Birzeit University

Institute of Environmental and Water Studies

Potential Impact of Climate Change on Agricultural Water Demand:
A case study of Jericho and Al Aghwar district, Palestine.

Master of Science Thesis
by
Sireen Jihad Abu-Jamous

Supervisor
Dr. Ziad Mimi (Birzeit University)

Examination committee
Dr. Ziad Mimi (Birzeit University)
Dr. Maher Abu-Madi (Birzeit University)
Dr. Amer Marei (Al Quds University)

Submitted in Partial Fulfillment of Requirements for the Masters of Science Degree in Water and Environmental Engineering at Birzeit University, Palestine.

November, 2008.

Dedication

To my little family … Ibrahim & Haifa

Abstract

Global climate change induced by increased greenhouse gas concentration has been widely accepted. Agriculture and water resources are the most vulnerable to climate change and are expected to be exposed to direct effects of temperature and precipitation change, but still the potential impact of global climate change is one of the least addressed factors in water resources planning in developing countries. Moreover, the potential impacts of climate change have not been quantified at local level yet. Considering this fact, this study aims to evaluate the agricultural water demand under different suggested climate change scenarios for Palestine.

To evaluate the potential impact of climate change on agricultural water demand, Jericho and Al Aghwar district was selected and the crop water requirements, for the irrigated open-field crops in the district, were estimated under different suggested scenarios of changing temperature and precipitation using the CROPWAT computer model.

The results clearly show that crop water requirement (CWR) is very sensitive to temperature increase; CWR increases by an average of 2.7%, 5.4% and 8% as temperature increases by 1°C, 2°C and 3°C, respectively, to compensate the water lost in evapotranspiration.

Changing precipitation doesn’t affect the crop water requirements, but it affects the amount of irrigation water requirements (IWR); as the effective rain provides part of the crop water requirement. Scenarios of changing precipitation show an increase in IWR by an average of 1.47 % and 5.53% for a decrease in precipitation by 10% and 20% respectively. The other scenario of increasing precipitation shows a decrease by an average of 1.44% and 2.84% in the IWR for an increase by 10% and 20% in precipitation respectively. The total amount of irrigation water required for the district gets greater when combined the scenario of increasing temperature with the scenario of decreasing precipitation.

Acknowledgment

I would like to express my sincere gratitude to my supervisor, Dr. Ziad Mimi for his support, guidance and cooperation throughout the progress of this study. Next I want to thank Dr. Erik de Ruyter van Steveninck from UNESCO-IHE, Delft, The Netherlands, for his fruitful advice and recommendations during developing the thesis proposal.

My special thanks also to Dr. Jetze Heun, PoWER director and Dr. Maher Abu-Madi, PoWER research coordinator for giving me this opportunity to visit UNESCO-IHE and benefit from its extensive resources. Also, a special thanks is extended to everybody at UNESCO-IHE for their help, support, comments and recommendations.

My thanks also to the Palestinian Ministry of Agriculture, Palestinian Water Authority, Palestinian Metrological Center/Geographical center and the Palestinian Hydrology Group for providing the data and references required.

This is a great opportunity to express my respect and gratefulness to my mother in law, Yusra Takrouri; I wouldn't have made it through all the hard work without her help and support.

Last and surely not least, I want to acknowledge my wonderful family, friends and colleagues, for their encouragement. It is always impossible to personally thank everyone who has facilitated successful completion of this study. To those of you who I did not specifically name, I also give my thanks for moving me towards my goal.

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List of Abbreviations and Symbols

ARIJ	Applied Research Institute – Jerusalem
CWR	Crop water requirement
GCM	General Circulation Models
IPCC	Intergovernmental Panel on Climate Change
IWR	Irrigation water requirement
MCM	Million cubic meter
MoA	Ministry of Agriculture
PHG	Palestinian Hydrology Group
PWA	Palestinian Water Authority
SAT	Surface Air Temperature
SRES	Special Report on Emission Scenarios

CO_2	Carbon Dioxide
ET	Evapotranspiration
ET_c	Crop evapotranspiration (mm day $^{-1}$)
$ET_{c\ adj}$	Crop evapotranspiration under non-standard conditions (mm day $^{-1}$)
ET_o	Reference evapotranspiration (mm day $^{-1}$)
K_c	Crop coefficient (-)
P	Precipitation
R.H	Relative humidity (%)
T	Temperature
T_{max}	Maximum temperature (°C)
T_{min}	Minimum temperature (°C)

1. Chapter 1: Introduction

1.1 Background

Climate change has been an active research topic in the last decade, as it's become widely accepted that human activities are leading to increase in greenhouse gas concentrations, which will lead to changes in climate. Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC, 2007a).

Although, global precipitation averages over land are not very meaningful and mask large regional variations; global mean surface temperatures have risen by 0.74°C ± 0.18°C when estimated by a linear trend over the last 100 years (1906–2005) (IPCC, 2007a).

The Middle East region has an arid climate with very scarce water resources, which are under heavy and increasing stress. Therefore, it is vulnerable to climate change that will eventually reduce rainfall, due to changes in oceano-atmospheric circulation patterns (ARIJ, 2008).

According to the Intergovernmental Panel on Climate Change (IPCC) agriculture impacts could be significant and water resources could be altered with relatively small climate changes causing large water supply problems in drought-prone areas, this implies that for regions already experiencing water supply problems, it's prudent to include a global climate change dimension in planning studies (Abu-Taleb, 2000).

1.2 Problem Definition

PWA (2007) stated that the water deficit in the West Bank is expected to be 260 MCM/year by the year 2015 and for Gaza the situation is even worse where it's currently facing a water deficit of about 40-50 MCM/year. These numbers are estimated assuming water supply will remain constant and population increase is the fundamental parameter affecting future water needs, but to date, the potential impact of global climate change is one of the least addressed factors in water resources planning in Palestine as well as other developing countries.

Palestine suffers additional stress for three reasons; first, the impact of the Israeli occupation; the Palestinian natural ecosystems are a casualty of the Israeli occupation, due to the systematic uprooting of both natural and planted trees, to the demolition of fertile agricultural land, and to the destruction of groundwater aquifers. Over 1.3 million trees have been uprooted by the Israeli Occupation Forces between September 2000 and March 2006 (ARIJ, 2008). This will have a destructive effect on Palestine's climate, by disrupting the natural carbon sequestration process, in which carbon dioxide (CO_2) from the atmosphere is absorbed by trees, plants and crops through photosynthesis, and is stored as carbon in biomass (tree trunks, branches and roots) and soils.

Second, even if no climate change takes place at all, the population growth rate is one of the highest worldwide; 3.06% in the West Bank and 3.71% in Gaza Strip, while that of the world averages 1.14% (ARIJ, 2008), and this puts a great stress on the water resources.

Third, the increased population and industrial zones, and the expanded human and industrial activities, especially under lack of regulations and as a result of 60 years of the ongoing military occupation, in the Occupied Palestinian Territory, have increased the amount of smoke and hazardous gases, which includes greenhouse gases emitted into the air. In addition, there are many Israeli industrial sites throughout the West Bank, which pollute the atmosphere with huge amounts of greenhouse gases.

Climatic variables such as temperature and precipitation are essential inputs to agricultural production (Schlenker *et al*, 2007), so, it's important to assess the potential effect of climate change, not only the direct effects of climate on crop yields and farm profit, but also the effects of climate change on the effective water supply and the availability of water for agricultural users.

Increases in agricultural water demand are expected to be significant in all countries of the Middle East region, and the Palestinian Authority is one of the countries that will face harder challenges to mitigate decreased water availability impact on agricultural economy (El-Fadel & Bou-Zeid, 2001).

1.3 Objectives

The main objective of this study is to evaluate the potential impact of climate change on agricultural water demand by estimating the crop water requirement.

The specific objectives are:

- To identify the observed trend and future predictions of temperature and precipitation in the literature for Palestine.
- To determine relative crop evapotranspiration under different suggested climate change scenarios for the case study area (Jericho and Al Aghwar district).
- To determine the crop water requirement for selected crops under different suggested scenarios.
- To determine the irrigation water requirements for the area under consideration under different suggested scenarios.

1.4 Structure of the Thesis

The basic structure of this thesis is organized in five chapters:

Chapter 1 gives an introduction along with a background information, problem definition and objectives of the study.

Chapter 2 summarizes the literature review related to climate change; observations from past century, projections for the future and its potential impacts on agriculture water demand.

Chapter 3 deals with the methodology used to achieve the objectives of the study.

Chapter 4 explains the findings, results and discussion on climate change in terms of temperature and precipitation change and the potential impacts on agriculture water demand.

Chapter 5 concludes the results of the study and recommendations suggested.

2. Chapter 2: Literature Review

2.1 Assessment of Observed Trends

2.1.1 Global climate change trends

a. Temperature:

Global mean surface temperatures have risen by 0.74°C ± 0.18°C when estimated by a linear trend over the last 100 years (1906–2005). The rate of warming over the last 50 years is almost double that over the last 100 years (0.13°C ± 0.03°C vs. 0.07°C ± 0.02°C per decade) (IPCC, 2007a). Eleven of the last 12 years (1995 to 2006) – the exception being 1996 – rank among the 12 warmest years on record since 1850 (IPCC, 2007a).

Figure 2.1 shows the annual global land surface temperature obtained from different analyses[1].

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[1] CRUTEM3: CRU/Hadley Centre gridded land-surface air temperature version 3, Brohan et al. (2006), NCDC: National Climatic Data Center, Smith and Reynolds, 2005, GISS: Goddard Institute for Space Studies, Hansen et al., 2001 and Lugina et al. (2005)

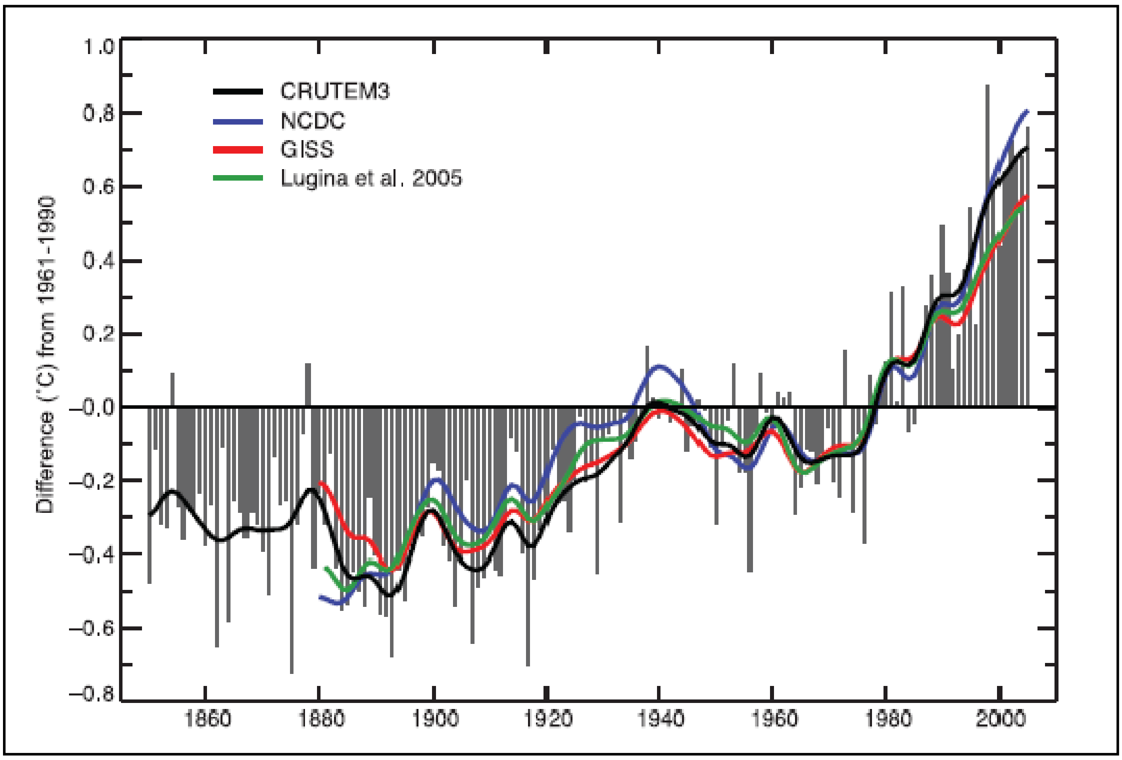

Figure 2.1 Annual global land surface temperature obtained from different analyses. Source: IPCC, 2007a.

Figure 2.2 shows the annual global mean observed temperatures (black dots) along with simple fits to the data; linear trend fits to the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red) are shown, and correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. Note that for shorter recent periods, the slope is greater, indicating accelerated warming.

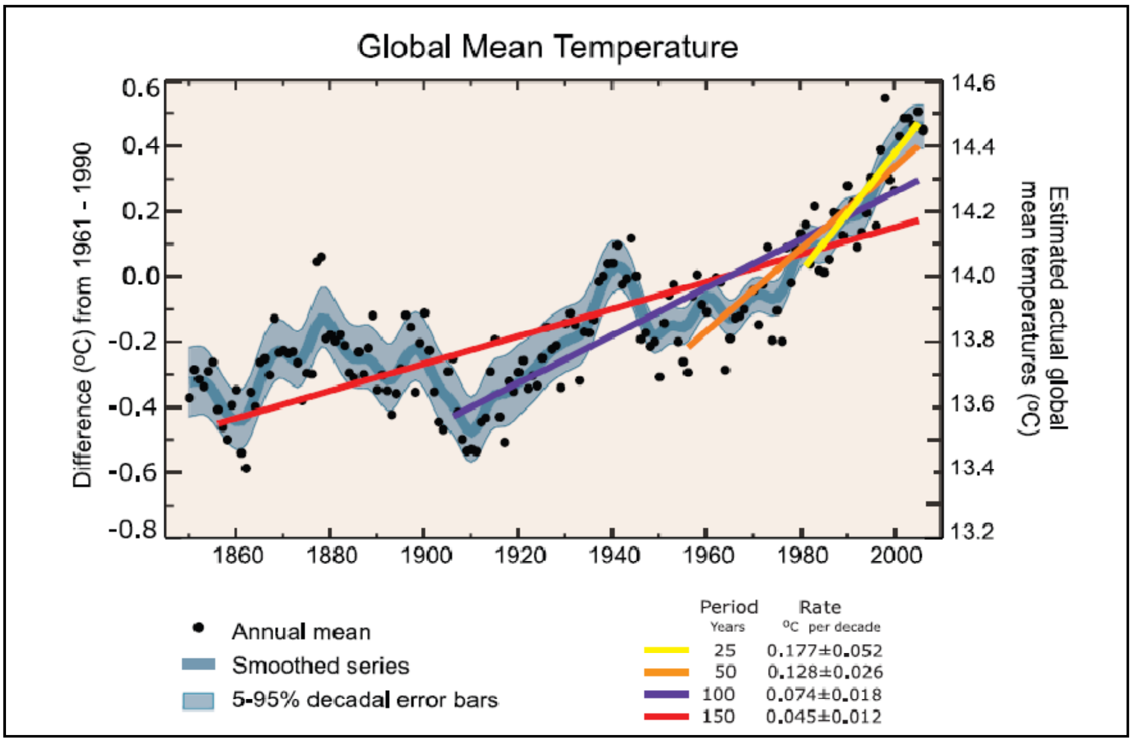

Figure 2.2 Annual global mean observed temperatures along with simple fits to the data. Source: IPCC, 2007a.

b. Precipitation:

Patterns of precipitation change are more spatially and seasonally variable than temperature change; global precipitation averages over land are not very meaningful and mask large regional variations (IPCC, 2007a).

It has become significantly wetter in eastern parts of North and South America, Northern Europe, and Northern and Central Asia, but drier in the Sahel, the Mediterranean, Southern Africa and parts of Southern Asia (IPCC, 2007a).

Droughts have become more common, especially in the tropics and subtropics, since the 1970s. Observed marked increases in drought in the past three decades arise from more intense and longer droughts over wider areas, as a critical threshold for delineating drought is exceeded over increasingly widespread areas. Decreased land precipitation and increased temperatures that enhance evapotranspiration and drying are important factors that have contributed to more regions experiencing droughts (IPCC, 2007a).

Figure 2.3 shows the Trend of annual land precipitation amounts; the top figure shows the trend as % per century for the period from 1901 to 2005 and the bottom figure shows the trend as % per decade for the period from 1979 to 2005.

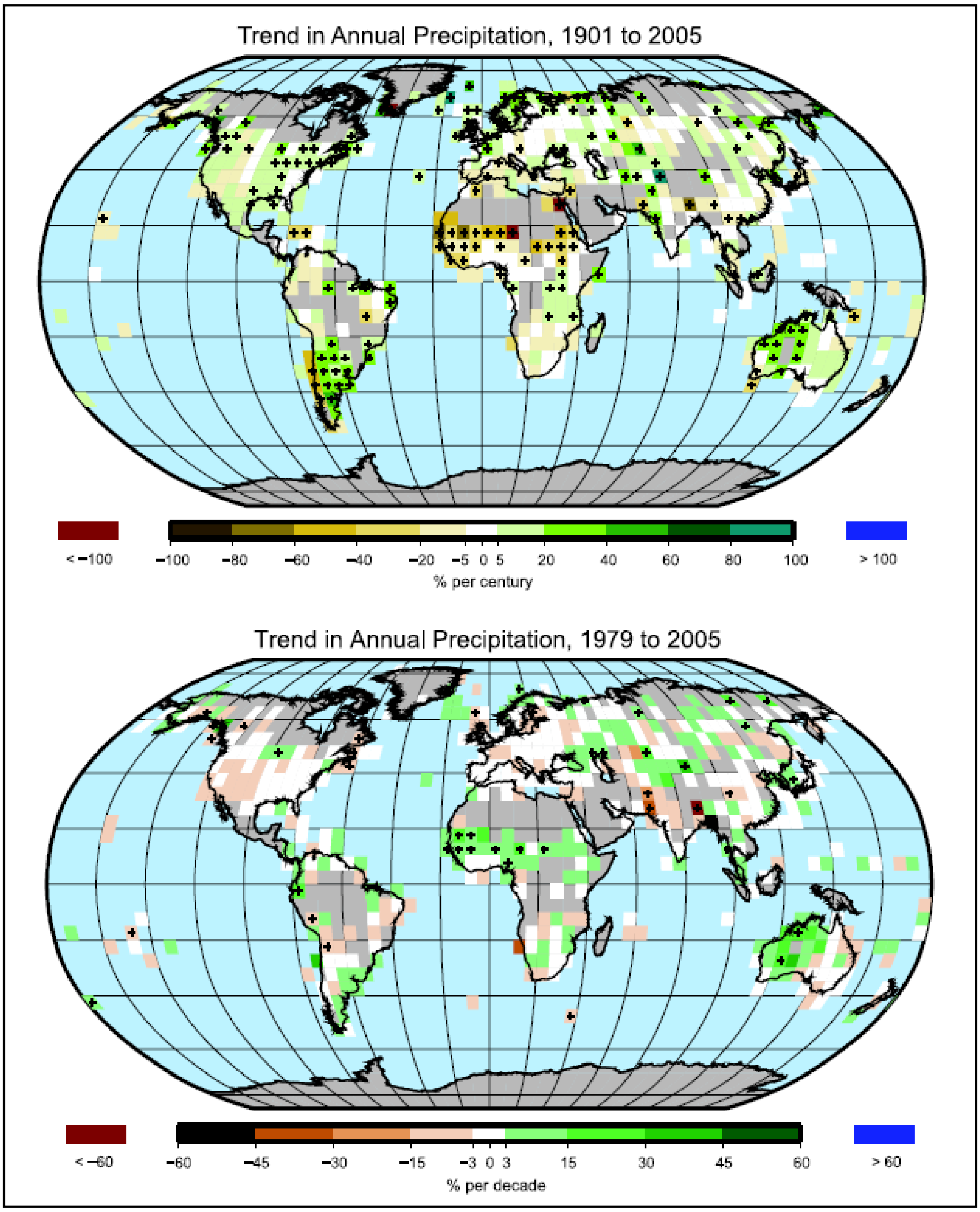

Figure 2.3 Trend of annual land precipitation amounts for 1901 to 2005 (top, % per century) and 1979 to 2005 (bottom, % per decade).
Source: IPCC, 2007a.

2.1.2 Observed trends for the Mediterranean and Palestine

Abu Sa'da (2007) analyzed the precipitation and Temperature records available for six metrological stations covering Historical Palestine for the last century (Figure 2.4), and the results were as summarized in Table 2.1;

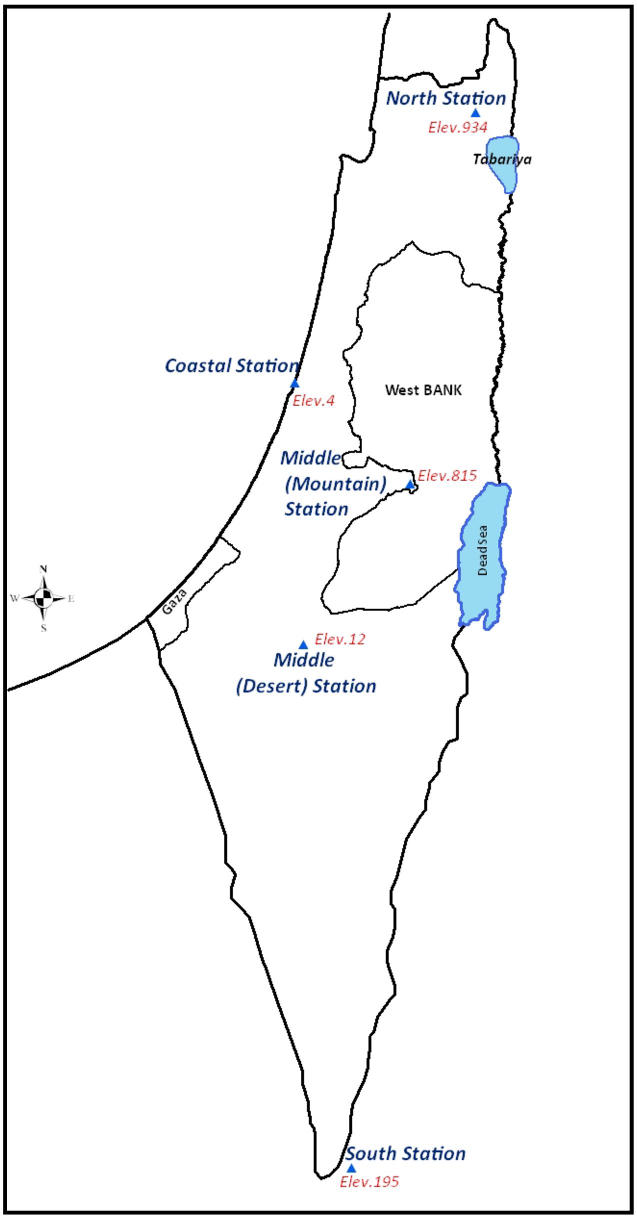

Figure 2.4 Map showing the locations of the metrological stations used in Abu-Sa'da's analysis.Source: Abu Sa'da, 2007.

Table 2.1 Temperature and precipitation trend analysis for the past century

		Coastal station	**North station**	**Middle (Mountain) Station**	**Middle (Dessert) Station**	**South station**
Temperature	Period	1965-2006	1965-1999	1965-1999	1965-2006	1968-1998
	Annual mean (°C)	24.3	20.3	21.4	25.6	31.1
	Trend	Increasing by 9.47%	Increasing by 0.49%	Increasing by 3.27%	Increasing by 0.78%	Increasing by 0.96%
Precipitation	Period	1941-2006	1939-1999	1910-1998	1923-1998	1967-1999
	Annual mean (mm/yr)	526	702	522.7	198.5	28.8
	Trend	Decreasing by -4.26%	Decreasing by -5.5%	Increasing by 20.28%	Increasing by 14.11%	Decreasing by - 52%

Khatib (2007) investigated the climate development in Eastern Mediterranean during the late 20th century, a distinct climate change could be observed with the development of temperature showing a positive trend in summer over most of the domain which fits well with the picture of global warming. On the other hand, precipitation does not show such distinct changes; however, analysis showed that the rainy season extends beyond the conventional winter season well into spring.

ARIJ (2008) indicated that the increase in temperature over the past 20th century in the Occupied Palestinian Territory was obvious. That increase was by no means, uniform during the last decade, with the year 1998 being the warmest. This trend continues until 2005, which surpassed 1998 to end as the hottest year globally in the 125 years, since reliable records have been kept. Generally speaking heat waves have become longer and more intense.

Moreover, Palestine, along with its neighboring countries of the Mediterranean region, has experienced tumultuous rains and flooding. Such events were not frequent in the past.

An increase in rain intensity, combined with a decrease in the overall precipitation, will certainly increase the surface runoff, and, thus, soil erosion and salinization income will also increase. Moreover, by the end of the last century, the autumn of 1999 across Occupied Palestinian Territory was worse than any year in the decade, which increased the drought to a critical value (ARIJ, 2008).

2.2 Projections of Future Climate Change

2.2.1 Global climate change- IPCC 4th assessment report

a. General

Continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century (IPCC, 2007b).

The IPCC "Special Report on Emissions Scenarios" (SRES) explored pathways of future greenhouse gas emissions, derived from self consistent sets of assumptions about energy use, population growth, economic development and other factors.
Scenario families contain individual scenarios with common themes. The six families of scenarios discussed in the IPCC's Third Assessment Report (TAR) and Fourth Assessment Report (AR4) are A1FI, A1B, A1T, A2, B1, and B2 (IPCC,2007c);

The A1 scenarios are of a more integrated world. The A1 family of scenarios is characterized by:

- Rapid economic growth.
- A global population that reaches 9 billion in 2050 and then gradually declines.
- The quick spread of new and efficient technologies.

- A convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide.

There are subsets to the A1 family based on their technological emphasis:

- A1FI - An emphasis on fossil-fuels.
- A1B - A balanced emphasis on all energy sources.
- A1T - Emphasis on non-fossil energy sources.

The A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by:

- A world of independently operating, self-reliant nations.
- Continuously increasing population.
- Regionally oriented economic development.
- Slower and more fragmented technological changes and improvements to per capita income.

The B1 scenarios are of a world more integrated, and more ecologically friendly. The B1 scenarios are characterized by:

- Rapid economic growth as in A1, but with rapid changes towards a service and information economy.
- Population rising to 9 billion in 2050 and then declining as in A1.
- Reductions in material intensity and the introduction of clean and resource efficient technologies.
- An emphasis on global solutions to economic, social and environmental stability.

The B2 scenarios are of a world more divided, but more ecologically friendly. The B2 scenarios are characterized by:

- Continuously increasing population, but at a slower rate than in A2.

- Emphasis on local rather than global solutions to economic, social and environmental stability.
- Intermediate levels of economic development.
- Less rapid and more fragmented technological change than in B1 and A1.

b. Temperature

All models assessed, for all the non-mitigation scenarios considered, project increases in global mean surface air temperature (SAT) continuing over the 21st century, driven mainly by increases in anthropogenic greenhouse gas concentrations, the results form the different IPCC (SRES) scenarios are shown in Table 2.2 below.

Table 2.2 Annual mean surface air temperature change obtained from different scenarios for four time periods.

Global mean warming (°C)				
	2011 - 2030	2046 - 2065	2080 - 2099	2180 - 2199
A2	0.64	1.65	3.13	
A1B	0.69	1.75	2.65	3.36
B1	0.66	1.29	1.79	2.10

Source: IPCC, 2007b.

c. Precipitation

Models simulate that global mean precipitation increases with global warming; however, there are substantial spatial and seasonal variations in this field. Increases of over 20% occur at most high latitudes, as well as in eastern Africa, central Asia and the equatorial Pacific Ocean. Substantial decreases, reaching 20%, occur in the Mediterranean region, the Caribbean region and the subtropical western coasts of each continent (IPCC, 2007b).

2.2.1 Projections for the Mediterranean

a) IPPC projections for the Mediterranean:

As regional climate change projections are now available for many regions of the world with increasing reliability, due to advances in modeling and understanding of the physical processes of the climate system, an important projections for temperature and precipitation were estimated for the Mediterranean;

- Mean temperature projection:

The warming is projected to continue at a rate somewhat greater than its global mean, the warming is *likely* to be largest in the Mediterranean area in summer (IPCC, 2007d). Likelihood, as defined in Table 2.3, refers to a probabilistic assessment by the IPCC of some well defined outcome having occurred or occurring in the future.

Figure 2.5 shows the annual mean temperature change, averaged over 21 models, for the Mediterranean.

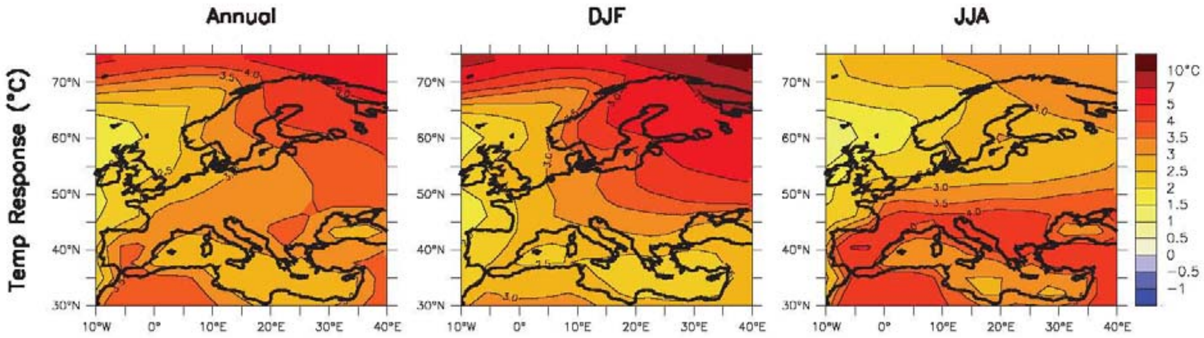

Figure 2.5 Annual mean, DJF[2] and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Palestine Coordinates lat 33° - 29° N; long 34° - 36° E

Source: IPCC, 2007d.

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[2] DJF: December, January and February, JJA: June, July and August.

- Mean precipitation projection:

Annual precipitation is *very likely* to decrease in most of the Mediterranean area. The annual number of precipitation days is very likely to decrease in the Mediterranean area. Risk of summer drought is *likely* to increase in the Mediterranean area (IPCC, 2007d). Figure 2.6 shows the annual mean precipitation fractional change, averaged over 21 models, for the Mediterranean.

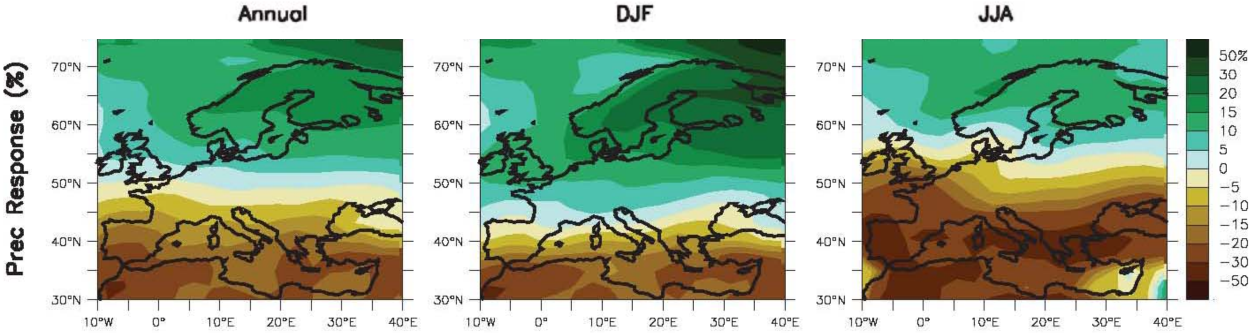

Figure 2.6 Annual mean, DJF and JJA precipitation fractional change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Palestine Coordinates lat 33° - 29° N; long 34° - 36° E

Source: IPCC, 2007d.

Table2.3 IPCC Likelihood scale

Terminology	Likelihood of the occurrence/ outcome
Very likely	> 90% probability
Likely	> 66% probability

Source: IPCC, 2007e.

b) Israeli projections

The following climate scenarios are projected for Israel by the year 2100 as stated in the first report of Israel to the Conference of the Parties of the United Nations Framework Convention on Climate Change (Pe'er and Safriel, 2000):

- Mean temperature increase of 1.6° to1.8°C

- Reduction in precipitation by (-8)% to (-4)%
- Increase in evapotranspiration by 10%
- Delayed winter rains
- Increased rain intensity and shortened rainy season
- Greater seasonal temperature variability
- Increased frequency and severity of extreme climate events
- Greater spatial and temporal climatic uncertainty

The presented information and assessments are based on a survey of literature and on interviews with Israeli scientists and policy makers.

c) Palestinian projections

According to climate models, it was found that a decrease in precipitation is likely to occur around the 300N latitude belt, and since Palestine lies around this belt, the consequence of any such projection may be hazardous for the status of its ecosystem (ARIJ, 2008).

El-Fadel and Bou-Zeid (2001), calculated, for the Middle East region, the temperature change during the winter (January, February, March) and summer (June, July, August), and the rainfall change during the wet season (October - April) using different models . Their results show minor changes in mean precipitation for the region, while temperatures are projected to increase in all seasons. Mean summer temperatures, already high in the region, will rise significantly (0.81-2.1°C). Mean winter temperature will also increase; whoever, the rise is lower than for the summer season.

2.3 Water Resources in Palestine[3]

Water is a main ingredient in most domestic, industrial and agricultural activities. Unfortunately, water resources in Palestine, just as in most of the other countries in the

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[3] All data used in this section are adopted from the “Water Resources Statistical Records in Palestine” published by Palestine Water Authority (PWA) in 2007.

Middle East, are scarce. The area is facing water shortages because of aridity and rapidly growing population with higher water demand. And in Palestine, because of the abnormal political conditions, Israel has been able to use more than 80% of the ground water resources of the West Bank and Gaza Strip and deny Palestinian access to their water rights in the Jordan River.

2.3.1 Groundwater

The West Bank overlies three groundwater basins jointly known as the Mountain Aquifer Basins: the Eastern Aquifer Basin, the Western Aquifer Basin and the Northeastern Aquifer Basin, (Figure 2.7).

Table 2.4 represents the annual recharge of the Mountain Aquifer's basins. From these three basins the Palestinian abstraction is about 119 MCM/year where the Israeli Abstraction reaches 648 MCM/year.

Table 2.4 Annual recharge of the Mountain Aquifer's three basins.

Basin	**Recharge (MCM/year)**
Eastern	100 - 172
Northern	130 - 200
Western	335 - 450
Total	**565 - 822**

Source: PWA, 2007.

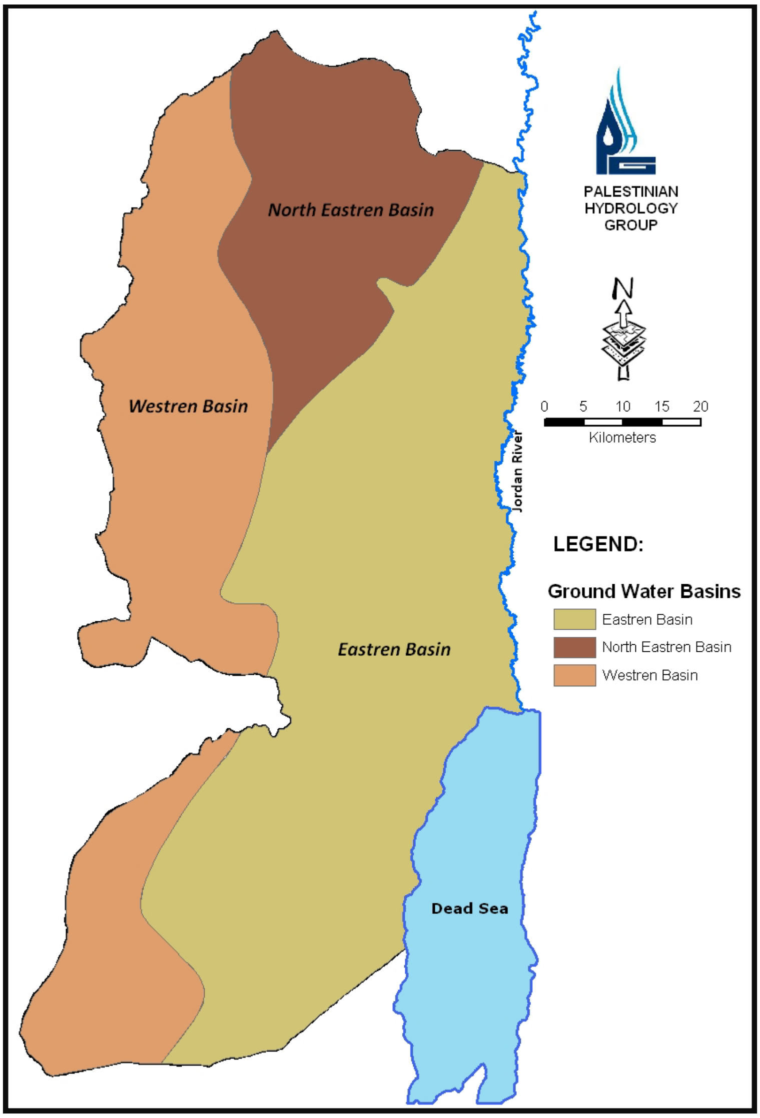


Figure 2.7 Mountain Aquifer's three basins.
Source: PHG data base, 2008.

2.3.2 Surface water

The surface water resources in the West Bank consist of three major components: the Jordan River Basin, the Dead Sea and the western wadis (the eastern wadis are all presented as part of the Jordan River and the Dead Sea).

Palestinians are currently denied the right to their share of water from the Jordan River and therefore groundwater is considered the major source.

Jordan River

The Jordan River is the most important surface water resource in the West Bank. It is considered as a shared river between Lebanon and Syria and flows through Israeli, Palestinian and Jordanian lands which are all legal riparian with legitimate legal rights.

The natural flow of the Jordan River in the absence of extraction ranges from 1485 to 1,671 MCM/year at the entrance to the Dead Sea. Israel is the greatest user of the Jordan River water where its present use is around 58.7% of the total flow.

At the same time Palestinians have been denied use of the Jordan River water by the Israeli occupation since the 1967 war while Jordan uses 23.4% of the flow, Syria uses 11% and Lebanon uses 0.3%.

Dead Sea

The total catchments areas within the Dead Sea Basin are 24185.4 km^2 of which Wadi Araba is 8,522.4 km^2. The total area inside Israel is 10,053.4 km^2 or 41.5%, Jordan 13,100 Km^2 or 54.2% and Palestine 1,032 km^2 or 4.3%.

Surface Runoff and Wadis

The total quantity of western catchments surface runoff that originates from the Palestinian Territories is 72 MCM/year, where as their total catchments areas equal 3,230 km^2 inside Palestinian Territories. The eastern catchments are all presented as part of the Jordan River Basin and Dead Sea Basin.

2.3.3 Water deficits

Based on previous demand projections Table 2.5 shows the future water deficit, in the West Bank, assuming that the supply would be constant during the coming years.

Table 2.5 Supply-demand gap estimation in the West Bank

Year	Supply	Demand (MCM/year)			Deficit (MCM/year)
		Municipal	Industrial	Agricultural	
2005	159	135	11	168	155
2010	159	156	25	190	212
2015	159	181	30	208	260

Source: PWA, 2007.

The numbers and data available in this report indicate that Palestinians are facing harsh and tragic water conditions. The available water volume is decreasing year after year, while the demand is continuously increasing due to population increase, the expansion of the inhabited areas and the industrial development.

Agriculture continues to be the largest consumer of water accounting for 70% of the total use in the West Bank and Gaza Strip (Nazer *et al*, 2007).

2.4 Agriculture in Palestine

2.4.1 General

Despite the small size of the West Bank and Gaza, the diversity of climatic regions makes it possible to grow a wide variety of crops throughout the year. In the West Bank the main crops include olives (76 percent of the tree crop area, field and forage crops (mostly grains and pulses), and vegetables (mainly tomato, cucumber, eggplant and cauliflower) (MoA, 2004a).

The total area suitable for cultivation is about 1.8 million dunums; of which 1.6 million are rainfed crops with the balance used for irrigated agriculture (MoA, 2004a). The cultivated areas in the West Bank and Gaza Strip are 1,640,000 dunums and 171,960 dunums respectively. Just over 200,000 dunums are dedicated to intensive irrigated farming, primarily in the Gaza Strip, the Jordan Valley and the Northern districts of the West Bank.

2.4.2 Rain-fed vs. irrigated agriculture

Each area has two types of irrigation system; rainfed and irrigated. In Palestine, most of the fruit trees are rainfed, with the area cultivated by olives being the most dominant with 83%, followed by grapes with 6.6%. Some fruit trees are irrigated such as citrus (1% of the total area of fruit trees). Field crops are mostly rainfed, the most dominant crop is wheat (36%) followed by barely (23%) of the area cultivated by field crops. 68% of the area cultivated by vegetables is irrigated. The main vegetable crops are tomatoes, cucumber, eggplants and squashes. These crops account for 51% of the area cultivated by vegetables (Nazer *et al*, 2007).

The total area under irrigated cultivation is 200,690 dunums, with 82,000 in Gaza, 52,980 in the semi-coastal area and 65,710 in the rest of the West Bank, primarily Jordan Valley (MoA, 2004a).Tomatoes, cucumbers, eggplants, squash and other vegetables occupy the largest portion of irrigated land.

2.4.3 Constraints on agriculture

Palestinian agriculture is constrained by available land and water, as well as access to markets; these constraints have been the object of political conflict between Palestine and Israel (Butterfield D. *et al*, 2000).

Natural resources are very limited in Palestine, land and water are the most limiting resources affecting the agricultural sector; taking into account areas not accessible to Palestinians due to Israeli security, settlements and bypass roads. There’s only about 0.06 hectare of cultivated land per capita (MoA, 2004b). Additionally, Palestine suffers from restricted water supplies; relatively low annual rainfall and Israeli control and exploitation of aquifers and surface water. Water problem, as a limiting resource for agriculture, is clearly shown in the 94% rainfed areas of the total cultivated area in Palestine.

2.4.4 Agriculture and the national economy

The agricultural sector was hit hard after Israel occupied the West Bank and Gaza Strip. Thereafter the sector's contribution to Gross Domestic Product (GDP) in the Palestinian Occupied Territories declined (Butterfield D. *et al*, 2000).

Agriculture's contribution to the economy has fluctuated widely in the recent years. This is due to several factors; they include: Israeli policies of land confiscation, limited Palestinian control over water resources, higher wages in the Israeli labour market encouraging workers to leave the agricultural sector and low returns to agriculture.

Thus, the 1990's have seen agricultural GDP as high as US$ 477 milllion in 1992 to as low as an estimated US$ 267 million in 1997 with up and down fluctuations in between. Despite this variable performance it is acknowledge that agriculture plays an important role Palestinian society and its economy (MoA, 2004b).

2.5 Climate Change and Agricultural Water Demand

As a consequence of climatic changes, a significant impact on hydrological parameters; runoff, evapotranspiration, soil moisture, groundwater etc. is expected (Goyal, 2004). Evapotranspiration (ET) is the major component of hydrological cycle after precipitation and determines the crop water requirement.

Previous researchers have investigated the impacts of climate change on irrigation water requirements at different locations, either using the results of climate change models directly or applying them to local climate datasets. However, the underlying climate and the climate changes are both spatially varied and the impacts also will be spatially varied.

De Silva *et al* (2007) used water balance modeling and a geographical information system to model and map the impacts on irrigation requirements for wet season paddy in Sri Lanka.

They examined two of the IPCC scenarios; the A2 scenario represents a heterogeneous, regionalized, market-led world, with high population growth, leading to a rapid increase in atmospheric carbon dioxide levels. The B2 scenario follows a similar regionalized future but with more moderate population growth and more concern for the environment and local sustainability, and a slower rate of increase in atmospheric carbon dioxide.

Results suggested that, during the wet season, average rainfall decreases by 17% (A2) and 9% (B2), with rains ending earlier, and potential evapotranspiration increasing by 3.5% (A2) and 3% (B2). Consequently, the average paddy irrigation water requirement increases by 23% (A2) and 13% (B2).

Elgaali *et al*, (2007) used the Integrated Decision Support Consumptive Use model, which accounts for spatial and temporal variability in evapotranspiration and precipitation, to model the expected impacts of climate change on irrigation water demand in the Arkansas River Basin in southeastern Colorado.

In the study two scenarios were examined; the two scenarios were extracted and scaled down from two general circulation models (GCMs), the HAD from the Hadley Centre for Climate Prediction and Research and the CCC from the Canadian Climate Centre. The results show significant changes in the water demands of crops due to climate change.

Based on this analysis, under the two climate scenarios applied, seasonal Evapotranspiration (ET) and irrigation water required (IWR) are expected to increase gradually towards the end of this century. For example, during the decade of the 2090s, the projected changes, under the CCC scenario, in seasonal IWR show an increase of 24% while ET increases by 22%.

Rodrı´guez Dı´az *et al*, (2007) modeled and mapped the climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain.

To evaluate the impacts of climate change on water demand, 14 representative irrigation districts within the river basin were chosen. Also, the impacts were examined under two of the IPCC developed scenarios, known as Special Report on Emission Scenarios (SRES). Although there are four SRES scenarios, for this study, the A2 and B2 scenarios have been used, respectively, representing strong economic values (A2) and strong environmental values (B2).

The modeled irrigation needs and peak demands, calculated using the CROPWAT model for the 14 selected irrigation districts, vary between districts but the average predicted increases are 9.4 and 8.3% (2050_A2 and 2050_B2), respectively.

Fischer *et al* (2006) predicted that by 2080 irrigation water requirements will increase over 50% in developing regions and by about 16% in developed regions.

In a study conducted by Goyal (2004), an attempt has been made to study the sensitivity of evapotranspiration to global warming for arid regions of Rajasthan (India). The Penman–Monteith equation was used to estimate reference evapotranspiration, and sensitivity of ET has been studied in terms of change in temperature, solar radiation, wind speed and vapor pressure within a possible range of ± 20% from the normal long-term meteorological parameters of 32 years (1971–2002). The study suggests an increase of 14.8% of total ET demand with increase in temperature by 20% (maximum 8 °C). ET is less sensitive (11%) to increase in net solar radiation, followed by wind speed (7%) in comparison to temperature. Increase in vapor pressure (20%) has a small negative effect on ET (−4.31%).

Other studies in Egypt and Jordan reported an increase of 2.3% of total irrigation water use for every degree rise in temperature (Abu-Taleb, 2000).

El-Fadel and Bou-Zeid (2001) stated that the trend is clearly towards increasing temperature for the Middle East, this will increase irrigation water demand due to higher evaporation. Increased temperature and evapotranspration coupled with constant precipitation are highly associated with desertification.

3. Chapter 3: Methodology

3.1 General

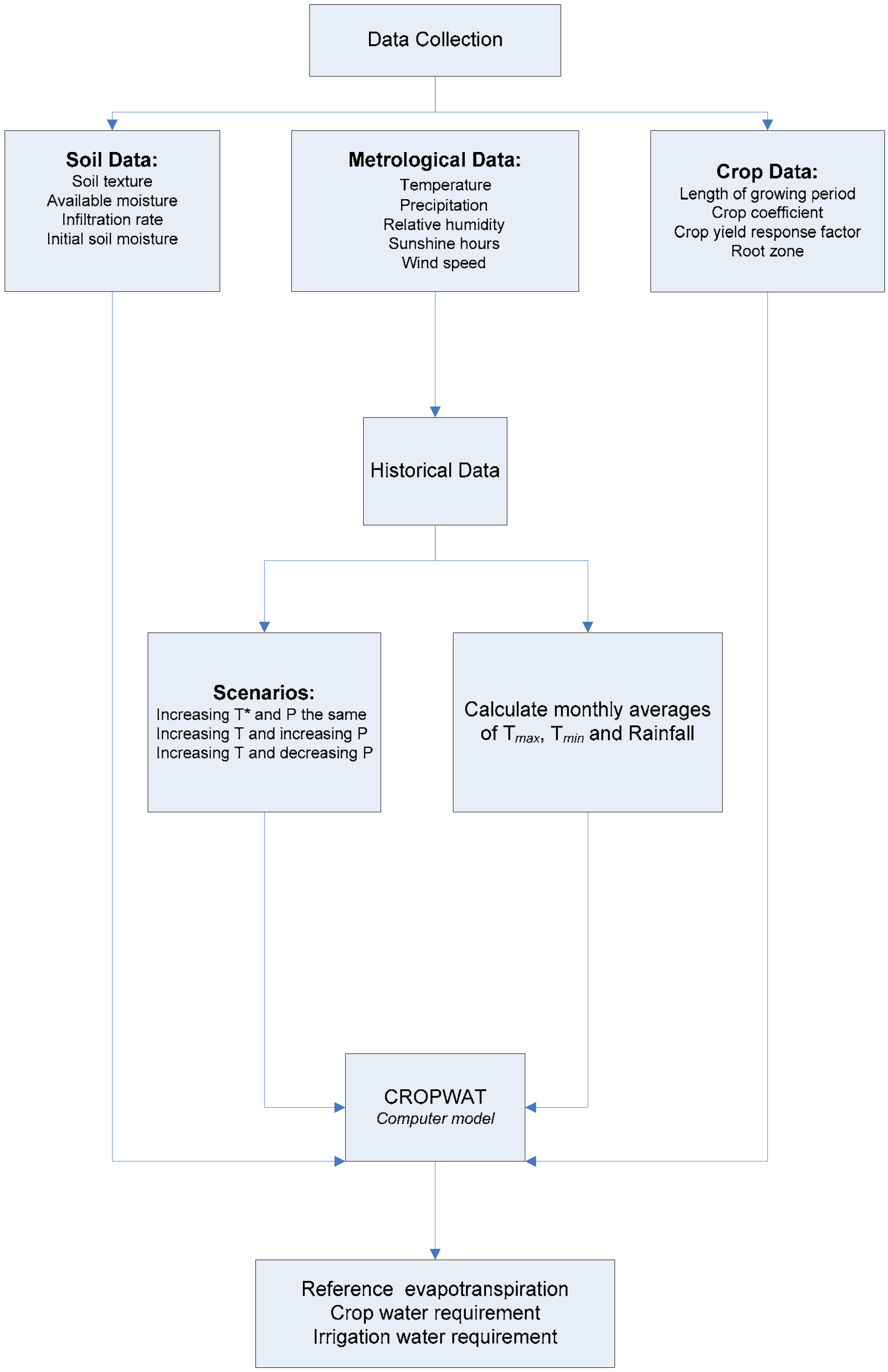
This study aims to analyze the potential impact of climate change on the agricultural water demand; in other words, to assess of the sensitivity of agricultural water demand to climate variables, mainly to temperature and precipitation change.

Jericho and Al Aghwar district was chosen as the study area to examine the impact of changing climatic parameters; temperature and precipitation on the irrigation water requirement of the district. The Jericho and Al Aghwar district was chosen for this study because it’s distinguished for its agricultural activities. Despite the high temperature, evaporation and low rainfall, the success of agriculture in the district is related to the combination of its below sea level, year-round warm weather and availability of water (from springs and wells) (ARIJ, 1995).

Also, Jericho was chosen because the variety of crops in the area; the warm winter temperature helps in cultivating vegetable crops which would not be possible during this season in other parts of Palestine, the Middle East and Europe. Thus, agriculture in the Jericho and Al Aghwar district has a high economic potential both in the local and export markets. Tropical crops are also possible, increasing the diversity of agriculture in Palestine (ARIJ, 1995).

The study uses the CROPWAT computer model to calculate the crop water requirement for the irrigated crops in Jericho and Al Aghwar district using historical metrological data of the area under consideration to provide the baseline data, and then re-calculate the crop water demand under different scenarios; including increasing temperature, decreasing precipitation and increasing precipitation, in order to see how the crop water requirement will change under temperature and precipitation variation. This could simulate the change in agricultural water demand under climate change.

Figure 3.1 shows the general framework of the methodology used in this study.



* T: Temperature, P: Precipitation.

Figure 3.1 Methodological framework of the study.

3.2 CROPWAT Computer Model

CROPWAT computer model was used in this study to calculate reference evapotranspiration (ET_o), crop water requirements (CWR) as well as irrigation water requirements (IWR) for different crops in the area under consideration.

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO; it uses the FAO (1992) Penman-Monteith methods for calculating reference crop evapotranspiration (FAO, 1998a)

It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain-fed conditions or deficit irrigation.

The underlying sections simplify the calculation procedures used in the CROPWAT software:

3.2.1 Calculating reference evapotranspiration (ET_o)

The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET) (FAO, 1998b).

The evapotranspirration rate is normally expressed in millimeters (mm) per unit time. The rate is expressed as the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, month or even the entire growing period or year.

The reference evapotranspiration (ET_o) is defined as the evpotranspiration from a reference surface; of a reference crop. FAO defined the reference crop as hypothetical crop with an assumed height of 0.12m having the surface resistance of 70 sm^{-1} and albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height which is actively growing and adequately watered.

Thus, ET_o is a climatic parameter expressing the evaporation power of the atmosphere and can be computed from meteorological data. CROPWAT uses the FAO Penman-Monteith method to calculate ET_o; the method was recommended as the standard method for the definition and computation of the reference evapotranspiration, ET_o.as a result of an expert consultation held in May 1990 and organized by the FAO.

The FAO Penman-Monteith equation to estimate ET_o is:

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T + 273}\,u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where;

ET_o	reference evapotranspiration [mm day^{-1}]
R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}]
G	soil heat flux density [MJ m^{-2} day^{-1}]
T	mean daily air temperature at 2 m height [°C]
u_2	wind speed at 2 m height [m s^{-1}]
e_s	saturation vapour pressure [kPa]
e_a	actual vapour pressure [kPa]
$e_s - e_a$	saturation vapour pressure deficit [kPa]
Δ	slope vapour pressure curve [kPa $°C^{-1}$]
γ	psychrometric constant [kPa $°C^{-1}$]

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

3.2.2 Calculating crop evapotrnspiration (ET_c)

Crop evapotranspiration (ET_c) refers to the evapotranspiration from excellently managed, large, well-watered fields that achieve full production under the given climatic conditions. Due to sub-optimal crop management and environmental constraints that affect crop growth and limit evapotranspiration, ET_c under non-standard conditions generally requires a correction to obtain $ET_{c\ adj}$ (FAO, 1998b).(Figure 3.4). For the purpose of this study $ET_{c\ adj}$ is not considered as we are interested in the impact of climate change only; optimal management and environmental conditions should be maintained.

Crop evapotranspiration can be determined using the following equation:

$$ET_c = K_c \times ET_o$$

Where;

ET_o reference evapotranspiration,

K_c crop coefficient.

At this stage, to calculate K_c using CROPWAT it is necessary to define the crop, select cropping pattern, determine time of planting or sowing, rate of crop development stage and growing period.

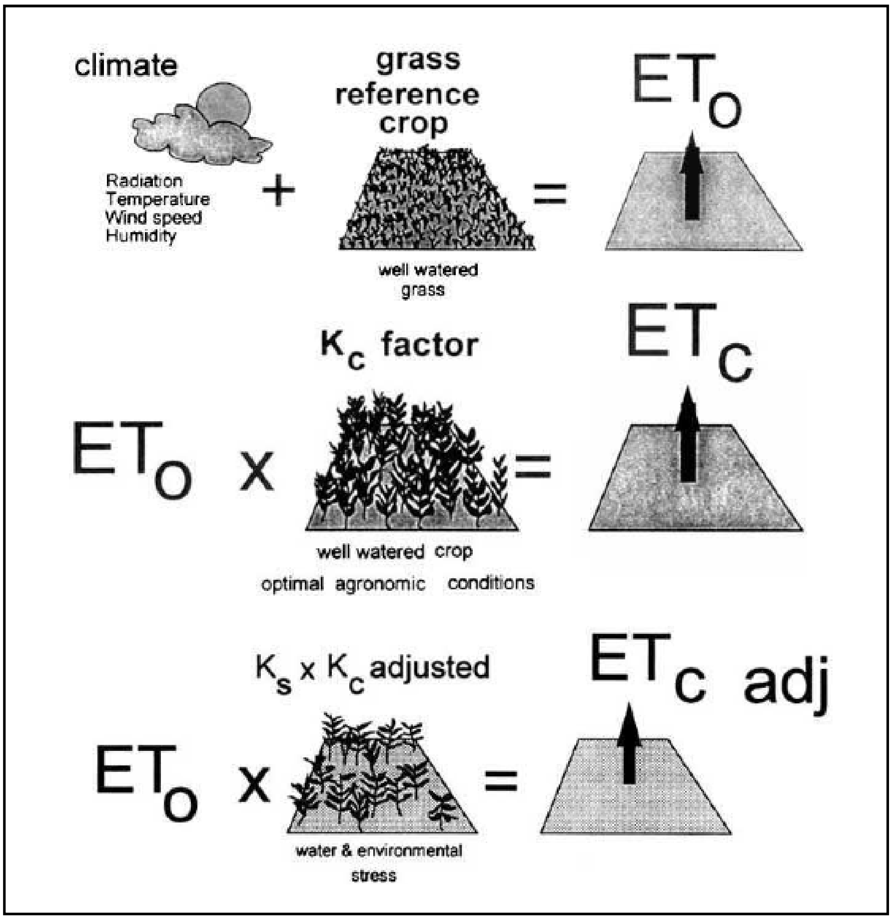


Figure 3.2 Reference (ET_o), crop evapotranspiration under standard (ET_c) and non-standard conditions ($ET_{c\ adj}$)
Source: FAO, 1998b.

3.2.3 Calculating crop water requirement (CWR)

Under optimal management and environmental conditions crop evapotranspiration is equal to the crop water requirements. In other words, the amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement.

Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration.

In CROPWAT, crop water requirement (CWR) is expressed as (ET_m); maximum/ potential evapotranspiration, and under optimal management and environmental conditions:

$$ET_m = ET_c = K_c \times ET_o$$

3.2.4 Calculating irrigation water requirements (IWR)

The irrigation water requirement of a crop is the total amount of water that must be supplied by irrigation to a disease free crop, growing in a large field with adequate soil water and fertility, and achieving full production potential under the given growing environment (FAO, 1998b).

The irrigation water requirement (IWR) basically represents the difference between the crop water requirement and effective rain, where the effective rain is defined as the portion of the rainfall that is effectively used by the crop after rain. The amount of effective rainfall depends on the precipitation rate and soil moisture conditions.

3.2.5 Data required for CROPWAT

For the CROPWAT to perform the procedures discussed earlier three types of data are required:

Metrological data, including:

- Mean monthly maximum temperature (°C)
- Mean monthly minimum temperature(°C)

- Mean monthly relative humidity (%)
- Sunshine hours (hours)
- Wind speed (km/day)
- Precipitation (mm)

Soil data, including:

- Soil texture
- Available moisture (mm/m depth)
- Infiltration rate (mm/day)
- Initial soil moisture (%)

Crop data, including:

- Length of growing period of crops
- Crop coefficient (K_c)
- Crop yield response factor (k_y)
- Root zone (m)

3.3 Study Area

The procedure discussed in section 3.2 was applied for the irrigated open-field agriculture in the study area selected for the purpose of this study; Jericho and Al Aghwar district. The following sections represent a simplified profile for the study area under consideration.

3.3.1 General

Jericho and Al Aghwar district is located on the eastern boundary of the West Bank; its boundaries extend from the Dead Sea in the south to the southern part of Fasayel in the north, and from the eastern slopes of the Jerusalem and Ramallah mountains in the west to the Jordan River in the east[4], (Figure 3.3). The district has an area of approximately 35,330 hectares; of this area, 591 hectares are inhabited by Palestinians and 517.4 hectares are occupied by Israeli settlement (ARIJ, 1995).

The only urban settlement in the district is the Jericho city which is considered the lowest city on earth; 250 m below sea level. It lies 10 km northwest of the Dead Sea and 7 km to the west of the Jordan River. While it has a desert climate, its abundant water resources give it the character of an oasis. It is this character which makes it an important agricultural area, especially for fruits and vegetables.

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[4] These boundaries were defined by ARIJ according to the pre-1967 Jordanian and the current Israeli designation.

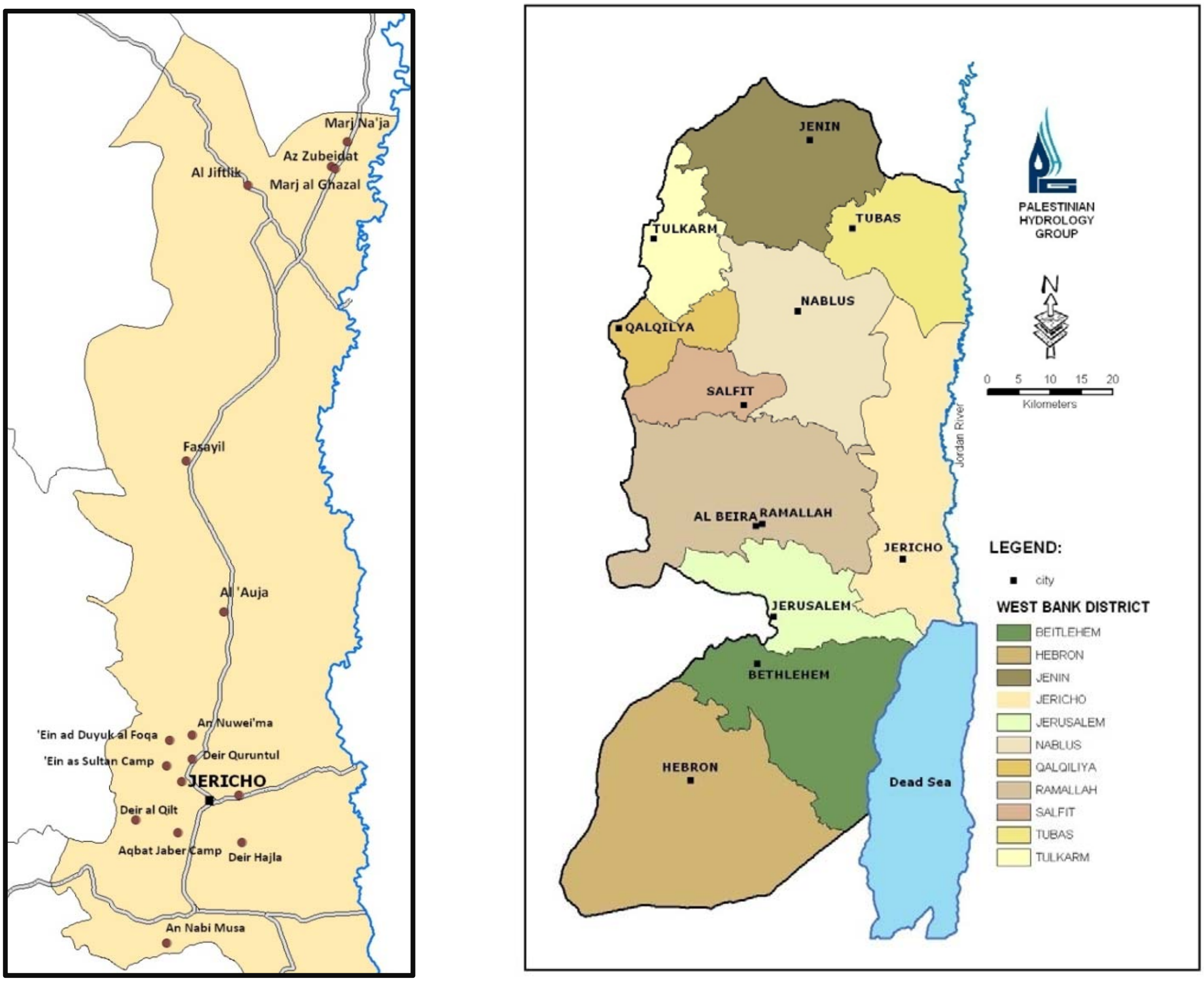

Figure 3.3 Location map of the Jericho and Al Aghwar district.
Source: PHG database, 2008.

3.3.2 Climate

The climate of Jericho and Al Aghwar district is classified as arid, which has hot summers and warm winters with very rare frosts incidents. January is the coldest month for the district and August is the warmest. The average maximum temperatures during January and August are around 20.7 °C and 38.8 °C respectively. The average minimum temperatures for the same months are around 8.2 °C and 24 °C respectively. The average relative humidity is 53%. The district receives an average of 146 mm total rainfall with more than 80% of the total rainfall occurring during December, January, February and March.

3.3.3 Land use

Jericho and Al Aghwar district has a total area of 353,300 dunums. Five major land use classes can be distinguished in the district; Palestinian built-up areas, Israeli settlements, closed military areas and bases, nature reserves and cultivated areas. The cultivated areas cover 45,606 dunums of the total area of the district (Figure 3.3).

Due to the limited rainfall combined with the hot weather, irrigated agriculture is dominant in the district. The cultivated areas are concentrated in Jericho city, Dyouk, Nuwe’ma and Al-Auja including the following major types of cultivation presented in Table 3.1.

Table3.1 Cultivated areas of fruit trees, vegetables and field crops in Jericho and Al Aghwar district

			Area (Dunum)[5]
Fruit trees	Bearing	Rainfed	0
		Irrigated	3,097
	Unbearing	Rainfed	0
		Irrigated	2,555
Vegetables	Rainfed		0
	Open irrigated		32,494
	Protected		999
Field crops	Rainfed		0
	Irrigated		6,461

Source: Ashqar, 2008.

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[5] Dunum = 1000 m^2.

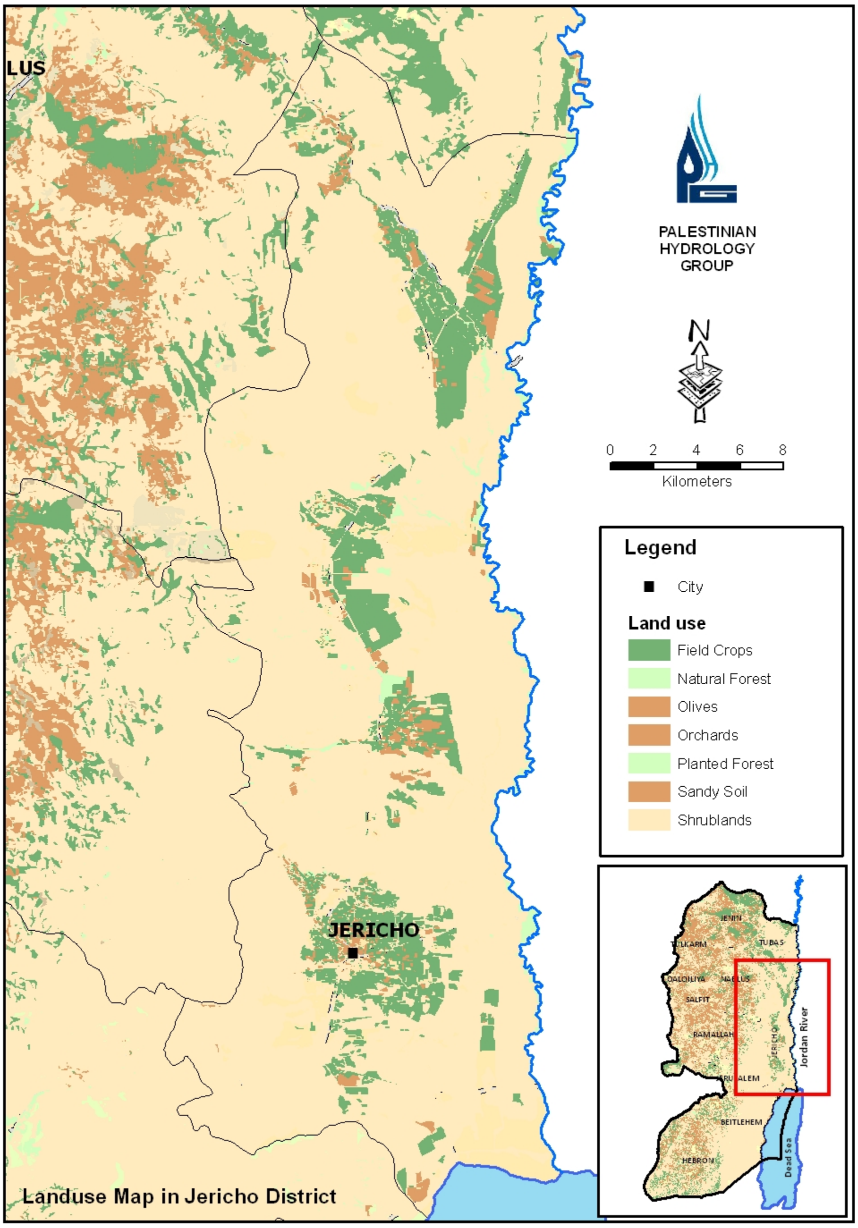

Figure 3.4 Land use map of the Jericho and Al Aghwar district
Source: PHG database, 2008.

3.3.4 Soils

In the Jericho and Al Aghwar district 9 soil associations can be distinguished; these are summarized in Table 3.2. The dominant soil texture, which is considered to determine the irrigation requirements, is sandy loam (ARIJ, 1995, ARIJ 1998).

Table 3.2 Soils classification in the Jericho and Al Aghwar district.

Soil association	Area (hectare)	American classification	General characteristics
1. Alluvial arid brown soils	6,470	Haplargids and Camborthids	The soils have brown color and loamy texture. Parent rocks are Calcareous silty and materials.
1. Lossial arid brown soils	1,290	Palexeralfs, Haploxeralfs and Xerochrepts	The soils have yellowish-brown color, loamy texture and subangular structure. Parent rocks are conglomerated chalk.
2. Reg soils and coarse desert alluvial	800	Gypsiorthid and Camborthids	The soils have very pale brown color. Texture is loamy. parent materials are of mixed stone.
3. Brown lithosolsand loessial serozems	4,670	Haplargids	The soils have yellowish-brown or very pale brown color, coarse texture, and subgranular structure. Parent rocks are limestone, chalk, dolomite and fint.
4. Calcareous serozems	2,400	Xerochrepts, Calciorthids and Gypsiorthids.	The soil is highly calcareous with grayish-brown color. The texture is medium to fine. Parent rocks are limestone, chalk and marl.

5. Solonchalks	3,460	---------	The texture ranges from sand to clay, suffering from high water table and in some cases is extremely saline, with up to 50% salts. The parent materials are recent alluvial deposits.
6. Loessial serozems	4,920	Haplargids	The soils have yellowish-brown to brown color, and coarse texture. Parent materials are lossial sediments, gravels and highly calcareous loamy sediment.
7. Regosols	8,880	Xerochrepts, Calciorthids and Gypsiorthids.	The soils have pale brown color, loamy texture. Parent materials are sands, clays and loess.
8. Brown lithosols and loessial arid brown soils	2,410	Haploxeralfs and Xerochrepts	The soils have yellowish-brown, coarse texture and subgranular blocky to massive structure. Parent rocks are chalk, marl, limestone and conglomerates.

Source: ARIJ, 1995.

3.4 Data Used in the Study

3.4.1 Climatic data

Precipitation, temperature, humidity, wind speed and solar radiation monthly records were taken from the Palestinian Metrological Center/Geographical Center for Jericho and

Al Aghwar district. Records were available with different periods for each parameter; for maximum and minimum temperatures records were available for 18 years, while for relative humidity, data were available for 38 years, with some missing years (1993, 1994, 1995 and 1996). Wind speed and sunshine duration records were available for 11 years and for rainfall 32 years record were available.

These records were used to calculate the monthly average for each parameter until 2007 for Jericho and Al Aghwar district, and the results were as listed in Table 3.3.

Table 3.3 Monthly averages for the climatic parameters obtained for the Jericho and Al Aghwar district.

	Rainfall (mm)	Temp $_{max}$ (c^0)	Temp $_{min}$ (c^0)	R.H (%)	Wind speed (km/hr)	Sunshine (hr/day)
January	34.4	20.7	8.2	70	5.3	5.8
February	30.6	20.4	8.4	65	5.9	6.6
March	23.3	23.5	10.9	57	8.1	7.6
April	4.7	29.4	14.8	45	9.3	8.9
May	0.1	34.5	18.9	39	9.9	10.2
June	0.0	37.0	21.5	40	9.6	11.8
July	0.0	39.2	23.6	41	9.5	11.8
August	0.0	38.8	24.0	45	8.7	11.4
September	0.0	36.6	22.1	47	7.8	10.2
October	2.6	33.1	19.3	52	6.4	8.4
November	18.5	27.3	13.9	59	5.1	7.2
December	31.7	20.7	10.0	70	5.5	5.6

These records were used as the entry data for the CROPWAT in order to calculate crop evapotranspiration and crop water requirement. But note that for the wind speed the records were available at 10 m, where it should be entered in the CROPWAT model at 2m, so the records were transformed to the required height using the following equation and the results are tabulated below;

$$U_2 = U_z \frac{4.87}{\ln(67.8z - 5.42)}$$

Where,

U_2 is wind speed at 2 m and U_z is wind speed at elevation z.

Table3.4 Wind speed for Jericho and Al Aghwar district in (km/hr) at 10 meters and 2 meters.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Wind speed @ 10 m	5.3	5.9	8.1	9.3	9.9	9.6	9.5	8.7	7.8	6.4	5.1	5.5
Wind speed @ 2 m	3.9	4.4	6.1	7.0	7.4	7.2	7.1	6.5	5.9	4.8	3.8	4.1

3.4.2 Crop data

Crops considered in this study are irrigated open-field crops only; rainfed agriculture and greenhouses are excluded from this study. A summary of the main crops grown in the Jericho and Al Aghwar district and their respective areas were obtained from the Palestinian Ministry of Agriculture and are summarized in Table 3.5.

All crops parameters were taken from the FAO, 1998b.

Table 3.5 Open field crops in Jericho and Al Aghwar district

	Crop	Name in Arabic	Area (Dunum)	Planting Date
Fruit Trees	Banana	موز	2100	Jan.
	Date	بلح	1882	Dec.
	Fig	تين	35	Mid Feb.
	Pomegranate	رمان	70	Mid Feb.
	Grape	عنب	348	Mid Feb.
	Citrus	حمضيات	1132	Jan.
	Olives	زيتون	85	Dec.
Vegetables	Squash	كوسا	9180	Sep.
	Corn	ذرة صفرا	6868	Oct.
	Eggplant	باذنجان	4817	Sep.
	Tomato	بندورة	3468	Sep.
	Green beans	فاصوليا خضرا	1760	Oct.
	Kidney beans	فاصوليا صفرا	290	Oct
	Fababeans	فول أخضر	835	Oct
	Cauliflower	قرنبيط	994	Oct.
	Jew's Mallows	ملوخية	782	Feb.
	cabbage	ملفوف أبيض	795	Oct.
	Snake Cucumber	فقوس	586	Jan.
	Pepper	فلفل حلو	569	Oct.
	chilli pepper	فلفل حار	499	Oct.
	Okra	بامية	570	Feb.
	Pumpkin	يقطين	455	Sep.
Field Crops	Wheat	قمح	3980	Nov.
	Barley	شعير	1180	Nov.
	Vetch	بيقا	89	Sep.
	Alfalaf	برسيم	820	Sep.
	Potato	بطاطا	105	Oct.
	Onion (Dry)	بصل	256	Oct.
	Garlic	ثوم	26	Oct.
	Thyme	زعتر	26	Oct
	Sage	مرمية	5	Oct

Source: Ashqar, 2008.

3.4.3 Soil data

ARIJ (1995) and MoA (2004) stated that the dominant soil in the Jericho and Al Aghwar district is sandy loam. Based on the details of soil strata from the FAO for different types of soil and typical soil water characteristics (FAO, 1998b), the total available soil moisture (TAW) data were taken as 100 mm/m depth of soil.

3.5 Scenarios Applied in the Study

Different scenarios were applied for the study area, and consequently, reference evapotranspiratio (ET_o), crop water requirement (CWR) and irrigation water requirement (IWR) were calculated under each scenario.
The scenarios were formulated based on changing Temperature (T) and precipitation (P); other metrological data, soil data and crop data are not changed and optimal management and environmental conditions are maintained.

Scenarios used in the study include:

- Temperature change scenario: a scenario of increasing temperature while keeping precipitation not changed was first examined; as the trends of temperature change discussed in Chapter 2 all indicated temperature increase for Palestine the Mediterranean. This scenario formulated was as follows:

	T	T+1	T+2	T+3
Reference evapotranspiratio (ET_o)	…..	…..	…..	…..
Crop water requirement (CWR)	…..	…..	…..	…..
Irrigation water requirement (IWR)	…..	…..	…..	…..

- Precipitation change scenario: as discussed in Chapter 2, there is no distinguished trend of precipitation change in the Mediterranean and analysis of previous records from Palestinian meteorological stations indicated increasing trend in some areas and decreasing trend in other areas.

For this purpose two precipitation scenarios were examined; increasing and decreasing. This scenario formulated was as follows:

	P-20%	P-10%	P	P+10%	P+20%
Reference evapotranspiratio (ET_o)	…..	…..	…..	…..	…..
Crop water requirement (CWR)	…..	…..	…..	…..	…..
Irrigation water requirement (IWR)	…..	…..	…..	…..	…..

- Temperature and precipitation change scenario: this scenario is a combination of the first two scenarios. The results were a matrix as follows:

	T	**T+1**	**T+2**	**T+3**
P-20%	…..	…..	…..	…..
P-10%	…..	…..	…..	…..
P	…..	…..	…..	…..
P+10%	…..	…..	…..	…..
P+20%	…..	…..	…..	…..

Actually several scenarios are imbedded in this matrix. Also, this scenario was applied three times to calculate reference evapotranspiration (ET_o), crop water requirement (CWR) and irrigation water requirement (IWR).

4. Chapter 4: Results and Discussion

4.1 Impacts of Climate Change

Any change in climatic parameters may affect the agricultural water demand, and this study examines the potential effect of changing temperature and precipitation on evapotranspiration rates and subsequently the additional amount of irrigation water that may be needed to overcome the increase in evapotranspiration.

4.1.1 Impact of increasing temperature on reference evapotranspiration

Reference evapotranspiration (ET_o) changes with changing temperature only; precipitation change has no effect on ET_o. Sensitivity analysis was conducted to estimate the change in reference evapotranspiration with increasing temperature and the results shows that with increasing T by 1 °C ET_o changes by an average of 2.6% , and for T+2 °C and T+3 °C the change rates were 5.3% and 8% respectively (Table b-Annex1).

The total ET_o for each crop in Jericho and Al Aghwar district is tabulated in Table a-Annex 1. It should be noticed that the reference crop evpotranspiration is calculated using climatic data input only using reference crop; its value does not depend on the crop type. The variation in ET_o values for each crop results from the variation in the planting date and crop cycle duration for each crop.

4.1.2 Impact of increasing temperature on crop water requirement

The impact of temperature increase on crop water requirement was examined; from analyzing the results it was shown that the main driving factor to increase crop water requirement is the increase in temperature. A sensitivity analysis of temperature change by +1 °C, +2 °C and +3 °C to the original has shown an average of 2.7%, 5.4% and 8% change in crop water requirement respectively (Table d-Annex1).

These results are well-matched with the results in section 4.1.1, which is reasonable; as crop evapotranspiration refers to the amount of water that is lost through evapotranspiration and crop water requirement refers to the amount of water that needs to be supplied to overcome the water lost in evapotranspiration.

The impacts of temperature increase on crop water requirement for each crop in Jericho and Al Aghwar district are tabulated in Table c-Annex 1. For example, the impact on Date, which has the highest water requirement of 1614.39 mm, showed that with each 1°C increase 38.4 mm is required to overcome the evapotranspiration increase. The results also showed that crops vary in their sensitivity to temperature increase; some crops are very sensitive to temperature increase, like barley for example.

Figure 4.1 below shows how the crop water requirement (CWR) for some selected crops changes with increasing temperature. Although crops have different crop water requirements but the increasing trend as shown in the graph is almost the same; for example when temperature increases by 1°C all crops water requirements change in the range between (2.25 -3.38)% , the change rates for all crops are shown in Table d-Annex 1.

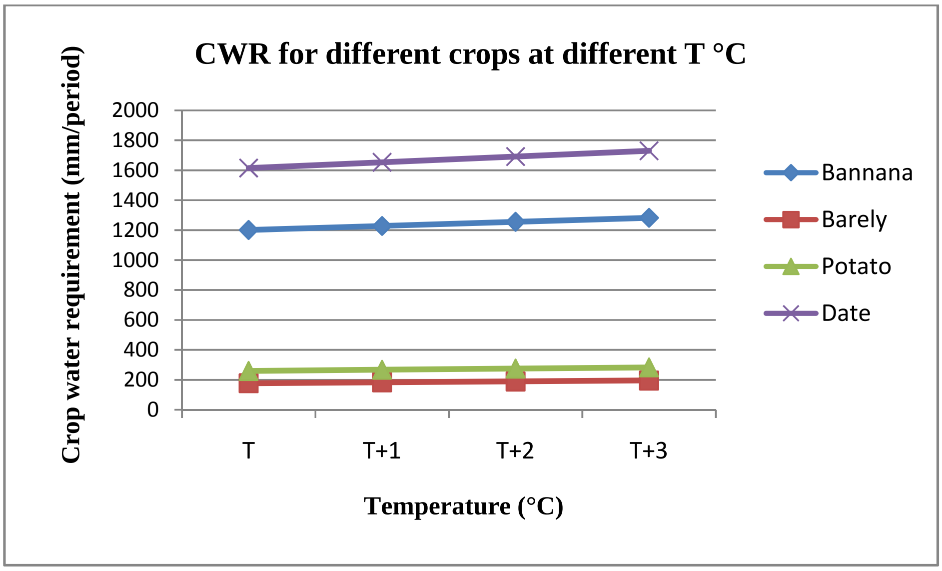

Figure 4.1 Crop water requirements for different crops at different temperature scenarios.

Table 4.1 shows the sensitivity analysis of crop water requirement to temperature increase for the total open-field agricultural area of the Jericho and Al Aghwar district.

Table 4.1 Sensitivity analysis of crop water requirement (CWR) to temperature increase.

	T	**T+1**	**T+2**	**T+3**
CWR (MCM)	23.34	23.93	24.53	25.13
Change rate %	0	2.5	5.1	7.7

4.1.3 Impact of changing precipitation

The impact of changing precipitation was examined under two scenarios; increasing precipitation and decreasing precipitation. A sensitivity analysis of precipitation resulted in an increase in irrigation required by an average of 1.47 % and 5.53% for a decrease in precipitation by 10% and 20%, respectively, as shown in Table 4.2. The other scenario; increasing precipitation, showed a decrease by an average of 1.44% and 2.84% in the irrigation required for an increase by 10% and 20% in precipitation, respectively. The change rate results for each crop are tabulated in Table f-Annex 1.

Table 4.2 Sensitivity analysis of irrigation water requirement (IWR) to precipitation change.

	P-20%	**P-10%**	**P**	**P+10%**	**P+20%**
IWR (MCM)	21.05	20.24	19.95	19.66	19.38
Change rate %	5.53	1.47	0.00	-1.44	-2.84

The sensitivity of irrigation required for each crop to precipitation change is listed in Table e-Annex 1.

4.1.4 Water demand deficits under different scenarios for Jericho and Al Aghwar district

Applying different scenarios for Jericho and Al Aghwar district, including increasing temperature, increasing precipitation and decreasing precipitation, where the base line scenario is the current situation under the current temperature and precipitation values, resulted in the matrices presented in Table 4.3 and Table 4.4.

Table 4.3 Total irrigation demand for Jericho under different scenarios in MCM/year.

	T	**T+1**	**T+2**	**T+3**
P-20%	21.05	21.63	22.23	22.83
P-10%	20.24	20.82	21.42	22.01
P	19.95	20.53	21.12	21.71
P+10%	19.66	20.24	20.83	21.42
P+20%	19.38	19.96	20.54	21.13

Table4.4 Additional water required under the different scenarios in MCM/year.

	T	**T+1**	**T+2**	**T+3**
P-20%	1.104	1.685	2.285	2.881
P-10%	0.294	0.877	1.469	2.065
P	0.00	0.581	1.172	1.763
P+10%	-0.286	0.291	0.880	1.470
P+20%	-0.566	0.010	0.596	1.181

The results clearly show that the scenario of increasing temperature gets worse when combined with the scenario of decreasing precipitation; where (T+3, P-20%) scenario being the worst scenario resulted in additional 2.9 MCM required annually to overcome the water lost in evapotranspiration under the proposed scenario.

Figures 4.2 & 4.3 below show the projected trend of total irrigation water required under decreasing precipitation and increasing temperature, respectively.

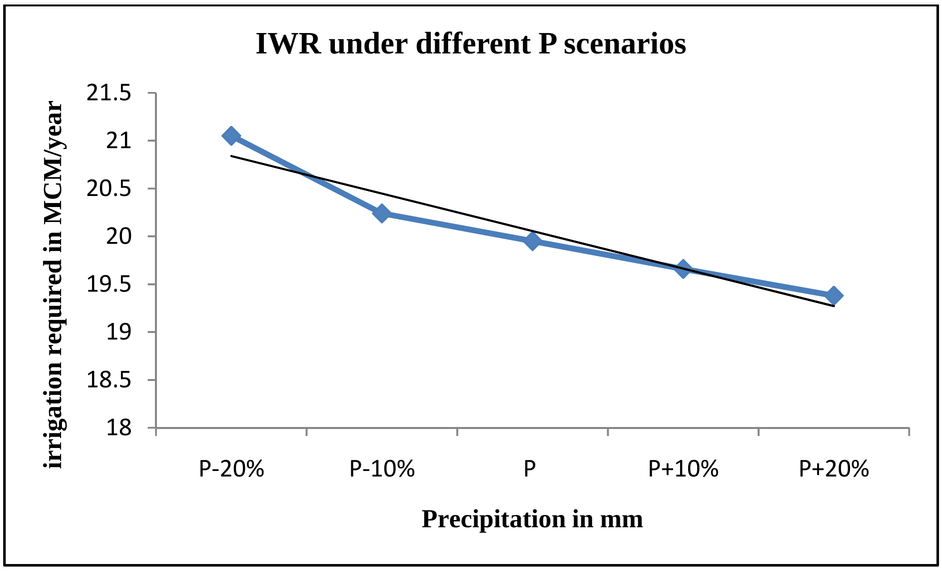

Figure 4.2 Total irrigation water requirement in (MCM/year) for different precipitation scenarios.

The relationship between IWR and precipitation is a linear relation according to the following equation:

$y = -0.287x + 20.812$

This means that the irrigation water requirement (IWR) decreases by 0.29 MCM/year with each increase of 10% in precipitation.

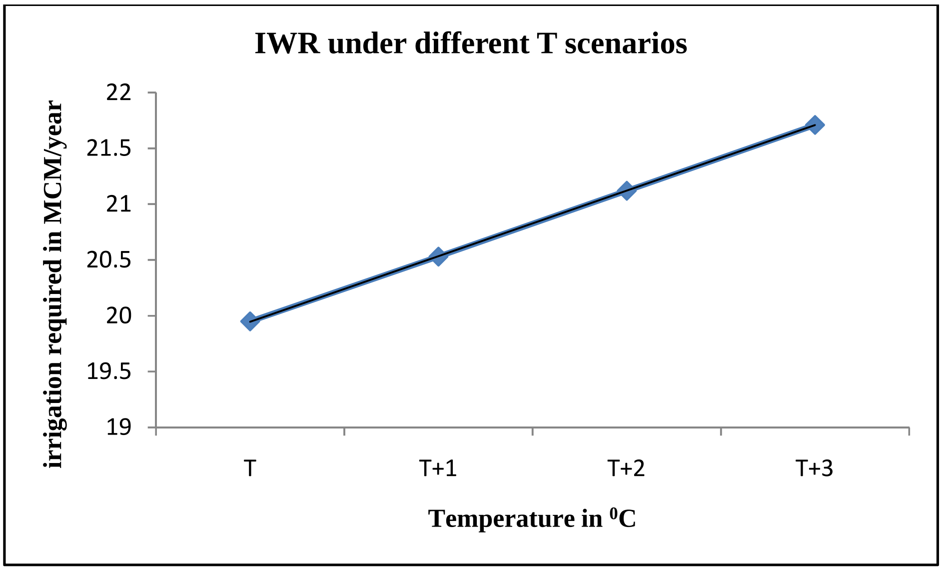

Figure 4.3 Total irrigation water requirement in (MCM/year) for different temperature scenarios.

The relationship between IWR and temperature is also a linear relation that follows:

$y = 0.587x + 19.36$

The irrigation water demand (IWR) increases by 0.59 MCM/year with each increase of 1°C in temperature.

It can be noticed that crops are highly affected by temperature change rather than precipitation change, and for the area under study; Jericho already experiences low rainfalls and already coping with agriculture under low rainfalls where most of the agriculture in the Jericho and Al Aghwar district are irrigated agriculture.

Chapter 5: Conclusion and Recommendation

5.1 Conclusion

Any change in the climate variables will have a significant impact on evapotranspiration and subsequently a profound effect on agricultural water demand. This research studies how climatic variables, specifically temperature and precipitation, affect irrigation water demand. The study takes the Jericho and Al Aghwar district (Palestine) as the case study and examining different climate change scenarios including increasing temperature, increasing precipitation and decreasing precipitation.

CROPWAT computer model is used in the present study to calculate evapotranspiration and irrigation demand under the different scenarios, the results are as follows:

- Under increasing temperature, reference evapotranspiration ET_o increases by 2.6%, 5.3% and 8% with temperature increases by 1°C, 2°C and 3°C, respectively.
- Crop water requirement increases by 2.7%, 5.4% and 8% as temperature increases by 1°C, 2°C and 3°C, respectively, to compensate the water lost in evapotranspiration.
- Irrigation water requirement (IWR) decreases by 0.29 MCM/year with each increase of 10% in precipitation, and increases by 0.59 MCM/year with each increase of 1°C in temperature.
- The results also show that the impact of the scenario of increasing temperature on the total irrigation demand for the Jericho and Al Aghwar district gets worse when combine with the scenario of decreasing precipitation; the worst scenario examined is when temperature increases by 3°C and precipitation decreases by 20% which result in additional 2.9 MCM of water required annually to overcome the impact of climate change under this scenario.

Although the results presented in the study are estimates, they provide a preliminary idea about the potential impact of climate change on agricultural water demand, taking into consideration that these results present the impact on irrigated open field agriculture only, which means that the deficit in agricultural water demand will become greater when considering the impact of climate change on rain-fed agriculture and greenhouses.

5.2 Recommendation

In response to the previous results and conclusions the following measures are recommended:

- It is time for planners to think in terms of expected change in water requirement due to climate change while estimating the future water demands and planning for development of future water resources in Palestine.
- Yet much remains to be done to improve the predictions of future irrigation water requirement for agriculture in Palestine; studies that consider the climate change impact on rain-fed and greenhouses agriculture and studies to cover the whole agricultural areas in Palestine.
- Adaptation measure should be considered to cope with climate change potential impacts on water demand, and it should be noted that most of the adaptation measures are no-regret options, in other words, they would be beneficial regardless of climate change impacts especially that Palestine is already facing water shortage due to natural water resources scarcity and other political restrictions. Fischer G. *et al*, (2006), showed in a study that mitigation reduced the impacts of climate change on agricultural water requirements by about 40% compared with unmitigated climate change.

  Most adaptation measures attempt to develop non-conventional sources of water that can be exploited in the future including use of surplus winter runoff, wastewater reclamation, seawater and brackish water desalination and rainfall enhancement by seeding clouds with silver iodide crystals, taking into consideration that adoption of any adaptation measure will need capital investment, institutional reform and capacity building.

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Annex 1

Table-a: Reference evapotranspiration(ET_o) in (mm) with increasing temperature for different crops.

	ET_o (mm)			
	T	**T+1**	**T+2**	**T+3**
Banana	1376.75	1408.87	1441.4	1473.21
Date	1727.48	1768.69	1810.55	1851.83
Fig	1727.48	1768.69	1801.55	1851.83
Pomegranate	1727.48	1768.69	1801.55	1851.83
Grape	1727.48	1768.69	1810.55	1851.83
Citrus	1727.48	1768.69	1810.55	1851.83
Olives	1727.48	1768.69	1810.55	1851.83
Squash	428.62	439.46	450.6	461.87
Corn	266.37	273.76	281.29	288.98
Eggplant	460.16	472.17	484.43	496.88
Tomato	460.16	472.17	484.43	496.88
Green beans	251.46	258.31	265.3	272.44
Kidney beans	251.46	258.31	265.3	272.44
Fababeans	369.76	380.67	391.56	402.75
Cauliflower	266.37	273.76	281.29	288.98
Jew's Mallows	1727.48	1768.69	1810.55	1851.83
cabbage	266.37	273.76	281.29	288.98
Snake Cucumber	274.05	281.72	289.52	297.51
Pepper	319.3	328.6	337.94	347.55
chilli pepper	319.3	328.6	337.94	347.55
Okra	753.15	771.35	789.57	807.34

Pumpkin	388.6	398.04	407.8	417.66
Wheat	957.25	981.77	1006.28	1030.52
Barley	248.09	256.09	263.96	272.08
Vetch	1727.48	1768.69	1810.55	1851.83
Alfalaf	1727.48	1768.69	1810.55	1851.83
Potato	319.3	328.6	337.94	347.55
Onion (Dry)	640.34	658.2	675.96	693.89
Garlic	640.34	658.2	675.96	693.89
Thyme	258.91	266.03	273.28	280.7
Sage	258.91	266.03	273.28	280.7

Table-b: Change rate (%) of reference evapotranspiration (ET_o) with increasing temperature for different crops.

	Change rate of ET_o (%)			
	T	**T+1**	**T+2**	**T+3**
Banana	0	2.33	4.70	7.01
Date	0	2.39	4.81	7.20
Fig	0	2.39	4.29	7.20
Pomegranate	0	2.39	4.29	7.20
Grape	0	2.39	4.81	7.20
Citrus	0	2.39	4.81	7.20
Olives	0	2.39	4.81	7.20
Squash	0	2.53	5.13	7.76
Corn	0	2.77	5.60	8.49
Eggplant	0	2.61	5.27	7.98
Tomato	0	2.61	5.27	7.98
Green beans	0	2.72	5.50	8.34
Kidney beans	0	2.72	5.50	8.34
Fababeans	0	2.95	5.90	8.92
Cauliflower	0	2.77	5.60	8.49
Jew's Mallows	0	2.39	4.81	7.20
cabbage	0	2.77	5.60	8.49
Snake Cucumber	0	2.80	5.64	8.56
Pepper	0	2.91	5.84	8.85
chilli pepper	0	2.91	5.84	8.85
Okra	0	2.42	4.84	7.20

Pumpkin	0	2.43	4.94	7.48
Wheat	0	2.56	5.12	7.65
Barley	0	3.22	6.40	9.67
Vetch	0	2.39	4.81	7.20
Alfalaf	0	2.39	4.81	7.20
Potato	0	2.91	5.84	8.85
Onion (Dry)	0	2.79	5.56	8.36
Garlic	0	2.79	5.56	8.36
Thyme	0	2.75	5.55	8.42
Sage	0	2.75	5.55	8.42
Average	**0**	**2.63**	**5.26**	**7.98**

Table-c: Sensitivity of crop water requirement (CWR) to temperature increase in (mm/period) for different crops.

	CWR (mm/period)			
	T	**T+1**	**T+2**	**T+3**
Banana	1200.85	1227.85	1255.41	1282.23
Date	1614.39	1652.79	1691.8	1730.27
Fig	1073.35	1099.42	1125.91	1152.19
Pomegranate	1073.35	1099.42	1125.91	1152.19
Grape	879.92	901.1	922.64	943.99
Citrus	1171.67	1199.66	1228.07	1256.09
Olives	1149.74	1177.28	1205.23	1232.82
Squash	387.29	397.31	407.59	418.02
Corn	191.73	197.43	203.19	209.1
Eggplant	382.77	393.15	403.71	414.48
Tomato	382.77	393.15	403.71	414.48
Green beans	189.14	194.49	199.94	205.51
Kidney beans	189.14	194.49	199.94	205.51
Fababeans	272.21	280.74	289.19	297.9
Cauliflower	224.24	230.61	237.08	243.71

Jew's Mallows	1437.72	1472.01	1506.96	1541.55
cabbage	224.24	230.61	237.08	243.71
Snake Cucumber	244.17	251.22	258.36	265.69
Pepper	253.96	261.65	269.34	277.25
chilli pepper	253.96	261.65	269.34	277.25
Okra	733.04	750.46	767.94	784.94
Pumpkin	289.98	297.2	304.65	312.21
Wheat	804.13	824.16	844.18	863.84
Barley	177.31	183.3	189.16	195.21
Vetch	1297.59	1327.94	1358.73	1388.89
Alfalaf	1297.59	1327.94	1358.73	1388.89
Potato	259.01	266.93	274.83	282.97
Onion (Dry)	586.47	603.12	619.64	636.34
Garlic	586.47	603.12	619.64	636.34
Thyme	223.8	230.08	236.48	243.03
Sage	223.8	230.08	236.48	243.03

Table-d: Change rate (%) of CWR with increasing temperature for different crops.

	Change rate of CWR (%)			
	T	**T+1**	**T+2**	**T+3**
Banana	0	2.25	4.54	6.78
Date	0	2.38	4.79	7.18
Fig	0	2.43	4.90	7.35
Pomegranate	0	2.43	4.90	7.35
Grape	0	2.41	4.85	7.28
Citrus	0	2.39	4.81	7.21
Olives	0	2.40	4.83	7.23
Squash	0	2.59	5.24	7.93
Corn	0	2.97	5.98	9.06
Eggplant	0	2.71	5.47	8.28

Tomato	0	2.71	5.47	8.28
Green beans	0	2.83	5.71	8.65
Kidney beans	0	2.83	5.71	8.65
Fababeans	0	3.13	6.24	9.44
Cauliflower	0	2.84	5.73	8.68
Jew's Mallows	0	2.39	4.82	7.22
cabbage	0	2.84	5.73	8.68
Snake Cucumber	0	2.89	5.81	8.81
Pepper	0	3.03	6.06	9.17
chilli pepper	0	3.03	6.06	9.17
Okra	0	2.38	4.76	7.08
Pumpkin	0	2.49	5.06	7.67
Wheat	0	2.49	4.98	7.43
Barley	0	3.38	6.68	10.10
Vetch	0	2.34	4.71	7.04
Alfalaf	0	2.34	4.71	7.04
Potato	0	3.06	6.11	9.25
Onion (Dry)	0	2.84	5.66	8.50
Garlic	0	2.84	5.66	8.50
Thyme	0	2.81	5.67	8.59
Sage	0	2.81	5.67	8.59
Average	**0**	**2.68**	**5.40**	**8.14**

Table-e: Sensitivity of crop's irrigation water requirements (IWR) to precipitation change in (mm/period).

	IWR (mm/period)				
	P-20%	**P-10%**	**P**	**P+10%**	**P+20%**
Banana	1134.83	1129.41	1124.98	1120.95	1117.51
Date	1519.89	1494.91	1482.51	1469.93	1457.58

Fig	978.85	953.87	941.47	928.89	916.54
Pomegranate	978.85	953.87	941.47	928.89	916.54
Grape	785.42	760.49	751.12	744.12	738.03
Citrus	1077.16	1052.19	1039.79	1028.7	1019.88
Olives	1055.24	1030.26	1017.86	1006.75	997.61
Squash	357.69	340.66	335.73	330.91	325.98
Corn	157.98	140.45	135.05	129.74	124.34
Eggplant	336.28	317.2	310.35	303.53	296.68
Tomato	336.28	317.2	310.35	303.53	296.68
Green beans	163.7	147.14	142.68	138.35	133.89
Kidney beans	163.7	147.14	142.68	138.35	133.89
Fababeans	196.29	173.59	163.36	153.05	142.82
Cauliflower	190.49	172.96	167.56	162.25	156.85
Jew's Mallows	1343.22	1318.24	1305.84	1293.26	1281.09
cabbage	190.49	172.96	167.56	162.25	156.85
Snake Cucumber	206.22	188.18	182.31	176.5	170.62
Pepper	194.51	173.84	165.5	157.15	148.82
chilli pepper	194.51	173.84	165.5	157.15	148.82
Okra	692.23	688.25	685.09	682.16	679.4
Pumpkin	280.7	265.96	263.34	260.92	258.3
Wheat	713.35	694.17	687.23	680.67	674.75
Barley	100.62	78.68	68.47	58.38	49.09
Vetch	1212.41	1192.65	1186.5	1180.69	1175.08
Alfalaf	1212.41	1192.65	1186.5	1180.69	1175.08
Potato	199.56	178.89	170.55	162.21	153.87
Onion (Dry)	491.96	466.98	454.58	442	429.65
Garlic	491.96	466.98	454.58	442	429.65
Thyme	194.19	177.17	172.24	167.42	162.49
Sage	194.19	177.17	172.24	167.42	162.49

Table-f: Change rate (%) of additional irrigation water requirement with increasing temperature for different crops.

	Change rate in IWR (%)				
	P-20%	**P-10%**	**P**	**P+10%**	**P+20%**
Banana	0.88	0.39	0.00	-0.36	-0.66
Date	2.52	0.84	0.00	-0.85	-1.68
Fig	3.97	1.32	0.00	-1.34	-2.65
Pomegranate	3.97	1.32	0.00	-1.34	-2.65
Grape	4.57	1.25	0.00	-0.93	-1.74
Citrus	3.59	1.19	0.00	-1.07	-1.91
Olives	3.67	1.22	0.00	-1.09	-1.99
Squash	6.54	1.47	0.00	-1.44	-2.90
Corn	16.98	4.00	0.00	-3.93	-7.93
Eggplant	8.36	2.21	0.00	-2.20	-4.40
Tomato	8.36	2.21	0.00	-2.20	-4.40
Green beans	14.73	3.13	0.00	-3.03	-6.16
Kidney beans	14.73	3.13	0.00	-3.03	-6.16
Fababeans	20.16	6.26	0.00	-6.31	-12.57
Cauliflower	13.68	3.22	0.00	-3.17	-6.39
Jew's Mallows	2.86	0.95	0.00	-0.96	-1.90
cabbage	13.68	3.22	0.00	-3.17	-6.39
Snake Cucumber	13.12	3.22	0.00	-3.19	-6.41
Pepper	17.53	5.04	0.00	-5.05	-10.08
chilli pepper	17.53	5.04	0.00	-5.05	-10.08
Okra	1.04	0.46	0.00	-0.43	-0.83
Pumpkin	6.59	0.99	0.00	-0.92	-1.91
Wheat	3.80	1.01	0.00	-0.95	-1.82
Barley	46.95	14.91	0.00	-14.74	-28.30

Vetch	2.18	0.52	0.00	-0.49	-0.96
Alfalaf	2.18	0.52	0.00	-0.49	-0.96
Potato	17.01	4.89	0.00	-4.89	-9.78
Onion (Dry)	8.22	2.73	0.00	-2.77	-5.48
Garlic	8.22	2.73	0.00	-2.77	-5.48
Thyme	12.74	2.86	0.00	-2.80	-5.66
Sage	12.74	2.86	0.00	-2.80	-5.66
Average	**10.10**	**2.75**	**0**	**-2.70**	**-5.35**