suffered from intense droughts, most remarkably in 1976 (Northern and Western Europe), 1989 (most of Europe), 1991 (most of Europe). The prolonged drought observed in Europe was due to heat waves of summer, it happened in 2003 (Dankers & Feyen, 2009). The number of dry events in America increased, hence, the impacts also increased due to number and severity of the droughts.

It is estimated that almost ten percent of the total land cover in America faced intense dry periods at different times in the previous century. It is based on the data collected from national climatic data centre also known as NCDC. Recurrent intense droughts during 1997, 1999, and 2002 in many areas of Northern China were observed. They affected society as well as the economy in a very devastating manner. (Zhang, 2003). In china, the severe dry period happened in 1997, it remained for two hundred and twenty-six days. At that time there was no streamflow in YELLOW RIVER, it was indeed the longest dry period on record. Since the late 1970s, there had been a great threat of dry events due to the evident higher temperatures resulting in global warming which ultimately leads to droughts. Drought has become a repeated theme in Australia. The recent one was so-called millennium drought, which lasted for almost a period of ten years (Singh *et al.*, 2014).

2.4 Snowmelt and Glacier Melt

Several major rivers in the world depend on snowpack and glacier melting. Day by day increasing temperature is causing increase in global warming which affect the time and frequency of snow melting as well as runoff associated with it.

Glaciers are dependent on and sensitive to various variables including humidity, rainfall and wind velocity. But the most important parameter is temperature to which glaciers are sensitive. Glaciers are considered good indicators of warmth environment and global temperature increase. It has been noticed that glaciers have melted faster than the replacement with new ice, it happened due to increasing global temperatures. (Haeberli *et al.*, 1999). The rivers which are present on high latitudes and high altitudes may undergo enhanced discharge due to glacier melting. A decrease in rainfall can also occur due to this. (Dyurgerov, 2003; Milliman *et al.*, 2008). Many changes in rivers geomorphology can be triggered by the increase in volume of river discharge. These changes include channel expansion and incision, higher sinuosity, enhanced bank erosion along with quicker channel relocation (Goudie, 2006).

Glaciers melting at a faster rate also affect society in many aspects. When glaciers melt, their water goes to many rivers. As we know river water is used for many purposes like energy generation, household supply and irrigation of crops, so, in all these ways, society will be affected badly. It is the need of hour to place proper infrastructure to prevent excessive water of glacier melting from causing floods. On the other side, if water continues to be part of runoff, associated areas may likely to face extreme dry periods with no water available. It can be very difficult to tackle. In some cases, we have to pay extra money to deal with the retreating glaciers consequences. For instance, expenses for extra power capacity to manage with retreating glaciers in Peru are predicted to be almost US$1 billion per gigawatt (Singh *et al.*, 2014)

2.5 Water Quality

Water quality especially ground water quality is affected by climate variations. Sometimes water quality is not affected by climatic variation rather the volume of ground water which enters other water arrangements gets reduced. Along with the quantity, quality of water is also affected in those water systems.

The precipitation is dilute and contains very little fraction of dissolved components. Most of the dissolved components in many aquifers, which are used to provide water to humans, are obtained by interactions between water and rock material in subsurface. The water coming from other sources having high saline concentration when mixed with normal water, it affects this water and increases salinity causing ingredients in it. It is also seen that with changing climate, timing as well as conditions of rock-water exposure can be disturbed. It might be the reason for deterioration of water quality. Furthermore, the water coming from a more saline water source when mix with less saline water, lead towards poor water quality sometimes. Bad quality of water can be caused by evaporation. With the reduction in replacement of water beneath the earth crust, hydraulic gradients are lowered. As a consequence, water stays for a longer time period in aquifers. It provides more time for the interaction of water and rock components. Consequently, salinity gets enhanced to a greater extent (Hem, 1992; Kayane, 1997).

If the replenishment of ground water commonly called ground water recharge is reduced, it will result in greater salinity in groundwater. It can be inferred that quality of water present underground will be improved by an increase in groundwater recharge. On the other hand, there is a possibility that increment in recharge can trigger increase in salts. There are many reasons behind it. There is also a chance of increasing salinity due to increase in groundwater recharge as excess water will enhance movement of salts from the unsaturated zones to less salty zones (Sugita & Nakane, 2007). Nitrogen is specifically of great concern. Nitrogen in form of nitrate, if consumed, causes methemoglobinemia. Nitrate is also prone to augmented discharge in many different weather sectors (Sugita & Nakane, 2007). Leakage of nitrate is especially damaging to the areas where arid climatic conditions prevail, because there are already high accumulation of nitrate by the natural phenomenon (Graham *et al.*, 2008; Walvoord *et al.*, 2003).

The contribution of groundwater to the volume of stream flow will be greatly reduced with the lower ground water replenishment as well as low storage. Increased pumping of water from underground water also decreases water reduction beneath earth crust. Its common impact is higher temperature in stream water because ground water is cooler than water flowing on land. Species survival is threatened by high temperature because some of the species cannot tolerate such higher temperature values (Coutant, 1999; Wissmar, 1994).

Instead on the other side, enhanced renewal of water under earth increases contribution of groundwater to the water in the streams. Water has to be used by humans and other species. This water having more proportion of ground water is more favourable for species survival. Water quality of stream water especially the chemical quality might vary in case if climatic conditions change the proportion of ground water in the water flowing in streams. However, ultimate effect will be based upon characteristics of stream water and water beneath earth.

It is said that sea levels have increased by about 22 cm in the 20th century worldwide. It is estimated that they will be getting higher continuously and at an accelerated rate. The reason for this fast increase in water level is earth warming temperature. As we know when temperature is high, glaciers melt and water falls in the sea. Higher the temperature more will be the water in sea. (Rahmstorf, 2007).

When water will be present in higher amounts in the sea, it is possible that this salty water gets mixed with fresh water causing more salinity in fresh water. In coastal areas, these higher sea levels are likely to increase the potential for intrusion of ocean water into fresh water aquifers, thus threatening to increase ground water salinity (Ranjan *et al.*, 2006; Sherif & Singh, 1999).These such sea level driven threats pressures triggered by high sea to levels to ground water salinity might get worse by reduction in water renewal rates. Sometimes, saltiness of those aquifers can get affected by climatic changes, which are far detached from oceans. It will be applicable in many conditions like if renewal rate is decreased or pumping of water is increased. In this way water from nearby resources having more salty water will move upwards and cause salinity increase may either be exacerbates by climate driven declines in recharge rates elsewhere in the basins, or ameliorated by increase in recharge. Even salinity in aquifers far removed from oceans may be affected by climate change reductions in recharge or increase in pump age of fresh water aquifers causing upwelling of saline water from surrounding formations (Chen *et al.*, 2001).

With the conversely, changes fluctuations in amount and quality groundwater, the chemical composition of ocean can be disrupts along the seashore quality and quantity also influences ocean chemistry, especially near coasts. So, the variations in the quality of water present underground can be a cause of fluctuations in chemistry of oceans near the ocean banks. The cycling of nutrients is also disturbed by it. The amount of underground water going into oceans is changed by alteration in the level of sea water and groundwater. It is initiated by fluctuations in the degree or path of the hydraulic gradient between aquifers and the oceans (Earman & Dettinger, 2011)

There are many studies which tried to estimate the weather change effect on the quality of water in future. The lakes in Europe will be at greater risk by an increment of 2 degree Celsius probably in 2070. The magnitude of the risk will depend on the attributes of lakes as well as the season. The effect will be prominent in low (shallow) lakes. The lakes with great depth are more prone to the weather fluctuations as they have a higher ability to retain heat. The temperature of water in these lakes will be higher during winter (Singh *et al.*, 2014).

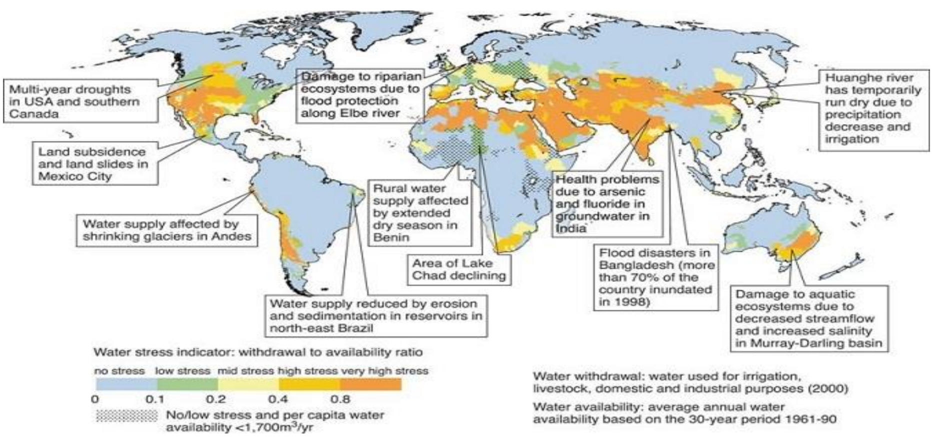

Figure 1: IPCC's Fourth Assessment Report shows the range of vulnerabilities that may be affected by future climate change, superimposed on a map of water stress (Singh et al., 2014)

3. Climate Change Impacts in China

3.1 Temperature Changes

Although, temperature has been altered to a great extent in previous two hundred years, it is mostly in the Northwest China. But a more prominent temperature change was observed in last fifty years (Wu *et al.*, 2010). Nonetheless, the heating effect varies with the season in the arid area of China. Heating effect is notable mostly in winter (about 0.5 per decade). In this way, it pays an important role in enhancing average temperature of the year. This heat variation is not very fast in summer but it is more dominant in spring (0.27 per decade) (Li *et al.,* 2013a; Yao *et al.*, 2013).

Moreover, there is more trend of change leading towards severe minimum temperature as compare to extreme higher temperatures. It is predominantly seen in winter. In the winter, higher minimum temperature triggers the average temperature of winter to be higher. (Chen *et al.*, 2015). Qaidam Basin, the Yili River Valley, Tacheng are those areas in which there is very dominant temperature trend (Zhang et al., 2006). These areas also include east of the Tianshan and Qilian Mountains (Ren & Yang, 2006; Yao *et al.*, 2013).

If we look at the sequence of the heat changes in China, the arrangement is described here. From the time period (1960-1980), it was noticed that temperature variation was very little. After that, it suddenly get enhanced in 1987 (Chen *et al.*, 2015). In another study (Li *et al.*, 2013b) reported that the recorded fast temperature increase before the 1990s happened in desert areas. And the temperature increase was slower in mountain regions. However, it was inferred from studies that fastest temperature increases after the 1990 was recorded in oases region and the slower increases was in deserts. It can be concluded that the temperature increase in previous 50 years was three times higher as compare to average temperature increase worldwide (IPCC, 2013), and is expressively higher than the national average level (Li *et al.,* 2012).

3.2 Precipitation Changes

A prominent heat change was observed in previous fifty years in China. Along with it, atmosphere experienced more humidity in the last fifty years. (Li *et al.*, 2016) reported that there was more rainfall from ‘’1960-2010’’ but if we look at the value of national trend, it was declined. The enhanced rate of rainfall during all months was most high in summer. The recorded value was 2.5 mm. Conversely, it was lowest in winter season. The value was 1.2 mm. (Chen *et al.*, 2015). Overall, all seasons contributed in a different manner to the precipitation. Spring, summer, autumn and winter played 21.6%, 42.4%,18.4%, and 17.6% role to changes in annual precipitation, respectively (Li *et al.*, 2016).

Looking at the data about precipitation change in a decade, it can be seen that rainfall was relatively steady during 1960-1986, then it rose after the year 1987. It was shown by different research works that climate change was very sudden after 1987 as climate shifted from warm and dry towards warm and humid. (Shi, 2002; Song, 2003). These variations should be further studied (Li *et al.*, 2013a).

(Chen *et al.*, 2015) indicated that rainfall declined in China especially in the Northwest in 2002.

Table 1: Summary Of Changes In Temperature And Precipitation Due To Climate Variation (Wang & Qin, 2017)

Summary Of Changes In Temperature And Precipitation Due To Climate Variation			
Region	**Temperature (°C per decade)**	**Precipitation (mm per decade)**	**Period**
Northwest arid region	0.22	3.2	1951-2000
Northwest arid region		5.41	1960-2009
Northwest arid region		6.1	1961-2010
Northwest arid region	Annual: 0.368 Spring: 0.356 Summer: 0.324 Autumn: 0.41 Winter: 0.506	Annual: 9.522 Spring: 3.315 Summer: 2.659 Autumn: 2.068 Winter: 2.342	1961-2010
Northwest arid region		Annual: 7.05 Spring: 1.23 Summer: 2.40 Autumn: 1.79 Winter: 1.57	1961-2010
Northwest arid region	Northern Xinjiang: 0.37 Southern Xinjiang: 0.29 Hexi corridor: 0.39	Northern Xinjiang: 11.7 Southern Xinjiang: 5.8 Hexi corridor: 3.2	1961-2010
Northwest arid region	Whole region: 0.343 Mountainous area: 0.325 Oasis: 0.35		1961-2010
Northwest arid region	Mountainous area: 0.325 0asis:0.339 Desert: 0.360	Mountainous area: 10.15 0asis:6.29 Desert: 0.87	1961-2010
Kaidu River basin	Upper reaches: 0.27 Lower reaches: 0.22	Upper reaches: 9.13 Lower reaches: 5.34	1960-2009
Hexi corridor	Whole region: 0.27 Shule River Basin: 0.21 Heihe River Basin: 0.29 Shiyang River Basin: 0.30	Whole region: 3.95 Shule River Basin: 2.33 Heihe River Basin: 3.71 Shiyang River Basin: 5.45	1955-2011
Tarim River	0.252	6.883	1955-2000

4. Impact Of Climate Change In Africa

4.1 Impacts On Temperature

Usually, the temperature has been increased in the last fifty to hundred years in the parts of Africa. Recorded increase is of 0.5 degree Celsius or greater than that. it is indicated by (IPCC, 2014). This report covers impacts, adaptability and vulnerability (Niang *et al.*, 2014). It is predicted that temperature will increase quite faster as compare to average temperature worldwide in 21st century (Christensen *et al.*, 2007). These unusual climate variations are predicted to arise one to two decades before than that of the changes in global temperature, particularly in tropical region of Africa. The reason lies in the fact that climate bounds are very narrow and they get disrupted by merely a slight change in weather. (Niang *et al.*, 2014).

In a study, (Dennis & Dennis, 2012) described that foreseen climatic deviations specifically for South Africa comprise an overall heating across the country of greater mean temperatures in sub-humid areas. According to (Mukheibir, 2008), it is expected that temperature will rise by 1.5C in the coastal areas in the 2050 (Cavé *et al.*, 2003). In the Western Cape, the summer season will be longer in the future.

4.2 Impact on Precipitation

Rainfall is considered as basic input process in the water cycle as well a basic driver of water system on the earth. In some of the studies like (Jacobs *et al.*, 2001) and (Xu, 2000), it is anticipated that the most deleterious effect of climate variation on the water resources will be in form of fluctuations affecting water cycle. The change in water cycle will ultimately affect both quality and amount of water. That is why the raining rate, time period and intensity will affect the water resources (Yilmaz & Yazicigil, 2011). In many regions of Africa, it is difficult to estimate or predict that what might be the possible trends of rainfall annually due to the deficient data in the previous century (Niang *et al.*, 2014).

Moreover, in many areas of Africa disagreements exist between diverse detected rainfall data sets (Nikulin *et al.*, 2012). Rainfall predictions are more ambiguous than temperature estimates (Rowell, 2012). Along with it, rain is more dependent on season as compare to temperature. (Orlowsky & Seneviratne, 2012).

5. Possible Future Impacts Of Climate Change On Different Continents

5.1 Europe

It is expected that average annual temperature will increase as compare to global average increase. It is predicted about North part of Europe that it will experience utmost heating in winter. The most rapid warming in the season of summer will be in the Mediterranean area. Rain will increase in the north part of Europe. A decline in rainfall will be observed in the Mediterranean area. In accordance with seasons, winter will be rainier in central Europe. On the other hand, summer will be dry experiencing less rainfall in this region. The number of rainy days is likely to reduce in the Mediterranean area.

There is a chance of increasing rainfall events in the north part of Europe. Rainfall will be of great intensity. Conversely, summer dry period will be longer in the central Europe as well as in the Mediterranean region. Snow fall will be reduced in most of the region of Europe. The snow depth will also be decreased (Christensen *et al.*, 2007).

There is probability that water demand will get enhanced for the irrigation of crops. It will place the region at high threat of drought. Mostly it is predicted about Mediterranean and few parts of central and eastern Europe (Donevska & Dodeva, 2004). Water need for irrigation purpose will also rise in the countries where irrigation water was not needed before (Holden *et al.*, 2003). It is forecasted that floods will increase in eastern as well as northern Europe. The floods will be more frequent and of high intensity. Atlantic coast and central Europe are also vulnerable for frequent flooding in the future. As far as droughts are concerned, they will be probably more prevalent in the south Europe. There are also some regions vulnerable to flooding and droughts at the same time. Interestingly, there are also such regions where annual average rainfall will be less but they will experience intense rainfall on daily basis. These areas include central Europe and Mediterranean (Giorgi *et al.*, 2004).

5.2 Asia

Asia is a continent that will experience high temperatures in the 21st century and warming effect will be different for different regions. For instance, temperature will exceed the average temperature of the world in Asia, the Tibetan Plateau and northern Asia. In south east Asia, temperature will be same as the global average temperature. Same like the temperature, rainfall patterns will also be changed. In the north part of Asia and Tibetan plateau, rain will be more in winter season. Summer rainfall will increase in eastern and southern Asia. Rainfall in summer season will decline in central Asia.

Extreme events are likely to increase in the Asia. The continent will face longer heat spells as well as more cyclones. Water resources in Asia will be affected in different ways (Bates *et al.*, 2008). Change of seasons and the change in the water amount flowing in rivers is the major change which is expected. It might change the runoff in a way like there would be a chance that low runoff events will be more frequent especially in the areas most favourable for agriculture. (Peterson *et al.*, 2002).

5.3 North America

In this continent, there is high chance that annual average temperature will be higher even it will beat the average temperature of world. It is also expected that winter season will be more warming in the north America. If we consider the lowest winter temperature recorded in this area, it can be anticipated that north America will be facing an elevated temperature that will be much higher than that of mean winter temperature. It is also predicted that the summer temperature will also go beyond the average summer temperature in south-eastern parts.

Precipitation is forecasted to get enhanced in the north-eastern parts of the USA and Canada, while it is predicted to be reduced in the southwest of America. Rainfall will increase in Canada during the winter and spring season. It will decline in summer. The snow will be penetrating in north parts of Canada. On the other hand, snow season will be shorter in America (Singh *et al.*, 2014). Average annual rainfall will be reduced in the south western America. It will increase in in rest of the areas of North America upto 2100 (Bates *et al.*, 2008).

6. Adaptation to Climate Variations In Terms Of Water Resources

Variations in the climate pose new risk, although humans are considered to be adaptable to the changes. Humans are also known for formulating methods and strategies to tackle water issues either it is water scarcity or water resources affected by climate. The main issue regarding adaptability is the difficulty faced due to the multiple dimensions involved. It is tough to take adoptive measures in all sectors like agriculture, water and industrial sector. The second hurdle is the scale of the issue like it is either on regional scale or on national scale. Furthermore, it depends on the kind of action which is necessary to tackle that particular climate problem, as it can be financial or technology based. Climatic zone is also very important in this regard whether the issue to be resolved is in the flood region or the mountainous region (Adger *et al.*, 2007).

The main emphasis on climate adaptation arose after the 3rd assessment report of IPCC. In this report, many strategies were defined like adaptations to climate variations and may more. Infrastructure design can be changed according to the requirement. Coastal zones should be managed properly. Adaptive capacity should be developed on appropriate scale (Adger *et al.*, 2005). By the proper understanding of climate effects along with their changeability, and developing better weather predicting methods and better risk assessment procedures, efforts had been put to mitigate climate impacts for many decades. Numerous sort of adjustments have been applied all over the world(Adger *et al.*, 2007). Here some examples are described related to water resources.

6.1 Drought

In Sudan and Africa, droughts can be handled by increasing rainwater storage and many other water saving techniques. Shelter belts along with the windbreaks help to better the recovering capacity of rangelands. Hence, they are beneficial. (Osman-Elasha *et al.*, 2006). In Mexico and Argentina, it was also practiced to prefer drought resistant plant species rather than other. Other adoption measures include, choosing of favourable crop in those particular climatic conditions and changing in planting period of crops. Some products which are mandatory for use, can be reserved to use in extreme dry periods of the year (Wehbe *et al.*, 2006). Moreover, employment opportunities should be enhanced. The farmers having limited land should be helped in order to enhance crop yield (e.g., in Botswana; (Mitigation, 2004)).

6.2 Sea-Level Rise

The areas which are at more risk to the coastal erosion, they can be protected by putting hard structures. A national action plan should be formed which can address climatic issues by making required policies (e.g., in Egypt) (El Raey, 2004). Capacity should be developed for making proper design of defence strategy for coastal areas. Such houses can be constructed which are more stable towards cyclones (e.g., in Philippines) (Lasco *et al.*, 2006).

Furthermore, flood defence act and coastal protection policy should be adopted. A storm surge hurdle can be built to encounter the sea level rise of up to fifty centimetres (e.g., in the Netherlands) (Singh *et al.*, 2014).

7. Effects of Climate Change on Agriculture

7.1 Carbon Dioxide Concentration

Carbon dioxide is a chief greenhouse gas which traps more heat. It is also an essential nutrient for plant. Despite being major culprit of climate change, in high concentrations it also favours high yields of some crops (Ainsworth & Long, 2005; Jablonski *et al.*, 2002). It reflects that high levels of carbon dioxide can enhance agricultural output. Some experiments, in which controlled air was used, showed enhanced output. While free-Air Carbon dioxide experiments showed that crop yield was not up to the mark. By making changes in crop administration, crop production under enhanced carbon dioxide conditions (Long *et al.*, 2006; Myers *et al.*, 2014; Tubiello *et al.*, 2000).

In some of the crop species like $C_{3,}$ nutritional quality of crops declined. Their protein, zinc and iron contents were less than required in enhanced carbon dioxide concentrations. On the other side, some crops were not affected like C_4 crops and legumes (Myers *et al.*, 2014; Uddling *et al.*, 2018). In that case, breeding and agronomic adaptations shall be needed.

Augmented CO_2 concentration is linked with dry period pressure suppleness (Jin *et al.*, 2018). When carbon dioxide is present in high amount, plants require small number of stomata for the exchange of gases. Consequently, plants do not lose much water by transpiration. The ability of plant to use water carefully get better to a great extent. In the short-term forecasting of intergovernmental panel on climate change, it is predicted that crop production will increase in Europe and America in high temperature and higher CO2 concentration. Growing seasons will be longer at higher latitudes. This assessment is made by viewing climate using different scenarios. Conversely, yield will be reduced in lower latitudes and enhanced carbon dioxide will be of no use for crop yield. It will be particularly in tropics (Pachauri *et al.*, 2014; Pugh *et al.*, 2016).

7.2 Abiotic Stress

The effects of climate change like floods, droughts and heat spells have greatly affected the agriculture in many ways. Cereal crops yield has reduced due to the severe heat and dry spells by almost nine to ten percent from 1964 to 2007. The dry periods of 1985 to 2007 also triggered almost 13.7% higher crop loss as compare to the loss that was predicted for previous period (1964–1984) (Lesk *et al.*, 2016).

Between the years 1981 to 2009, wheat production was greatly reduced in India due to warm temperatures. The percentage of decline was 5.2% (Gupta *et al.*, 2017). The Hindu-Kush Himalayan region faced severe weather conditions more frequently in the previous ten years. In this period dryness and floods both affected agriculture in a very bad manner. As a result, crop yields were greatly reduced. The pattern is quite different for Europe. There is a definite reduction noticed in the production of wheat as well as barley. The percentage reduction was 2.5% for wheat and 3.8% for barley since 1989. However, it is also evident that effects were not uniformly spread as reduction was 5% or even greater than it is in south part of Europe (Moore & Lobell, 2015).

In the Czech Republic, heating has enhanced the crop of fruiting vegetables by 4.9–12%. Root vegetable production have decreased (Potopová *et al.*, 2017). The higher temperature has caused long period season of growth in Scotland. Potato production has enhanced since 1960 (Gregory & Marshall, 2012).

Even the alterations in temperature and precipitation for a short time can induce prominent variations in crop yield. More high temperatures and reduced rainfall were noticed in some areas like the Southern U.S., Western Russia, and East Africa. It prevailed from 2010 to 2012. The reduction of nearly fourteen to eighty percent was noticed in production of crops which include wheat, sorghum and barley. Due to these reductions in aforementioned crops, food shortage and diseases in the area of east Africa are expected. In Ethiopia, rainfall pattern change was observed in the year 2015 and 2016. It resulted in crop growth. Due to this, famine was experienced in these years.

In the south eastern part of Australia, decreased temperature and increased precipitation resulted in increased flooding as well as double yield of cotton. It happened in year 2010 to 2012. Overflowing and cold temperatures decreased the wheat yield in United Kingdom in the year 2007. It was less as compare to last year yield. According to an assessment, flooded regions faced a production decline of almost forty percent (Posthumus *et al.*, 2009).

Under different climate scenarios, it is predicted by many researches that there will be a clear imbalance between the crop yield of poor countries and rich countries. In this way, mostly developed countries will get more profit in economic terms. On the other hand, poor and under-developed countries will face crop yield decline. It will widen the economic gap between developed and developing countries (Bathiany *et al.*, 2018).

7.3 Biotic Stress

The carbon dioxide affects the ability of pathogens to infect. It is also affected by water, and temperature. The risk of disease is increased for plants in the land where there is more precipitation and soil is moister. Infection is spread at a higher rate. In some exceptional cases, disease does not spread even in high moisture rate. Favourable temperature for every disease spread is different. The difference of temperature and accordingly response of different infecting pathogens, which exists in different geographic places, have been observed. (Mariette *et al.*, 2016). Increased carbon dioxide concentration became a cause for increased disease spreading ability of Fusarium graminearum on wheat (Váry *et al.*, 2015).

A species named Peronospora Manchuria disease ability actually reduced in the enhanced carbon dioxide amounts. Plant immunity varies from plant to plant and according to their immunity, species response towards humid and warm environment. (Velásquez *et al.*, 2018). Change of merely five degree Celsius on daily basis made potatoes more vulnerable to the P. infestans infection (Shakya *et al.*, 2015). Along with it, temperature alterations also pose great threat to the bacterial populations by making them more accessible to the and temperature fluctuations also make bacterial communities more susceptible to attack of new taxa(Saarinen *et al.*, 2019).

It is generally predicted that increment in warming and rain along with their variable patterns will lead towards introduction of new pathogens. It will also be supported by altered distribution. The new disease carriers will be more challenging for farmers. They will not be familiar with the mode of action of pathogens and measures necessary to tackle them (Saarinen *et al.*, 2019; Velásquez *et al.*, 2018).

Pathogens have a short reproduction cycle and hence they increase in number very fast. They also fast development. Therefore, they respond towards atmospheric variations immediately. It is necessary to adopt better plant management methods in order to overcome the disease spread issue (Velásquez *et al.*, 2018). The types of plants and crops, which need longer time periods for their growth, will be more vulnerable to the attacking pathogens. Mostly forest plants and orchard crops fall in this category (Shaw & Osborne, 2011). It is indeed very tough to forecast the possible outcomes of pathogen related disorders. It greatly depends upon the vulnerability of plant towards that disease and the nature of infection. It is the need of the hour that we should use better modelling techniques. Urgent response towards disease spread is also required. In this way, food insecurity can be prevented.

As climate change adversely impact crop yield, let us have an example to better understand the impacts of fluctuating climate on crops.

Table 2: Summary On The Impacts Of Climate Change On Wheat Yield In China (Wang *et al.*, 2014)

Table 2. Summary On The Impacts Of Climate Change On Wheat Yield In China		
Study region	**Period**	**Impacts on yield**
Positive impact		
China	1990-1999	Climate change →Yield (↑)
Jiangsu	1951-1980	Under doubled CO_2 :Tem. (↑)→ Yield (↑)
Henan	1971-2004	Tem. (↑)→ Yield (↑)
Xinjiang	1979-2002	Pre. (↑)→ Yield (↑)
Tianjin	1979-2002	T_n ↑(1°C) →Yield ↑ (4.2-12.0%)
Negative impacts		
China	1979-2002	Climate change →Yield (↓)
Jiangsu	1979-2002	Pre. (↑)→ Yield (↓)
Gansu and Henan	1981-2000	Tem. (↑)→ Yield (↓)
Guanzhong Plain	1949-1999	Tem. (↑)→ Yield (↓)
Jiangsu and Shandong	1951-1980	Pre. (↓)→ Yield (↓)
Zhejiang, Fujian and Guangdong	1981-2000	Pre. (↑)→ Yield (↓)
Lower Haihe Plain and Hebei	1985-2000 : 1975-2006	T_m ↑(>1.2°C) →Yield (↓)
Liaoning, Hubei and Hunan	1979-2002	T_m ↑(>1°C) →Yield (↓)

Tem., temperature; Pre., precipitation; Tm, maximum temperature; Tn, minimum temperature (Wang *et al.*, 2014)

Table 3: Summary On The Impacts Of Climate Change On Maize Yield In China (Wang *et al.*, 2014)

Table 3. Summary On The Impacts Of Climate Change On Maize Yield In China		
Study region	**Period**	**Impact on yield**
Positive impacts		
China	1980-2008	Pre. (↑)→ Yield (↑)
China	1990-1999	Climate change →Yield (↑)
Heilongjiang	1981-2000	Tem.(↑)→Yield (↑) (271.1kg ha^{-1} yr^{-1})
Negative impacts		
China	1979-2002	Tem.(↑)→ Yield (↓)
China	1980-2008	Tem.(↑)→ Yield (↓) in 50% of the provinces
Henan	1981-2000	Tem. (↑)→ Yield (↓) (168.8 kg ha^{-1} yr^{-1})
China	1980-2008	T_m (↑)→Yield (↓); T_n (↑) → yield (↓)
8 provinces and 1 city (Liaoning, Tianjing, Shanxi, Gansu, Shaanxi, Anhui, Jiangsu, Guizhou, and Xinjiang)	1979-2002	T_m (↑) →Yield (↓)

Tem., temperature; Pre., precipitation; Tm, maximum temperature; Tn, minimum temperature (Wang *et al.*, 2014)

8. Adaptive Strategies in China For Agriculture

China is now concerned about climate change and its impacts. It is working to minimize its share in the weather variations worldwide. Along with all these efforts to lessen the greenhouse gas emissions, it is also working to adopt such circumstances.

As China has formulated a plan named (National Climate Change Programme). It was finalized in the year 2007. In accordance with this plan, the governance bodies are putting all the possible efforts to address the climate change issue along with the adaptation. Many strategies are under consideration for this purpose. Few adaptation strategies are described here. They will help the people related to agriculture to better adapt to the climate variations.

8.1 Improve Agricultural Infrastructure

Adaptation could be facilitated by investing to improve infrastructure. This can be done on priority basis by the government. A number of opportunities exist for the government to invest in infrastructure that could facilitate adaptation.

At the first stage, government can support larger plans for water conservation. The areas which are neglected so far, should be considered for initiating new irrigation plans on smaller scale. That areas which have poor irrigation systems should be priority sites for these projects.

Government representatives have recommended that they will also put efforts for the rehabilitation of degraded agricultural lands. They also plan to manage the low yield agricultural land. agricultural zones and strengthen the restoration of degraded farmland. For instance, in areas that are influenced by salinity, they need to be treated. For this purpose, finance used for the rehabilitation of such soils can be beneficial. In this way, treated land will more beneficial in terms of crop yield. It will also be helpful in the unusual situation of high temperature and change precipitation patterns.

So, government is planning to construct water conservation plans and the infrastructure needed for this purpose. These plans will be helpful in the water deficient areas like desserts to enhance water use efficiency. (Wang *et al.*, 2014).

8.2 Strengthen Research and Development for New Technologies

One of the foremost roles of administration has been investment for the research and progress of new technical strategies for innovation in the field of agriculture. The main focus should be on small systems that are deficient of financial support by large companies. The industries which are involved in research of different seed varieties should support these small-scale farmers. Research should be increased on those kinds of seeds which are more tolerant towards harsh environmental conditions. These conditions include warmer environment, pathogens, excessive water and diseases. The government should also fund such research works. Along with these programs, government is also looking for the new methods of research in climate variation. With help of these methods, they will be able to better perceive the extent, origin and pattern of weather changes and their results. Moreover, government should make farmer community aware of existing technical advancement for their betterment.

Though, many adaptation methods are still under development phases. China has achieved little success in implementing such method. Few examples are described here. The best effort is to incorporate weather adaptation plans into development programs of agriculture. The results of these programs, either negative or positive, will provide strong foundation for the further research. One of the prominent examples is the administration's effort to enhance the political profile of community investment in the research of weather variation. Many funding mechanisms are in progress for adaptation to weather fluctuations. The first such scheme in China was introduced in 2007 (Zhang *et al.*, 2008).

Some provinces have started to invest in those technically sound mechanisms that will encourage precipitation being part of this scheme. The precipitation is being induced by spreading substances like dry ice or silver iodide. These substances will cause rainfall artificially. It can be done in the Sichuan and Tibet. In some areas like Xinjiang, rain water can be harvested. In another example, the provincial Science and Technology Department also intends to devote money in better weather predictions in Ningxia. The provincial Academy of Agricultural Sciences has been working on research that specially targets the adaptation ways in agriculture sector. These adaptations comprise better seed types as well as migration of species in a more favorable environment. However, success of these projects and plans has not recognized yet, as they are recently started and results are not properly known.

8.3 Adoption of Water Saving Technologies

Along with the government policies and plans some adaptations are being adopted by farmers. In a survey, including 6 provinces of China, it was reported that farmers are intended to shift towards water efficient procedures of farming. And water deficiency situations can be effectively handled in this way. The water shortage will prevail probably due to the changing climate (Blanke *et al.*, 2007). In another survey, it was also revealed that around forty two percent of villages in the country were using various water use efficient techniques on household level. This data was gathered in 2004. These technologies include plastic sheeting, drought tolerant types of seeds, and surface level plastic irrigation pipe (Wang *et al.*, 2014).

9. Conclusion

Climatic variations pose a serious risk to water as well as agriculture. The continuously changing climatic conditions may cause excess water as well as deficiency of water. Both of them are quite difficult to handle and can cause devastating impacts including floods, damage to crops, soil salinity and water-logging. As economy of any country greatly depends on agriculture. Therefore, it is damaging in terms of the economy, especially for agriculture-based countries. Predictions about the future climate change are also being made but we should improve our modelling methods. Different adaptation strategies are also considered like technological advancement, financial assistance for infrastructure and individual efforts by affectees. More research is needed in order to find better climate modelling and adoption methods. Furthermore, we should implement plans and programmes in an effective way.

10. References

Adger, W. N., Agrawal, S., Mirza, M., Conde, C., O'brien, K., Pulhin, J., . . . Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity.

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change, 15*(2), 77-86.

Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2. *New Phytologist, 165*(2), 351-372.

Anderson, R., Bayer, P. E., & Edwards, D. (2020). Climate change and the need for agricultural adaptation. *Current Opinion in Plant Biology*.

Bates, B., Kundzewicz, Z., & Wu, S. (2008). *Climate change and water*: Intergovernmental Panel on Climate Change Secretariat.

Bathiany, S., Dakos, V., Scheffer, M., & Lenton, T. M. (2018). Climate models predict increasing temperature variability in poor countries. *Science advances, 4*(5), eaar5809.

Blanke, A., Rozelle, S., Lohmar, B., Wang, J., & Huang, J. (2007). Water saving technology and saving water in China. *Agricultural water management, 87*(2), 139-150.

Caspary, H. (2004). The August 2002 flood in Central and Eastern Europe and results from teh EU'STARDEX'Project: STARDEX Information Sheet.

Cavé, L., Beekman, H. E., & Weaver, J. (2003). 14. Impact of Climate Change on Groundwater Recharge Estimation. *Groundwater recharge estimation in southern Africa*, 189.

Chen, C.-C., Gillig, D., & McCarl, B. A. (2001). Effects of climatic change on a water dependent regional economy: a study of the Texas Edwards aquifer. *Climatic Change, 49*(4), 397-409.

Chen, Y., Li, Z., Fan, Y., Wang, H., & Deng, H. (2015). Progress and prospects of climate change impacts on hydrology in the arid region of northwest China. *Environmental Research, 139*, 11-19.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, R., . . . Laprise, R. (2007). Regional climate projections *Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press, Cambridge, Chapter 11* (pp. 847-940).

Coutant, C. C. (1999). Perspectives on temperature in the Pacific Northwest's fresh waters: Oak Ridge National Lab., TN (US).

Dankers, R., & Feyen, L. (2009). Impact of global warming on stramflow droughts in Europe. *Journal of Geophysical Research*.

Dennis, I., & Dennis, R. (2012). Climate change vulnerability index for South African aquifers. *Water SA, 38*(3), 417-426.

Donevska, K., & Dodeva, S. (2004). *Adaptation measures for water resources management in case of drought periods.* Paper presented at the Proceedings, XXIInd Conference of the Danubian Countries on the Hydrological Forecasting and Hydrological Bases of Water Management.

Dyurgerov, M. (2003). Mountain and subpolar glaciers show an increase in sensitivity to climate warming and intensification of the water cycle. *Journal of hydrology, 282*(1-4), 164-176.

Earman, S., & Dettinger, M. (2011). Potential impacts of climate change on groundwater resources–a global review. *Journal of Water and Climate Change, 2*(4), 213-229.

El Raey, M. (2004). ENV/EPOC/GF/SD/RD.

Gedney, N., Cox, P., Betts, R., Boucher, O., Huntingford, C., & Stott, P. (2006). Detection of a direct carbon dioxide effect in continental river runoff records. *Nature, 439*(7078), 835-838.

Giorgi, F., Bi, X., & Pal, J. (2004). Means, trends and interannual variability in a regional climate change experiment over Europe. Part II: future climate scenarios (2071-2100). *Clim Dyn, 23,* 839-858.

Goudie, A. S. (2006). Global warming and fluvial geomorphology. *Geomorphology, 79*(3-4), 384-394.

Graham, R. C., Hirmas, D. R., Wood, Y. A., & Amrhein, C. (2008). Large near-surface nitrate pools in soils capped by desert pavement in the Mojave Desert, California. *Geology, 36*(3), 259-262.

Gregory, P. J., & Marshall, B. (2012). Attribution of climate change: a methodology to estimate the potential contribution to increases in potato yield in S cotland since 1960. *Global change biology, 18*(4), 1372-1388.

Gupta, R., Somanathan, E., & Dey, S. (2017). Global warming and local air pollution have reduced wheat yields in India. *Climatic Change, 140*(3-4), 593-604.

Haeberli, W., Frauenfelder, R., Hoelzle, M., & Maisch, M. (1999). On rates and acceleration trends of global glacier mass changes. *Geografiska Annaler: Series A, Physical Geography, 81*(4), 585-591.

Hem, J. (1992). US Geological Survey Water-Supply Paper 2254: Study and Interpretation of the Chemical Characteristics of Natural Water. *United States Government Printing Office, Washington, DC.*

Holden, N., Brereton, A., Fealy, R., & Sweeney, J. (2003). Possible change in Irish climate and its impact on barley and potato yields. *Agricultural and Forest Meteorology, 116*(3-4), 181-196.

Jablonski, L. M., Wang, X., & Curtis, P. S. (2002). Plant reproduction under elevated CO2 conditions: a meta-analysis of reports on 79 crop and wild species. *New Phytologist, 156*(1), 9-26.

Jacobs, K., Adams, D. B., & Gleick, P. (2001). Potential consequences of climate variability and change for the water resources of the United States (pp. 405-435): Cambridge University Press.

Jin, Z., Ainsworth, E. A., Leakey, A. D., & Lobell, D. B. (2018). Increasing drought and diminishing benefits of elevated carbon dioxide for soybean yields across the US Midwest. *Global change biology, 24*(2), e522-e533.

Kayane, I. (1997). *Global warming and groundwater resources in arid lands.* Paper presented at the Freshwater Resources in Arid Lands: UNU Global Environmental Forum V.

Lasco, R., Cruz, R., Pulhin, J., & Pulhin, F. (2006). Tradeoff analysis of adaptation strategies for natural resources, water resources, and local institutions in the Philippines: AIACC Working paper.

Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature, 529*(7584), 84-87.

Li, B., Chen, Y., Chen, Z., Xiong, H., & Lian, L. (2016). Why does precipitation in northwest China show a significant increasing trend from 1960 to 2010? *Atmospheric Research, 167*, 275-284.

Li, B., Chen, Y., Li, W., Chen, Z., Zhang, B., & Guo, B. (2013a). Spatial and temporal variations of temperature and precipitation in the arid region of northwest China from 1960–2010. *Fresenius Environmental Bulletin, 22*(2), 362-371.

Li, B., Chen, Y., & Shi, X. (2012). Why does the temperature rise faster in the arid region of northwest China? *Journal of Geophysical Research: Atmospheres, 117*(D16).

Li, B., Chen, Y., Shi, X., Chen, Z., & Li, W. (2013b). Temperature and precipitation changes in different environments in the arid region of northwest China. *Theoretical and Applied Climatology, 112*(3-4), 589-596.

Li, R.-l., & Geng, S. (2013). Impacts of climate change on agriculture and adaptive strategies in China. *Journal of Integrative Agriculture, 12*(8), 1402-1408.

Long, S. P., Ainsworth, E. A., Leakey, A. D., Nösberger, J., & Ort, D. R. (2006). Food for thought: lower-than-expected crop yield stimulation with rising CO2 concentrations. *Science, 312*(5782), 1918-1921.

Mariette, N., Androdias, A., Mabon, R., Corbiere, R., Marquer, B., Montarry, J., & Andrivon, D. (2016). Local adaptation to temperature in populations and clonal lineages of the Irish potato famine pathogen Phytophthora infestans. *Ecology and evolution, 6*(17), 6320-6331.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2): Cambridge University Press.

McCluskey, A., & Strzepek, K. (2007). *The impacts of climate change on regional water resources and agriculture in Africa*: The World Bank.

Milliman, J. D., Farnsworth, K., Jones, P., Xu, K., & Smith, L. (2008). Climatic and anthropogenic factors affecting river discharge to the global ocean, 1951–2000. *Global and planetary change, 62*(3-4), 187-194.

Milly, P. C. D., Wetherald, R. T., Dunne, K., & Delworth, T. L. (2002). Increasing risk of great floods in a changing climate. *Nature, 415*(6871), 514-517.

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of hydrology, 391*(1-2), 202-216.

Mitigation, D. I. (2004). Prevention in the Limpopo River Basin: A Situation Analysis. *Roma, Italy: Food and Agriculture Organization of the United Nations*.

Moore, F. C., & Lobell, D. B. (2015). The fingerprint of climate trends on European crop yields. *Proceedings of the National Academy of sciences, 112*(9), 2670-2675.

Mote, P. W. (2003). Trends in snow water equivalent in the Pacific Northwest and their climatic causes. *Geophysical Research Letters, 30*(12).

Mukheibir, P. (2008). Water resources management strategies for adaptation to climate-induced impacts in South Africa. *Water Resources Management, 22*(9), 1259-1276.

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D., Bloom, A. J., . . . Hasegawa, T. (2014). Increasing CO 2 threatens human nutrition. *Nature, 510*(7503), 139-142.

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., & Padgham, J. (2014). Africa In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, et al., editors. Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: USA: Cambridge University Press.

Nikulin, G., Jones, C., Giorgi, F., Asrar, G., Büchner, M., Cerezo-Mota, R., . . . Hänsler, A. (2012). Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. *Journal of climate, 25*(18), 6057-6078.

Obasi, G. (1994). WMO's role in the international decade for natural disaster reduction. *Bulletin of the American Meteorological Society, 75*(9), 1655-1662.

Orlowsky, B., & Seneviratne, S. I. (2012). Global changes in extreme events: regional and seasonal dimension. *Climatic Change, 110*(3-4), 669-696.

Osman-Elasha, B., Goutbi, N., Spanger-Siegfried, E., Dougherty, B., Hanafi, A., Zakieldeen, S., . . . Elhassan, H. M. (2006). Adaptation strategies to increase human resilience against climate variability and change: Lessons from the arid regions of Sudan. *Assessments of impacts and adaptations to climate change (AIACC) working paper, 42.*

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., . . . Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*: Ipcc.

Peterson, B. J., Holmes, R. M., McClelland, J. W., Vörösmarty, C. J., Lammers, R. B., Shiklomanov, A. I., . . . Rahmstorf, S. (2002). Increasing river discharge to the Arctic Ocean. *Science, 298*(5601), 2171-2173.

Posthumus, H., Morris, J., Hess, T., Neville, D., Phillips, E., & Baylis, A. (2009). Impacts of the summer 2007 floods on agriculture in England. *Journal of Flood Risk Management, 2*(3), 182-189.

Potopová, V., Zahradníček, P., Štěpánek, P., Türkott, L., Farda, A., & Soukup, J. (2017). The impacts of key adverse weather events on the field-grown vegetable yield variability in the Czech Republic from 1961 to 2014.

International Journal of Climatology, 37(3), 1648-1664.

Pugh, T., Müller, C., Elliott, J., Deryng, D., Folberth, C., Olin, S., . . . Arneth, A. (2016). Climate analogues suggest limited potential for intensification of production on current croplands under climate change. *Nature communications, 7*(1), 1-8.

Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. *Science, 315*(5810), 368-370.

Ranjan, P., Kazama, S., & Sawamoto, M. (2006). Effects of climate change on coastal fresh groundwater resources. *Global Environmental Change, 16*(4), 388-399.

Regonda, S. K., Rajagopalan, B., Clark, M., & Pitlick, J. (2005). Seasonal cycle shifts in hydroclimatology over the western United States. *Journal of climate, 18*(2), 372-384.

Ren, C., & Yang, D. (2006). Study on the division and trends of temperature variation in Northwest arid area of China in resent 50 years. *Journal of Arid Land Resources and Environment, 20*(1), 5.

Rowell, D. P. (2012). Sources of uncertainty in future changes in local precipitation. *Climate dynamics, 39*(7-8), 1929-1950.

Saarinen, K., Lindström, L., & Ketola, T. (2019). Invasion triple trouble: environmental fluctuations, fluctuation-adapted invaders and fluctuation-mal-adapted communities all govern invasion success. *BMC evolutionary biology, 19*(1), 42.

Shakya, S., Goss, E., Dufault, N., & van Bruggen, A. (2015). Potential effects of diurnal temperature oscillations on potato late blight with special reference to climate change. *Phytopathology, 105*(2), 230-238.

Shaw, M. W., & Osborne, T. M. (2011). Geographic distribution of plant pathogens in response to climate change. *Plant Pathology, 60*(1), 31-43.

Sherif, M. M., & Singh, V. P. (1999). Effect of climate change on sea water intrusion in coastal aquifers. *Hydrological Processes, 13*(8), 1277-1287.

Shi, Y. (2002). A preliminary study of signal, impact and foreground of climatic shift from warm-dry to warm-humid in Northwest China. *J Glaciol Geocryol, 24*(3), 219-226.

Singh, V. P., Mishra, A. K., Chowdhary, H., & Khedun, C. P. (2014). Climate Change and Its Impact on Water Resources *Modern Water Resources Engineering* (pp. 525-569): Springer.

Song, L. (2003). Changing features of precipitation over northwest China during the 20^< th> century. *J Glaciol Geocryol, 25*(2), 143-148.

Sugita, F., & Nakane, K. (2007). Combined effects of rainfall patterns and porous media properties on nitrate leaching. *Vadose Zone Journal, 6*(3), 548-553.

Tubiello, F. N., Donatelli, M., Rosenzweig, C., & Stockle, C. O. (2000). Effects of climate change and elevated CO2 on cropping systems: model predictions at two Italian locations. *European Journal of Agronomy, 13*(2-3), 179-189.

Uddling, J., Broberg, M. C., Feng, Z., & Pleijel, H. (2018). Crop quality under rising atmospheric CO2. *Current Opinion in Plant Biology, 45*, 262-267.

Váry, Z., Mullins, E., McElwain, J. C., & Doohan, F. M. (2015). The severity of wheat diseases increases when plants and pathogens are acclimatized to elevated carbon dioxide. *Global change biology, 21*(7), 2661-2669.

Velásquez, A. C., Castroverde, C. D. M., & He, S. Y. (2018). Plant–pathogen warfare under changing climate conditions. *Current Biology, 28*(10), R619-R634.

Walvoord, M. A., Phillips, F. M., Stonestrom, D. A., Evans, R. D., Hartsough, P. C., Newman, B. D., & Striegl, R. G. (2003). A reservoir of nitrate beneath desert soils. *Science, 302*(5647), 1021-1024.

Wang, J., Huang, J., & Yang, J. (2014). Overview of impacts of climate change and adaptation in China's agriculture. *Journal of Integrative Agriculture, 13*(1), 1-17.

Wang, Y.-J., & Qin, D.-H. (2017). Influence of climate change and human activity on water resources in arid region of Northwest China: An overview. *Advances in Climate Change Research, 8*(4), 268-278.

Wehbe, M., Eakin, H., Seiler, R., Vinocur, M., Ávila, C., & Marutto, C. (2006). Local perspectives on adaptation to climate change: Lessons from Mexico and Argentina.

Wheaton, E. (2000). Canadian Prairie Drought Impacts and Experiences in Drought. A Global Assessment-Volume 1 ed. DA Wilhite: London: Routledge.

Wissmar, R. C. (1994). *Ecological health of river basins in forested regions of eastern Washington and Oregon* (Vol. 326): US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Wu, Z., Zhang, H., Krause, C. M., & Cobb, N. S. (2010). Climate change and human activities: a case study in Xinjiang, China. *Climatic Change, 99*(3-4), 457-472.

Xu, C.-y. (2000). Modelling the effects of climate change on water resources in central Sweden. *Water Resources Management, 14*(3), 177-189.

Yao, J., Yang, Q., Chen, Y., Hu, W., Liu, Z., & Zhao, L. (2013). Climate change in arid areas of Northwest China in past 50 years and its effects on the local ecological environment. *Chinese Journal of Ecology, 32*(5), 1283-1291.

Yilmaz, K. K., & Yazicigil, H. (2011). Potential impacts of climate change on Turkish water resources: a review *Climate change and its effects on water resources* (pp. 105-114): Springer.

Zhang, L., Luo, R., Yi, H., & Tyler, S. (2008). Climate adaptation in Asia: knowledge gaps and research issues in China; the full report of the China team: Institute for Social and Environmental Transition (ISET), Kathmandu, NP.

Zhang, Q. (2003). Drought and its impacts. *China Climate Impact Assessment*, 12-15.