Assessment of the Agricultural Water Use in Jericho Governorate Using Sefficiency Under Climate Change Uncertainty

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Doctoral Thesis
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DECLARATION

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I dedicate this work to the memory of my late father. To my inspiring mother. To Ammar who was the first to support it. To the future of Sophia.

To Lama who never gave up on me.

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

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ABSTRACT

Addressing water use efficiency in the Middle East is challenging due to the limited water resources availability, geopolitical complexity, climatic conditions, and a variety of managerial issues. Groundwater is the dominant water resource for Palestinians amid their inability to access other natural water resources. Jericho Governorate constitutes most of the Palestinian part of the Jordan Valley and represents a high economic significance for the nation, especially in agriculture. This made the agricultural water use in Jericho as the main user of the Eastern Aquifer Basin (EAB). The objective of this doctoral work is to assess the efficiency of the agricultural water use in Jericho, which we defined as the Water Use System (WUS), and its interaction with the main source, the Eastern Aquifer Basin (EAB), using the Sustainable Efficiency (Sefficiency) method. In addition, we aim, through developing scenarios, to understand the impacts of the uncertainty associated with climate change on our WUS's performance and its water variables. Sefficiency is a composite multi-level efficiency indicator that is based on water balance and considers the usefulness criterion of the WUS's variables. As Sefficiency requires, the analysis was not limited to the quantities of the different water path types within our WUS, but it also considered their quality and beneficial weights. We surveyed local farmers, interviewed a water manager, and collected an extensive dataset to achieve an understanding of the water paths dynamics and conclude our water balance schematic. Besides, we simulated six different scenarios under two representative concentration pathways (RCPs), namely RCP2.6 and RCP6.0, corresponding to the projected changes in temperature and precipitation in three intervals (years 2025, 2055, and 2090) to assess the impact of climate change on water use efficiency. The results demonstrated that: 1. Improving the quality of returns has a great positive impact. 2. Increasing water abstractions is not beneficial if it is not linked to an increase in yield production. 3. Precipitation rates can influence water use efficiency. 4. More careful treatment of the unwanted plants and a selection of high socio-economic value crops would enhance Sefficiency. Finally, the results of the developed scenarios under climate change projections indicated a minor impact on the efficiency itself, since the system is already operating under scarce water conditions; however, it showed an anticipated significant impact on the sustainability of the main source, EAB.

Keywords: Eastern Aquifer Basin; irrigation management; Sefficiency; water crisis in Palestine; water use efficiency.

RESUMO

Avaliar a eficiência do uso da água no Médio Oriente constitui um desafio importante uma vez que a disponibilidade de água é muito limitada, a situação geopolítica é muito complexa, as condições climáticas são desfavoráveis e a gestão de recursos hídricos apresenta diversas fragilidades. A água subterrânea constitui o recurso hídrico dominante para os Palestinianos, não sendo possível o acesso a outras massas de água. A província de Jericó é a maior área da Palestina no vale do rio Jordão e apresenta um papel económico importante, especialmente no sector da agricultura. Assim, o uso agrícola em Jericó é responsável pelas captações mais intensas no aquífero leste (*Eastern Aquifer Basin* - EAB). O objetivo deste trabalho é avaliar a eficiência do uso da água na agricultura em Jericó, sendo este o sistema selecionado para estudo (*Water Use System* – WUS), assim como a sua interação com a principal fonte de água (EAB), utilizando-se o Método de Eficiência Sustentável (*Sefficiency*). Além desta avaliação, foram considerados cenários para analisar mudanças circunstanciais no sistema, tais como as mudanças climáticas, de modo a quantificar o seu impacto no desempenho do WUS. O *Sefficiency* é um indicador composto por vários níveis de eficiência, que é baseado no balanço hídrico e considera um critério de utilidade das variáveis do WUS. Em conformidade com os requisitos do *Sefficiency*, a análise considerou, além das quantidades dos diferentes tipos de fluxos de água, a sua qualidade e o seu benefício. Foram entrevistados agricultores locais e um gestor responsável pela gestão da água e foi recolhido um conjunto de dados para compreender a dinâmica dos fluxos da água no sistema selecionado, concluindo-se com a imposição de balanço hídrico nulo para o WUS. Foram simulados seis cenários de alterações climáticas correspondentes a diferentes valores de emissões combinados com distintos horizontes temporais (*representative concentration pathways* - RCP) — RCP2.6 e RCP6.0 — considerando as mudanças previstas para a temperatura e a precipitação (anos 2025, 2055 e 2090). Os resultados demonstraram que: (1) melhorar a qualidade dos fluxos de retorno tem um grande impacto positivo; (2) o aumento da captação de água não é benéfico se não estiver vinculado a um aumento na produção agrícola; (3) as variações de precipitação podem influenciar a eficiência; e (4) um tratamento mais cuidadoso das espécies vegetais invasoras e uma seleção de culturas de alto valor socioeconómico aumentariam a eficiência do uso da água. Por fim, os cenários desenvolvidos para avaliação do impacto das mudanças climáticas indicaram uma menor influência nos valores da eficiência, uma vez que o sistema já está sob condições de escassez de água severas, mostrando, no entanto, um impacto significativo na sustentabilidade da principal fonte de água, a EAB.

Palavras-chave: *Eastern Aquifer Basin*; eficiência do uso da água; escassez da água na Palestina; gestão de irrigação; *Sefficiency*.

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GLOSSARY OF ACRONYMS

AMS	American Meteorological Society
AQUASTAT	FAO's Global Information System on Water and Agriculture
ARIJ	Applied Research Institute–Jerusalem
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
BAU	Business as Usual
BC	Before Christ
BGR	German acronym of "Bundesanstalt für Geowissenschaften und Rohstoffe", meaning: German Federal Institute for Geosciences and Natural Resources
CCME	Canadian Council of Ministers of the Environment
CE	Classical Efficiency
CGE	Computable General Equilibrium
CIA	Central Intelligence Agency
CIHEAM	French acronym of "Centre International de Hautes Études Agronomiques Méditerranéennes", meaning: International Centre for Advanced Mediterranean Agronomic Studies
CMIP5	Coupled Model Intercomparison Project - Phase 5
CROPWAT	Crop water requirements calculation tool under climatic circumstances
CRU CL	Climatic Research Unit - Climatology
CWD	Crop Water Demand
CWQGs	Canadian Water Quality Guidelines
CWQI	Canadian Water Quality Index
DC	District of Columbia
EAB	Eastern Aquifer Basin
EE	Effective Efficiency

EQA	Palestinian Environment Quality Authority
ET	EvapoTranspiration
FAO	Food and Agriculture Organization of the United Nations
FI	Farmer Irrigation
GDP	Gross Domestic Product
GDWQI	Global Drinking Water Quality Index
GHG	GreenHouse Gas
GIS	Geographic Information System
GTZ	German acronym of "Deutsche Gesellschaft für Technische Zusammenarbeit", meaning: German Agency for Technical Cooperation
HYDE	History Database of the Global Environment
ICC	International Criminal Court
ICID	International Commission on Irrigation & Drainage
IHP	Intergovernmental Hydrological Programme
IPCC	Intergovernmental Panel on Climate Change
IS	Irrigation Sagacity
JAWRA	Journal of the American Water Resources Association
JWC	Joint Water Committee
KRB	Kano River Basin
MOA	Palestinian Ministry of Agriculture
MOPIC	Palestinian Ministry of Planning and International Cooperation
NAP	National Adaptation Plan
NEAB	North-Eastern Aquifer Basin
NGO	Non-Governmental Organisation
NIGP	Portuguese acronym of "Núcleo de Investigação em Geografia e Planeamento", meaning: Research Group on Geography and Planning
NIS	New Israeli Shekel

NR	NonReusable
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OLR	Outgoing Longwave Radiation
OS	Other Sources
PCBS	Palestinian Central Bureau of Statistics
PCM	Parallel Climate Model
PM	Penman-Monteith
PNA / PA	Palestinian National Authority / Palestinian Authority
PP	Precipitation
pp	Percentage point
PRECIS	Providing REgional Climates for Impacts Studies
PWA	Palestinian Water Authority
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RF	Return Flow
RFF	Resources for the Future
RP	Potential Return
SAM	Social Accounting Matrices
SDG	Sustainable Development Goals
SOMs	Self-Organising Maps
SSP	Shared Socioeconomic Pathway
SWR	Solar Shortwave Radiation
TI	Tensiometer Irrigation
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development

UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-ESCWA	United Nations Economic and Social Commission for Western Asia
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USCID	United States Committee on Irrigation and Drainage
USD	United States Dollar
VA	Volume of Abstracted water
VD	Volume of water Upstream
VU	Volume of water Downstream
WAB	Western Aquifer Basin
WAFA	Arabic acronym of "وكالة الأنباء الفلسطينية", meaning: Palestine News Agency
WBWD	West Bank Water Department
WEAP	Water Evaluation and Planning
WHO	World Health Organisation
WIT	Wessex Institute for Health Research & Development
WPI	Water Path Instances
WPT	Water Path Types
WQI	Water Quality Index
WQSAM	Water Quality Systems Assessment Model
WUS	Water Use System
WWAP	World Water Assessment Programme
WWDR	World Water Development Report
WWTP	WasteWater Treatment Plant

CHAPTER ONE. INTRODUCTION

Water is a life main component that guarantees creatures' existence, continuity, and thrive. For humankind, one of the essentials that made us who we are and let us achieve what we have accomplished is the colour of our planet, blue. Water extends beyond being the substance in which the first form of life on earth developed. It has undoubtedly become a wealth indicator, a basic element in health and hygiene, an important driver of renaissance, a war cause, and a peace guardian.

Back in history, humans chose to establish their early forms of communities often in proximity to a water body. The more complex and developed human communities became over time, the greater such choice our ancestors had enhanced in planning and development. Thinking of all of the great ancient civilisations, from the Mesopotamian civilisations (including the Sumerian, Assyrian, Akkadian, and Babylonian) to the succession of the great Pharaoh monarchies, we intuitively link them to a water body. It did not take much for old cities' founders to realise that water bodies are not only crucial to support basic life needs (drinking, irrigation, fishing, and sanitation), but their importance further extends to include other vital elements such as transportation, trade, entertainment, military purposes, and protection. Most if not all great ancient cities, which made it until today, if not flourished, have a great level of proximity to at least one water body, especially rivers.

The way we previously interacted with water bodies had contributed to different perceptions about water as a resource. Nowadays, although we no longer have that much dependence when we build our new cities or grow the existing ones on the proximity to water bodies, nevertheless this is only because our understanding of water as a resource and the way we approach its management has become more advanced.

Water today has a level of engagement in human activities that is unprecedented. Food, energy, manufacturing, global trade, and even modern technology are only a few examples of sectors of which their development is dependent on water.

1.1. Water Resources in Nature

Water is continuously in motion. Scholars characterise that motion in what we know as the hydrological cycle, which is constrained by the law of conservation of mass (water balance). Such dynamics resulted to have water as a renewable source (resource). While water is preserved in quantity, however, it may very well change in location, form, quality, and thus usefulness.

As we understand water resources today, we can split them into two main categories:

1. **Conventional resources**
    a. Surface water:
        i. Rivers
        ii. Lakes
        iii. Ice and snow
    b. Groundwater
        i. Wells
        ii. Springs
    c. Glaciers and icecaps
2. **Unconventional resources**
    a. Desalination
    b. Wastewater treatment and reuse
    c. Rainwater harvesting
    d. Atmospheric moisture harvesting

Scholars have widely considered water as the most essential among natural resources (C. J. Vörösmarty et al., 2010) covering 70.90% of the blue planet's surface (CIA, 2013). As illustrated in Figure 1.1, 96.5% of earth's water is found in seas and oceans, while 1.7% in groundwater (0.77% fresh and 0.93% saline). There is 1.7% in glaciers and the ice caps of Antarctica and Greenland, and a smaller fraction in other large water bodies; 0.001% in the air as vapour, clouds (formed of solid and liquid water particles suspended in air), and precipitation. Only 2.5% of the Earth's water is freshwater, and 98.7% of that quantity is in ice and groundwater. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) is contained within biological bodies and manufactured products (Peter H. Gleick, 1993).

It is important to understand that freshwater is continuously moving, flowing in rivers, evaporating and spreading as vapour, falling as rain or snow, or infiltrating slowly through soil textures as groundwater (Bidlack, Wang, & Clemens, 2004). Water evaporates annually from the oceanic surface (502,800 km^3) and lands (74,200 km^3). The same amount of water falls as atmospheric precipitation (458,000 km^3 on oceans and 119,000 km^3 on lands). The difference between precipitation and evaporation from the land surface (44,800 km^3/year) represents the total runoff of the Earth's rivers (42,700 km^3/year) and direct groundwater runoff to the ocean (2,100 km^3/year) (Shiklomanov, 1998). This water cycle, which is constantly controlled by the law of conservation of mass, is the principal source of freshwater to support life essentials and human activities.

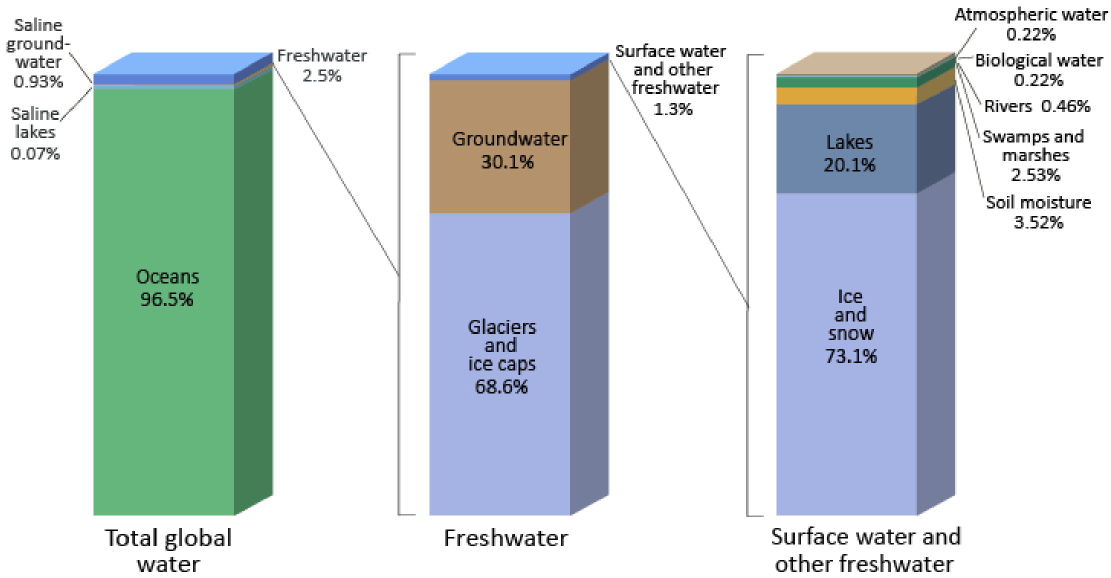


Figure 1.1: Distribution of Earth's water
Source: (Peter H. Gleick, 1993)

1.2. Water Use Systems and Sectors

Since water contributes to all human development activities, it is highly competitive among several users. Categorising water use by sectors has a considerable significance for management-related purposes. Such activity is basic for water resources' allocation, offers a tool for better understanding of the complex water use systems, and plays a key role in shaping stakeholders' decisions.

While the definition of a water resource system is ambiguous, a water use system (WUS) is a system that has a defined boundaries (a basin, city, or farmland), and characterised by its water path types (WPTs) and their attributes (Haie & Keller, 2014). These attributes are defined as quality and beneficial dimensions, which are incorporated into a "usefulness criterion" (Haie & Keller, 2012). The various stakeholders and decision-makers within a WUS set and define its characteristics according to their preferences.

There is no universal standard in categorising the water use sectors. In fact, these sectors can vary between different regions, fields of study, or analysis context. For instance, Alcamo et al. (2003) break the sectors down into domestic, industry, and agriculture. The domestic sector includes household use, small businesses, and other municipal uses. The industry sector includes power plants and manufacturing facilities, while the agriculture sector covers irrigation and livestock water uses. Although any water use activity can go under one of these three main categories, it is often necessary in certain regions to consider the uses from a more activity-based perspective in order to distinguish major water users. For instance, authors such as Gibbons (1986) in his book "The Economic Value of Water" expand the categories to include energy and hydropower as it is evidently one of the main water users in many regions and globally. Other activities to consider in categorisation can include recreation, navigation, and waste assimilation.

From a global angle, UN-Water came across two types of categorisations in their consecutive World Water Development Reports (WWDRs) series. The first type breaks the sectors down into municipal, industrial, and agriculture, while the other is activity-based and categorises the uses into irrigation, domestic, livestock, manufacturing, and energy. For example, Figure 1.2 presents the global water withdrawal and use by sector as a baseline scenario of 2014, 2025 and 2040 according to the WWDR of 2019.

It is of crucial importance, from a water resources management perspective, to differentiate between the terms demand, withdrawal, use, and consumption. There is no confusion about the definition of water "demand" as it is self-explanatory; demand is the volume of water required to satisfy all of the different needs of a WUS. Such needs are not limited to the different use sectors, the environmental requirements for instance are also among the WUS's demands. "Withdrawals" are the volume of abstracted water from a source. Correspondingly, water "use" is the total volume of water that has been used by a WUS, including every water path, while "consumption" is the volume of those water paths that do not return to the source nor can be reused in any form within the defined WUS (regardless of quality). One of the most famous examples of consumption is evapotranspiration. By definition, water consumption is only a portion of water use, or at maximum equal to it in highly improbable scenarios.

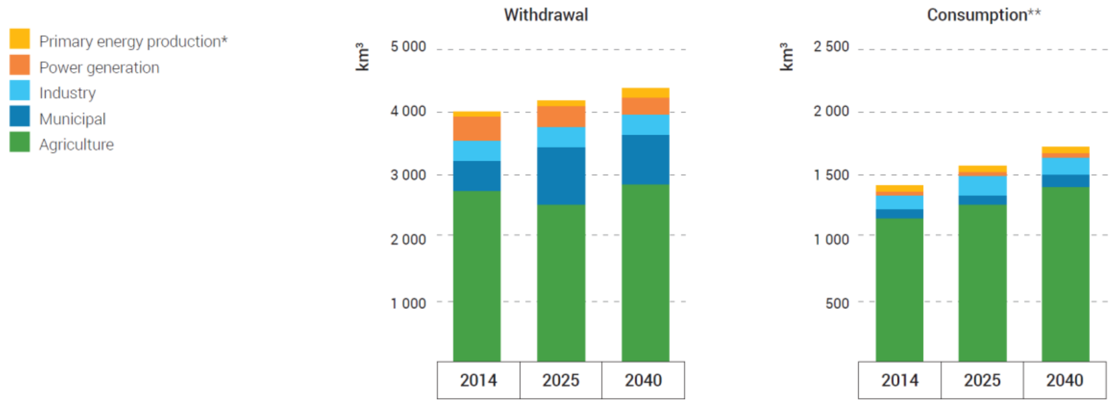


Figure 1.2: Global water withdrawal and consumption by sector to 2040
Source: (WWAP & UNESCO Director-General, 2019)
** Primary energy production includes fossil fuels and biofuels. Water used in crops grown as feedstock for biofuels is included in primary energy production, not in agriculture.*
*** The WWDR authors define consumption as: "The volume withdrawn that is not returned to the source (i.e. it is evaporated or transported to another location) and by definition is no longer available for other uses locally"*

As per the latest WWDR (Figure 1.2), global water withdrawal was on 4,000 km^3 in 2014, where around 68% of it goes for agricultural uses (including irrigation and livestock), 12.5% for municipal, 8.5% for industrial and 11% for power generation and energy production. As a result of irrigation efficiency enhancement practices, UN-Water anticipates the agricultural water use to decrease in quantity and as a percentage of the overall use in 2025, and in percentage in 2040. The overall use and particularly consumption projections are in a steady linear increase.

Regardless of the number, type, or size of the different water use sectors, in a scarcity scenario, the competition between these users raises serious challenges for the decision-makers to deal with amid this conflict of interest.

1.3. Water Use Efficiency

Efficiency is the useful portion of a total, or from a technical standpoint, the ratio of the usefulness of a process, system, tool, machine, etc. Unambiguously, notwithstanding the exact way of narrating the definition, the key is usefulness.

Similarly, all potential definitions of water use efficiency will have some measure of water in exchange for some units of production (Condon, Richards, Rebetzke, & Farquhar, 2004). For example in irrigation, we can consider the ratio of harvested yield to the total amount of water withdrawn for irrigation as a simple form of efficiency (i.e. tons of yield per cubic meter of water, which is mostly called irrigation water productivity). For management convenience, since it is a ratio, we often express efficiency in percentages, which requires uniformity in the units of measurement. Thus, back to the irrigation example, instead of expressing yield in tons, we can use evapotranspiration.

Considering the projected increase in demand and the competition between the different water users and stakeholders, the continuous challenge then is to make the most out of the available, and limited, water supplies to meet the minimum demand requirements. This means, by definition, to increase the efficiency of water use. Moreover, the high uncertainty of the future scenarios due to the potential consequences of climate change adds another layer of complexity to the challenge. As a result, the core objective of the different management approaches is to help the relevant policymakers, who decide on allocation, achieve the most efficient water use system.

The methods of water use efficiency assessment vary. That is of no surprise considering the great level of complexity of the variables in a water user system. Although it may seem obvious, but it is vital to keep in mind that water resources managers can only do their job if equipped with a reliable performance assessment tool. Therefore, scholars and authors have been spending extensive efforts to understand how the dynamics in a water use system work, the variables controlling the process, and the best way to mathematically represent these variables and dynamics. As a central part of this research, we will come back to a water-centric definition of efficiency later in this document.

1.4. Water Crisis in Palestine

Palestine is a Mediterranean country that has been in the centre of the Middle East conflict in the post-war era. The current international geographic recognition of Palestine includes two main areas: West Bank and Gaza Strip (Ronen, 2014) with a total area of 6,020 km^2 (United Nations Statistics Division, 2012) – widely known as the 1967 borders.

As Palestinians have no access to Jordan River since 1967 (UNCTAD, 2015), which is their only surface water resource, groundwater is the primary freshwater source and provides more than 95% of all supplies (PWA, 2017). There are two main aquifer systems in Palestine: the Mountain Aquifer, where West Bank lays above, and the Coastal Aquifer (for Gaza Strip). The Mountain Aquifer, which is a considerably high-quality freshwater resource in the region, has three basins: the Western Aquifer Basin (WAB), the North-Eastern Aquifer Basin (NEAB), and the Eastern Aquifer Basin (EAB) (Lazarou, 2016).

Lack of access to adequate, safe, and clean water has been a longstanding problem for the Palestinians, which have resulted in widespread difficulties for an adequate standard of living, including the rights to adequate food and housing, the right to work, and sustained clean water (World Bank, 2009). The average daily consumption for Palestinians is about 88.3 litres per capita per day (PCBS & PWA, 2019), which is below the 100 litres per capita per day recommended by the World Health Organisation (Howard, Bartram, & WHO, 2003) to ensure meeting all hygiene and basic domestic needs.

Water issues in Palestine extend beyond being a scarce resource. Other factors contribute to the water crisis in that region. Those factors include, but are not limited to: climate change impacts (J. Chenoweth et al., 2011; La Jeunesse et al., 2016; Mizyed, 2009; Sowers, Vengosh, & Weinthal, 2011); the exponential population growth (J. Chenoweth, 2011; J. Lautze & Kirshen, 2009); and that the major freshwater resources are mostly transboundary with political complexity (P. H. Gleick, 1993; Lowi, 1993). Furthermore, the absence of official strategic water policies and the low level of unconventional resources (e.g., wastewater reuse and desalination) development (Haddad & Lindner, 2001; Judeh, Haddad, & Ozerol, 2017) are critical components of the crisis.

Hence, and especially when the uncertainty incorporated with future scenarios in terms of the potential changes in water resources is considered, water resources management in that region is a challenge. The stability and welfare of the entire region is directly connected to the best possible water allocation between Palestine and Israel.

1.5. Water Resources in Palestine

As mentioned earlier, the West Bank and Gaza Strip are the two main areas included in the international geographic recognition of Palestine. As per the Palestinian Water Authority (PWA), which is the governing body of water resources for Palestinians, water resources in Palestine (PWA, 2018) can be classified into surface water and groundwater resources as detailed in the next subsections.

1.5.1. Surface Water Resources

(a) Jordan River

Located on the borders between the Hashemite Kingdom of Jordan and the West Bank, the Jordan River is the only conventional surface water resource that is naturally available for the Palestinians. It has an estimated 1,300 million cubic meters (Mm^3) of historical-average annual discharge, whereas the recent estimates are much lower and widely vary between 20-200 Mm^3/year (UN-ESCWA & BGR, 2013). The river is shared between five riparian countries: Syria, Jordan, Lebanon, Israel, and Palestine.

(b) Wadis

A small number of runoff streams that flow across the local valleys in West Bank and Gaza. They represent a real opportunity to access additional water quantities for the Palestinians during flood seasons considering their annual discharge quantities in the West Bank as in Table 1.1. However, Isreal is denying the Palestinians from developing the required infrastructure (i.e. dams) to invest in this source.

Table 1.1: West Bank Wadis Long-term Annual Discharge
Source: (PWA, 2018)

Wadis Group	**Long-term Average Discharge (Mm^3/year)**
West Wadis (flow towards the Mediterranean)	123
East Wadis (flow towards the Dead Sea)	20.5
East Wadis (flow towards Jordan River)	21.5

1.5.2. Groundwater Resources

As Palestinians have restricted access to surface water, groundwater is the primary freshwater source and provides more than 95% of all supplies (PWA, 2017). There are two main aquifer systems in Palestine (Figure 1.3): the Mountain Aquifer (for West Bank) and the Coastal Aquifer (for Gaza Strip).

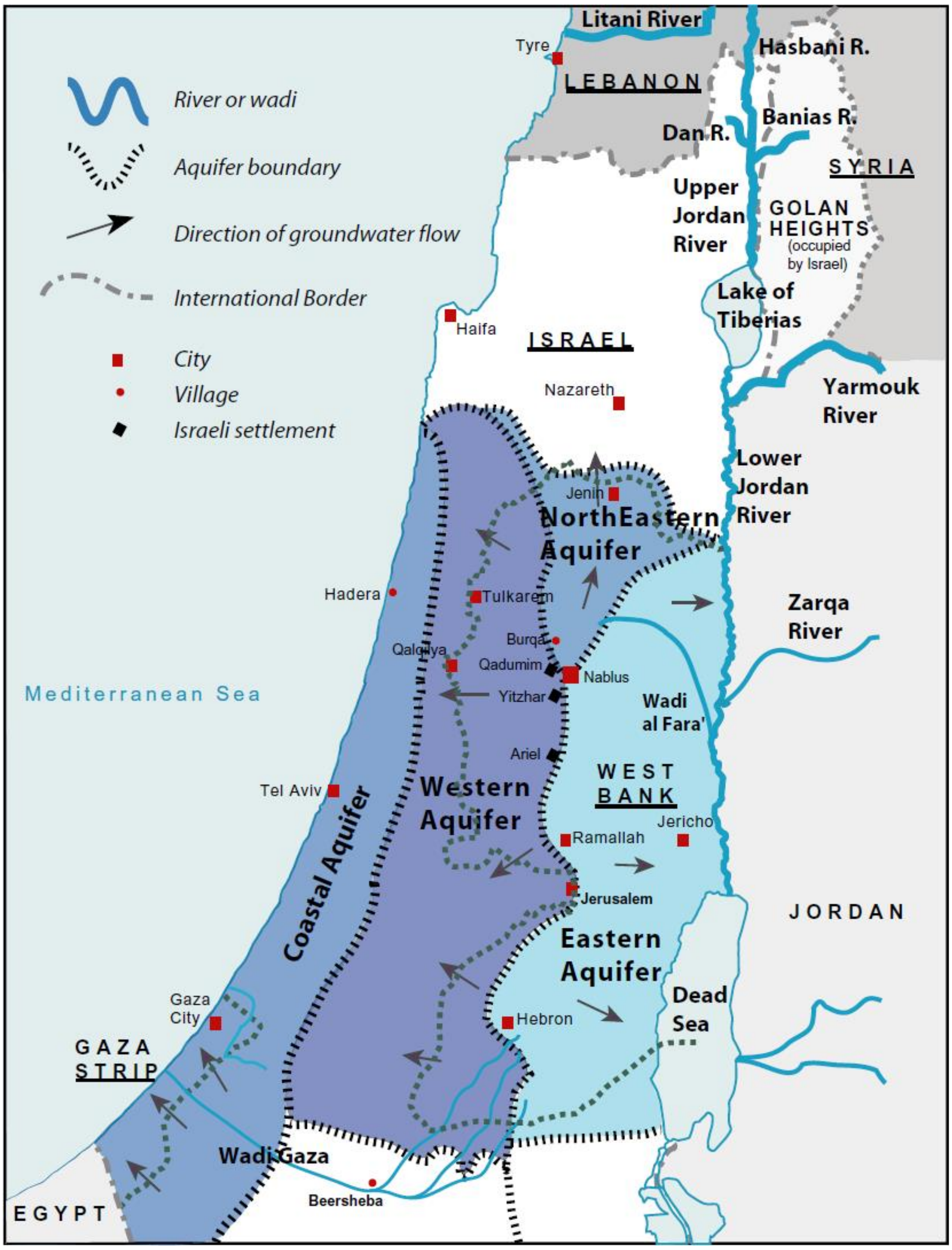


Figure 1.3: Palestinian Aquifers
Source: (Zeitoun, Messerschmid, & Attili, 2008)

(a) The Mountain Aquifer

A high-quality freshwater resource in the region (Lazarou, 2016) that has three main basins:

1. **The Western Aquifer Basin (WAB)**

   It is the largest basin among the three, where 1,767 km^2 of the entire basin's area is within the West Bank borders. Its long-term recharge ranges between 318-430 Mm^3 (PWA, 2018). In 2011, Israelis withdrew 411 Mm^3 from WAB, while Palestinians had 25 Mm^3 (PWA, 2012).

2. **The North-Eastern Aquifer Basin (NEAB)**

   It is the smallest basin among the three, where 981 km^2 of the entire basin's area is within the West Bank. Its long-term recharge ranges between 135-187 Mm^3 (PWA, 2018). In 2011, Israelis withdrew 103 Mm^3 from NEAB, while Palestinians had 20 Mm^3 (PWA, 2012).

3. **The Eastern Aquifer Basin (EAB)**

   It is located entirely in the West Bank and has an area of 2,767 km^2. Its long-term recharge ranges between 125-197 Mm^3 (PWA, 2018). The low volume of recharge is due to the climatic conditions of its location, which we will elaborate on later. In 2011, Israelis withdrew 50 Mm^3 from EAB, while Palestinians had 42 Mm^3. PWA claims that Israel abstracts an additional 100 Mm^3 from Dead Sea springs; and restricts the Palestinians from developing any infrastructure to get additional abstractions (PWA, 2012).

(b) The Coastal Aquifer

The entire Gaza Strip (365 km^2) lays above the coastal aquifer basin, which has a long-term recharge ranges between 55-60 Mm^3. Palestinians withdraw from the coastal aquifer in staggering numbers. For example, in 2011, the total number of abstractions for both agricultural and urban uses was around 178.8 Mm^3, three times the long-term average recharge. As a result, the quality of these abstractions suffers from seawater intrusion and uplift of the deep brine water level. The Palestinian Authority reported that more than 97% of the water tested samples did not meet the water quality standards of the World Health Organization (PCBS & PWA, 2019).

1.6. Overview of the Agricultural Water Use in Jericho Governorate and Problem Statement Description

The Jordan Valley (Figure 1.4) is named after its divider the Jordan River. It extends between Nablus, Jerusalem, and Hebron Mountains chain (known in Israeli sources as Judaean and Samaria Mountains) in the west and the northwestern Jordanian highlands in the east. The Palestinian part of the valley has an estimated area of 845 km^2. Administratively, two Palestinian governorates share the vast majority of the valley: the entire *Jericho & Al-Aghwar* Governorate (in short, Jericho) and the eastern half of *Tubas and the Northern Valleys* Governorate (in short, Tubas).

The Valley represents a great economic value, mainly in agriculture due to its yearlong convenient climatic conditions, for both Palestinians and Israelis. Although the area under consideration falls entirely within the West Bank, it is part of a region where Israel produces 80% of its dates and 45% of its bananas (Israeli Ministry of Agriculture, 2019). As for Palestinians, the Jordan Valley contains 50% of their agricultural lands in the West Bank, producing 60% of the Palestinian's total yield of vegetables there (WAFA, 2015).

According to the latest census of the Palestinian Central Bureau of Statistics (PCBS) in 2017, the population of Jericho is 50,001, which accounts for 1.1% of Palestine's population and makes it the least populous governorate (PCBS, 2018). The main reason behind this low population density is due to constraints that are limiting the economic development, especially in agriculture as suggested by multiple local, Israeli, and international reports (ARIJ, 2016; B'Tselem, 2013; UNCTAD, 2015). That is of no surprise considering the geopolitical complexity of this specific part of West Bank. The Oslo II Agreement in 1995 (a follow-up agreement to the Declaration of Principles known as Oslo I, which both sides signed in 1993) come in interest. The agreement designed the territorial jurisdiction dividing the West Bank into areas A, B, and C. Palestinians have control over areas A and B, but substantial restrictions in regards to land access, infrastructure and water resource development in area C (World Bank, 2009).

In regards to the main water issues of concern that impact the agricultural water use sector in the Jordan Valley, it can be identified as the following:

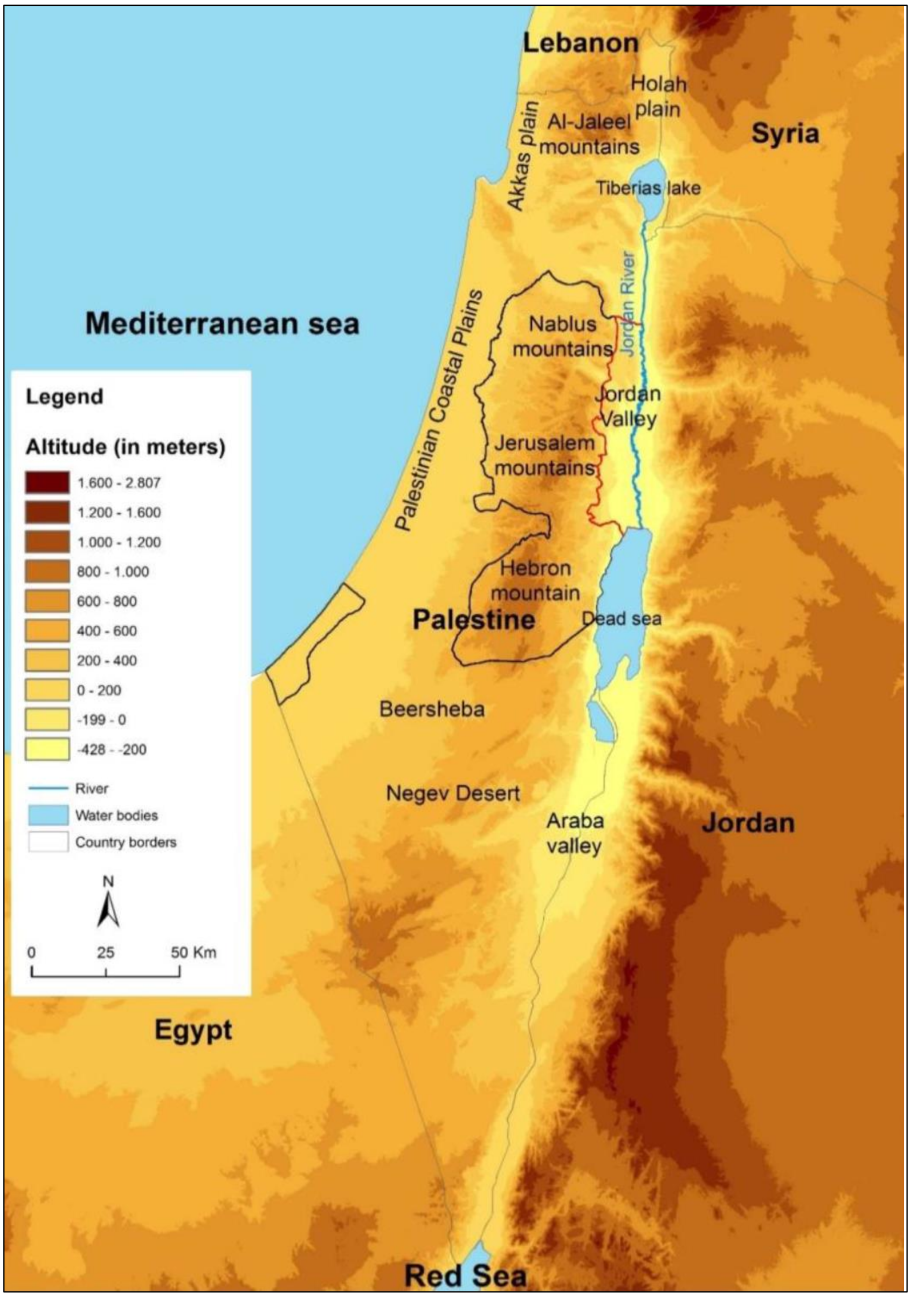


Figure 1.4: Location of the Palestinian part of Jordan Valley
Source: (Hamada, Vieira, & Ghodieh, 2015)

1.6.1. Limited Water Resources

As mentioned earlier, Palestinians rely on groundwater for 95% of their supplies. Purchased water from Israel, treated wastewater and desalination constitute the remaining 5%. The primary purpose of the purchased water from the Israeli national water company Mekorot is for municipal uses only. In addition, the level of wastewater treatment is below the standards for direct reuse in municipal and agricultural uses. Last, the desalinated Mediterranean seawater is a source that is only available in Gaza Strip. All PWA reports suggested that Palestinians in Jericho solely depended in 2011 on abstracted water from the Eastern Aquifer Basin (EAB) for their agricultural activities (PWA, 2012, 2013, 2016, 2017).

1.6.2. Arid Climatic Conditions

The area is generally characterised as arid. In terms of topography, elevations vary from around 300 m above to 400 m below sea level (elevation tends to decrease heading southeastward closer to the Dead Sea) (MOPIC, 1998). Such weather conditions are suitable for growing fruits and vegetables, including dates, banana, tomato, and cucumber. Moreover, the typical Jordan Valley's warmer winters enable farmers to have early harvest seasons, which is economically advantageous, especially for exports.

Precipitation rates vary within a short distance from up to 300 mm per year in the north, down to less than 100 mm per year close to the Dead Sea (EcoPeace Middle East, 2015). The 25-year-average of annual precipitation recorded by the Jericho weather station is 147 mm. These precipitation rates accompanied by high evaporation records result in a greater dependence on irrigation. The PCBS reported in 2011 that 97% of the cropland areas in Jericho were irrigated (PCBS, 2012).

1.6.3. Water Management Shortcomings

The Palestinians have been placing their efforts into expanding access to the available resources and exploring the potentials to develop additional resources. An extensive review of the governmental reports exposes a clear absence of strategic planning and management insights apart from the aforementioned efforts. For instance, the PWA Strategic Water Resource and Transmission Plan (PWA, 2014) and the Water Sector Reform Plan 2016–2018 (PWA, 2016) tackle filling the water gap mainly through reallocation. There is an absence of discussion about enhancing efficient use practices, facilities rehabilitation, and demand management, however, multiple scholars have suggested the latter two approaches as viable options to address water shortage in the region (Bursche, 2011; Haddad, 1998; Shevah, 2017).

1.6.4. Geopolitical Complexity

87% of the Palestinian part of the Jordan Valley falls within Area C (EcoPeace Middle East, 2015), making the sustainability of the Palestinian agricultural activities in that area very difficult. According to an economic monitoring report to the Ad Hoc Liaison Committee of The World Bank (World Bank, 2012), agriculture's contribution to the Palestinian GDP dropped from 9.3% in 1999 to 4% in 2012. The report immediately links the drop to have the Jordan Valley by itself constituting 46% of total area C, denying Palestinians from a major portion of one-third of groundwater reserves and thousands of fertile hectares in the West Bank. In light of these circumstances, what Palestinians can do is to ensure making the most of every single drop of water, thus efficiency arises a key factor.

1.7. Research Framework

In the following subsections, we will layout the research framework by stating the research's motivation, clarifying its objectives, highlighting its contribution, and presenting a summary of the thesis structure.

1.7.1. Research Motivation

Amidst the efforts to reach peace in the Middle East, water arises as one of the most controversial topics. One of the main discussion points on the negotiation table between the different rivals have been circling water shares' allocation. While exploiting the different options to get access to additional water resources and to develop a solid infrastructure to enhance the adopted management approaches are all viable efforts, they become less effective as long as the water use efficiency was not made at the core of the decision-making process. In reality, the Palestinians are failing to address this matter thus far.

One of the key challenges, which participates in the Palestinian failure to address water use efficiency as a decision-making indicator, is the capability to construct a comprehensive understanding of the dynamics of a water use system (WUS) and the interactions between its different variables. Moreover, the limited resources (financial, human, and technical) and expertise shape a perception of urgency among the water managers to prioritise investment in expanding water quantities rather than increasing efficiency.

Under informal coordination with the Palestinian Water Authority, we attempt in this work to highlight the significance to consider water use efficiency as a decision-making indicator to establish solid water policies. Furthermore, we aim to highlight the role of understanding efficiency dynamics in order to achieve a better understanding of the potential future scenarios and thus adding the comprehensiveness element into the policies.

1.7.2. Research Objectives

The main objective of this research is to assess the agricultural water use efficiency in the Palestinian part of Jordan Valley during the 2010/2011 season. We selected this season in particular because it is the most recent season for which the Palestinian official sources provide a complete data set that fits the purpose of this study. Jericho governorate, which constitutes more than 70% of the Valley's area, used more than 62% of the total Palestinian abstractions from the Eastern Aquifer Basin (EAB) (PWA, 2012) making the governorate's agricultural sector the main user of EAB. It represents the major economic activity in the region due to the yearlong favourable climatic conditions. As mentioned earlier, the Jordan Valley contains 50% of the Palestinian agricultural lands in the West Bank, being responsible for 60% of their total vegetables' production there (WAFA, 2015).

The main research objective can be broken down into the following five sub-objectives:

1. To achieve a comprehensive understanding of the different water variables in the hydrological cycle of the water use system (WUS) under consideration, which is the agricultural water use sector in Jericho Governorate. This understanding must satisfy the law of water balance.
2. To demonstrate the relationship between the different water variables considering quantity, quality, and beneficial dimensions in terms of their impact on the WUS's efficiency.
3. To highlight the significance of water use efficiency as a tool in the decision-making process and the water management approaches.

4. To demonstrate how Sefficiency can be an effective tool in highlighting the weak points and improvements opportunities within our WUS in particular, and the Palestinian agricultural sector in general.
5. To understand the impacts on our WUS's performance and its water variables considering the uncertainty associated with climate change and future demand increases.

1.7.3. Research Contribution

This research work contributes directly to the knowledge in the field of water use efficiency assessment. Its added value is represented in providing a model that can be followed in Palestine to fill the gap created by the absence of any official water use efficiency discussions. Up to the author's knowledge at the time of writing this thesis, there are no publications that assess the performance of any water use in the study area. We could hardly find studies about assessments of water use efficiency in Palestine, apart from a few but important publications that come across efficient irrigation techniques to maximise local crop yields, e.g., Rahil and Qanadillo (2015), which are not water-centric and consider water as one of the inputs into the evaluation of other resources or outputs. For example, crop yield, as an objective, is influenced by water as well as fertilisers, seed variety, pesticides, soil types, etc.

Other attempts, such as Al-Juneidi and Isaac (2000) and Alsharif, Feroz, Klemer, and Raab (2008), assessed the efficiency of local irrigation methods and the relative efficiencies of water supply systems at the municipal level as water management strategies. However, all of these assessments were based on an outdated efficiency evaluation approach, namely Classical Efficiency (CE), which is defined as the ratio of the water beneficially used to total water applied. As simple and basic as it may appear, there is a fundamental flaw behind CE, which is the absence of water balance. Many researchers highlighted the CE's inability to address critical elements such as irrigation water recovery, water reuse, water quality, beneficial aspects of all the water flows, and to distinguish between water consumption and water use. This study will rely on one of the most novel water use efficiency assessment approaches called Sustainable Efficiency (Sefficiency), which is comprehensively water-centric and systemic.

1.7.4. Thesis Structure

The structure of this thesis consists of seven chapters. In chapter one, we present a general overview of the field related to this research, a brief background of the water problem in Palestine, and the research framework. In the second chapter, we provide a detailed review of the available literature in this domain of research. Chapter three covers Sefficiency, which is the method that the efficiency assessment is based on, and present the methodology that our climate change scenarios' building will follow. Then, in chapter four, we enrich the reader with an extended set of data and maps of the study area, its water resources, and general characteristics. In addition, we provide in chapter four details about the different variables needed to apply Sefficiency (water quality, quantity, and beneficence). In the fifth chapter, we present the results and their interpretation of the Sefficiency application and apply a sensitivity analysis through hypothesising four scenarios in order to understand the impacts of some potential changes or suggested improvements on the results. In chapter six, we develop different scenarios under climate change uncertainty and discuss the impacts. Finally, in chapter seven, we present the conclusion of this research work and recommendations for future potential developments.

CHAPTER TWO.LITERATURE REVIEW

In this chapter, we will navigate through the available literature in relevance to this research. First, we will come across the emerging issue of water scarcity from a global perspective in order to provide a brief overview of the latest global position in this regard. Then, we will briefly explore the most common water resources management approaches to highlight the need for integrated efforts. In the third section, we will introduce to the reader climate change as a concept, the main drivers behind it, and a brief overview of the available literature about its impact on water resources. In section 2.4, we will briefly review some of the publications that investigated the impact of water reallocation policies.

Then, section 2.5 will enrich the reader with a historical presentation of the evolution in the approaches to assess water use efficiency starting from classical efficiency, reaching the Sefficiency method. The sixth section will elaborate on the available literature that addressed the different water crisis factors in Palestine including the population growth, climate, water management, and the geopolitical complexity. Last, section 2.7 will go through the available studies and publications that investigated water use efficiency of the agricultural sector in Palestine and Jericho Governorate.

2.1. Global Water Scarcity

Freshwater is an essential element for well-being and sustainable socio-economic development. According to the UN World Water Development Report (WWDR) of 2014, volume 1: Water and Energy, a range of serious global and regional issues that threaten the livelihood of a huge population, especially the three billion living on less than 2.5 USD per day, has a link to water (WWAP & UNESCO Director-General, 2014). These issues include climate, poverty, hunger, health, and finance.

Demographers and archaeologists in the extensive research of Goldewijk, Beusen, Drecht, and Vos (2011) estimates the global population in 10,000 BC was 2 million. 10,000 years later, it was still under the 200 million threshold (Figure 2.1). As we already know today, the global population exceeded 7,600 million people and fast approaching 8 billion. While the human population is booming, individual life expectancy has remarkably increased and our lifestyle has dramatically changed during the last 100 years. Besides, governance approaches changed significantly in the post-war era in a way that accentuated economic growth as a top priority. As a result of all of these rapid unprecedented changes, our ecosystem and natural resources suffered an extraordinary degradation.

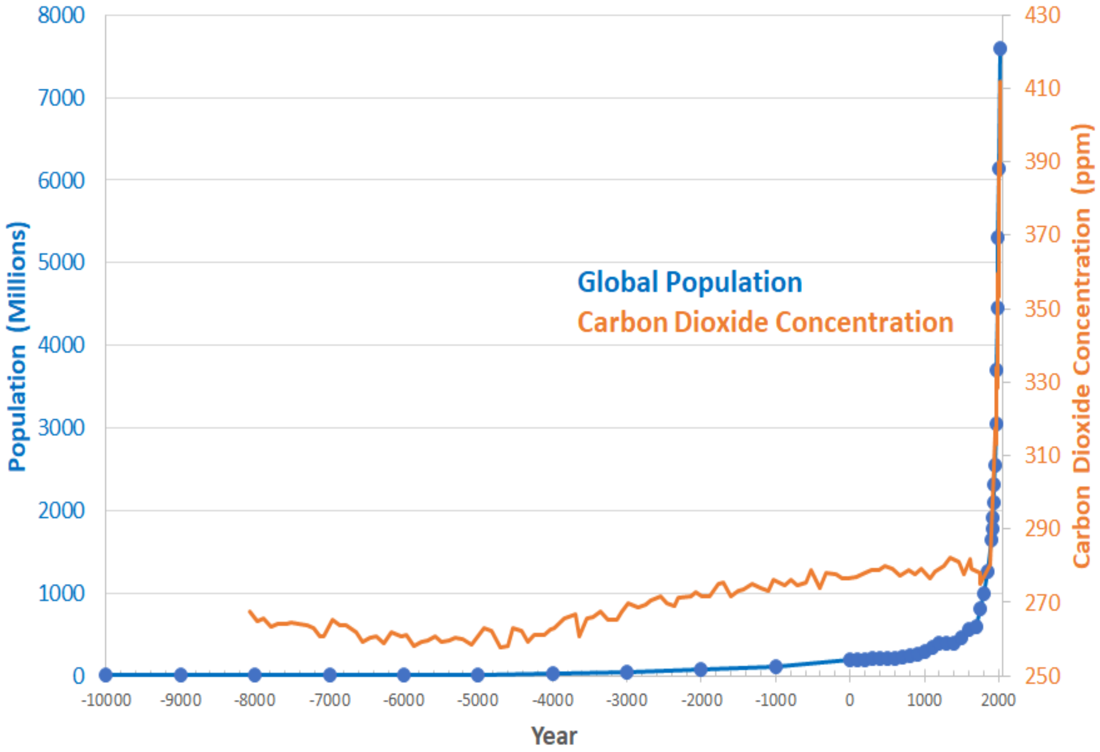


Figure 2.1: 10,000 years of global population and carbon dioxide concentration
Sources: Population data from Hyde 3.1 database. CO_2 concentration data from Dome C and Mauna Loa datasets. Plotted by Peter Gleick in 2019

In many regions, water shortage is considered as one of the most crucial issues. One-fourth of the world's population is concentrated in arid or semi-arid areas, where water resources management is evolving as one of the most difficult and urgent problems (Kondili, Kaldellis, & Papapostolou, 2010). Water demand and supply substantially vary in those regions periodically, which makes the management practices, including demand management and supply chain management, very challenging. UN estimates the number of people whose right to water is not satisfied (regardless of the reason) could be as high as 3.5 billion, while 2.5 billion remain without access to improved sanitation (WWAP & UNESCO Director-General, 2014).

Figure 2.2, which the UN published in 2014, categorises the global physical and economic surface water scarcity into four different classes according to the type of water scarcity worldwide:

1. **Little or no water scarcity:** abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
2. **Physical water scarcity** (water resources development is approaching or has exceeded sustainable limits): More than 75% of river flows are withdrawn for agriculture, industry and domestic purposes. This definition – relating water availability to water demand – implies that dry areas are not necessarily water scarce.
3. **Approaching physical water scarcity:** More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
4. **Economic water scarcity** (human, institutional and financial capital limit access to water even though the water in nature is available locally to meet human demands): Water resources are abundant relative to water use, with less than 25% of the water from rivers withdrawn for human purposes, but malnutrition exists.

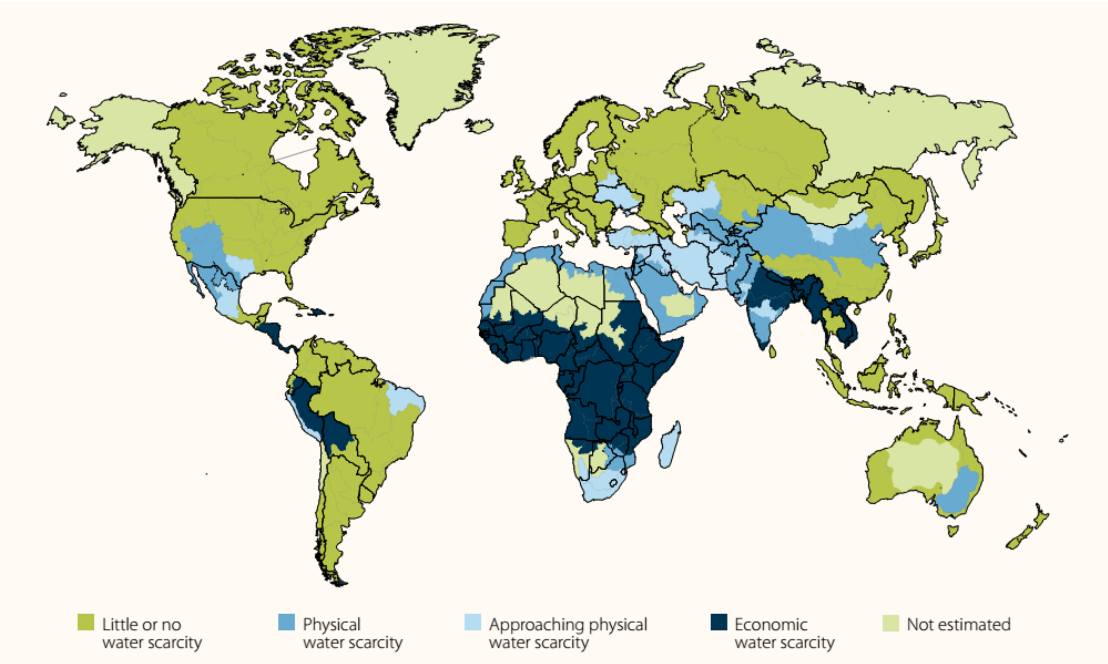


Figure 2.2: Global physical and economic surface water scarcity
Source: (WWAP & UNESCO Director-General, 2014)

The challenge today is to step up and expedite the global progress in order to meet the 6th Sustainable Development Goal (SDG): "**Ensure availability and sustainable management of water and sanitation for all**". In 2012, the 192 UN Member States declared the SDGs agenda beyond 2015 at the United Nations Conference on Sustainable Development (Rio+20) in its outcome document "The Future We Want". As SDGs' predecessor, the Millennium Development Goals (MDGs), considered water as a sub-issue within MDG7: "Ensure Environmental Sustainability", the International Hydrological Program of UNESCO (UNESCO-IHP) proposed a stand-alone sustainable development goal dedicated unequivocally to water (UNESCO-IHP, 2014) transmitting a clear message about the severity of the water scarcity challenge.

In 2015, the United Nations General Assembly adopted SDG6, among a group of 17 global SDGs, which intended to be achieved by the year 2030. As of the progress in 2019, quoting the official UN SDG website:

"Despite progress, billions of people still lack safe water, sanitation and handwashing facilities. Data suggests that achieving universal access to even basic sanitation service by 2030 would require doubling the current annual rate of progress. More efficient use and management of water are critical to addressing the growing demand for water, threats to water security and the increasing frequency and severity of droughts and floods resulting from climate change."

That challenge will be most severe in regions where a large portion of the population lacks access to modern services, or even in those that are going through accelerated development and rapid economic growth. UN estimates that global water withdrawals have been increasing on an annual 1% rate since the 1980s and expects that this increase rate will remain until 2050, leading to a demand growth of 20 to 30% above the current water use levels (WWAP & UNESCO Director-General, 2019). If we fail to achieve SDG6, and as a result of the increased demand, more than 40% of the global population will potentially be living in areas of severe water stress through 2050.

Figure 2.3: SDG6 logo

2.2. Water Resources Management Approaches

Water quantity is limited, while the world's population keeps increasing and the human lifestyle develops rapidly. Moreover, due to the possible impacts that are linked to climate change, the uncertainty of the upcoming scenarios is high. As the water demand increases, while the supply is limited, the challenge is to utilise the available and limited water supplies to meet the minimum requirements of water demand. The variables of this utilisation process, especially the demand of highly competitive users, are normally addressed through different management approaches in order to achieve the most efficient utilisation, where relevant policymakers take allocation decisions.

The traditional water supply enhancement approaches proved inadequacy to address increasing water-related challenges and meet the newly adopted standards in water allocation (Deng, Ma, Zhang, & Zhang, 2020; Falkenmark, 1986; Yamout & El-Fadel, 2005; Yue & Tang, 2011). Besides, demand management is critically important but without being complemented with other approaches, it would be unsatisfactory for growth, development, and adaptation to climate change for most developing countries (Brooks, 2006; Russell & Fielding, 2010). Topics such as quality management, environmental integrity, efficient allocation of water resources, and cost-effectiveness must be addressed in integrated water management (Bouwer, 2000; Haie, 2016; Kampragou, Lekkas, & Assimacopoulos, 2011). Figure 2.4 illustrates the paradigm shifts or evolution of water management levels regarding the population increase in relation to water availability, and the increase of problem variables complexity.

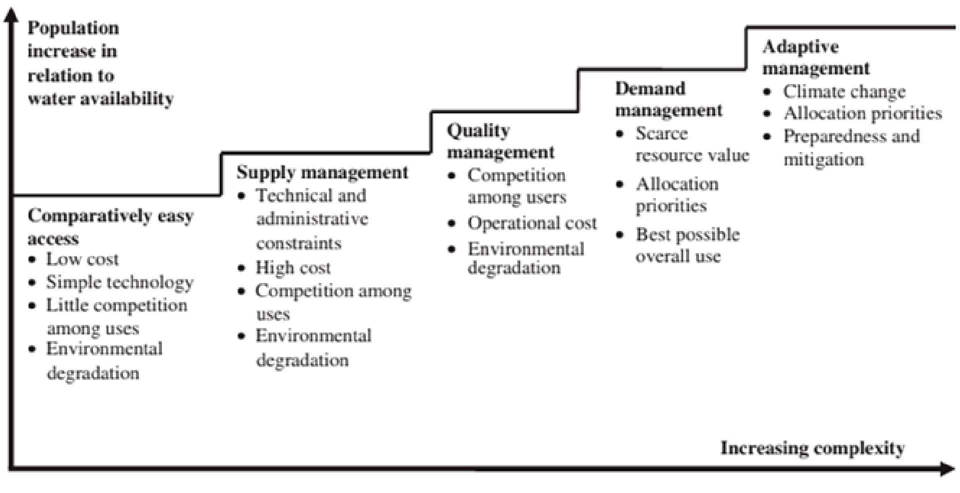


Figure 2.4: Paradigm Shifts in Water Management Levels
Source: (Kampragou et al., 2011)

The systematic processes of continuously improving management policies and practices by learning from the outcomes of previously applied management strategies are known as adaptive management (Pahl-Wostl, 2007). Although neither the concept of adaptive management itself nor its implementation in natural resources management are new (Stankey, Clark, & Bormann, 2005), but the current level of water adaptive management, globally, needs to upgrade in order to meet the recent and foreseeable challenges.

Such an upgrade has to be based on a comprehensive shift towards participatory management and collaborative decision-making. This necessarily means engagement of all related beneficiaries, decentralised management system (including open and shared information sources), higher attention towards the social aspects, consideration of the environmental issues as priorities, and reliance on iterative learning cycles (Figure 2.5) integrated with the overall management approach (Lankford, 2008).

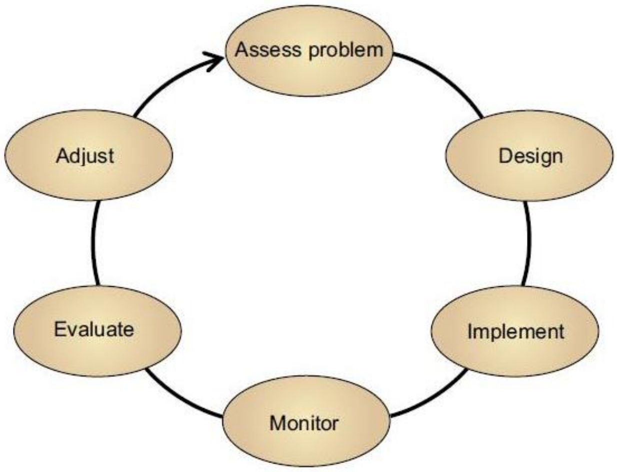


Figure 2.5: Adaptive Management Cycle
Source: (Williams, Szaro, & Shapiro, 2009)

2.3. Water Under Climate Change

Climate is the periodically statistical description in terms of the mean and variability of the relevant quantities of weather conditions such as temperature, precipitation, humidity, and wind. Besides, climate definition includes the associated statistics linked to these conditions such as frequency, magnitude, persistence, trends, etc. (Cubasch et al., 2013), which contribute to help explain phenomena such as droughts, floods, heatwaves, hurricanes and others. Climate change, therefore, refers to a long-term change in the state of these conditions, the variability of their properties, or a combination of both. While weather conditions are classically reported over 30 years, climate change is addressed if the change persists for an extended period (decades or more).

2.3.1. Climate Change Drivers

The dynamics of each of the weather conditions are complex and highly dependent on many components. The process that controls the climate on earth is the radiative balance between incoming solar shortwave radiation (SWR) and outgoing longwave radiation (OLR) (Forster et al., 2007). This process is influenced by the climate change drivers, which are illustrated in Figure 2.6.

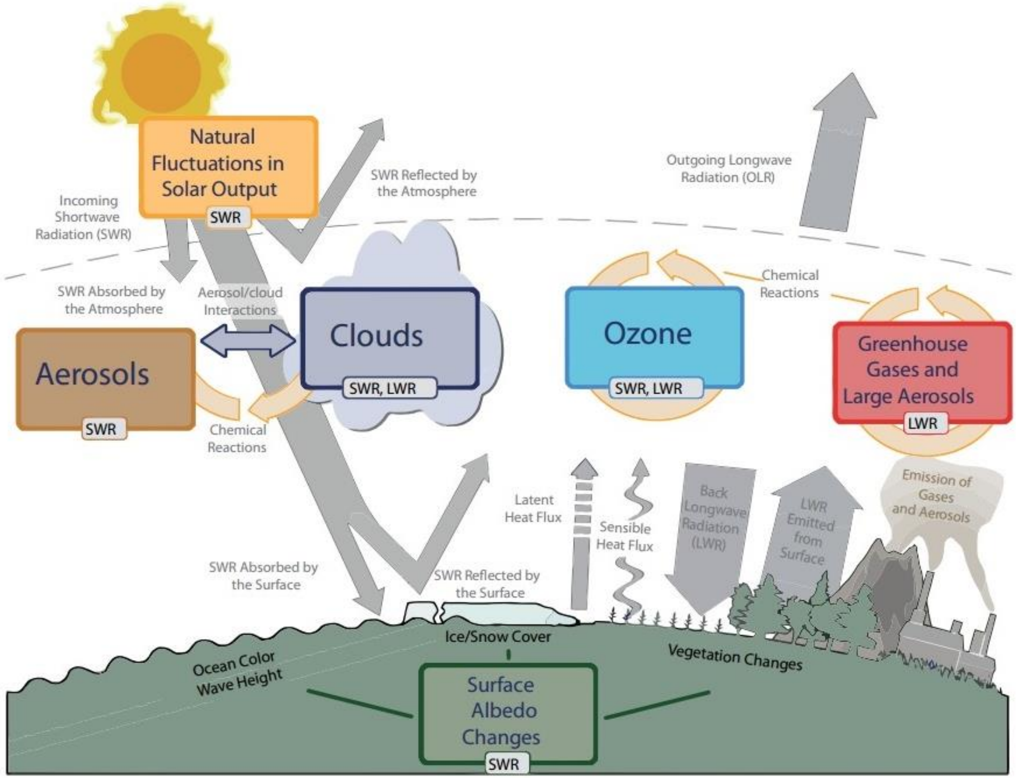


Figure 2.6: Main drivers of climate change
Source: (Cubasch et al., 2013)

To elaborate, the four main drivers of climate change are:

1. Natural fluctuations in solar output (solar cycles). This fluctuation can cause changes in the energy balance through fluctuations in the amount of incoming SWR.
2. Human activities that increase gases and aerosols emissions. These gases and aerosols are directly involved in atmospheric chemical reactions, resulting in modified O_3 and aerosol amounts. O_3 and aerosol particles absorb, scatter and reflect SWR, changing the energy balance. Moreover, some aerosols act as cloud condensation nuclei modifying the properties of cloud droplets and possibly affecting precipitation.

3. Anthropogenic changes in greenhouse gases (GHGs) (e.g. CO_2, CH_4, N_2O, O_3, CFCs) and large aerosols (>2.5 µm in size) modify the amount of OLR by absorbing more of it and reemitting less energy at a lower temperature.
4. Natural seasonal and diurnal changes (e.g., snow cover), as well as human influence (e.g., changes in vegetation types). These factors drive changes in vegetation or land surface properties, snow or ice cover and ocean colour, which cause surface albedo change.

Three out of the four main drivers of climate change are related to human interventions. Hence, climate change is largely driven by human behaviours, such as the burning of fossil fuels, decomposition of organic waste in landfills, and the industrial processing of animals for food production (Gifford, Kormos, & McIntyre, 2011). Hence, there are many voices worldwide calling governments, institutions, and individuals to enforce changes on those behaviours. However, unfortunately, what makes the issue more problematic is that human behaviour is the least-understood part of climate change drivers.

Historical records and observations of different climatic conditions, especially temperature, has indicated, beyond doubt that the earth is warming. This phenomenon intensified in the last 70 years (Figure 2.7) and became known as Global Warming.

Climate change has major potential effects on water resources regarding its impact on water quantity, quality, variability, frequency, and intensity. Impacts of global climate change include increased evaporation rates, higher variations of precipitation temporally and spatially, higher portions of precipitation received in the form of rain (rather than snow), variations in runoff seasons timing, increased water temperatures, and decreased water quality in both inland and coastal areas (Adams & Peck, 2008).

2.3.2. Impact of Climate Change on Water Resources

The uncertainty associated with future scenarios in water management is a complex and multifaceted issue. Climate change has major potential effects on water resources regarding its impact on water quantity, quality, variability, frequency, and intensity. Many authors including Arnell (1999), Adams and Peck (2008), and C. J. Vörösmarty et al. (2010) discussed these effects from different perspectives.

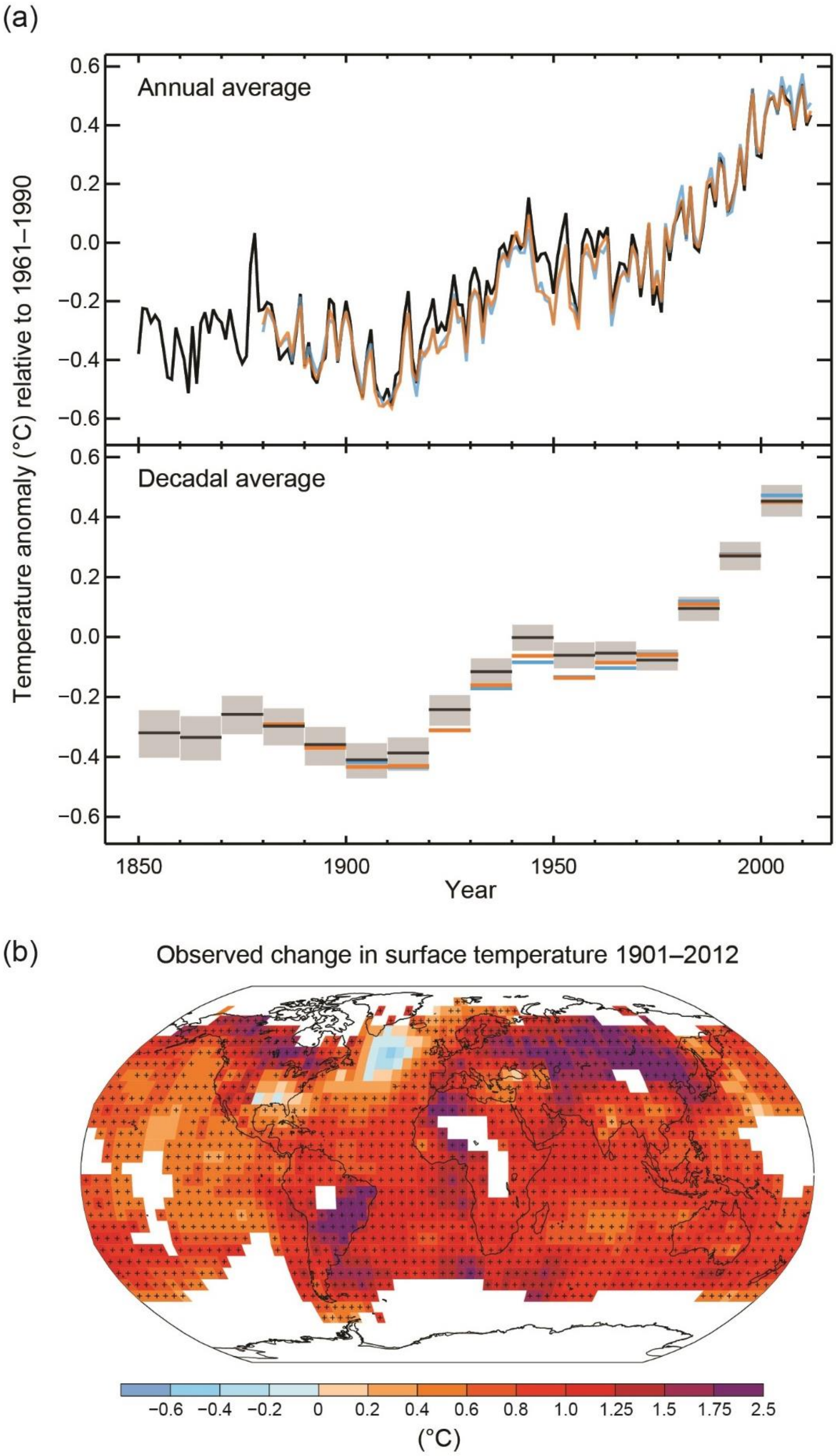


Figure 2.7: Recorded global mean temperature variance for land and water from 1850 to 2012
(a) Recorded global average for land and water surface temperature variances between 1850 and 2012 relative to the mean temperature of 1961–1990. The upper series represent the annual average values, while the lower series represent the decadal average values. (b) Map of the recorded land and water surface temperature variances between 1901 and 2012. Source: (Cubasch et al., 2013).

Starting with Arnell (1999), he provided a detailed assessment of the potential consequences of climate change, which will affect the global hydrological systems and water resources. Relatedly, Adams and Peck (2008) provided an informative overview of the expected physical and economic effects of climate change on water resources (focusing on water scarcities). Whereas, C. J. Vörösmarty et al. (2010) presented a comprehensive assessment of global threats to human water security, among which climate change is one of the most serious.

Moreover, other authors investigated the effects of climate change on water resources in certain regions rather than the entire globe. This is useful since climate change effects are not the same everywhere. For instance, Barnett et al. (2004) described the results of an assessment of the potential effects of climate change on water resources in the western United States (the river basins of Columbia, Sacramento/San Joaquin, and Colorado). Also, Warren and Holman (2012) used baseline and future climate projections and a daily soil water balance model in order to determine the potential impacts of climate change on the Elan Valley, mid-Wales, which supplies the public water network of Birmingham city in the United Kingdom.

Anyhow, when talking about the nation-scale effects of climate change on water resources, the world's most populous country and a massive emitter of greenhouse gases, China, has to be mentioned. A comprehensive investigation about the impacts of climate change on China's water, especially precipitation, was presented by Piao et al. (2010). They argue that, aside from the clear warming that has occurred in China in recent decades, current understanding does not allow a clear assessment resources and agriculture, and thus they recommend future work to improve regional simulations.

Modelling methods of climate change impacts on water resources constitute a considerable portion of the available literature in this field. For example, the Parallel Climate Model (PCM), which is supported by the US Department of Energy, was inclusively explained and studied by Washington et al. (2000). Additionally, Guo, Wang, Xiong, Ying, and Li (2002) proposed and developed a macro-scale and semi-distributed monthly water balance model to simulate and predict the sensitivities of hydrology and water resources to global warming. Other authors contributed to this subject by making comparisons between different models, such as Slaughter, Mantel, and Hughes (2014). They compared the Water Evaluation and Planning (WEAP) model and the Water Quality Systems Assessment Model (WQSAM) regarding possible climate change effects on water quality. Their results showed that WEAP does not simulate water quality within reservoirs and water quality simulation facilities within WEAP are too simple, while WQSAM demonstrated several advantages to water quality modelling.

As there are many works in the literature demonstrating water resources sensitivity to climate change, upgrading water resources planning approaches, therefore, is a necessary action. In this regard, Wood, Lettenmaier, and Palmer (1997) identified major uncertainties in water resources climate change assessments as: a) climate modelling skill; b) errors in regional downscaling of climate model predictions; and c) uncertainties in future demands. They designed a simulation study to provide a better understanding of these uncertainties. Also, Charles J. Vörösmarty, Green, Salisbury, and Lammers (2000) presented numerical experiments combining climate model outputs, water budgets, and socioeconomic information in order to assess the future adequacy of freshwater resources. Moreover, Arnell and Lloyd-Hughes (2014) provided a preliminary assessment of the effects of climate change rates, its patterns, and the expected population growth on regional and global exposure to water resources stress. Relatedly, from another perspective though, Leavesley (1994) reviewed the assessment of climate change impacts using hydrologic models, which provides a framework to conceptualise and investigate the relationships between climate and water resources.

2.4. Impacts of Water Allocation Policies

Decision-makers adopt water (re)allocation policies to deal with challenges, improve conditions, or mitigate severe impacts for the benefit of the users, water resources, and the surrounding environment of a WUS. Topics such as water shortage, enhancing growth and development, adapting to climate change impacts on water resources, the sustainability of the available resources and the environment, etc. have to be addressed and reflected in these policies.

Many authors addressed the impacts of water (re)allocation policies on several aspects. For example, Seung, Harris, and MacDiarmid (1998) and Seung, Harris, Englin, and Netusil (2000) analysed the economic impacts of transferring surface water from irrigated agriculture to recreational use using the Computable General Equilibrium (CGE) model. Also, Fang, Roe, and Smith (2006), Juana, Strzepek, and Kirsten (2010), Qin, Su, Bressers, Jia, and Wang (2013), Qtaishat (2013), Dai, Zhang, Han, Huang, and Geng (2016), and Garrick, Chautard, and Rawlins (2019) analysed the impact of water reallocation from agriculture to other sectors (urban, industrial, and others) on the economy and household income in different regions. Whereas, Rosegrant and Ringler (1999) investigated the potential impacts of water transfers from agricultural to urban and industrial areas on global food supply and demand. They found that comprehensive reforms are required to mitigate the potentially inconvenient impacts of water transfers for local communities and to sustain crop yield and output growth to meet increasing food demands at the global level.

In addition, Bjornlund, Zuo, Parrack, Wheeler, and de Loë (2011) approached the same issue of irrigation water reallocation from another perspective. They investigated the public acceptance of this matter, in addition to whether such acceptance differs between urban and rural residents. They concluded that urban inhabitants are more likely to prefer government intervention while rural inhabitants are more likely to support policies that aim to protect farmers' water rights. They also found that people, both in urban and rural areas, could be categorised into three categories depending on their attitudes towards water and the environment: 1) pro-environment, 2) pro-economy, and 3) undecided. In the same context, Savenije and van der Zaag (2002) argued from a different perspective about water pricing which should primarily serve the purpose of financial sustainability through cost recovery in addition to necessarily drive adequate attention for equity considerations. On the other hand, Fielding et al. (2013) made a huge effort to promote water conservation in the field experimentally. They reported an experimental study to test the long-term impact of three different interventions on household water consumption. Also, Araral and Wang (2013) and Tortajada and Joshi (2013) focused on the important issue of public participation, where water conservation requires the engagement of the public and private sectors as well as of the society at large.

Regarding the environmental impacts of water (re)allocation policies, Colby, McGinnis, and Rait (1991) argued about the continuity of water reallocation to reflect environmental benefits alongside the traditional uses of water. They presented some examples from the American recent history about changes in water allocation, forced by law, to mitigate hazards threatening the nature. Also, Howe, Schurmeier, and Shaw Jr (1986) discussed the shortcomings of water users, especially related to quantity and quality return flow effects, confirming that they can be minimised through changes in the administrative framework of the water rights system. They proved that an efficient water allocation system must integrate quantity and quality management. Furthermore, Weber (2001) modelled a suggested optimal allocation of surface water and pollution rights in a river system with water quality constraints in order to answer the question of whether it is possible to maintain water quality under a certain alternative mechanism for allocating surface water and pollution rights.

2.5. Evolution of Water Use Efficiency From Classical Efficiency to Sefficiency

The approaches and methodologies to assess water use efficiency vary because reaching a comprehensive approach that represents and evaluates the dynamics and performance of a certain water use system (WUS) is a complex matter. The better we understand the complexity of the great number of variables influencing water use systems, the more critical scholars have been toward the classical definition of efficiency – Classical Efficiency (CE): the ratio of the water beneficially used to total delivered. CE was adopted by Orson Winso Israelsen (1932) and O. W. Israelsen (1950), which are pioneered publications in irrigation. Later, further studies went more in-depth about CE in irrigation such as Feddes, Kowalik, and Zaradny (1978) in their book about the theory of field water use and crop production, and French and Schultz (1984) who investigated the relations between the crop of wheat yield and water use from a technical standpoint. Following the same path, Burt et al. (1997) presented a detailed definition and framework of CE in irrigation during their presentation and evaluation of irrigation performance indicators.

The technical engineering element in enhancing water use efficiency in irrigation gained attention among several authors. For instance, Onta, Loof, and Banskota (1995) developed and applied an optimisation model for an irrigation system for land and water allocation during the dry season in order to obtain optimum cropping patterns for different management strategies. Similarly, Small and Rimal (1996) evaluated under varying degrees of water shortage, using a simulation model, the irrigation performance implications of alternative water distribution rules for a dry season. Within this context, Howell (2001) discussed the concept of enhanced CE in irrigation and its impacts on water conservation from different viewpoints. In order to approach enhanced water efficient use in irrigation, he recommended increasing the output per unit of water and reducing water losses to unusable sinks (engineering aspects), reducing water degradation (environmental aspects), and reallocate water to higher priority uses (societal aspects). One last example, Gohar and Ward (2011) evaluated the potential economic benefits that can be supported by Egypt's irrigation water use through developing an integrated catchment scale framework.

CE's use as an efficiency assessment method in irrigation is common worldwide up to date (Al-Juneidi & Isaac, 2000; Çakir, Kanburoglu-Çebi, Altintas, & Ozdemir, 2017; Ibragimov et al., 2007; Liu et al., 2017). However, many researchers highlighted the CE's inability to address critical elements such as irrigation water recovery, water reuse, water quality and to distinguish between water consumption and water use (Haie & Keller, 2014; M. E. Jensen, Harrison, Korven, & Robinson, 1980; Marvin E. Jensen, 2007; Pereira, Cordery, & Iacovides, 2012; Willardson, Allen, & Frederiksen, 1994). They emphasized the necessity of improving the definition of water use efficiency using a more comprehensive approach. Furthermore, Willardson et al. (1994) and Allen, Clemmens, and Willardson (2005) discussed terms such as evaporated, reusable, non-reusable, and consumed fractions.

Hence, important contributions aiming toward a more comprehensive and complete understanding of water use efficiency and water system performance evaluation started taking place in the last couple of decades. An explicit example of this transition is Irrigation Sagacity (IS), which is defined as the ratio of irrigation water beneficially and reasonably used to the total irrigation water applied. This new efficiency term (IS) was first presented by Kruse (1978) and later improved by Solomon and Burt (1999). Nevertheless, Keller and Keller (1995) introduced a more comprehensive concept into the knowledge and understanding of water use efficiency to overcome the limitations of CE, which is Effective Efficiency (EE). They defined EE as the irrigation water consumed (evaporated) by crops divided by the effective use of water (the effective inflow minus the effective outflow).

The major step forward in the definition and approach of Keller and Keller (1995) is the ability of its application on other uses of water and other measures of change in water quality or value, in other words, the inclusion of water quality dimension. This important addition, which came after solely quantitative approaches of water use efficiency, paved the road toward other significant contributions in this regard. Later, Haie and Keller (2008) developed EE models based on water quantity and quality, with the possibility of considering water reuse (recycling), for two scales (the first is called Project EE and the second is called Basin EE). They compared then between CE and EE results and found that CE values were less than EE due to water reuse absence in calculations. Thus, the real importance of their work comes from their defence favouring EE over

CE, especially after the increased voices among researchers advocating the use of different concepts instead of efficiency concepts.

Finally, Haie and Keller (2012) made another major step forward by incorporating a third dimension to the definition of water use efficiency, which is the beneficence of water use. They employed the concept of water balance, based on conservation of mass, to develop three levels of composite efficiency indicators (macro, meso, and micro levels) called Sustainable Efficiency, or Sefficiency. They achieved that through the definition of Usefulness Criterion, which is defined as the product of quality and beneficial weights assigned to the quality and the beneficial attributes of water use. The authors continued their efforts with other informative publications (Haie, 2016; Haie & Keller, 2014) to better describe and, at the same time, examine the terminology associated with water use efficiency. Also, they proposed integrated terminologies, starting from flow-path types in water balance and expanded into the three-level efficiencies formulation. Lately, Professor Naim Haie has gathered the available knowledge about Sefficiency in his book "Transparent Water Management Theory" (Haie, 2020).

Sefficiency application to evaluate the performance of the water use system started to emerge recently. Apart from the publication produced out of this work (Tuqan, Haie, & Ahmad, 2020), two studies by M.T. Ahmad and Haie (2018) and Muhammad Tajuri Ahmad, Haie, Yen, and Tuqan (2018) used Sefficiency to evaluate the efficiency and water allocation of the Kano River Basin (KRB) project in Nigeria. In addition, they assessed the impacts of population growth and climate change on the system's performance. Another example is a study by Kazem Attar, Noory, Ebrahimian, and Liaghat (2020), who used Sefficiency to investigate the quality of return flows and to examine its impact on the assessment of efficiency in irrigation.

2.6. Water Crisis in Palestine

Water resources management in the Middle East is challenging due to the variety of complex issues that threatens water sustainability in that region. Palestine is no exception. Scholars have addressed the different elements in Palestine that construct a crisis level of water resources' availability, accessibility, quality, and efficiency. These elements include, but are not limited to: 1. Increased demand due to the high population growth rates. 2. The impact of a changing climate in a semi-arid to arid region. 3. Absence of the strategic dimension within the national-level of water resources management and planning. 4. The geopolitical complexity caused by sharing the transboundary freshwater resources between hostile neighbours.

2.6.1. Increased Demand Due to Population Growth

The Palestinian Water Authority (PWA) estimates the projected demands for all sectors according to the population. As in the Water Status Report of 2011 (PWA, 2012), they estimated the demand of each governorate on the basis of 150 litres per capita per day (l/c/d). They do not provide a clear justification for the adoption of this criterion other than the referral to the World Health Organisation (WHO) standards. However, the purpose of the WHO's recommendations of minimum water requirement for water service level is to promote health. Moreover, in their Domestic Water Quantity, Service, Level and Health 2003 guidelines, the WHO estimated that 100 l/c/d is sufficient to ensure meeting all hygiene and basic domestic needs (Howard et al., 2003). While the WHO estimation mainly refers to domestic use, the PWA however, refers to the total demand of all use sectors. Whether the 150 l/c/d criterion is well developed and justified or not, the bottom line is that the PWA estimates the Palestinian demand based on population, which is, in fairness, not unique by all means.

According to the latest estimates of the Palestinian Central Bureau of Statistics (PCBS, 2020) in Figure 2.8, the average population growth rate in Palestine is around 2.66%, which led to an increase in population from 2.78 million in 1997 to 4.73 million in 2017 (the year in which PCBS conducted the most recent census). The projections for the four years that follow the last census (from 2018 until 2021) show a continuation of the same trend, where the population is expected to reach 5.23 million in 2021.

Since PWA estimates water demand based on population, such an increasing trend consequently means a continuous increase in demand. Among the few authors who addressed this issue and its impact on the future scenarios of the region were Jayyousi, Jarrar, McKee, and Kaluarachchi (2004). They presented a short but focused estimation of the supply-demand gap due to the population growth reaching the year 2020 according to the Palestinian national targets at the time of publishing their work. As shown in table 2.1, they concluded that the deficit in 2004 was around 177 Mm^3/year and quickly increasing to reach a supply-demand gap of 513 Mm^3/year in 16 years if the existing supplies at that time are not expanded.

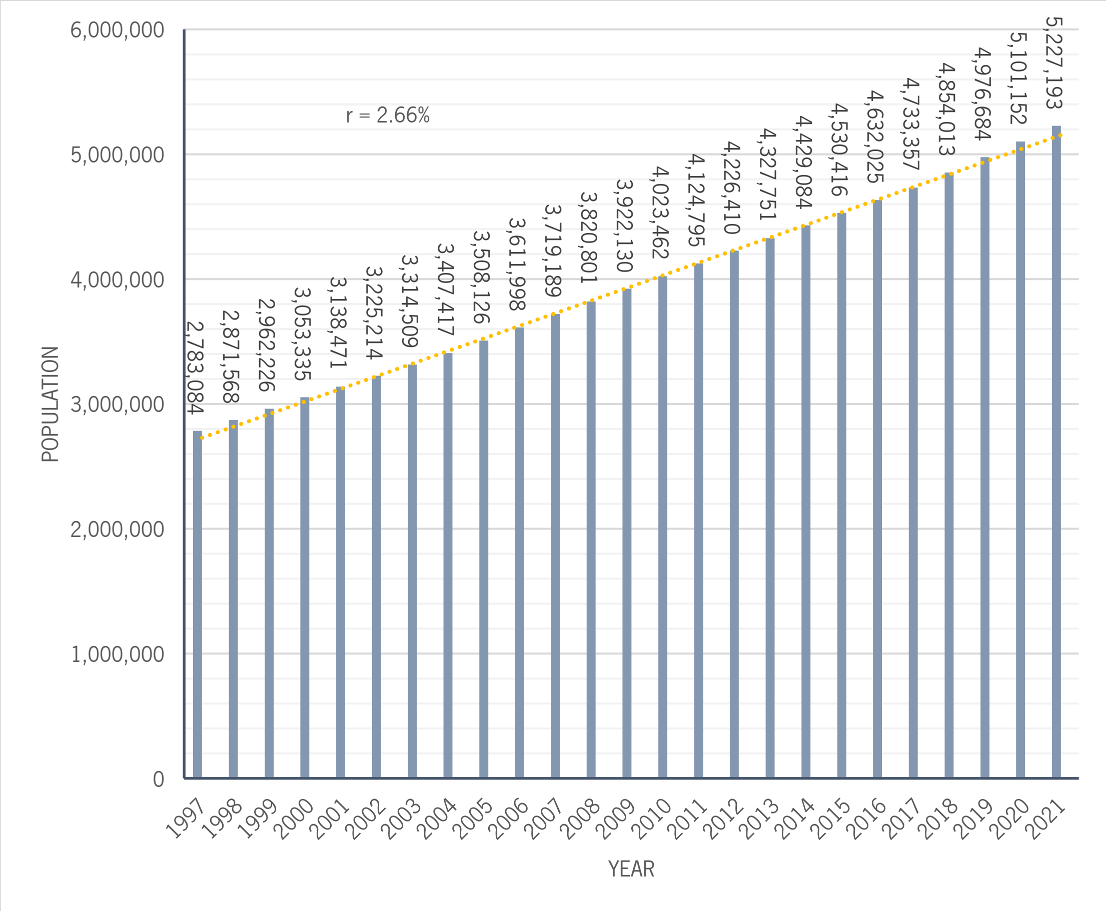


Figure 2.8: Population of Palestine from 1997 to 2021 (Projection)
Where r: the population growth rate. Source: (PCBS, 2020)

It is worth mentioning that Jayyousi et al. (2004) differentiated between the urban and domestic demands and the agricultural demand. They followed the national targets that were based on the WHO guidelines of 150 l/c/d in the urban areas and 100 l/c/d in the rural areas. As for agriculture, they adopted a local study conducted at An-Najah National University and sponsored by the *Deutsche Gesellschaft für Technische Zusammenarbeit* (GTZ) in 1996. It estimated the average annual consumption of irrigated crops around 272 kg per capita; broken down into 179 kg vegetables, 40 kg melons, and 53 kg oranges and bananas. Such a distinction is absent in the national water strategic development reports and literature.

Others, such as J. L. Chenoweth and Wehrmeyer (2006) and J. Chenoweth (2011), analysed the impact of population increase among the three neighbouring countries, Jordan, Isreal, and Palestine, which share the transboundary surface and groundwater resources. They used the population growth projections for the year 2050 based on the United Nations Population Division estimates. In regards to Palestine, their analysis concluded that a stable political environment is necessary and predicted that the West Bank will be able to cover the increased demand only through gaining a larger share of the available resource. Nevertheless, the Gaza Strip will need desalination, water imports, or a combination of both to bridge the gap.

Table 2.1: Projected water demand and deficit (assuming no increase of 2004 supplies) Presented by (Jayyousi et al., 2004)

	Year							
	2000		**2005**		**2010**		**2020**	
Sector	**Demand**	**Deficit**	**Demand**	**Deficit**	**Demand**	**Deficit**	**Demand**	**Deficit**
Domestic	226	125	288	187	332	231	432	331
Agriculture	224	52	266	94	299	127	353	182
Total	**450**	**177**	**554**	**281**	**631**	**358**	**785**	**531**

Similarly, J. Lautze and Kirshen (2009) and Jonathan Lautze, Reeves, Vega, and Kirshen (2005) have simulated eight different scenarios to project the conditions in the years 2020 and 2025. The scenarios varied between Business as Usual (BAU) to the official Palestinian desired and claimed position under population growth and climate change uncertainties in both years. The results showed, on the one hand, that these uncertainties would create an allocation's disproportion and environmental vulnerabilities within the BAU scenarios. On the other hand, under the Palestinian desired position, conditions are more equitable, but associated with critical ecological consequences, especially when considering climate change impacts.

2.6.2. Vulnerability to the Climatic Conditions

Palestine has a total area of 6,020 km^2 (United Nations Statistics Division, 2012). Despite the small number, the variation in climatic zones is considerable due to the variation in topography. Within tens of kilometres, the elevation could drop from more than 800 m above mean sea level at some points in the central part of West Bank down to less than 400 m below mean sea level next to the Dead Sea.

A considerable number of authors addressed the great vulnerability to a change in the climatic conditions in Palestine and its impact on the availability and distribution of the water resources, especially amidst the other complications. For example, as mentioned earlier in their discussions about the population growth issue J. L. Chenoweth and Wehrmeyer (2006), J. Lautze and Kirshen (2009), and J. Chenoweth (2011) could not but to include the climate changes potential impacts in their scenario analysis and future projections. They have concluded that the impact of climate change and reallocation policies have direct consequences on the sustainability of the resources.

In their extensive publication, J. Chenoweth et al. (2011) assessed the impact of climate change on the water resources of the eastern Mediterranean and Middle East region across the 21st century's projections. For water resources data, they relied in their analysis on the AQUASTAT database and CRU CL 2 of the Climate Research Unit at the University of East Anglia. Besides, they used the PRECIS regional climate model (RCM), which was developed by the Hadley Centre, to project the climate changes in the study area. Their results showed that, contrary to southeast Europe, where population growth is relatively low, climate change joined with a population increase in the Middle East is expected to noticeably decrease the individual shares of water. Furthermore, the authors elaborated on the projections of each country in the region. In regards to Palestine, they anticipated a 15% and a 23% drop in precipitation by mid-century and by the end of the century, respectively. At the same time, the projected a doubled Palestinian population by mid-century, and therefore the annual per capita share of water resources by mid-century will be one-third of those available at the time of the publication.

Another publication by Mizyed (2009) addressed the climate change impacts on the water resources, taking the West Bank as a case study and focusing on the agricultural demand. The analysis of this study considered two main variables, namely, temperature and precipitation. As for temperature, and following the Intergovernmental Panel on Climate Change (IPCC) projections in 2007, the author hypothesised three scenarios of 2, 4, and 6°C. Likewise, using IPCC projections, for precipitation changes, he assumed a scenario of no change, and another scenario of 16% precipitation decrease. The results of this study were very interesting. They demonstrated that agricultural water demands could potentially increase by up to 17% due to the anticipated increase in temperatures. Besides, such an increase could potentially result in an annual groundwater replenishment reduction by up to 21% of the values at the time of publication. Furthermore, the study demonstrated that the 16% reduction in precipitation would have far more severe impacts. It could result in an annual groundwater replenishment reduction, when combined with a temperature increase of 6°C, by up to 50% of the replenishment rates in the West Bank at the time of publication.

The same author in a later publication (Mizyed, 2018) applied the same methodology but focusing on the climate change impacts on groundwater recharge instead. The results of his analysis provided that a 2 to 3°C increase in temperature could result in a 6 to 13% decrease in the yearly Palestinian aquifer replenishment. Furthermore, the results showed that these replenishments are fragile to the modelled 3 to 10% decrease in the annual precipitation rates and it may lead to somewhere between 3 to 25% decrease in the yearly rates of replenishment.

Other authors addressed this topic through similar approaches compared to the publications presented in this section. For instance, Sowers et al. (2011) assessed the impacts of climate change on a regional scale, similar to J. Chenoweth et al. (2011). They differed, however, in shedding light upon the governance factors and the decision-making role in the mitigation and adaptation efforts. Also, Ziad A. Mimi and Abu Jamous (2010) hypothesised different scenarios of temperature increase and precipitation decrease, similar to Mizyed (2009). They also concluded that a scenario of a 3°C increase in temperature and a 20% simultaneous decrease in precipitation would require a significant increase in water supplies to satisfy the increased agricultural demand under this scenario.

Finally, some studies, including Feitelson, Tamimi, and Rosenthal (2012), Messerschmid (2012), and Mason (2013), have discussed the impact of the vulnerability under climate change uncertainty on the Palestinian-Israeli conflict. They all agree that climate change is a real threat to any peace efforts in the region, and therefore it has to be addressed in the upmost serious manner.

2.6.3. Strategic Management Concerns

Most of the studies that we have reviewed thus far have suggested that the increase in water supply in Palestine is a must to meet the future demand. The Palestinians Water Authority (PWA), which is the governing body of water resources in Palestine, is no exception. An extensive review of the official PWA reports exposes a clear absence of strategic planning and management insights apart from calls to expand access to the available resources and explore the potentials to develop additional resources. For instance, the PWA Strategic Water Resource and Transmission Plan (PWA, 2014) and the Water Sector Reform Plan 2016–2018 (PWA, 2016) tackle filling the supply-demand deficit mainly through reallocation. There is an absence of discussion in these reports about enhancing efficient use practices, facilities rehabilitation, and demand management. Nevertheless, multiple scholars, including Haddad (1998), Bursche

(2011), and Shevah (2017), have suggested the latter two approaches as viable options to address water shortage in the region.

Important publications have shed light on the absence of official strategic water policies and the low level of the development of unconventional resources. For example, Haddad and Lindner (2001) addressed the importance of a sustainable water demand management approach versus developing additional water resources. The authors outlined a group of suggested managerial approaches and activities, on both local and regional levels, to tackle the projected water gap in Palestine.

Furthermore, La Jeunesse et al. (2016) made a study on five catchments in the Mediterranean region, including the Gaza Strip. The distinguishable part of this publication is the stakeholders' participation in the analysis. Their analysis focused on water use in the region and its advancement in the water management context. The results of this analysis demonstrated that the classic answer to the increasing water demands is to expand water resources options and access within the limits of local capability. The study refers to the clear absence of climate change impacts consideration by the various stakeholders, including the water managers. Similarly, while Sowers et al. (2011) were assessing the climate change impacts on water resources, they concluded that there is a substantial lack of public and social participation considered in the policymaking. Moreover, they found that the foundations to achieve an adaptive management approach to water scarcity in the region are immature.

Through the important publication of Klawitter (2007), the author presented the water issue in Palestine from a human right perspective. One of the key outcomes of this article was that the institutional structure of the Palestinian water sector (Figure 2.9) is not on the required level of development to achieve what the article referred to as the UN concept. In summary, the UN concept is to ensure: 1. Enough water resources to satisfy the domestic demand according to the WHO guidelines. 2. Water quality level that is safe for all domestic uses. 3. Equitable accessibility to water resources for all individuals. The third point must be satisfied in light of the following considerations: physical accessibility (infrastructure), economic accessibility (affordability), non-discriminative accessibility against the marginalised areas or groups (especially women and children), and information accessibility (governmental transparency).

As in Figure 2.9, the policymaking, sector planning, institutional and infrastructural development, and regulations adoption are the responsibility of the Palestinian Water Authority and (PWA) and the Ministry of Agriculture (MOA). These tasks are macro-level of management activities, where the PWA is responsible for water resources management, especially in matters such as water supplies management, infrastructure maintenance and development, and water quality control. On the other hand, the MOA is responsible for the management of agricultural water use, the most dominant water use sector in Palestine.

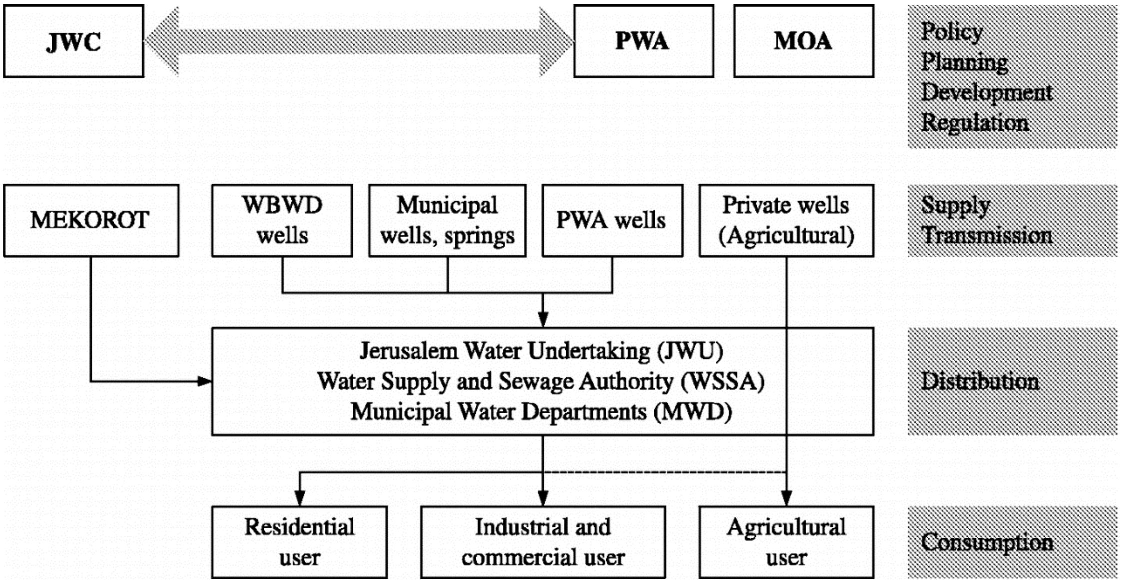


Figure 2.9: Institutional structure of the Palestinian water sector.
JWC: Joint Water Committee, PWA: Palestinian Water Authority, MOA: Ministry of Agriculture, WBWD: West Bank Water Department, and Mekorot: the Israeli national water company. Source: (Klawitter, 2007)

In the same context, authors such as Alsharif et al. (2008) and Judeh et al. (2017) assessed the governance model of water resources in Palestine. Both articles have highlighted essential areas of needed improvements. These areas include the social status (equitable access rights for all areas and groups including the marginalized ones), political status (sustainability of the peace agreements with Isreal), and critically, water use efficiency.

2.6.4. Lack of Public Participation

As evident in many cases, active stakeholders' involvement in an integrated water resources management strategy is key to achieve its objectives (Muhammad Tajuri Ahmad et al., 2018; Priscoli, 2004; Zhou, Deng, Wu, Li, & Song, 2017). Public participation of local communities in Palestine to prioritise their needs is a recently trending practice amid the limited funds allocated – nongovernmental organisations (NGOs) conduct most of such activities since the international donors often require that. Despite the trend and having studies such as Haddad and Bakir (1998) and Haddad (2005) stressing the need for public participation in the decision making, however, no track of active stakeholders' participation in irrigation management in Palestine, let alone efficiency assessment.

2.6.5. Unstable Political Climate

The unstable political climate is considered to be one of the most, if not the most, challenging factors in that part of the world. It has attracted a variety of authors, organisations, and official entities to look into this sensitive matter for different reasons and motives. Nonetheless, as we intend to keep the political dimension beyond the scope of our research work, we review here only a few pieces that addressed the geopolitical complexity as a managerial challenge.

Important studies, such as Elmusa (1995), Jad Isaac and Selby (1996), and Klawitter (2007), highlighted the significance of resolving the allocation disputes on the basis of the international water law principles. They all argued that the only way forward is to address water deficiency in the region through a joint and integrated effort by both sides. Correspondingly, they all argued that a proper application on the international laws of water resources shall lead a more favourable position for the Palestinians in terms of reallocation. Klawitter stated that, while addressing the managerial issues, the insubstantiality of the Palestinian National Authority (PNA) (or Palestinian Authority (PA) in other sources) resembles a scenario of long-lasting fall of the basic state roles of governance.

Looking back at Figure 2.9, the third element in the macro-management level (first row) is the Joint Water Committee (JWC). This committee, which started to meet as a result of the Oslo II interim agreement in 1995, consists of two groups of Palestinian and Israeli water experts. It has the purpose to cooperate and agree on how to implement the water-related principles agreed upon in Oslo. Authors such as Kliot and Shmueli (1998), Feitelson (2006), Katz and Fischhendler (2011), and especially Selby (2013), have all highlighted the great challenges that led to a substantial poor delivery of the purpose it was initiated for. The last clearly stated, after reviewing the minutes of 176 JWC meetings between 1995 and 2008, that the Palestinians were forced to approve projects that threaten the very concept of an independent Palestinian State, such as the expansion of water infrastructural facilities for the Israeli settlements in the West Bank.

Apart from Selby (2013), Professor Jad Selby has several contributions about the Palestinian-Israeli conflict of water resources (Jad Isaac & Selby, 1996; Selby, 2003, 2007).

2.7. Water Use Efficiency in Palestine

Water use efficiency assessment, promotion of efficient use practices, and enhancing efficient irrigation techniques are underinvestigated topics in Palestine. The absence of addressing such matters is more apparent in the official publication of the PWA. Broadly, the authors who addressed these topics in the available literature founded their approaches to efficiency based on the classical definition of efficiency. We came across the shortcomings of classical efficiency in section 2.5.

2.7.1. Agricultural Water Use Efficiency in Palestine

Studies about assessments of agricultural use efficiency in Palestine are rare, apart from a few but important studies such as the interesting publication of Al-Juneidi and Isaac (2000). Although they founded their efficiency assessment based on the classical efficiency method, they successfully attempted to be comprehensive through accounting for the different water resources, irrigated crops, irrigation techniques, and irrigation patterns. The results of their study indicated relatively high rates of water use efficiency, and they justified these results due to the low volume of supplies rather than good management. In terms of data collected, extensiveness, and clarity, we consider this publication as a very useful reference and one of the most inclusive amongst the studies in the field of irrigation management in Palestine.

Other studies came across efficient irrigation techniques to maximise local crop yields. For example, Rahil and Qanadillo (2015) presented a study that was a product of a controlled field experiment to assess the impact of four different irrigation systems under greenhouse farming on the yield, growth parameters, and water use efficiency of cucumber. The four systems were farmer irrigation (FI), tensiometer based irrigation (TI), irrigation with actual crop evapotranspiration (ET_c), and irrigation with 70% of ET_c (70% ET_c). The results of that assessment concluded that 70% ET_c provided the highest crop yield followed by full ET_c, FI, and TI systems.

Besides, McNeill, Almasri, and Mizyed (2009) addressed the important topic of using treated wastewater in irrigation in Palestine. They presented in their publication a basic engineering design for the city of Tubas as a study area and a brief plan for a sustainable implementation of such a project. Although they did not assess efficiency, but their article is useful in promoting a sustainable practice that would enhance the efficiency of agricultural water use systems. A similar attempt on a small scale in Jenin city as a study area can be found in the publication of Z. A. Mimi, Ziara, and Nigim (2003).

2.7.2. Water Use Efficiency in Jericho

When it comes to the Jordan Valley area and the city of Jericho, the studies become scarcer. One of the few local attempts was Barghouthi (2009), who addressed the water use efficiency, especially in irrigation, through investigating the water use variables of a local important spring called Ein Sultan. Although the study is not very well structured and has some flaws from a technical perspective, it is unique in introducing terms such as micro and meso levels of efficient allocation of irrigation water. The author concluded that there are water use inefficiencies in the utilisation of the spring, and the potential cause behind these efficiencies is mainly having a supply-driven rather than demand-based management approach. While the argued cause makes sense considering the managerial challenges in the region, however, the author's conclusions are not strongly supported by the article's methodology and results.

Nonetheless, although Ziad A. Mimi and Abu Jamous (2010) approached water use efficiency in a primitive way, they importantly attempted to assess the impact of climate change on the total crop water demand in Jericho. They followed standard models to estimate evapotranspiration, effective precipitation, and leaching requirements. Their results showed that a 3°C increase in temperature combined with a 20% decrease in precipitation would require a 2.9 Mm^3 increase in water supplies in order to compensate for the increased crop water demands.

Besides, Al-Khatib, Shoqeir, Özerol, and Majaj (2017) addressed the reuse of treated wastewater in irrigation in Jericho city area as a case study. They focused their analysis on the understudied governance element. Their study managed to identify governance-related concerns, including the weak coordination between the different governance stakeholders. This gab is obvious in the overlapping responsibilities. Other concerns they identified included the absence of a robust legislative system and a set of laws to govern the overall processes, in addition to the absence of infrastructure development.

Apart from wastewater reuse, Al-Jayyousi (1999) suggested to enhance irrigation efficiency in Jericho through rehabilitation of the existing irrigation distribution network. The author proposed a design that is based on transforming the existing irrigation open channel system to a distribution network of pressurised pipes.

Finally, and after careful consideration of the available literature up until the time of writing this thesis, we can confidently state that the topic of water use efficiency of the agricultural sector in Palestine, especially under climate change impacts, is understudied. This is more evident when it comes to the area of Jericho city and Eastern Aquifer Basin. Furthermore, among the tens of articles we reviewed, we could find no publication that addressed any of those topics in Palestine using an efficiency evaluation approach other than classical efficiency.

CHAPTER THREE. METHODOLOGY

In this chapter, we will clarify the methodology of which this research work is based on. First, we will provide a brief description of Sefficiency, which is the adopted method for the water use efficiency assessment that is carried out in this research. Then, in the following three sections (3.2 to 3.4), we will explain the definitions and estimation methods of the different variables required to apply Sefficiency in regards to their quantity (section 3.2), quality weight (section 3.3), and beneficial weight (section 3.4). Finally, section 3.5 will come across the approach to construct the different climate change scenarios.

3.1. Sefficiency

Sefficiency was first introduced by Haie and Keller (2012) in their extensive publication: *"Macro, Meso, and Micro-Efficiencies in Water Resources Management: A New Framework Using Water Balance"*. It is a composite indicator to estimate efficiency using the law of mass conservation (water balance), considering two types of total flows: total inflow and total consumption. The preliminary steps are to characterise a water use system (WUS), whether that system was a farm, basin, region, city, or something else. WUS characterisation in Sefficiency is to locate WUS boundaries; to distinguish between the different inflow and outflow water path types (WPTs) (Figure 3.1); and to define the associated attributes, namely quality and benefits — the useful dimension.

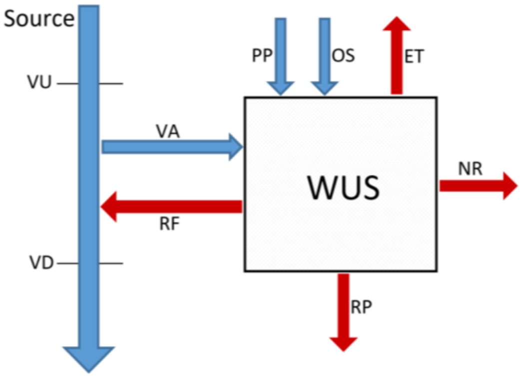
3.1.1. Water Path Types

Water path types (WPTs) are the nine different possible flow types in any given WUS. Any WPT can potentially consist of zero, one, or more water path instances (WPIs), which are the real water instances flowing in or out of the WUS.

As shown in Figure 3.1, there are two categories of WPTs based on the flow direction, namely, inflow and outflow pathways. Inflow paths can be of three sources:

- VA: Volume of abstracted water from the main source or alternatively VU; the level of the aquifer at the beginning of the period

- PP: Precipitation
- OS: Volume of water from other sources (e.g., purchased water)



Variable	Meaning
ET	Evapotranspiration
NR	Nonreuseable
OS	Other source
PP	Precipitation
RF	Return flow
RP	Potential return
VA	Volume of abstracted water
VD	Volume of water at down stream
VU	Volume of water at upper stream

Figure 3.1: Generic water use system (WUS) schematic including all water path types.

Outflow paths can be of four types:

- RF: Return flow to the main source or alternatively VD; the level of the aquifer at the end of the period
- ET: Evapotranspiration
- RP: Potential return (the water returned to the environment, but not the main source)
- NR: Nonreusable, non-ET water consumption (e.g., evaporation resulting from non-agricultural activities)

Useful remarks about the distinction between the different WPTs are available in (Haie & Keller, 2014).

3.1.2. Water Balance

The change in storage over the analysis period (for example annually) should sum to zero, thus: total inflow = total outflow. Translating water balance:

$$(\mathrm{VA} + \mathrm{OS} + \mathrm{PP}) - (\mathrm{ET} + \mathrm{RP} + \mathrm{RF} + \mathrm{NR}) = 0 \qquad (3.1)$$

It is important to bear in mind the consistency of flow units, e.g., Mm^3.

The (VA + OS + PP) part of the equation is the total inflow, which will be denoted by index i (inflow models), and subtracting ET and NR from the total inflow (VA + OS + PP – RF – RP) represents the WUS effective consumption, which will be denoted by index c (consumption models). i and

c are binary indices with values 0 or 1, where $i + c = 1$, in order to differentiate between the two models. To clarify, Equation (3.1) can be rewritten to include these two types of totals:

$$[(\mathrm{VA} + \mathrm{OS} + \mathrm{PP}) - \mathrm{c}(\mathrm{RF} + \mathrm{RP})] - [(\mathrm{ET} + \mathrm{NR}) + \mathrm{i}(\mathrm{RF} + \mathrm{RP})] = 0 \tag{3.2}$$

For example, giving the values $i = 1$ and $c = 0$ in Equation (3.2) will result in Equation (3.1). The significance of considering these two totals is a result of their association with real-water saving mechanisms, whether it was consumptive or abstraction savings. Further details about the link between the two totals and the saving mechanisms can be found in the method's development publication (Haie & Keller, 2012).

3.1.3. Usefulness Criterion

Sefficiency considers two dimensions for making a variable useful: beneficial dimension, b, and quality dimension, q. Having both dimensions defined, then, the useful dimension of a WPI = X is $\mathrm{X_s}$:

$$\begin{gathered} \mathrm{X_q} = \mathrm{W_{qX}} \times \mathrm{X} \\ \mathrm{X_b} = \mathrm{W_{bX}} \times \mathrm{X} \\ \mathrm{W_{sX}} = \mathrm{W_{bX}} \times \mathrm{W_{qX}} \\ \mathrm{X_s} = \mathrm{W_{sX}} \times \mathrm{X} \end{gathered} \tag{3.3}$$

Where:

$\mathrm{X_q}$: the quality dimension of X.

$\mathrm{X_b}$: the beneficial dimension of X.

$\mathrm{W_{qX}}$: the quality weight of X.

$\mathrm{W_{bX}}$: the beneficial weight of X.

$\mathrm{W_{sX}}$: the usefulness weight of X.

Weights are between zero and one with zero being the poorest. The quality weight of a water instance can be quantified based on its physical, chemical, and biological characteristics. While its beneficial weight, however, can be quantified according to tangible and intangible values of water and in accordance with stakeholder participation processes.

3.1.4. Levels of Water Management

Sefficiency assesses the WUS's performance at three different levels: macro-, meso-, and micro-Efficiencies (3ME). Macro-Sefficiency ($MacroSE$) assesses the impact of a WUS on the main source. Meso-Sefficiency ($MesoSE$) relates to a situation between micro and macro levels indicating, for example, the impact of return flows generated by a WUS. Micro-Sefficiency ($MicroSE$) is about the internal efficiency of a WUS, i.e., no consideration of its returns nor impact on the main source (Haie, 2016; Haie & Keller, 2012, 2014).

$MacroSE$ is more suitable for a larger (transboundary) scale assessment that is centred on the aquifer. It would require measures of water table level at the beginning and end of the analysis period to replace VA and RF with VU and VD, respectively. $MicroSE$, on the other hand, ignores the impact of the return flow on the main source, which is an important objective for this work.

Therefore, the assessment in this study will focus on Sefficiency at meso level in order to reflect on the interaction between the useful outflow and total flow. A proper application would be the impact of return instances the system generates. Such an application examines, among different aspects, the impact of the WUS on the downstream users, including the ecosystem.

To calculate the Sefficiency of a WUS at the meso level, we use the following equation – for its proof see (Haie & Keller, 2012) or (Haie, 2020):

$$\mathrm{MesoSE} = \left[\frac{\mathrm{ET} + \mathrm{NR} + i(\mathrm{RF} + \mathrm{RP})}{\mathrm{VA} + \mathrm{OS} + \mathrm{PP} - c(\mathrm{RF} + \mathrm{RP})}\right]_{\mathrm{s}} \tag{3.4}$$

The presence of i or c indicates the I/O models, i.e., $iMesoSE$ means $MesoSE$ calculated as in full inflow model, while $cMesoSE$ means meso-Sefficiency calculated as in consumption model. Full inflow $MesoSE$ gives the percentage of total useful inflow that is useful outflow, whereas consumptive $MesoSE$ provides the percentage of effective consumption that is useful consumption.

3.2. Water Instances Quantities

As mentioned earlier, water instances are categorised based on their paths into three inflow paths types and four outflow paths types. Based on a robust analysis and understanding of the variables of the water use system (WUS), we can determine how many instances each path type consists of, if any. The first step into characterising the WUS is to estimate the volumes of each of the instances that constitute the different WPTs in that WUS.

3.2.1. Precipitation (PP)

Precipitation (PP) is the amount, usually expressed in millimeters or inches of liquid water depth, of the water substance that has fallen at a given point over a specified period of time (AMS, 2019). Typically, meteorological agencies and specialists frequently report precipitation rates for a given area using their field measurements from one or more meteorological stations in that area. In lack of field measurements, PP amounts can be estimated using techniques such as the isohyetal maps of the area under consideration, which are maps constructed of lines that connect points of equal long-term averages of precipitation depth.

As we are looking for a volume of water rather than depth, and to keep consistency in units, average PP depth is multiplied by the area under consideration to estimate the volume of precipitation in a volumetric unit such as Mm^3.

3.2.2. Abstraction From the Main Source (VA)

The amount of water abstracted from the single main water source of the WUS, which could be a river, a basin, or any other source that is central to the stakeholders and users in the WUS. At a national level, official water authorities and agencies measure and control such amounts. Alternately, the volume of water upstream or water table before abstraction (VU) can replace VA value if the assessment considers the macro-level Sefficiency.

For this study, the main source is an aquifer basin. Thus, we will depend on the water authority official reports of withdrawals. Such reports commonly include details about the distributions of withdrawals among the different sectors of water use.

3.2.3. Other Sources (OS)

It is not rare for a large size WUS to have additional sources besides the precipitation and main source's abstractions. For instance, abstractions from secondary sources, purchased water, and reclaimed water reuse can be forms of other sources.

3.2.4. Evapotranspiration (ET)

Evapotranspiration is the combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soil, and vegetation that make up the earth's surface (AMS, 2019). ET estimation, alternatively, the total crop water demand (CWD), is of high complexity due to the variety of the included variables. We will use the CROPWAT model (Smith, 1992), which is based on the Penman-Monteith method, illustrated in FAO Irrigation and Drainage Paper 56 by Allen, Pereira, Raes, and Smith (1998).

To estimate the reference ET (ET_o), which is the evapotranspiration rate of a referenced crop (usually alfalfa) at standard meteorological conditions, the PM equation is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3.5)$$

Where

ET_o: Referenced evapotranspiration in $mm.day^{-1}$

R_n: Net radiation at the crop surface in $MJ.m^{-2}.day^{-1}$

G: Soil heat flux density in $MJ.m^{-2}.day^{-1}$

T: Mean daily air temperature at 2 m height in °C

u_2: Wind speed at 2 m height in $m.s^{-1}$

e_s: Saturation vapor pressure in kPa

e_a: Actual vapor pressure in kPa

$e_s - e_a$: Saturation vapor pressure deficit in kPa

Δ: Slope vapor pressure curve in $kPa.$°C^{-1}

γ: Psychrometric constant in $kPa.$°C^{-1}

Then, to convert ET_o to actual crop ET (ET_c), the crop coefficient approach shall be used:

$$ET_c = K_c \times ET_o \quad (3.6)$$

Where:

ET_c: crop evapotranspiration in mm.day-1

K_c: crop coefficient (dimensionless)

The crop coefficient, K_c, is the ratio of the crop ET_c to the reference ET_o, and it represents an integration of the effects of primary characteristics that distinguish the crop under consideration from a reference crop. The crop coefficient integrates the effect of characteristics that distinguish a typical field crop from a reference grass, which has a constant appearance and a complete ground cover. Consequently, different crops will have different K_c coefficients. The changing characteristics of the crop over the growing season also affect the K_c coefficient. Finally, as evaporation is an integrated part of crop evapotranspiration, conditions affecting soil evaporation will also affect K_c.

We will use the metrological data from the Jericho station to estimate the reference crop evapotranspiration (ET_o) per each growing period. The growing period and the crop coefficient (K_c) for each of the different crop types were estimated based on the extensive local research work in this field conducted by the Applied Research Institute—Jerusalem (ARIJ) in 1998 (J. Isaac & Sabbah, 1998). Then, we utilised K_c to estimate the actual crop evapotranspiration (ET_c) per the growing period of each crop. The areas of irrigated farmland in the governorate for each crop were acquired from the 2010 agricultural census (PCBS, 2012). Furthermore, we verified the growing periods in ARIJ's book for each crop by comparing them with the growing periods of several crops listed by the surveyed farmers in one of the questions in the survey, and with the opinion of local agricultural engineers.

3.2.5. Return Flow (RF)

Return flow is the volume of water that returns to the main source. Such volume can be one or more of different forms including runoff outflowing to a stream, infiltration within an aquifer basin, discharge of urban wastewater networks (as long as its destination is the main source), etc. The quality of the returned flow is not considered here. Alternately, in case of using VU as a type of inflow when the assessment considers the macro-level Sefficiency, the volume of water downstream after the occurrence of the return flow (VD) can replace RF, regardless of the water source type.

Estimation of RF depends on the form of it, which by itself varies from a WUS to another. In this study, as the main source in question is an aquifer basin, we will analyse the spatial characteristics, the used irrigation methods, and the soil classification of the area under consideration. In addition, we will include questions to the local farmers in the survey that will help us to draw a better understanding of the study area, including the irrigation patterns, methods, and the irrigation equipment's conditions and quality.

3.2.6. Potential Return (RP)

The definition of potential returns is very comparable to RF, but differs in terms of the outflow destination downstream. Hence, it is the volume of water that returns to a different downstream destination other than the main source. The estimation of RP is also similar to RF while bearing in mind the downstream direction.

3.2.7. Nonreusable (NR)

The nonreusable is the consumed volume of water, apart from ET, that does not return to the main source nor can be reused in any form within the defined WUS. Similar to the other variables, the identification, and thus the estimation, of the nonreusable volumes differ between the different types of water use systems. For agricultural systems, the evaporation that is not accounted for in ET is an example of NR.

NR can be estimated either through analysis or by using it the slack variable to achieve water balance. In this study, we will use the same approach to estimate NR and RP to account for NR as well. The next chapter includes details about the applied approach to estimate RF, RP, and NR.

3.3. Quality Weights

Water quality variables are of high complexity due to the variety of conditions and characteristics under consideration from physical to chemical and biological conditions. Moreover, the quality dimension is not only about the quality of water and the system that water flows through, but also the level of toleration for a design quality, which is a management decision (Haie & Keller, 2012).

Water quality is a qualitative characteristic that is usually indicated by a lot of field or lab tests and measurements. There are several quantification approaches to quantify water quality. For example, the water quality index (WQI) (Lumb, Sharma, & Bibeault, 2011) is a single number that expresses water quality by aggregating the measurements of water quality parameters (such as dissolved oxygen, pH, nitrate, phosphate, ammonia, chloride, hardness, metals, etc.). Usually, a higher score alludes to better water quality (excellent, good) and a lower score to degraded quality (bad, poor). The index provides a simple and concise method for expressing the quality of water bodies for varied uses such as recreation, swimming, drinking, irrigation, or fish spawning, etc.

Another example among the quantification approaches is the Canadian Water Quality Index (CWQI) (CCME, 2001). The Canadian water quality guidelines (CWQGs) of the Canadian Council of Ministers of the Environment (CCME) presented this index in 2001 and is still used until nowadays. It has also been endorsed by the United Nations Environmental Program (UNEP) in 2007 as a model for Global Drinking Water Quality Index (GDWQI). CWQI or CCME WQI produces a value of between 0 and 100, where a zero value implies very poor water quality, whereas a value close to 100 denotes excellent water quality.

After an extensive investigation, we concluded to a severe lack of water quality data in the area under consideration. Moreover, the funding allocated to this research is well below the capacity to perform field tests. Therefore, we will depend on the available limited data, farmers surveying, and local experts' opinions to estimate water quality weights through a relative approach, which will be explained in the following chapter.

3.4. Beneficial Weights

Water beneficial weight is a value that represents how much beneficial a specific water path instance is. Such a value depends on the perspective of the scorer. For instance, in urban areas, wastewater has a very low benefit for the average resident, however, the opposite is true from the perspective of water resources managers if that urban area is served with a wastewater treatment plant.

Several factors influence this weight including political issues, economic variables, environmental considerations, health and sanitation requirements, social analysis of water needs, etc. Such factors are identified via continuous efforts of monitoring and evaluation activities using tools such as impact assessments, standards and guidelines, surveys of public participation, and many others. The results of these studies should steer the managerial decisions of defining water beneficial weights.

In order to acquire the stakeholder and public participation data, we interviewed the Director-General of Water Resources Management at PWA, Eng. Deeb Abdulghafour, and surveyed a random sample of 40 local farmers. The selection of farmers considered both population density and geographic distribution across the study area. For instance, 30% of the sample were farmers from Jericho city, which is the area of highest population density, another 30% from the northern villages, which have a high rate of agricultural activities, and the remaining 40% were from the remaining villages across the governorate. Full details about the survey's content and results are available in Appendix I, and a summary of the interview transcript with Eng. Abdulghafour is available in Appendix II.

3.5. Climate Change Scenarios

The Intergovernmental Panel on Climate Change (IPCC) of the United Nations, based in Geneva since 1988, is the world's leading organisation in humankind's understanding of Climate Change. The knowledge presented in this section and most of the explanatory information and supporting materials are based on the IPCC's fifth assessment report (AR5), Work Group 1 report, AR5 Climate Change 2013: The Physical Science Basis (Cubasch et al., 2013). AR5 is the latest full assessment report. The next version (AR6) is expected to be published in 2021.

IPCC uses the Representative Concentration Pathways (RCPs) scenarios to simulate climate change models. The concentrations they refer to here are not labelled after greenhouse gases (GHGs) emissions, but after a range of changes in radiative forcing values reaching the year 2100. The radiative forcing is the difference in energy flux (in watts per square meter, or W/m^2) between the solar radiation absorbed by Earth and the one radiated back to space. For instance, RCP2.6 refers to the pathway under a change in climate resulting from a target change in energy flux equals 2.6 W/m^2 by the year 2100. Human activities that increase GHGs emissions are the main driver to increase the atmospheric concentrations leading to an increase in radiative forcing, and thus changing the climate.

There are four original RCPs adopted in the series of IPCC assessment reports, namely RCP2.6, RCP4.5, RCP6.0, and RCP8.5. In their renowned publication, van Vuuren, Edmonds, et al. (2011) clarified the IPCC's methodology and selection criteria behind the decision on these targets. In short, RCPs shall be representative of the existing literature, inclusive of the different elements of radiative forcing, construct for a proper transition between different periods' analyses, and have the year 2100 as a target. Correspondingly, AR6 is expected to introduce new RCPs called the Shared Socioeconomic Pathways (SSPs). IPCC adopted new radiative forcing targets, such as 1.9, 3.4, and 7.0 W/m^2, to represent pathways of terms such as sustainability, middle of the road, and inequality.

IPCC provided projections of the future potential changes in temperature and precipitation across the globe. They conducted in AR5 simulations under the framework of the Coupled Model Intercomparison Project - Phase 5 (CMIP5) of the World Climate Research Programme. For example, Figures 3.2 shows the projected global changes in temperature and precipitation for the period from 1986-2005 to 2081-2100 under RCP2.6 and RCP8.5.

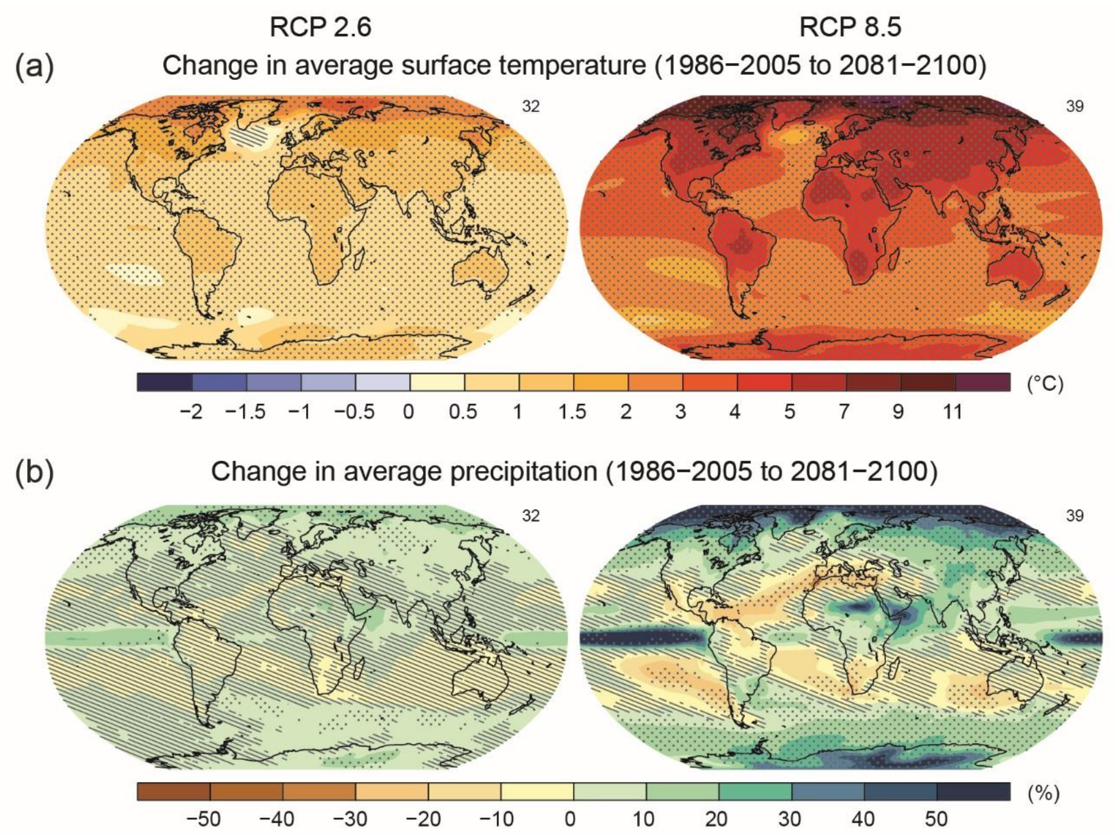


Figure 3.2: IPCC projections for temperature and precipitation based on RCP2.6 and RCP8.5. Source: (Cubasch et al., 2013)

In the Palestinian context, the Palestinian Environment Quality Authority (EQA) published in 2016 the National Adaptation Plan (NAP) to Climate Change (Smithers et al., 2016) under the guidelines of the United Nations Framework Convention on Climate Change (UNFCCC). The report provides an extensive assessment of several projections achieved following the AR5 dataset and using the self-organising maps (SOMs) simulation technique. The authors of the report presented the results of the four original RCPs but focused their analysis on RCP2.6 and RCP6.0. They justified their decision because the first RCP represents the UNFCCC's target for the maximum increase in global mean temperature of 2.0°C, while the latter is the more realistic pathway given UNFCCC measures fail.

For this study, we will follow the same logic of RCPs' selection and adopt the simulation results of the Palestinian NAP to Climate Change report.

3.5.1. RCP2.6 Scenarios

As mentioned earlier, RCP2.6 refers to the pathway under a change in climate resulting from a target change in energy flux equals 2.6 W/m^2 by the year 2100. This pathway is meant to be representative of the various literature that came across the optimistic scenarios of limiting the increase of global mean temperature down to 2.0°C. These literature works typically refer to a decrease in GHGs emissions throughout the second half of the current century by 70% compared to a baseline scenario (van Vuuren, Stehfest, et al., 2011). This pathway, which represents the UNFCCC's target, can be only achieved by adopting measures such as enhancing the use of bio-energy and reforestation.

As in Figures 3.3, 3.5, and 3.6, according to the Palestinian NAP, the most likely changes under RCP2.6 pathway in Palestine are a temperature increase of 0.5°C in 2025, 1.0°C in 2055, and 1.5°C in 2090. For precipitation, there is a projected slight decrease of 2% in 2025, 5% in 2055, and goes up to 10% in 2090.

3.5.2. RCP6.0 Scenarios

Similarly, RCP6.0 refers to the pathway under a change in climate resulting from a target change in energy flux equals 6.0 W/m^2 by the year 2100 without reaching a higher rate prior to the target year. This pathway represents the scenarios under climate policies' intervention. Unlike RCP2.6 and RCP4.5, the required GHGs emissions reduction is lower under RCP6.0 until the year 2060, which is the year when these emissions peak. Nevertheless, it shows a significant decline after that year (Masui et al., 2011). The predicted change in global mean temperature under this pathway is 4.9°C.

As in Figures 3.4, 3.5, and 3.6, according to the Palestinian NAP, the most likely changes under RCP6.0 in Palestine are a temperature increase of 0.5°C in 2025, 1.5°C in 2055, and 3.0°C in 2090. When it comes to precipitation, there is no projected change in 2025, but a projected decrease of 10% in 2055 that goes up to 20% in 2090.

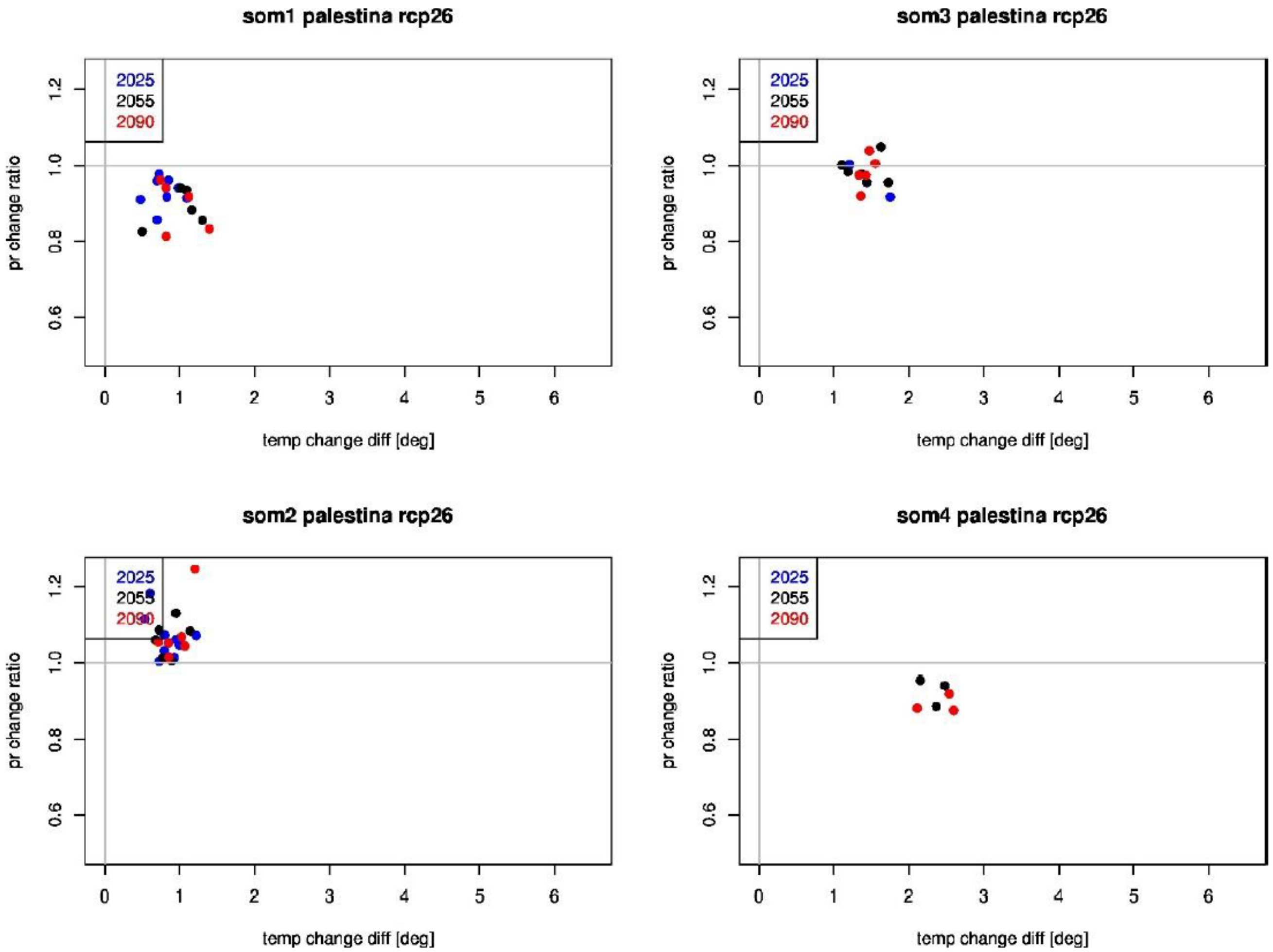


Figure 3.3: SOMs analysis of average temperature and precipitation changes in Palestine under RCP2.6 using CMIP5. Source: (Smithers et al., 2016)

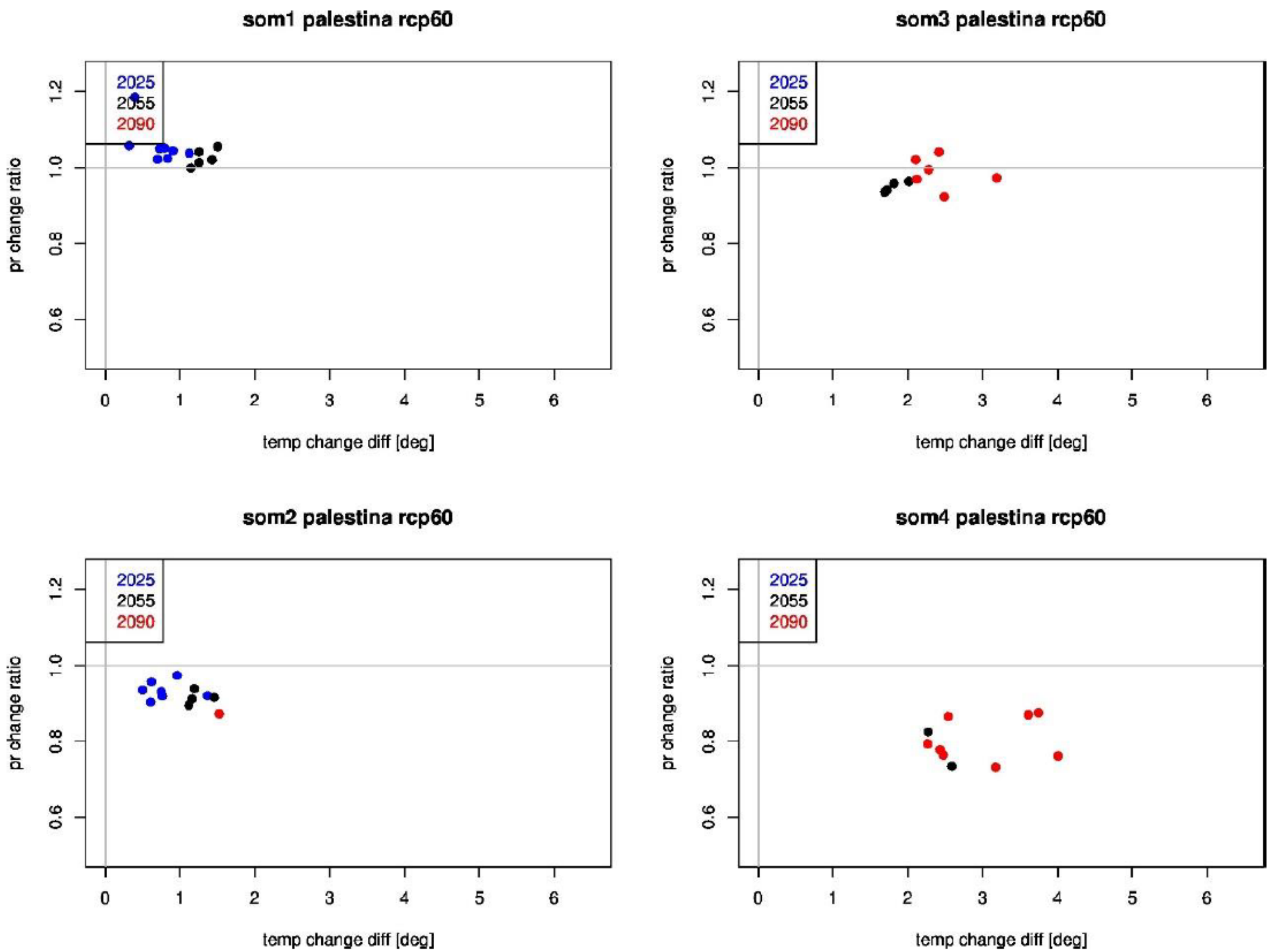


Figure 3.4: SOMs analysis of average temperature and precipitation changes in Palestine under RCP6.0 using CMIP5.
Source: (Smithers et al., 2016)

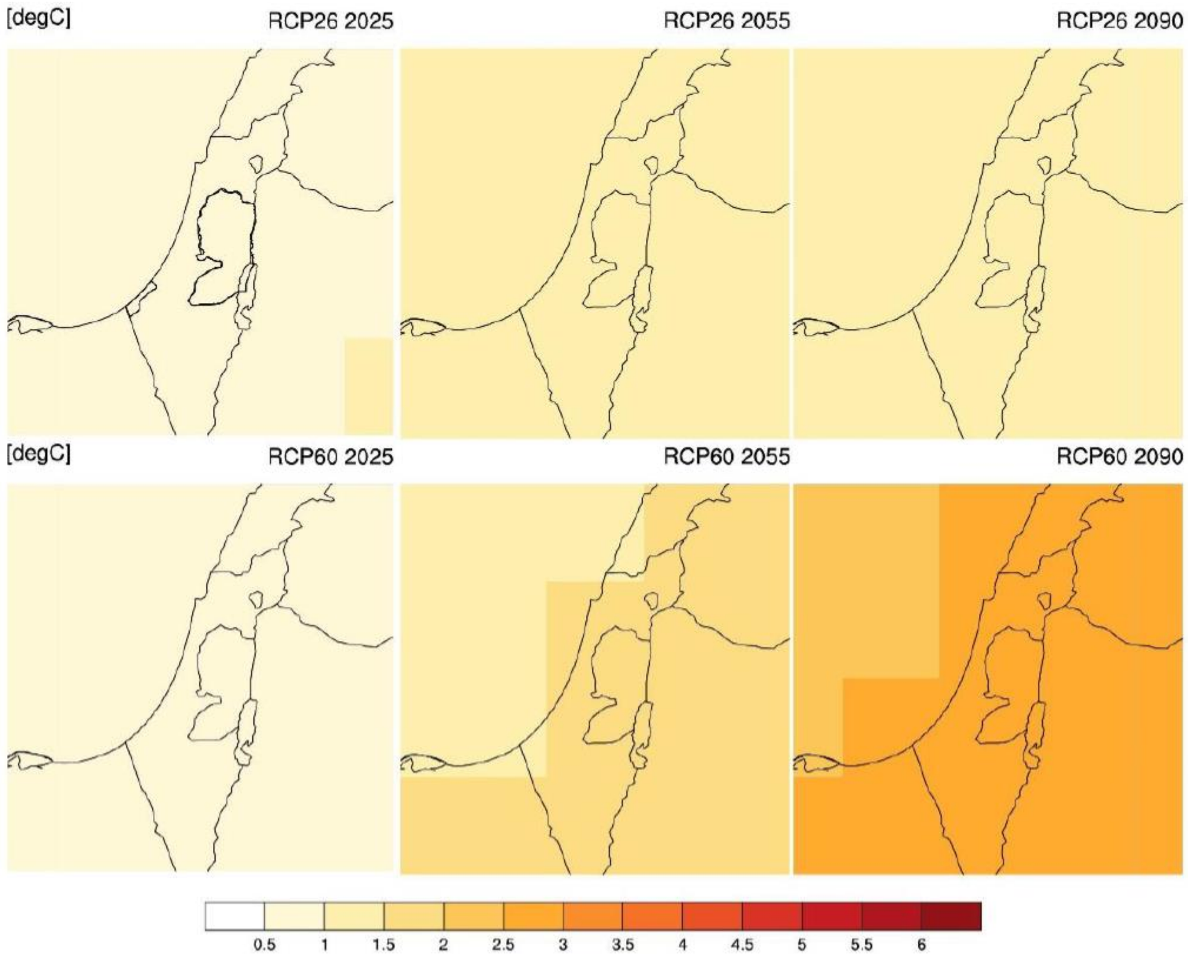


Figure 3.5: Projected changes in temperature in Palestine under RCP2.6 and RCP6.0 for the years 2025, 2055, and 2090. Source: (Smithers et al., 2016)

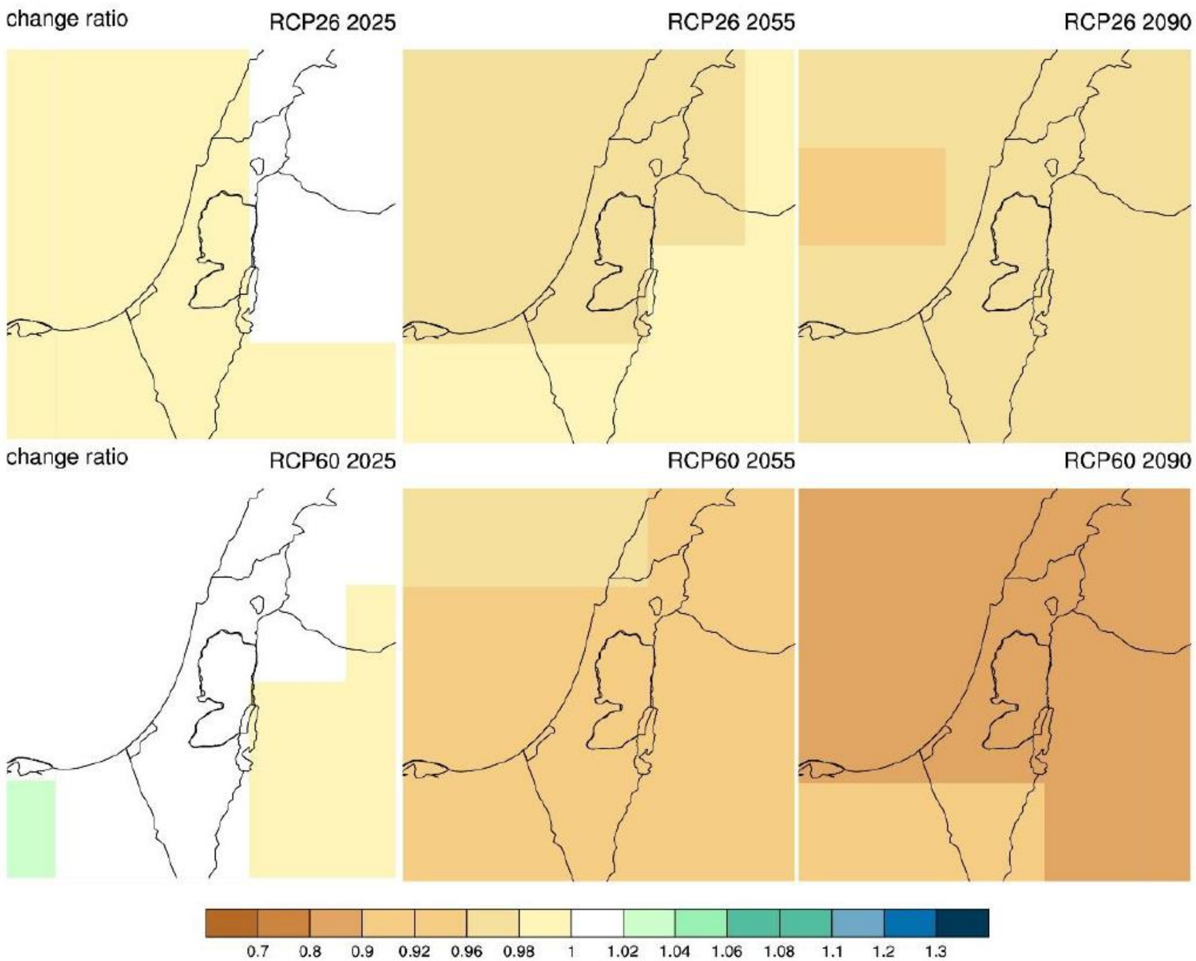


Figure 3.6: Projected changes in precipitation in Palestine under RCP2.6 and RCP6.0 for the years 2025, 2055, and 2090. Source: (Smithers et al., 2016)

CHAPTER FOUR. CHARACTERISING THE WATER USE SYSTEM

In this chapter, we will enrich the reader with an extended set of data and maps of the study area, its water resources, and general characteristics. Then, we will provide details about the characterisation approaches to achieve a representative understanding and estimation of the different variables needed to apply Sefficiency (water quantity, quality, and beneficence). The maps included in this chapter, where there is no reference indicated below the map, are a result of the author's ArcMap GIS work based on the shapfiles provided from the Palestinian Ministry of Planning and International Cooperation (MOPIC, 1998). This ministry was later renamed as the Ministry of Planning.

4.1. Study Area

This study will use Sefficiency as an approach to assess the agricultural water use efficiency in the Palestinian part of Jordan Valley during the 2010/2011 season. We selected this season in particular because it is the most recent season for which the Palestinian official sources provide a complete data set that fits the purpose of this study.

The Jordan Valley is one of the most significant areas in Palestine for several reasons. It represents a great economic value and sustainable development potentials for the Palestinians. The main water source in the Palestinian part of the Jordan Valley is the Eastern Aquifer Basin (EAB). Jericho governorate, home of Jericho city, which some scholars including Kenyon (1954) claimed to be the oldest town in the world, is selected as the study area.

The main reasons for selecting Jericho as a study area are:

1. During the season under consideration, Jericho used more than 62% (26.0 Mm^3) of the total Palestinian abstractions (41.7 Mm^3) from EAB (PWA, 2012). The governorate's agricultural sector used 24.2 of the 26.0 Mm^3, making it, by far, the main user of EAB in Palestine.
2. It constitutes more than 70% (592.9 km^2) of the total area of the Jordan Valley.

3. Jericho has a vital position within the Palestinian national economy. It is a governorate with a substantial volume of agricultural activities in addition to its being an attractive destination for religious, archaeological, and medical tourism.
4. It has a weather station providing metrological data for the governorate.

4.1.1. Location

The Jordan Valley extends between the Nablus, Jerusalem, and Hebron Mountains chain (known in Israeli sources as Judaean and Samaria Mountains) in the west and the northwestern Jordanian highlands in the east. The Palestinian part of the valley has an estimated area of 845 km^2 (MOPIC, 1998). Administratively, two governorates share the vast majority of the valley: the entire *Jericho and Al-Aghwar* Governorate (in short, Jericho) with an area of 592.9 km^2 and the eastern half of *Tubas and the Northern Valleys* Governorate (in short, Tubas) with an area of 252.1 km^2.

As in Figure 4.1, Jericho is located in the central-eastern part of the West Bank. It shares boundaries with the Hashemite Kingdom of Jordan to the east, Nablus, Ramallah & Al-Bireh, and Jerusalem governorates to the west, Tubas governorate to the north, and Jerusalem governorate and the Dead Sea to the south.

4.1.2. Topography

As shown in Figure 4.2, the elevations in Jericho Governorate vary from around 300 m above to 400 m below sea level. The elevation tends to decrease heading southeastward closer to the Dead Sea.

4.1.3. Climate and Precipitation

The area under consideration is arid. Jericho enjoys relatively warm winters compared to the rest of the Palestinian governorates, hence it became a destination for winter housing. Summers are considerably hot with temperatures that exceed 40°C in a typical summery day there. Meteorological characteristics of Jericho are summarised in Table 4.1.

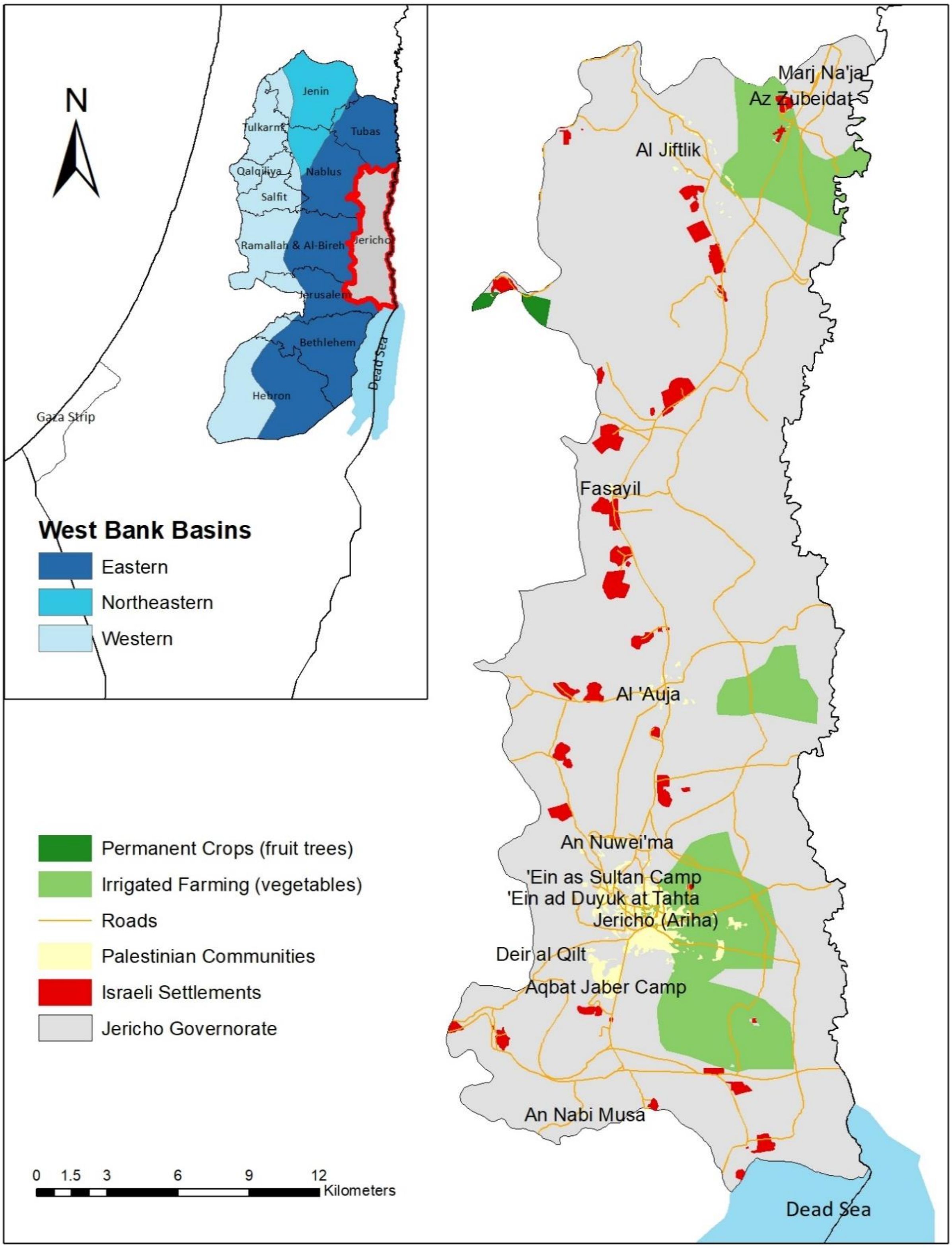


Figure 4.1: Location and land use of the study area

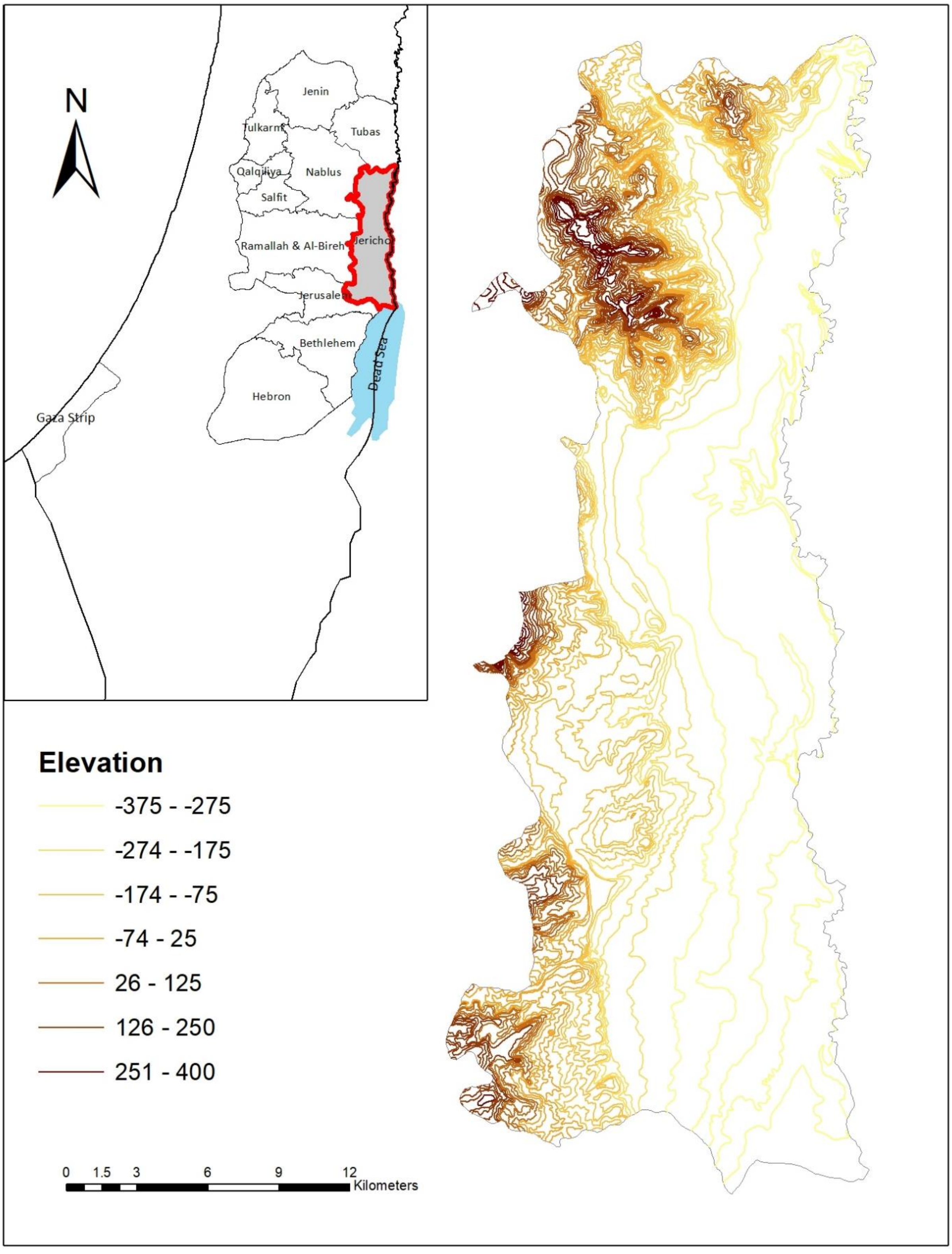


Figure 4.2: Topography of the study area

Precipitation rates (Figures 4.3) vary within a short distance from up to 300 mm per year in the north, down to less than 100 mm per year close to the Dead Sea (EcoPeace Middle East, 2015). The 25-year-average of annual precipitation recorded by the Jericho weather station is 147 mm. These precipitation rates accompanied by high evaporation records result in a greater dependence on irrigation. The Palestinian Central Bureau of Statistics (PCBS) reported in 2011 that 97% of the cropland areas there were irrigated (PCBS, 2012).

Table 4.1: Meteorological characteristics of study area extracted from Jericho weather station.
Weather conditions data cover years 1972–1997. Evaporation and precipitation data cover years 1988–2012.
Source: Palestinian Meteorological Department—Ministry of Transport.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. high Temp. (°C)	19.1	20.9	24.3	29.3	33.7	36.7	37.8	37.6	36.1	32.3	26.4	20.5
Avg. low Temp. (°C)	7.4	8.3	10.5	14.2	17.6	20.4	22.1	22.4	21.2	17.9	12.9	9
Mean Temp. (°C)	13.2	14.6	17.4	21.7	25.6	28.5	29.9	30	28.6	25.1	19.6	14.7
Avg. relative humidity (%)	70	65	57	45	38	38	40	44	47	51	60	70
Avg. daily sun (h)	5.5	5.9	7.7	9.3	9.4	11.8	11.7	11.6	10.5	8.7	6.5	5.6
Avg. atm pressure (mbar)	1048	1046	1044	1041	1040	1037	1034	1035	1039	1042	1046	1048
Avg. wind speed (km/h)	4.5	5.2	6.5	8.1	7.9	7.7	8	7.4	6.3	4.7	4	3.8
Avg. evaporation (mm)	71	74	128	182	259	288	294	274	225	148	96	62
Avg. precipitation (mm)	36	29	20	9	1	1	0	0	0	6	17	28

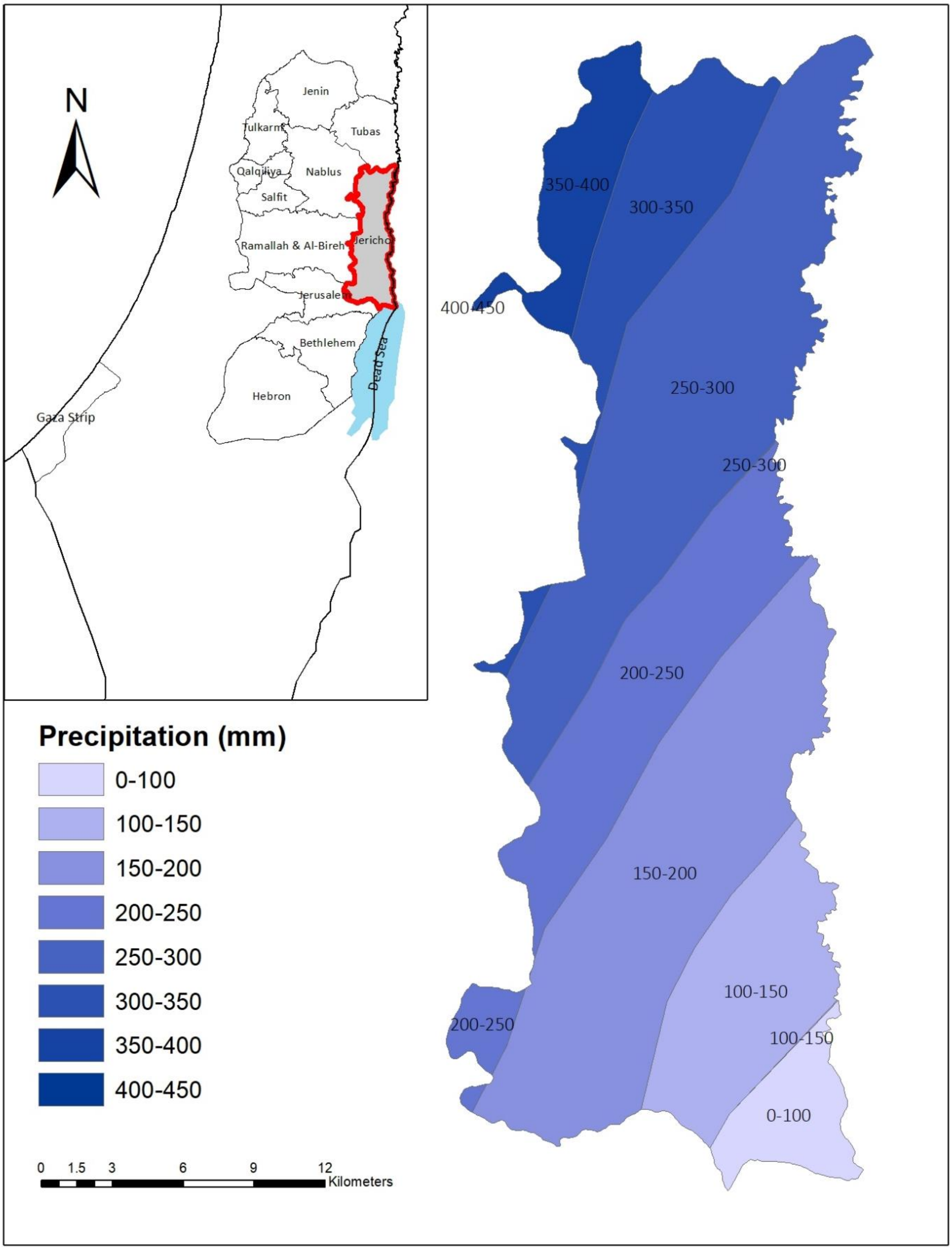


Figure 4.3: Long-term average annual precipitation of the study area

4.1.4. Water Resources

On the topic of water supplies, as mentioned earlier, Palestinians rely on groundwater for 95% of their supplies. Purchased water from Israel, treated wastewater and desalination constitute the remaining 5%. The primary purpose of the purchased water from the Israeli national water company Mekorot is for municipal uses only. In addition, the level of wastewater treatment is below the standards for direct reuse in municipal and agricultural uses. Last, the desalinated Mediterranean seawater is a source that is only available in Gaza Strip. In 2011, all PWA reports suggested that Palestinians in Jericho solely depended on abstracted water from the Eastern Aquifer Basin (EAB) for their agricultural activities (PWA, 2012, 2013, 2016, 2017).

EAB has a total area of 2,767 km^2 (PWA, 2018), which is around half of the total area of the West Bank, and a long-term average recharge of 125–197 Mm^3 (PWA, 2013). The annual yield abstracted from EAB by Palestinians tends to increase: 23 Mm^3 in 2003 (J. Lautze & Kirshen, 2009), 42 Mm^3 in 2011 (PWA, 2012), 53 Mm^3 in 2012 (PWA, 2013), up to 64.8 Mm^3 in 2015 (latest published PWA update) (PWA, 2017).

Israelis also abstract from EAB their allocation (40 Mm^3) according to the Oslo II Agreement in 1995 (a follow-up agreement to the Declaration of Principles known as Oslo I, which both sides signed in 1993). The Palestinian's share in the agreement is set to be 54 Mm^3 per year, while "an additional 78 Mm^3 are to be developed" (Shamir, 1998) – presumably by both sides. PWA claims that the Israeli side abstracts from EAB an estimated additional 100 Mm^3 (PWA, 2012), exceeding the agreed 78 Mm^3 while preventing Palestinians from developing any further abstractions there. On the other hand, the Israeli Water Authority reports Palestinian undesirable practices, including the drilling of 300 unauthorised wells until 2011, the disposal of untreated wastewater, and the dereliction of developing unconventional sources (Israel Water Authority, 2012; Tal-Spiro, 2011).

Out of the 42 Mm^3 that the Palestinian abstracted from EAB in 2011, Jericho got 26 Mm^3 (62%). Jericho's share in that year was broken down into 24.19 Mm^3 for the agricultural sector and 1.81 Mm^3 for the domestic use. This is a clear indicator of the volume of the agricultural activities in the governorate.

Figure 4.4 provides an overview of the water resources movement in the region. It shows the main catchments around Jericho and the wadies that runoff as a result. As mentioned earlier in subsection 1.5.1, the Palestinians do not benefit from the water quantities of these wadies due to a substantial underdevelopment of the necessary infrastructure. The figure also shows the locations of the different wells and springs in the governorate.

4.1.5. Population and Economy

Jericho is the least populous governorates in Palestine (West Bank and Gaza Strip), where only 1.1% of the Palestinians reside (PCBS, 2018). As per the latest Palestinian Central Bureau of Statistics (PCBS) census in 2017, the population of Jericho was 50,001. As in Figure 4.5, the average population growth rate in Palestine is around 2.27%, compared to 2.66% on the national level. The population increased from 31,089 in 1997 and it is projected to reach 53,317 in the year 2021.

The main reason behind the low population density is due to limitations in the economic development, especially in agriculture as suggested by multiple local, Israeli, and international reports, e.g. (ARIJ, 2016; B'Tselem, 2013; UNCTAD, 2015). That is of no surprise considering the geopolitical complexity of this specific part of West Bank.

The Oslo Accords I and II come in interest once more. The agreement designed the territorial jurisdiction dividing the West Bank into areas A, B, and C. Palestinians have administrative and security control over area A, administrative control only over area B (security control is with Isreal), but substantial restrictions in regards to land access, infrastructure and water resource development in area C, where Israel have administrative and security control (World Bank, 2009). The majority of that region, with estimates up to 87% of the Palestinian part of Jordan Valley, especially within the boundaries of Jericho governorate, falls in Area C (Figure 4.6), the breakdown of this percentage includes 56% Israeli military areas, 15% settlements and 20% Israeli natural reserves (OCHA, 2012).

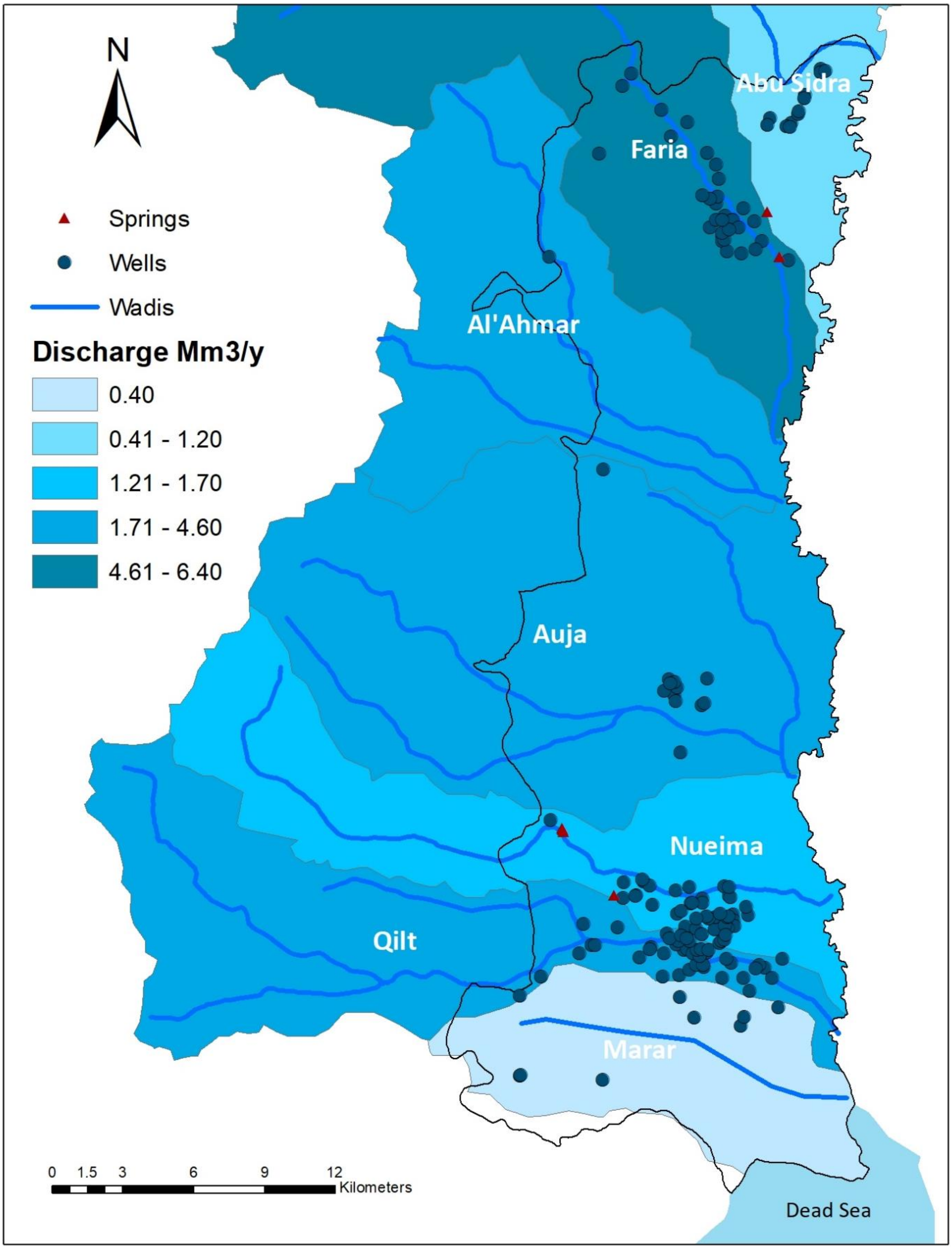


Figure 4.4: Water movement and resources in the study area

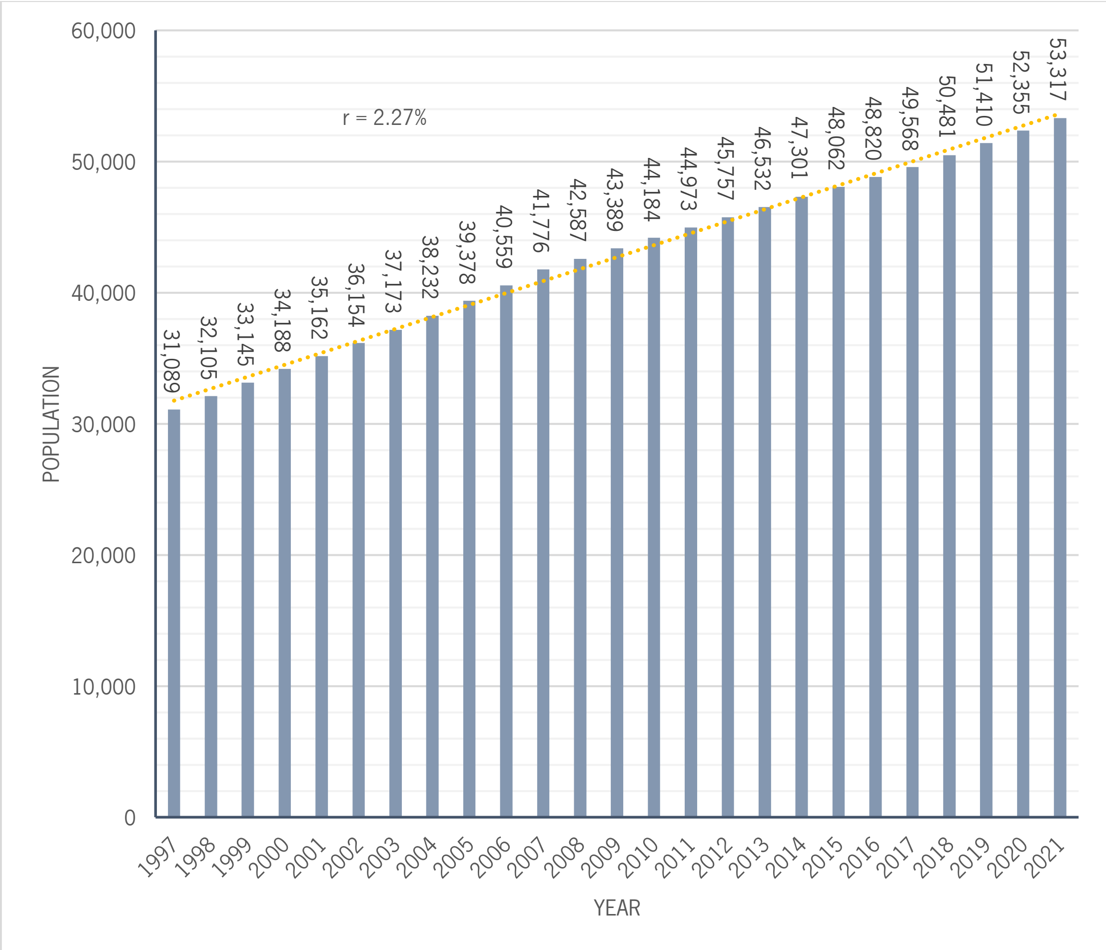


Figure 4.5: Population of Jericho Governorate from 1997 to 2021 (Projection)
Where r: the population growth rate. Source: (PCBS, 2020)

From an economic perspective, Jericho plays a significant role in Palestine. Its weather conditions are suitable for growing fruits and vegetables, including dates, banana, tomato, and cucumber. In addition, the typical Jordan Valley's warmer winters enable farmers to have early harvest seasons, which is economically advantageous, especially for exports. For instance, 50% of the West Bank's agricultural lands, where 60% of the total vegetable production takes place, are located in Jericho (WAFA 2015).

Furthermore, Jericho is the home for a collection of holy and archaeological sites that attract annually a significant number of tourists of the three Abrahamic religions (Christianity, Judaism, and Islam). These sites include the holy Baptismal Site on the Jordan River (*Qasr Al-Yahud*), Hisham's Palace (a renowned early Islamic archaeological site of the Umayyad dynasty), and the *Nabi Musa* (Arabic translation of Prophet Moses) site, which is believed to be the tomb of Prophet Moses.

However, according to a 2012 economic monitoring report to the Ad Hoc Liaison Committee of The World Bank (World Bank, 2012), agriculture's contribution to the Palestinian GDP dropped from 9.3% in 1999 to 4% in 2012. The report immediately links the drop to have the Jordan Valley by itself constituting 46% of total area C, denying Palestinians from a major portion of one-third of groundwater reserves and thousands of fertile dunums in the West Bank.

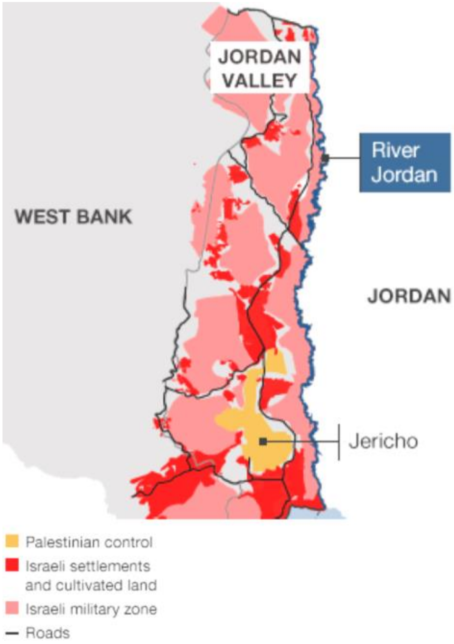


Figure 4.6: Territorial Jurisdiction Division in Jordan Valley.
Source: (EcoPeace Middle East, 2015)

4.1.6. Soil Characteristics

As in Figure 4.7, the soil classification in the region ranges from clay loam (50.3% of Jericho's total area) to sandy loam (39.6%). This classification will be useful to understand the runoff movement against the groundwater recharge potentials after precipitation events. Moreover, Figure 4.8 presents the geological layers of the area under consideration. The dominant two layers are: 1. A layer of marls, clays gypsum sulfur and clastic intercalations (49.4% of Jericho's area); and 2. A layer of landslides and fans (24.9%).

Considering the aforementioned complexity and the involvement of various parties in the region, including both sides' governments, international bodies, academic institutions, and a wide range of NGOs and local research centres, data collection was a challenging task. For the quantitative characterisation of our WUS, we prioritised the official PWA and PCBS published data for 2010/2011 as it is the latest documented season (PCBS, 2012; PWA, 2012).

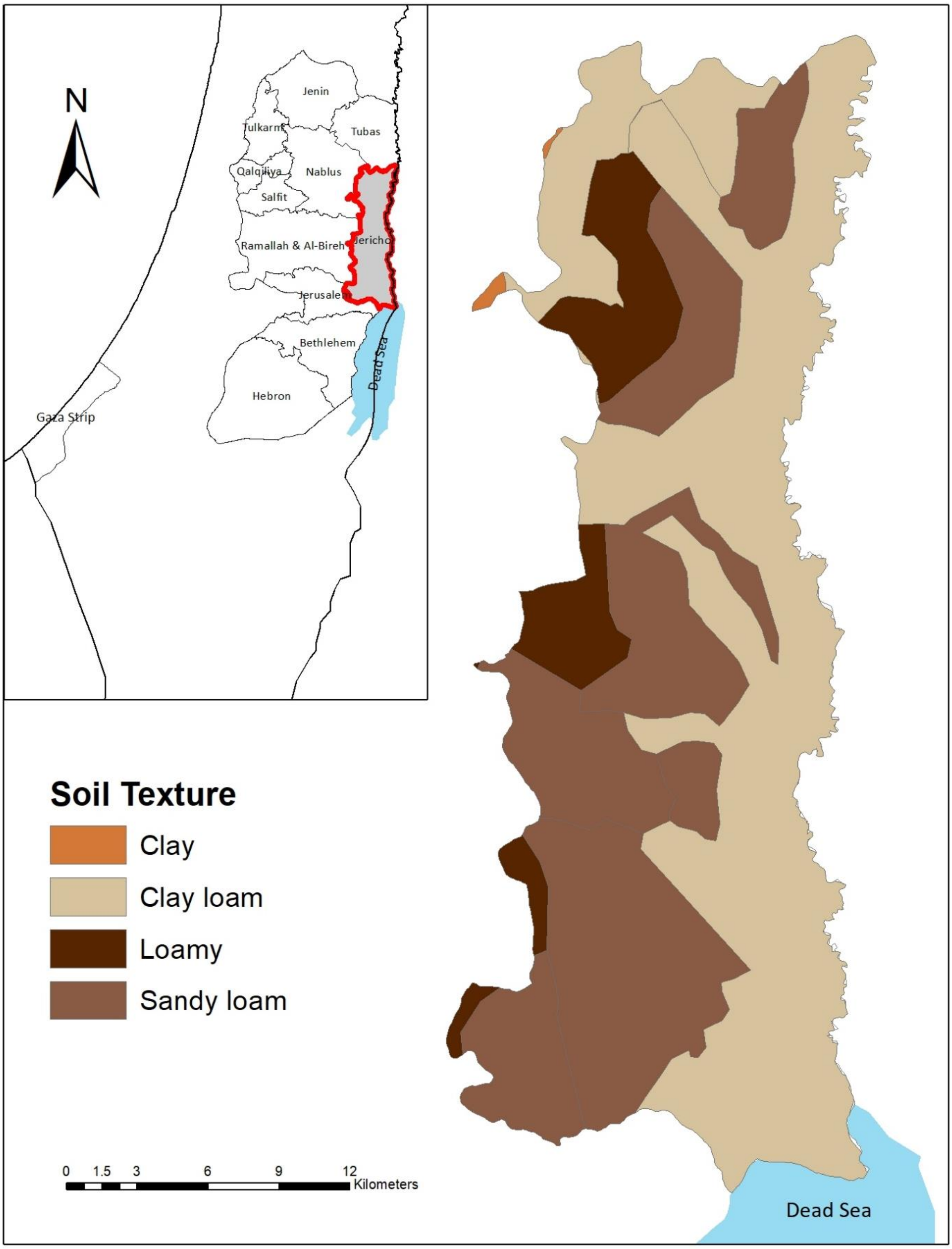


Figure 4.7: Soil classification of the study area

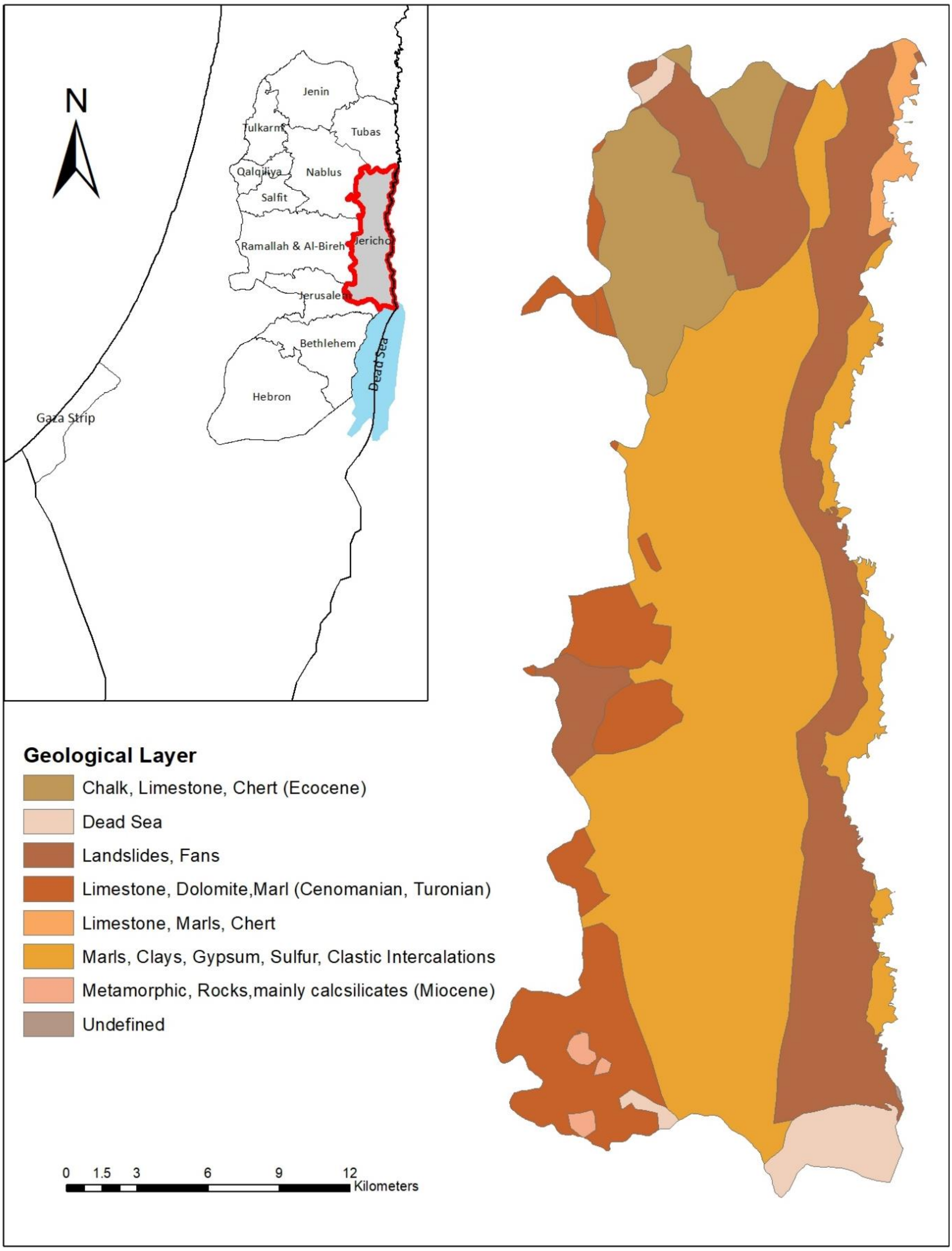


Figure 4.8: Geology of the study area

In addition, in order to acquire the stakeholder and public participation data, we interviewed the Director-General of Water Resources Management at PWA, Eng. Deeb Abdulghafour, and surveyed a random sample of 40 local farmers. The selection of farmers considered both population density and geographic distribution across the study area. For instance, 30% of the sample were farmers from Jericho city, which is the area of highest density, another 30% from the northern villages (green areas in the north of Jericho in Figure 4.1) and the remaining 40% were from the remaining villages across the governorate.

4.2. WPIs Quantities Estimation

Considering the generic schematic in Figure 3.1, the three main inflow path types are water abstractions from EAB (VA), precipitation (PP), and other sources (OS). In the opposite direction, the four main outflow path types are evapotranspiration (ET), aquifer basin recharge (RF), other return types replenishing any source other than the aquifer (RP), and what flows out without replenishment potentials within the system itself nor its neighbour(s) (NR).

4.2.1. Inflow WPIs

The total abstracted water from the Eastern Aquifer Basin as reported from the Palestinian Water Authority (PWA) for agricultural use during the 2010/2011 season, abbreviated here as $\mathbf{VA_{PWA}}$, was 24.19 Mm^3 (PWA, 2012).

Precipitation inflow during the same season was noticeably low, with a total of 99 mm, which is 48 mm below the 25-year-average. In fact, multiple Palestinian sources refer to 2010/2011 as a drought season. The Palestinian Central Bureau of Statistics (PCBS) surveyed 36.28 km^2 of irrigated farmland in the area (PCBS, 2012), hence, the 99 mm precipitation produced 3.59 Mm^3 (**PP**).

Finally, as there was no water supplied from other sources than EAB, the water path type of other sources (**OS**) is assumed to be negligible.

The outflow variables, estimated in the next subsection, will suggest that there must be additional inflows to satisfy the law of water balance. Due to the absence of any further data in regards to water supplies, we will need to consider an inflow slack variable for water balance.

4.2.2. Outflow WPIs

To estimate **ET**, alternatively, the total crop water demand (CWD), as explained in subsection 3.2.4, we used the CROPWAT modelling tool. Metrological data from the Jericho station (Table 4.1) were used to estimate the reference crop evapotranspiration (ET_o) per each growing period. The growing period and the crop coefficient (K_c) for each of the different crop types were estimated based on J. Isaac and Sabbah (1998). Then, we utilised K_c in order to estimate the actual crop evapotranspiration (ET_c) per the growing period of each crop. Irrigated areas for each crop were acquired from the 2010 agricultural census (PCBS, 2012).

Table 4.2 shows CWD modelling results for the top five planted crops of each category (categorised into trees, vegetables, and field crops following the baseline of PCBS). The final estimated value of the total crop water demand was 33.09 Mm^3 for the season under consideration (2010/2011). Full details about ET data are available in Appendix III.

Table 4.2: Evapotranspiration (ET) modelling results for the top 5 planted crops of each category

	Crop	Area (km^2)	ET_o (mm/period)	K_c	ET_c (mm/period)	CWD (Mm^3/year)
Trees	**Date**	4.79	1668	0.935	1559	7.47
	Banana	1.11	1330	0.872	1160	1.29
	Lemon	0.25	1668	0.796	1327	0.33
	Grape	0.25	1668	0.509	850	0.22
	Valencia Orange	0.14	1668	0.678	1132	0.16
Vegetables	**Squash**	7.60	983	0.904	888	6.75
	Eggplant	3.88	1504	0.751	1130	4.38
	Maize	3.83	806	0.720	580	2.22
	Tomato	2.38	806	0.832	670	1.59
	Jew's Mallow	0.71	1668	0.832	1388	0.98
Field Crops	**Wheat**	0.66	925	0.840	777	0.51
	Sorghum	1.18	257	0.720	185	0.22
	Dry Onion	0.10	1145	0.916	1049	0.10
	Mint	0.04	1668	0.832	1388	0.05
	Barley	0.29	240	0.715	171	0.05

In order to estimate **RF**, **RP**, and **NR**, we analysed the spatial characteristics and the used irrigation methods in the region. The soil classification of the area under consideration ranges from clay loam to sandy loam. In addition, the entire sample of farmers who participated in our survey mentioned that they use drip irrigation as their only irrigation technique, which confirms the PCBS and Ministry of Agriculture 2010 agricultural census results as shown in Table 4.3.

Table 4.3: Area under different irrigation methods (km²).
Source: (PCBS, 2012)

Crop Type	Surface Irrigation	Drip Irrigation	Sprinklers Irrigation
Field Crops	0.17	1.91	0.07
Vegetables	1.28	24.65	0.37
Trees	0.43	5.46	0.06
Total (%)	**1.88 (5.5%)**	**32.01 (93.0%)**	**0.51 (1.5%)**

Despite the common perception among farmers that drip irrigation's non-beneficial water consumption is nearly negligible, scholars have been less keen on this idea. A number of studies such as Burt, Mutziger, Allen, and Howell (2005) demonstrated that classic (surface) drip irrigation could produce non-beneficial consumption in evaporation. Moreover, one of the main issues of drip irrigation is the high potential of excess deep percolation (J. Schwankl & R. Hanson, 2007), which can occur as a result of applying the total crop water demand to a relatively small soil surface area.

We have asked the farmers to assess the drip irrigation systems they use in terms of technical quality. Survey results in Figure 4.9 indicate 42% of farmers use the best available drip irrigation options in the market, while 45% and 13% use systems that need improvements or require replacement, respectively. Although drip irrigation systems' design imperfections and technical malfunctions are beyond the scope of this work, we understand that such issues lead to a higher percentage of water consumed in non-beneficial forms for the farmers.

On a different note, we asked the local experts about the time interval in which farmers typically irrigate, which helps in understanding the direction of these non-beneficially consumed quantities. Irrigation application during warm times of the day could lead to higher evaporation, while application during the cold times of the day potentially generates higher infiltration rates. Every expert confirmed that farmers irrigate during the cold periods, in either mornings, evenings, or a combination of both.

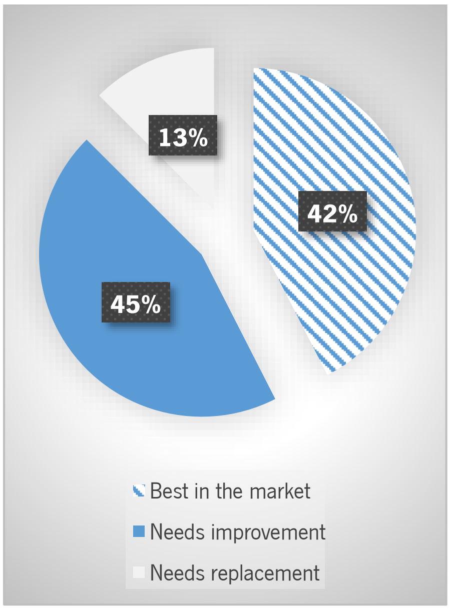


Figure 4.9: Farmers' assessment of their drip irrigation systems' quality

To summarise, we are assessing the agricultural water use of an area that has precipitation in low intensity and frequency, high permeable soil types, semi-arid to arid weather conditions all-year-long, and a dominance of irrigated farmlands via drip irrigation. Based on the available data and survey results, it was estimated that 15% of the applied irrigation from abstractions were flowing into directions other than satisfying CWD, which agrees with previous studies such as Martínez and Reca (2014). Thus:

$$\mathrm{RF_{Eq}} + \mathrm{NR_{Eq}} = 0.15 \times \mathrm{VA} \quad (4.1)$$

Where:

$\mathrm{RF_{Eq}}$: Infiltration back to EAB due to irrigation equipment shortcomings.

$\mathrm{NR_{Eq}}$: Evaporation caused by irrigation equipment shortcomings.

Similarly, we cannot anticipate that the crop will benefit from the entire rainfall quantity to achieve its water demand under the aforementioned circumstances. Following the FAO guidelines about effective rainfall (Brouwer & Heibloem, 1986; Smith, 1992), if the monthly precipitation rate is lower than 17 mm, the effective rainfall is negligible, meaning that the crop will get none of this rain to meet its water demand. In only 3 months (January, February, and December), the precipitation rate exceeded the 17 mm/month threshold by a small margin, which indicates that only 8 mm of effective precipitation out of the 99 mm total precipitation was available over the entire growing season.

The remaining 91 mm, therefore, flows into other directions. Due to soil type, low intensity, and quantity of rain events and weather conditions, it was assumed that the surface runoff was negligible. Thus, RP = zero, and:

$$\mathrm{RF_{PP}} + \mathrm{NR_{PP}} = 91\ \mathrm{mm} \times \mathrm{Area} \tag{4.2}$$

Where:

$\mathrm{RF_{PP}}$: Infiltration back to EAB after rainfall events.

$\mathrm{NR_{PP}}$: Evaporation after rainfall events.

4.2.3. Water Balance Application

Applying water balance (Equation (3.1)) of the quantities calculated thus far indicates an excess of water flowing out of the system compared to inflows from groundwater withdrawal and precipitation. According to the PWA official reports and local agricultural experts, there are no other water resources available, hence, the difference is compensated through unreported abstractions from local wells or springs. This instance will be abbreviated as $\mathbf{VA_{Unr}}$. Engineer Deeb Abdulghafour confirmed this conclusion during our interview. He also explained that a substantial number of unreported wells and springs are old and family inherited properties, which farmers do not report in fear of closure.

Therefore, and in order to reflect the actual flows in and out of the WUS, Equation (3.1) was adapted to:

$$\mathrm{VA_{PWA}} + \mathrm{VA_{Unr}} + \mathrm{PP} = \mathrm{ET} + \mathrm{RF_{Eq}} + \mathrm{NR_{Eq}} + \mathrm{RF_{PP}} + \mathrm{NR_{PP}} \tag{4.3}$$

As a result, the generic schematic in Figure 3.1 can be transformed to represent the actual water flow instances depicted in Figure 4.10.

Applying Equations (4.1), (4.2), and (4.3) resulted in the values of $\mathbf{RF_{Eq}}$, $\mathbf{NR_{Eq}}$, $\mathbf{RF_{PP}}$, $\mathbf{NR_{PP}}$, and $\mathbf{VA_{Unr}}$, taking into consideration that $\mathbf{VA_{Unr}}$ is the slack variable in order to maintain water balance as explained.

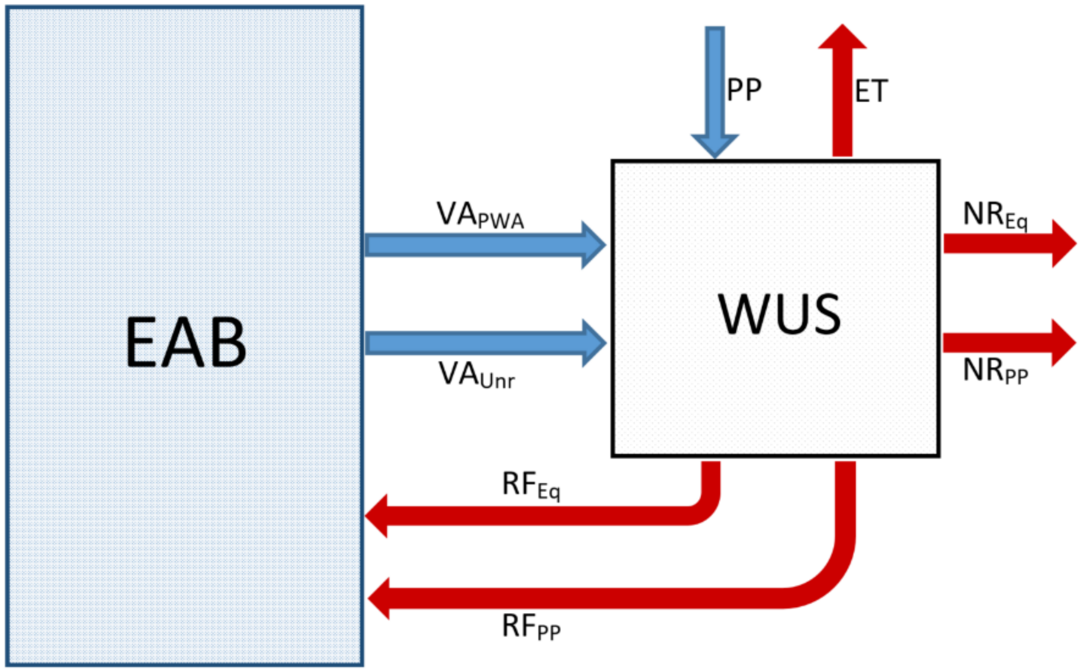


Figure 4.10: Schematic of the actual water path instances (WPIs) flowing in and out of water use system (WUS)

Table 4.4 summarises the final estimation results of the quantities of the different water instances in our water use system.

Table 4.4: Summary of the water instances quantities

Variable	PP	VA_{PWA}	VA_{Unr}	ET	RF_{Eq}	NR_{Eq}	RF_{PP}	NR_{PP}
X (Mm^3)	3.59	24.19	14.40	33.09	3.47	2.32	1.98	1.32

4.3. Quality Weights Assessment

Water quality variables are of a high complexity due to the variety of conditions and characteristics under consideration. Moreover, the quality dimension is not only about the quality of water and the system that water flows through, but also about the level of toleration for a design quality. For instance, PWA reported around 45% of EAB wells' abstraction in 2011 from shallow layers of poor water quality (i.e. brackish). This becomes more noticeable among the springs' abstraction, especially the closer we move towards the Dead Sea area. Therefore, we would anticipate the quality weight to reflect that by being less than 1. Yet, if farmers used such water for planting high tolerance crops, such as dates, that should mitigate the impact of salinity on the quality weight.

As farmers adapt their practices to the available level of water quality, it was assumed that the quality of the water abstracted would be as high as 0.9. Note that, as Eng. Abdulghafour confirmed, the PWA applies some basic level of treatment on the abstracted quantities, hence, we could not set this value to be as high as 1.

In regard to the precipitation, evapotranspiration, and the nonreuseables, since they are WPTs of pure water forms, their quality values were assumed to be 1 for each.

The nitrate concentration results of the PWA-tested samples of randomly selected wells in the region between 2005 and 2009 (Figure 4.11) indicate a trend of increase.

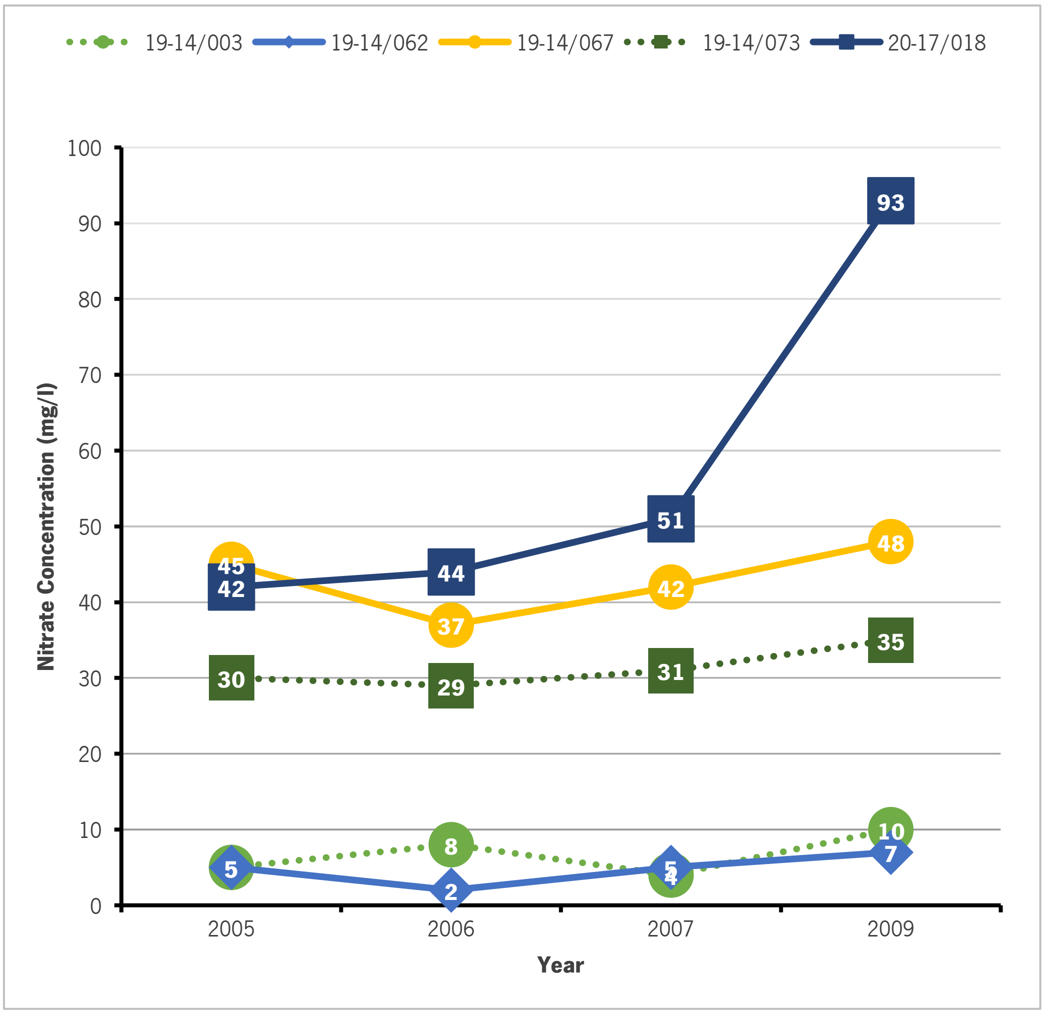


Figure 4.11: Annual average nitrate content in selected wells in the Jordan Valley

It is important to note here that:

1. FAO's guidelines for interpretations of water quality for irrigation suggest a slight to moderate degree of restrictions on use at 5–30 mg/l nitrate concentration range (Ayers;

& Westcot, 1985), which includes 3 of the 5 tested wells and provides a sense of controllability.

2. Nitrate is not the only parameter that defines water quality.

Despite these two facts, the aim here is not to assess the water quality itself but to estimate the impact weight of the WUS's return flow on the main source. Although this trend is more apparent in certain wells than others, it indicates a considerable intensity of agricultural activities, especially between 2007 and 2009. Consequently, the quality weight of the return flow would be significantly low. We assumed this weight to be 0.2, and then made part of the scenario analysis later.

4.4. Beneficial Weights Assessment

Sefficiency reflects on the system's objectives of each of the stakeholders via quantifying the benefit of a water use accordingly. Typically, the different interests of stakeholders vary from being economic, social, environmental and even political. The key here is to realise the differences in objectives and in water management and efficiency perceptions between the local farmers and the local managers in the Palestinian Water Authority (PWA).

From the survey conducted, farmers clearly expressed their main objective from using the abstracted water is to maximise their yield. While 4 out 10 farmers expressed difficulty in getting access to the water they need, around 58% mentioned they will expand their agricultural activity if they get access to more water.

From the managers' perspective, the Director General of Water Resources Management at PWA, Eng. Deeb Abdulghafour, mentioned that their main objective is, on the one hand, to keep a balance between satisfying the high demand, which is vital for the economy and, on the other hand, to preserve the aquifer from its steady-state of deterioration. He added that the PWA plans to do that through getting access to other resources, mainly unconventional resources such as wastewater treatment, in order to mitigate the pressure on the EAB system. In fact, 70% of the surveyed farmers indicated they were willing to use treated wastewater in irrigation.

When it comes to the beneficial weight for all forms of inflow, both sides agree to set the beneficial weights for these instances at relatively high values. Although this is true for the abstracted water instances (VA_{PWA} and VA_{Unr}), our analysis of the effectiveness of rainfall events for crop demand suggests that the beneficial weight of PP cannot be as high. Based on that analysis, we estimated the beneficial weight of PP for both managers and farmers as equal to 0.6.

For the outflow instances, however, managers consider preserving the long-term level of the basin, while farmers do not share such concerns. Thus, the beneficial value for RF is quite different between the two parties. Engineer Abdulghafour confirmed that all returned quantities to the aquifer are essential, hence we set the beneficial values of RF instances to be as high as 1 for managers. On the other hand, only 2 out of every 10 farmers expressed interest or showed awareness about the significance of these quantities, thus we set the W_{bRF} value for farmers to be 0.2. Note that the aforementioned 70% of farmers, who are willing to use treated wastewater, were referring to the planned PWA projects of municipal wastewater treatment plants.

The NR instances are non-useful by definition. Neither the interviewed manager nor the surveyed farmers expressed an interest in it. Therefore, we assumed the beneficial weight values of NR instances to be as low as 0.1 for both stakeholders. We could have assumed this weight to be 0 as well, nevertheless, the influence of such difference (0 or 0.1) on the final results is rather negligible.

In regard to ET's beneficial value, which represents the yield, although the entire WUS is designed to maximise it, in reality, it cannot be set to the highest possible value. This is because of the unwanted plants (weed) issue. In the survey, 47.5% of farmers claimed they treat these plants proactively using pesticides and do not suffer this issue. The remaining 52.5% of farmers estimate the size of these plants as a percentage of their total farmlands: two-third estimated 15%, while the other third estimated 10%. Based on these estimates, the beneficial weight value of ET was set to 0.92.

Finally, Table 4.5 summarises the full characteristics of our water use system, including the WPIs' quantities, quality, and beneficial weights.

Table 4.5: WUS full characteristics

Variable	X (Mm³)	W_{qX}	W_{bX} Farmers	W_{bX} Managers	X_s (Mm³) Farmers	X_s (Mm³) Managers
PP	3.59	1	0.6	0.6	2.15	2.15
VA_{PWA}	24.19	0.9	1	1	21.77	21.77
VA_{Unr}	14.40	0.9	1	1	12.96	12.96
ET	33.09	1	0.92	0.92	30.44	30.44
RF_{Eq}	3.47	0.2	0.2	1	0.14	0.69
NR_{Eq}	2.32	1	0.1	0.1	0.23	0.23
RF_{PP}	1.98	0.2	0.2	1	0.08	0.40
NR_{PP}	1.32	1	0.1	0.1	0.13	0.13

CHAPTER FIVE. SEFFICIENCY RESULTS

After achieving a complete characterisation of the water use system under consideration that satisfies water balance, we will present in this chapter the results of applying Sefficiency at meso-level. In addition, we will hypothesise four different scenarios that represent four possible improvements in the WUS and present the changes in Sefficiency under these scenarios. Climate change scenarios are not among these included in this chapter as they will be the subject of the following chapter.

5.1. Sefficiency of the Existing Conditions

The efficiency assessment at meso level ($MesoSE$) will help us understand the water path instances' impact on the aquifer and the potential downstream users according to the WUS's objectives, which differ between the stakeholders.

The $MesoSE$ results were calculated based on Equation (3.4). It distinguishes between the full inflow model ($iMesoSE$) that reflects on the percentage of total useful inflow that is useful outflow, and the consumptive flow model ($cMesoSE$) that reflects on the percentage of effective consumption that is useful consumption. We also assessed the performance according to the classical efficiency approach for comparison.

The results in Figure 5.1 show that the WUS's Sefficiency in season 2010/2011 considering farmers' and managers' objectives for both inflow and consumption models was 84% and 86%, respectively. It is not surprising to see that the Sefficiency results are higher with respect to the managers' objectives since the assessment considers the return flow. On the other hand, CE results indicate lower efficiency percentages regardless of the system's objectives since it does not consider the return flows. It is evident here that neglecting the other water path types, even if relatively small in quantity, could reflect significantly (around 11 to 13 percentage points in our WUS) on the assessment.

From the management perspective, there is a small difference between $iMesoSE_S$ and $cMesoSE_S$ as the low quality of return flow (RF) in the inflow model reduces the Sefficiency nearly as much its beneficence does in the consumption model. In order to illustrate this, we assessed the difference between $iMesoSE_b$ and $cMesoSE_b$ values, where the quality weights were excluded (all set to be one), and only the beneficial weights were considered, and thus the percentage difference became wider. Another trend is the difference between $MesoSE_b$ and $MesoSE_s$ (especially in the inflow model). This is clear evidence of the heavy agricultural activities' impact in the area and the excessive use of chemical substances.

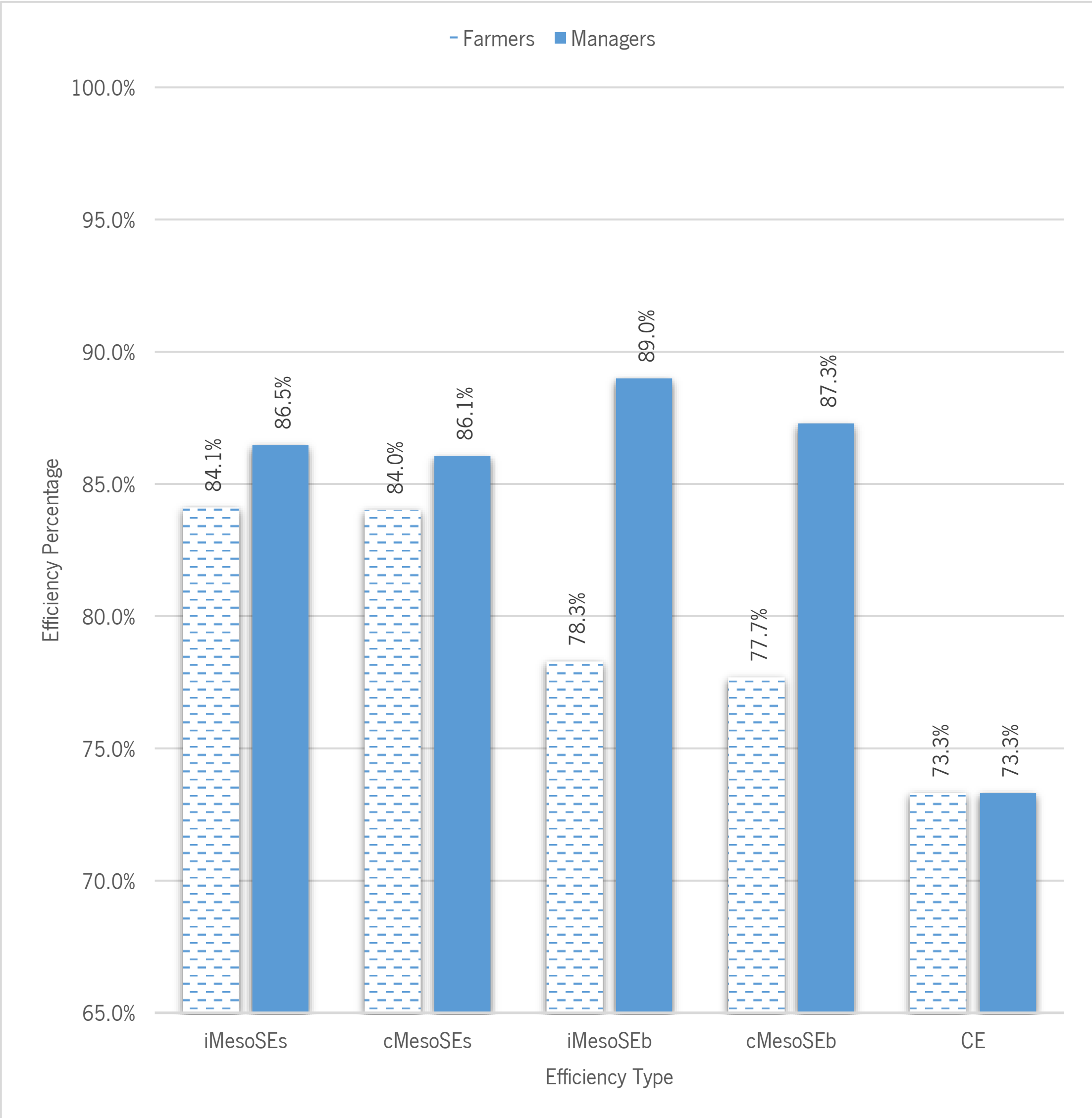


Figure 5.1: Sefficiency results at meso level considering farmers and managers objectives.
$iMesoSE_s$: inflow meso-Sefficiency; $cMesoSE_s$: consumptive meso-Sefficiency; $iMesoSE_b$: inflow meso-Sefficiency without considering quality; $cMesoSE_b$: consumptive meso-Sefficiency without considering quality; CE: Classical Efficiency.

From the farmers' perspective, the changes are minor between the inflow and consumptive meso Sefficiencies due to their low interest in any type of returns (beneficial weights for these instances are very low). The impact of low interest in RF, which is a system objective, is clearer in the values of $iMesoSE_b$ and $cMesoSE_b$. While the efficiency from a managers' perspective slightly improved when we excluded the quality weight, it decreased significantly on the farmers' side.

One key variable does not directly appear in the efficiency percentages, but it appears in the water balance equation (Equation (4.3)). That is the high value of VA_{Unr}. We estimate that farmers got at least 37% of their supplies during that season from channels that PWA does not monitor nor report. Such an anomaly makes PWA's efforts to manage the available resources, develop future supplies, and manage the supply-demand deficit very challenging.

5.2. Sefficiency Under Scenarios of Potential Improvements

In a water-scarce region, improvements are necessary. To help to understand what changes could lead to improvements, we hypothesised four different scenarios. The first scenario (SC1) suggests improving the quality weight of the return flow (RF) from 0.2 to 0.8. Then, the second scenario (SC2) will examine increasing the reported abstractions (VA_{PWA}) by 10% while maintaining the same yield production. Similarly, the third scenario (SC3) assumes to have a precipitation rate equal to the 25-year-average (147 mm). Finally, the fourth scenario (SC4) suggests increasing the beneficial weight of ET to 0.99. Figure 5.2 summarises the meso-level Sefficiency results after applying these scenarios.

5.2.1. SC1 – Improving the Quality of Returns

In this first scenario, we have only changed the value of W_{qX} of both RF instances (RF_{Eq} and RF_{PP}) to be 0.8 while keeping all of the other variables and weights as they were. Such a change, in reality, can take place as a result of one or a combination of activities such as reducing the use of chemical substances in agriculture and reusing the agricultural wastewater.

Although the values of RF are relatively small, results in Figure 5.2 show the hypothesised increase in its quality can potentially lead to more than a ten percentage point increase in the overall meso Sefficiency from the management perspective in both inflow and consumption models.

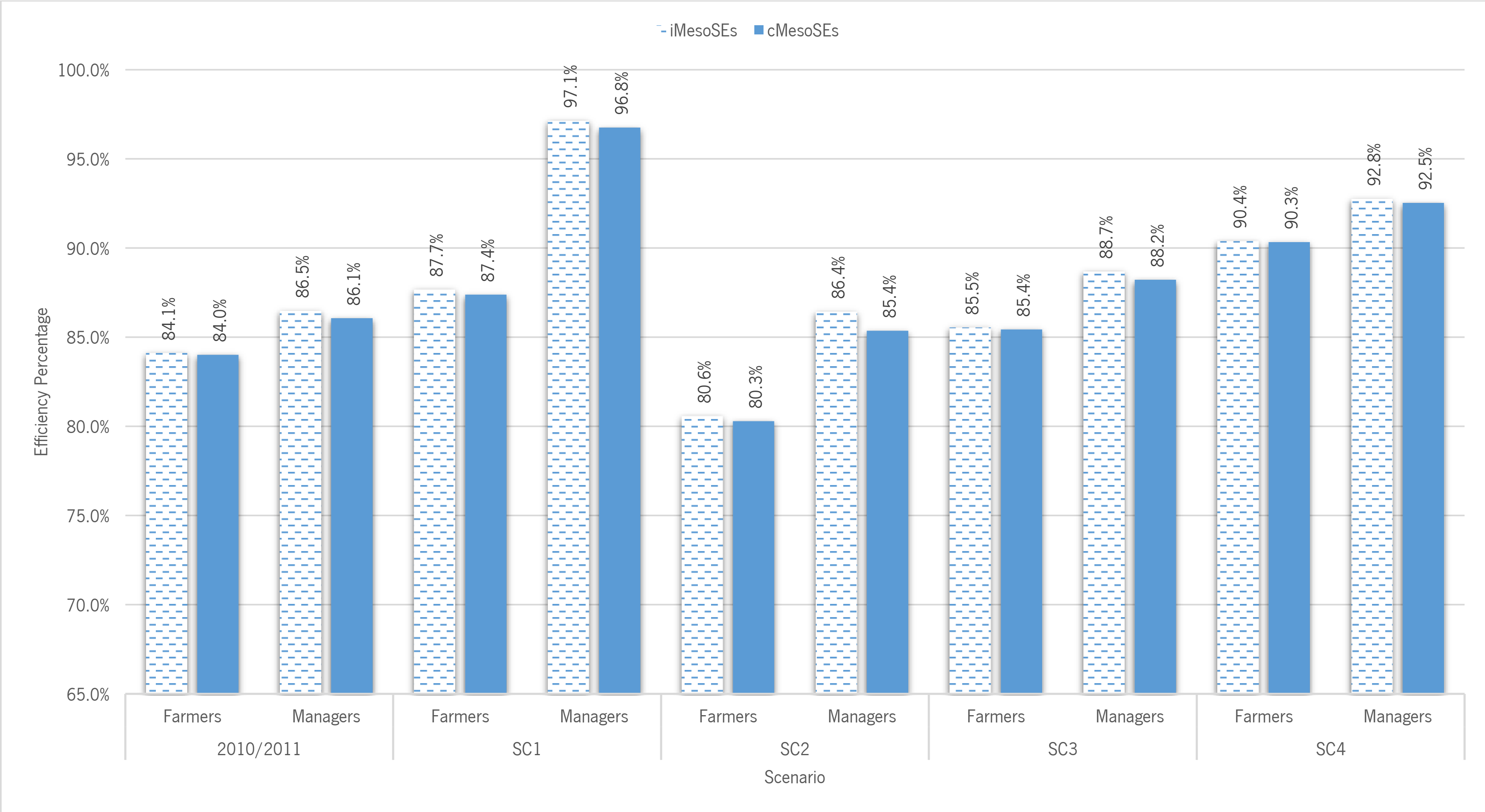


Figure 5.2: Sefficiency results of SC1, SC2, SC3, and SC4

Such a high Sefficiency result from the managers' perspective (around 97%) in this case makes sense because the high quality of returns satisfies an important system objective for managers, which is the ecological sustainability of the main source.

5.2.2. SC2 – Expanding the Abstractions

SC2 represents the consistent PWA efforts to increase the Palestinian water share of EAB withdrawals. This will arguably lead to an increase in the agricultural activities in the regions as confirmed by 58% of the surveyed farmers who stated that if they get access to more water, they would expand their business. In order to perform sensitivity analysis on Sefficiency results, we hypothesised a 10% increase in the reported withdrawals (VA_{PWA}) and maintained the current size of agricultural activities unchanged.

Such an increase will result in a series of changes in the system. First, as we have to maintain water balance, the additional inflow should appear in the outflow as well. In numbers, a 10% increase in VA_{PWA} will give 26.61 Mm^3 total reported abstraction, and assuming no changes in ET values, the added quantity will flow out of the system via RF_{Eq} and NR_{Eq}. Consequently, W_{bX} for the three variables and W_{qX} for VA_{PWA} and NR by definition should not change, but W_{qRF} should. As RF_{Eq} showed a 42% increase in high-quality water in its volume, its quality weight will increase as a result to be 0.5.

The results of SC2 are discouraging for both managers and farmers because, despite supplying more water into the system, that did not have any positive impact on the overall efficiency. There was not even an increase in Sefficiency from the managers' perspective despite the increased quality of RF that we saw in SC1. In fact, for better judgement under this scenario, we will have to understand if and how much the agricultural activities will actually increase, if more water becomes available. The argument we are making here, however, is that stakeholders have to consider any increase in supply carefully.

Furthermore, the results of SC2 scenario reflect on the consequences in case we underestimated the unreported abstractions. As proven in this scenario, if the unreported abstractions were higher, the Sefficiency will consequently be lower. This conclusion underlines the necessity for the water authorities in Palestine to tackle this matter as it occurs in the core efficiency assessment of the system under their management.

5.2.3. SC3 – Precipitation Equal to the Long-Term Average

SC3 demonstrates how the Sefficiency results would change if our season had a PP value equals to the 25-year-average of annual precipitation (147 mm), which helps us understand the inter-annual variability of the water use efficiency. As mentioned earlier, PP of season 2010/2011 was 33% lower than the 25-year-average. In fact, between 1996 and 2018, there were two other dry seasons: 1998/99 with 48.7 mm and 2016/17 with 45.8 mm. On the contrary, 1996/97 and 2014/15 seasons with 224.6 mm and 200.5 mm (PCBS, 2010, 2019), respectively, may be considered as relatively wet.

Assuming no changes in the size of agricultural activities, an increase in PP, similar to the increase in VA_{PWA} in SC2, will lead to a sequence of changes in the quantity and quality of the return flow. In addition, we needed to account for the changes in the effective precipitation values in order to estimate the values of RF_{PP} and NR_{PP}. In numbers, PP volume increased to 5.33 Mm^3. Quantity of RF_{PP} increased by 30%, and thus its quality weight increased from 0.2 to 0.3 (with no significant changes in NR_{PP}). Moreover, as precipitation increased, the effective PP ratio had also increased; hence, we can deduct that value (0.85 Mm^3) from VA_{Unr}.

The Sefficiency results of SC3, in contrast to SC2, show an improvement in Sefficiency for both managers and farmers. This is an indication of the positive impact of PP since its effective portion directly contributes to the abstraction savings and the other portion improves the quality of returns.

5.2.4. SC4 – Increasing the Beneficence of ET

The fourth scenario SC4 results demonstrate that a 7% increase in a single weight (increasing W_{bET} from 0.92 to 0.99) can lead to a significant improvement in the overall efficiency results. We got under this scenario a 6% increase in $iMesoSE_b$ and $cMesoSE_b$ for both farmers and managers.

The beneficial weight of ET could increase by actions from both stakeholders. Farmers could contribute to a higher value of W_{bET}, if they treat the unwanted plants at higher rates. It is highly important to carefully consider the treatment method, especially the use of pesticides. An additional increase in the nitrate levels in Figure 4.11 would affect the sustainability of EAB's water quality. Hence, classic methods such as mulching, had-digging and solarising, are more advantageous. Likewise, managers could also contribute through establishing policies and programmes that enhance the selection of high socio-economic value crops.

Since yield production is the centre of this WUS, the results of this scenario show a significant increase in the system performance with such a change. The performance of both farmers' and managers' objectives increased significantly in both models by more than 6 pp.

CHAPTER SIX. IMPACTS OF CLIMATE CHANGE ON SEFFICIENCY

In this chapter, we will examine the climate change impacts on the different water path instances and Sefficiency results. In order to do that, we will construct in section 6.1 different scenarios that include potential changes in temperature and precipitation under the climate change projections presented in the Palestinian National Adaptation Plan (NAP) to Climate Change. In addition, we will evaluate the validity of including the population growth in these scenarios. In sections 6.2 and 6.3, we will present and discuss the changes in the water use system's variables under the constructed scenarios, and the impact of these changes on the Sefficiency results.

6.1. Scenarios Building

No one can predict future events; instead, scientists attempt to simulate the potential impacts of likely changes following a scientific methodological approach within a margin of uncertainty. Most of the common approaches to simulate changes are based on analysing historical trends and existing conditions to project future behaviours. Climate change is a clear example of where such approaches are used.

6.1.1. Climate Change Considerations

In this study, we are assessing the efficiency of agricultural water use in a defined WUS in which farmers mainly depend on irrigated farming. Among the most critical factors that influence irrigated farming are the climatic conditions. Such influence is most evident in precipitation and evapotranspiration.

In the upcoming sections and subsections, we will focus our analysis on temperature and precipitation variations due to their significance. On the other hand, we will neglect the variations in sunshine hours, relative humidity, and wind speed despite their influence in ET. This is because, according to Forster et al. (2007), the projected changes in these variables are insignificant and widely uncertain.

As explained in section 3.5, we will rely in this domain on the simulation results of the Palestinian National Adaptation Plan (NAP) to Climate Change report (Smithers et al., 2016). Consequently, we will adopt their time intervals for scenarios' building, RCPs' selections, and results of the temperature and precipitation projections. These projections are outcomes of a simulation on an annual basis and we assumed them to be uniform over the 12 months. We understand that such an assumption does not represent reality, however, the objective here is to assess a range of impacts, and thus we claim that the effect of the monthly variations of these changes is minor to our objective.

Under two representative concentration pathways (RCPs), namely RCP2.6 and RCP6.0, we will hypothesise six different scenarios corresponding to the projected changes in three years. These scenarios will be identified as the following:

- RCP2.6-2025
- RCP2.6-2055
- RCP2.6-2090
- RCP6.0-2025
- RCP6.0-2055
- RCP6.0-2090

To clarify, for instance, RCP2.6-2055 corresponds to the projected temperature and precipitation changes under RCP2.6 in the year 2055. RCP2.6 is the pathway considering a change in climate resulting from a target change in energy flux equals 2.6 W/m^2 by the year 2100.

6.1.2. What About Population Growth?

Undoubtedly, the Middle East is one of the regions where the population is growing. Palestine and Jericho are not an exception with positive population growth rates of 2.66% and 2.27%, respectively. If this study had been about domestic water use, population growth would have been a key. Nonetheless, since the WUS under consideration for this study is the agricultural water use, the argument may differ.

Despite Jericho's size that represents around 9% of the total area of Palestine, it is home for around 50% of West Bank's agricultural lands, where 60% of the total vegetable production in that region takes place (WAFA 2015). Hence, the impact of any growth in the overall Palestinian population, not only in Jericho Governorate, on the agricultural sector has to be carefully examined.

From a broad perspective, population growth as an indicator of the agricultural activities' expansion in a given region is a robust approach. As discussed in subsection 2.6.1, Jayyousi et al. (2004) adopted a local study to estimate the average annual consumption of irrigated crops, which was around 272 kg per capita; broken down into 179 kg vegetables, 40 kg melons, and 53 kg oranges and bananas. An analysis could follow a similar approach to estimate the increased demand, and thus the projected increase in the agricultural activities according to the population growth. However, by following that, such an analysis would be falling under the assumption that the potential to develop additional farmlands exists.

On the contrary, taking a closer look at the agricultural development in Jericho over the past 25 years, we cannot see a trend of expansion. Although 2010/2011 was the only season in which the Palestinian Central Bureau of Statistics conducted a comprehensive agricultural census, we could gather from scattered reports PCBS previously published rough estimates of the total number of farmland dunums.

The data we found covers most of the seasons in the period between 1993 and 2011. For the seasons with no data, we assumed their inputs based on interpolation for simplicity since we are looking for a trend rather than accurate estimates. Table 6.1 and Figure 6.1 summarise these data against the population growth during these years to compare. Besides, we thought it would be useful to include in this analysis the annual precipitation rates in each of those years to reflect if there was any correlation between the volume of agricultural activities and the precipitation rate in a given season.

According to the outcomes of Figure 6.1, we can observe no correlation between the precipitation rates and the agricultural activities in a given season. This is quite expected in an arid region that heavily depends on irrigated farming. More importantly, over the 18-year-period shown in the graph, there is an apparent irregularity in the number of farmland dunums from one year to another. Nonetheless, several indicators lead us to believe farmlands are not expanding (if not shrinking). First, the season that has the most farmlands dunums is the oldest among those analysed (1993/1994). In addition, the most recent season shown in the graph has the third least number of farmland dunums. Finally, as we have discussed earlier, agriculture's contribution to the Palestinian GDP dropped from 9.3% in 1999 to 4% in 2012 (World Bank, 2012).

Table 6.1: Area of farmlands, population, and precipitation per season between 1993 and 2011 in Jerich governorate
Source: A collection of reports that can be found in (PCBS, 2016)

Season	Area of Farmlands (Dunums)	Population	Precipitation (mm)
1993/1994	57,467	28,116··	147.0···
1994/1995	46,276	29,106··	147.0···
1995/1996	39,547	30,098··	147.0···
1996/1997	36,037	31,089	224.6
1997/1998	36,749	32,105	90.1
1998/1999	34,179	33,145	48.7
1999/2000	41,159	34,188	152.8
2000/2001	37,524	35,162	148.4
2001/2002	39,399·	36,154	147.0···
2002/2003	41,274	37,173	194.0
2003/2004	50,089	38,232	128.5
2004/2005	44,752	39,378	117.0
2005/2006	45,194	40,559	147.0···
2006/2007	45,607	41,776	115.2
2007/2008	52,150	42,587	118.8
2008/2009	46,859·	43,389	115.7
2009/2010	41,569·	44,184	124.2
2010/2011	36,278	44,973	99.0

· *Area was estimated via interpolation due to lack of official data*
·· *Population was estimated according to the growth rate due to lack of official data*
··· *Due to lack of official records, the number presented is the long-term annual average*

As a result, we can conclude that the assumption of a potential expansion in the agricultural activities in the region is not an accurate representation of reality. Therefore, we assumed that the population growth will not have a significant impact on the size of the agricultural activities, and henceforth excluded from our scenario analysis.

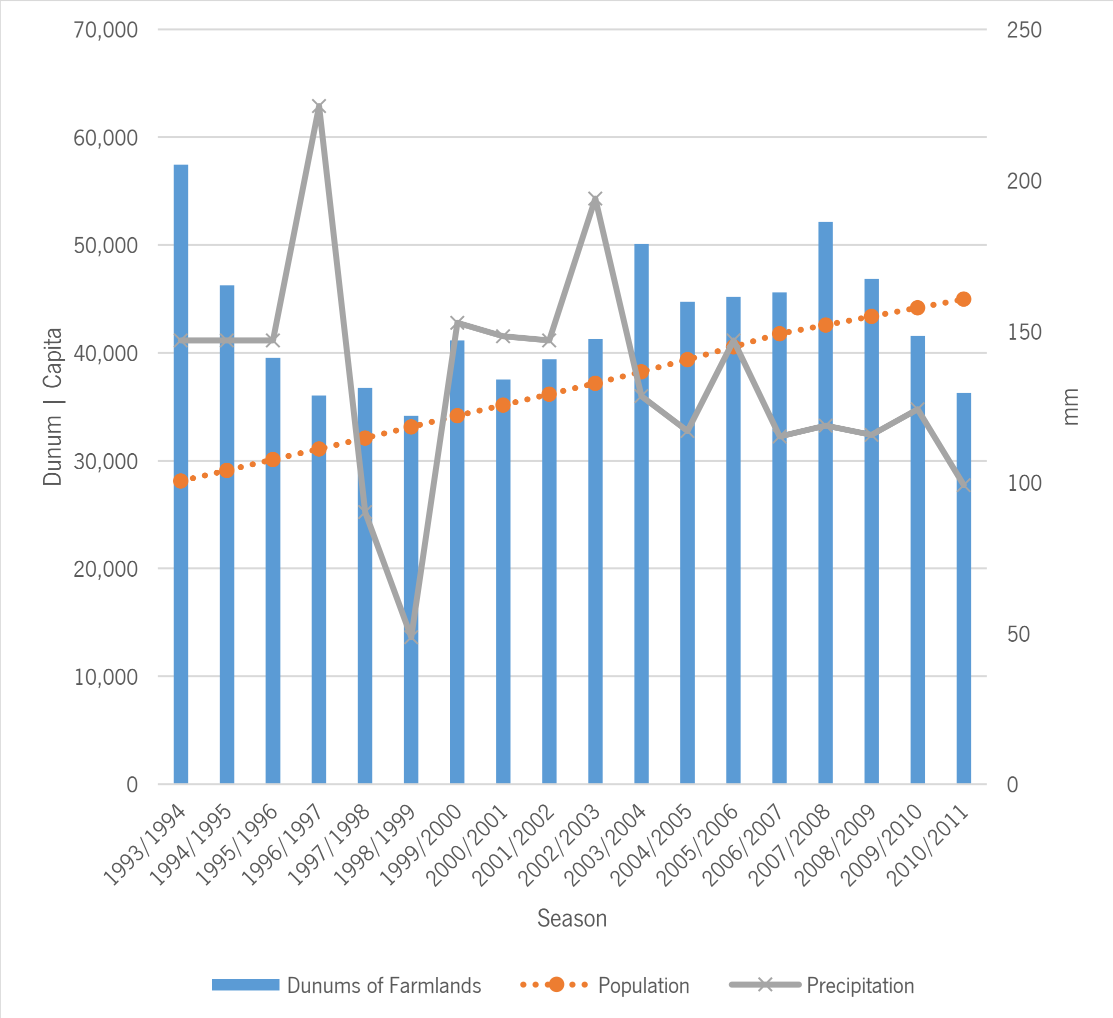


Figure 6.1: Area of farmlands variation, population growth, and precipitation per season between 1993 and 2011 in Jericho governorate

6.2. Sefficiency Under RCP2.6 Pathway

RCP2.6 pathway represents the UNFCCC's target for the maximum increase in global mean temperature of 2.0°C. According to the Palestinian NAP, the most likely changes under RCP2.6 pathway in Palestine are a temperature increase of 0.5°C in 2025, 1.0°C in 2055, and 1.5°C in 2090. For precipitation, there is a projected slight decrease of 2% in 2025, 5% in 2055, and goes up to 10% in 2090.

In the following subsections, we will present for each year's scenario a table that summarises the new quantities of the water paths instances and the changes in Sefficiency at meso level ($MesoSE_s$) comparing to the values in the 2010/2011 season.

6.2.1. RCP2.6-2025 Scenario

Under this scenario, the temperature will increase by 0.5°C and the precipitation will decrease by 2%. Table 6.2 presents the new values of each variable in our WUS considering these temperature and precipitation changes. The full details about the changes in ET values for each crop under this scenario and the following remaining scenarios are available in Appendix III. As shown in the table, along with the anticipated decrease in precipitation that leads to a 1% decrease in both RF_{PP} and NR_{PP}, there is a relatively significant 4% increase in ET. These increases have necessarily to be compensated by additional abstractions to maintain water balance. The WUS will need as much as an 11% increase in abstractions considering the aforementioned changes under RCP2.6-2025 to maintain the same yield production, which will result in a 4% increase in both RF_{Eq} and NR_{Eq}. Under this scenario and the following remaining scenarios, we assumed the additional abstractions to be unreported abstractions rather than VA_{PWA}, but in either way, each would have the same influence on Sefficiency results.

Besides, we analysed the impact of these changes on the values of the quality and beneficial weights of each variable and found that there would be no tangible change.

Table 6.2: WUS characteristics under RCP2.6-2025

Variable	X (Mm³)	% of Change	X_S (Mm³) Farmers	X_S (Mm³) Managers
PP	3.52	-2	2.11	2.11
VA_{PWA}	24.19	0	21.77	21.77
VA_{Unr}	15.94	11	14.35	14.35
ET	34.37	4	31.62	31.62
RF_{Eq}	3.61	4	0.14	0.72
NR_{Eq}	2.41	4	0.24	0.24
RF_{PP}	1.96	-1	0.08	0.39
NR_{PP}	1.31	-1	0.13	0.13

Figure 6.2 illustrates the changes in Sefficiency results under RCP2.6-2025 scenario from both managers' and farmers' perspectives. As shown in the figure, from the managers' perspective, each of $cMesoSE_S$ and $iMesoSE_S$ has insignificantly increased by 0.1 percentage points (pp).

Similarly, from the farmers' perspective, $cMesoSE_s$ and $iMesoSE_s$ has both slightly improved by 0.2 pp. The absence of a significant change (neither positive nor negative) clearly shows that the increase in ET value under such a change in climatic conditions would not impact the WUS's performance if it was accompanied by a proportionate increase in groundwater withdrawals. This is expected in a region under water shortage, where higher quantities of withdrawals above the demand are not expected.

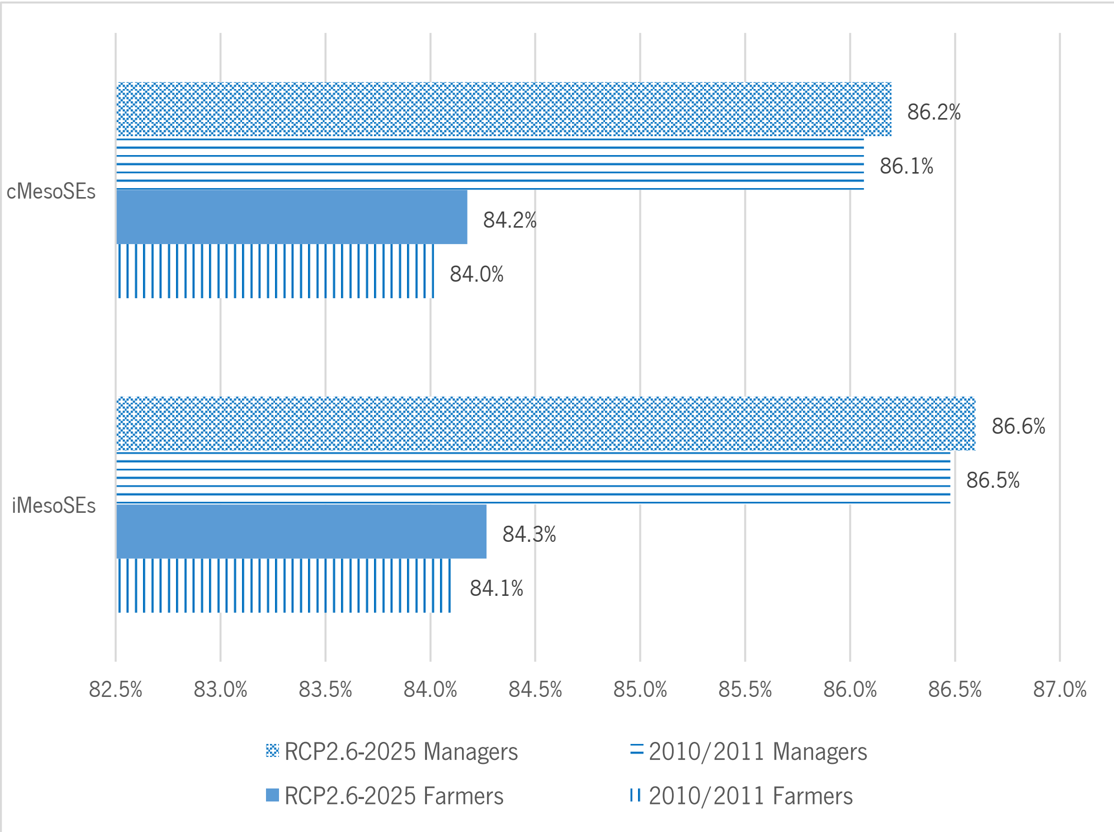


Figure 6.2: Sefficiency results under RCP2.6-2025

6.2.2. RCP2.6-2055 Scenario

Under this scenario, the temperature will increase by 1.0°C and the precipitation will decrease by 5%. Table 6.3 provides the new values of each variable in our WUS considering these temperature and precipitation changes. As shown in the table, along with the anticipated 5% decrease in precipitation that leads to a 3% decrease in both RF_{PP} and NR_{PP}, there is a 5% increase in ET. These changes have inevitably to be compensated by more groundwater withdrawals to maintain water balance. The WUS will need up to a 15% increase in abstractions considering the changes under RCP2.6-2055 to maintain the same level of agricultural activities, which will lead to a 5% increase in each of RF_{Eq} and NR_{Eq}.

We analysed the impact of these changes on the values of the quality and beneficial weights of each variable and found that there would be no tangible change.

Table 6.3: WUS characteristics under RCP2.6-2055

Variable	X (Mm³)	% of Change	X_S (Mm³) Farmers	X_S (Mm³) Managers
PP	3.41	-5	2.05	2.05
VA_{PWA}	24.19	0	21.77	21.77
VA_{Unr}	16.52	15	14.87	14.87
ET	34.82	5	32.03	32.03
RF_{Eq}	3.66	5	0.15	0.73
NR_{Eq}	2.44	5	0.24	0.24
RF_{PP}	1.92	-3	0.08	0.38
NR_{PP}	1.28	-3	0.13	0.13

Figure 6.3 shows the changes in Sefficiency results under RCP2.6-2055 scenario from both managers' and farmers' perspectives. Similar to the results under RCP2.6-2025, for each of $cMesoSE_S$ and $iMesoSE_S$ considering both perspectives, there is no significant change in Sefficiency results due to the allocation of enough abstractions to address the aforementioned increases in ET, RF_{Eq}, and NR_{Eq}.

6.2.3. RCP2.6-2090 Scenario

Under this scenario, the temperature will increase by 1.5°C and the precipitation will decrease by 10%. Table 6.4 presents the new values of each variable in our WUS considering these temperature and precipitation changes. As shown in the table, along with the anticipated considerable decrease in precipitation that leads to a 7% decrease in both RF_{PP} and NR_{PP}, there is a relatively weighty 7% increase in ET. These increases shall be compensated by additional abstractions (a significant 19% increase in VA_{Unr}) to maintain water balance and the same rate of yield of production, which will result in a 7% increase in both RF_{Eq} and NR_{Eq}.

The impacts of these changes on the values of the quality and beneficial weights of each variable are negligible.

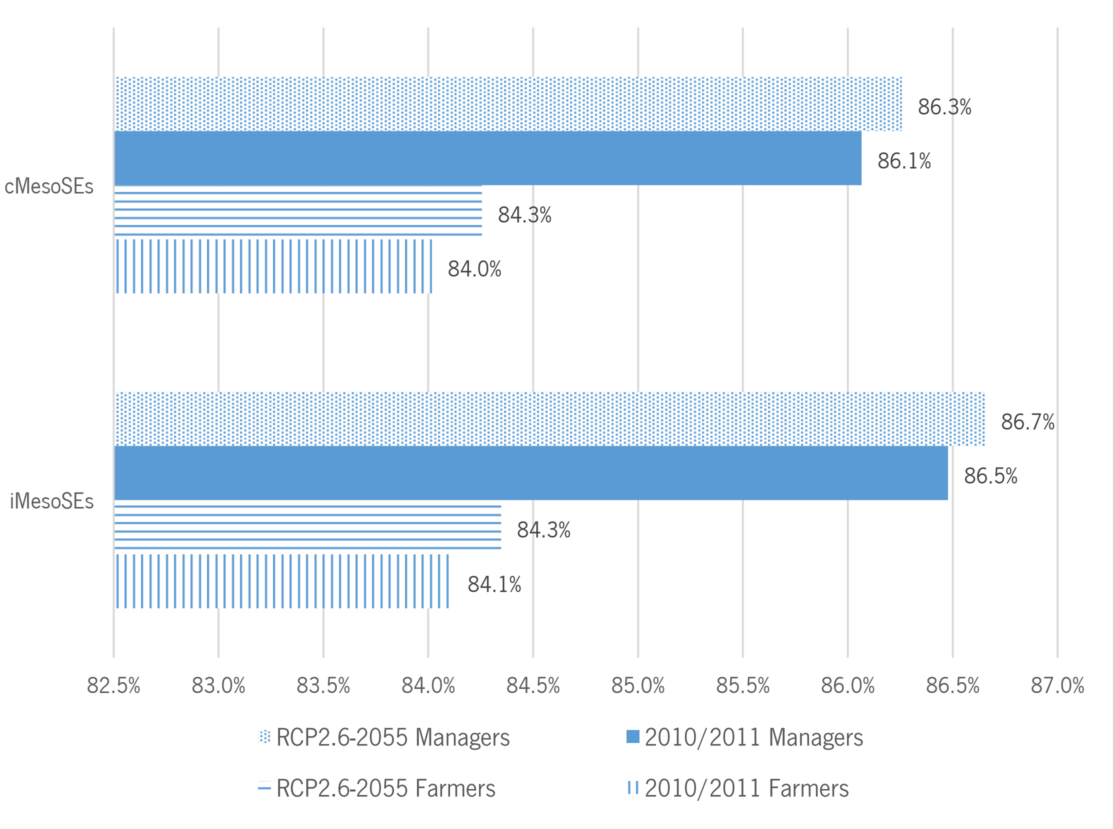


Figure 6.3: Sefficiency results under RCP2.6-2055

Figure 6.4 illustrates the changes in Sefficiency results under RCP2.6-2090 scenario from both managers' and farmers' perspectives. As shown in the figure, from the managers' perspective, each of $cMesoSE_s$ and $iMesoSE_s$ has insignificantly increased by 0.2 percentage points (pp). Similarly, from the farmers' perspective, $cMesoSE_s$ and $iMesoSE_s$ has both slightly improved by 0.4 pp.

The overall results of the three intervals' scenarios under RCP2.6 pathway indicate a minor impact on the Sefficiency results, meaning that the WUS will maintain a similar performance at the meso level considering the projected climatic changes under this pathway. However, the more the temperature increases and precipitation decreases, the further abstractions that the system will need to maintain the same level of agricultural activities, which represents a substantial concern on the aquifer's sustainability.

Table 6.4: WUS characteristics under RCP2.6-2090

Variable	X **(Mm³)**	**% of Change**	X_s **(Mm³) Farmers**	X_s **(Mm³) Managers**
PP	3.23	-10	1.94	1.94
$\mathbf{VA_{PWA}}$	24.19	0	21.77	21.77
$\mathbf{VA_{Unr}}$	17.20	19	15.48	15.48
ET	35.33	7	32.50	32.50
$\mathbf{RF_{Eq}}$	3.73	7	0.15	0.75
$\mathbf{NR_{Eq}}$	2.48	7	0.25	0.25
$\mathbf{RF_{PP}}$	1.85	-7	0.07	0.37
$\mathbf{NR_{PP}}$	1.23	-7	0.12	0.12

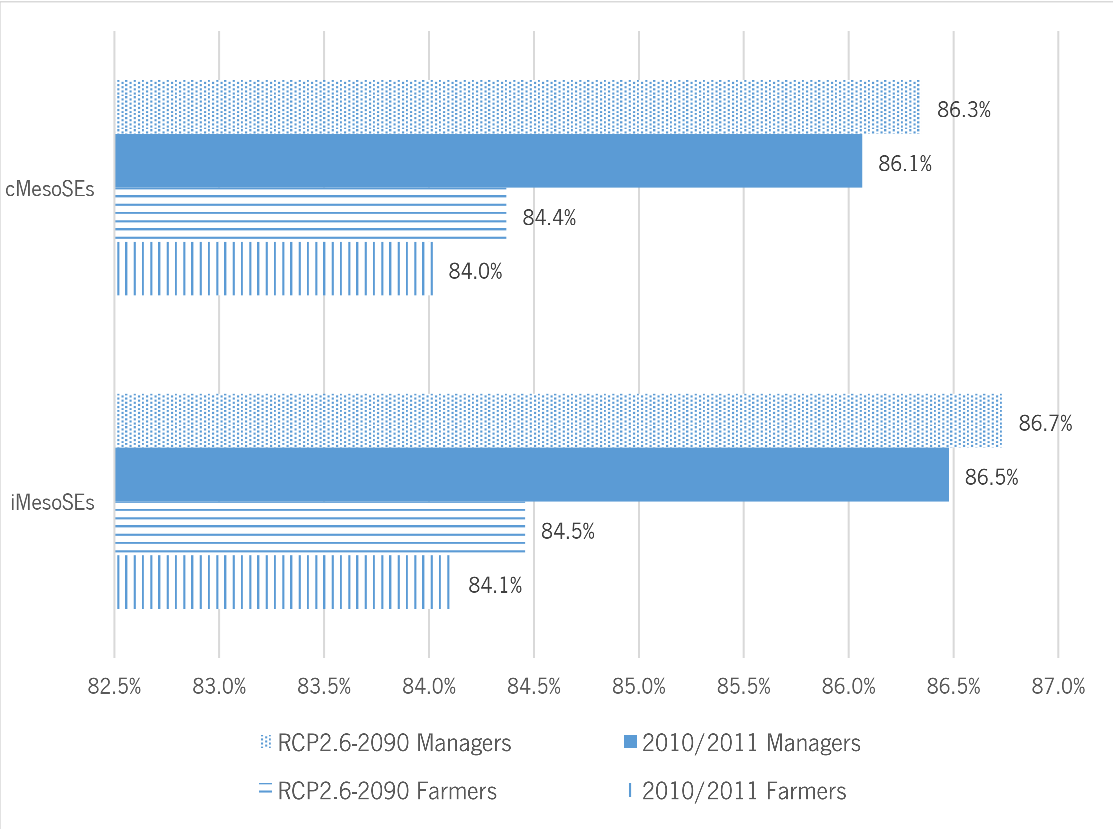


Figure 6.4: Sefficiency results under RCP2.6-2090

6.3. Sefficiency Under RCP6.0 Pathway

RCP6.0 pathway represents the more realistic pathway given UNFCCC measures fail. According to the Palestinian NAP, the most likely changes under RCP6.0 in Palestine are a temperature increase of 0.5°C in 2025, 1.5°C in 2055, and 3.0°C in 2090. In regards to precipitation, there is no projected change in 2025, but a projected decrease of 10% in 2055 that goes up to 20% in 2090.

In the following subsections, we will present for each year's scenario a table that summarises the new quantities of the water paths instances and the changes in Sefficiency at meso level ($MesoSE_s$) comparing to the values in the 2010/2011 season.

6.3.1. RCP6.0-2025 Scenario

Under this scenario, the temperature will increase by 0.5°C, while the precipitation will remain unchanged. Table 6.5 gives the new values of each variable in our WUS considering these temperature and precipitation changes. As shown in the table, as the precipitation rates will not change, there will be no changes in both RF_{PP} and NR_{PP}. However, the temperature increase will lead to a 4% increase in ET. This increase has to be compensated by more groundwater withdrawals to maintain water balance. The WUS will need as much as a 10% increase in abstractions considering the changes under RCP6.0-2025 scenario to maintain the same level of agricultural activities in Jericho Governorate. This increase in VA_{UNR} will lead to a 4% increase in each of RF_{Eq} and NR_{Eq}

The impacts of these changes on the values of the quality and beneficial weights of each variable are negligible.

Figure 6.5 presents the changes in Sefficiency results under RCP6.0-2025 scenario. Similar to the results under RCP2.6 pathway scenarios, for each of $cMesoSE_s$ and $iMesoSE_s$ considering both managers' and farmers' perspectives, there are no considerable changes in Sefficiency results in both inflow and consumption models due to the allocation of enough abstractions to address the increases in ET, RF_{Eq}, and NR_{Eq}.

Table 6.5: WUS characteristics under RCP6.0-2025

Variable	X **(Mm³)**	**% of Change**	X_s **(Mm³) Farmers**	X_s **(Mm³) Managers**
PP	3.59	0	2.15	2.15
$\mathbf{VA_{PWA}}$	24.19	0	21.77	21.77
$\mathbf{VA_{Unr}}$	15.91	10	14.32	14.32
ET	34.37	4	31.62	31.62
$\mathbf{RF_{Eq}}$	3.61	4	0.14	0.72
$\mathbf{NR_{Eq}}$	2.41	4	0.24	0.24
$\mathbf{RF_{PP}}$	1.98	0	0.08	0.40
$\mathbf{NR_{PP}}$	1.32	0	0.13	0.13

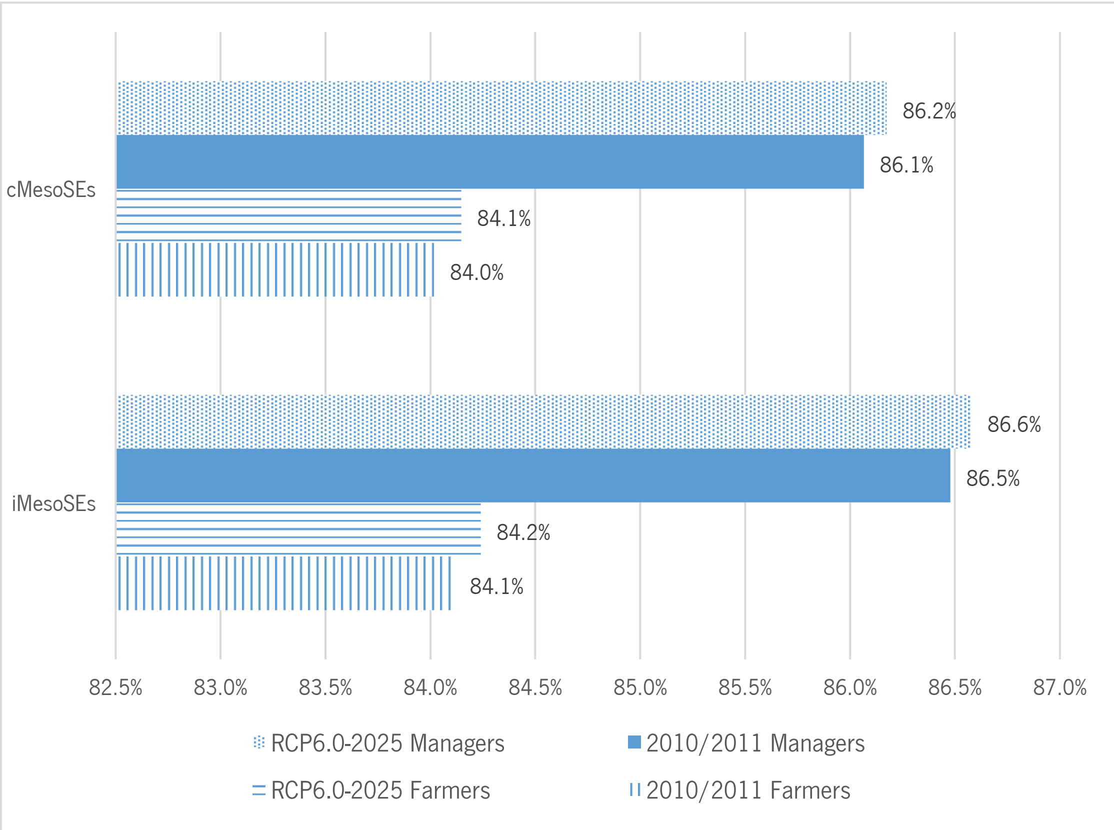


Figure 6.5: Sefficiency results under RCP6.0-2025

6.3.2. RCP6.0-2055 Scenario

Under this scenario, the temperature will increase by 1.5°C and the precipitation will decrease by 10%. Table 6.6 shows the new values of each variable in our WUS considering these temperature and precipitation changes. As shown in the table, the changes are identical to those in scenario RCP2.6-2090. Along with the anticipated considerable decrease in precipitation that leads to a 7% decrease in both RF_{PP} and NR_{PP}, there is a significant 7% increase in ET. The WUS will need as much as a 19% increase in abstractions considering the aforementioned changes under RCP6.0-2055 scenario, which will result in a 7% increase in both RF_{Eq} and NR_{Eq}, in order to maintain both water balance and the same yield production.

We analysed the impact of these changes on the values of the quality and beneficial weights of each variable and found that there would be no tangible change.

Figure 6.6 illustrates the changes in Sefficiency results under RCP6.0-2055 scenario from both managers' and farmers' perspectives. As shown in the figure, from the managers' perspective, each of $cMesoSE_S$ and $iMesoSE_S$ has insignificantly increased by 0.2 percentage points (pp). Similarly, from the farmers' perspective, $cMesoSE_S$ and $iMesoSE_S$ has both slightly improved by 0.4 pp.

Table 6.6: WUS characteristics under RCP6.0-2055

Variable	X (Mm³)	% of Change	X_S (Mm³) Farmers	X_S (Mm³) Managers
PP	3.23	-10	1.94	1.94
VA_{PWA}	24.19	0	21.77	21.77
VA_{Unr}	17.20	19	15.48	15.48
ET	35.33	7	32.50	32.50
RF_{Eq}	3.73	7	0.15	0.75
NR_{Eq}	2.48	7	0.25	0.25
RF_{PP}	1.85	-7	0.07	0.37
NR_{PP}	1.23	-7	0.12	0.12

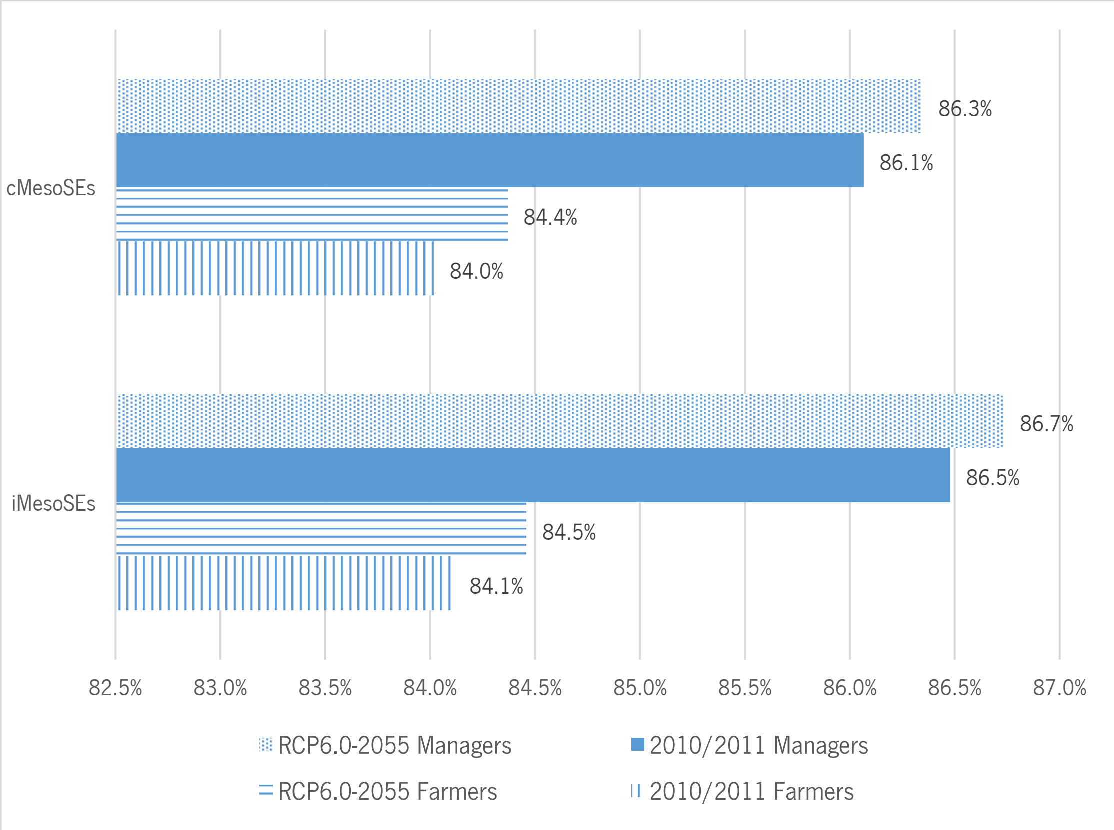


Figure 6.6: Sefficiency results under RCP6.0-2055

6.3.3. RCP6.0-2090 Scenario

This scenario is projected to have the most severe changes among the six scenarios under consideration. The temperature will increase by 3.0°C and the precipitation will decrease by 20%. Table 6.7 provides the new values of each variable in our WUS considering these temperature and precipitation changes. As shown in the table, along with the projected considerable decrease in precipitation that leads to a 14% decrease in both RF_{PP} and NR_{PP}, there is a significant 10% increase in ET. These three significant changes have necessarily to be compensated by further substantial groundwater withdrawals up to 30% increase to maintain water balance and the same level of yield production, which will lead to an 11% increase in both RF_{Eq} and NR_{Eq}.

We analysed the impact of these changes on the values of the quality and beneficial weights of each variable and found that there would be no tangible change.

Figure 6.7 illustrates the changes in Sefficiency results under RCP6.0-2090 scenario from both managers and farmers perspectives. As shown in the figure, from the managers perspective, each of $cMesoSE_s$ and $iMesoSE_s$ has insignificantly increased by 0.5 pp and 0.4 pp, respectively. Similarly, from the farmers perspective, $cMesoSE_s$ and $iMesoSE_s$ have both slightly improved by 0.7 pp and 0.6 pp, respectively. Despite the dramatic changes in the WUS's variable, yet there has been no significant change in its performance.

Table 6.7: WUS characteristics under RCP6.0-2090

Variable	X **(Mm³)**	**% of Change**	X_s **(Mm³) Farmers**	X_s **(Mm³) Managers**
PP	2.87	-20	1.72	1.72
VA_{PWA}	24.19	0	21.77	21.77
VA_{Unr}	18.74	30	16.87	16.87
ET	36.53	10	33.61	33.61
RF_{Eq}	3.86	11	0.15	0.77
NR_{Eq}	2.58	11	0.26	0.26
RF_{PP}	1.70	-14	0.07	0.34
NR_{PP}	1.13	-14	0.11	0.11

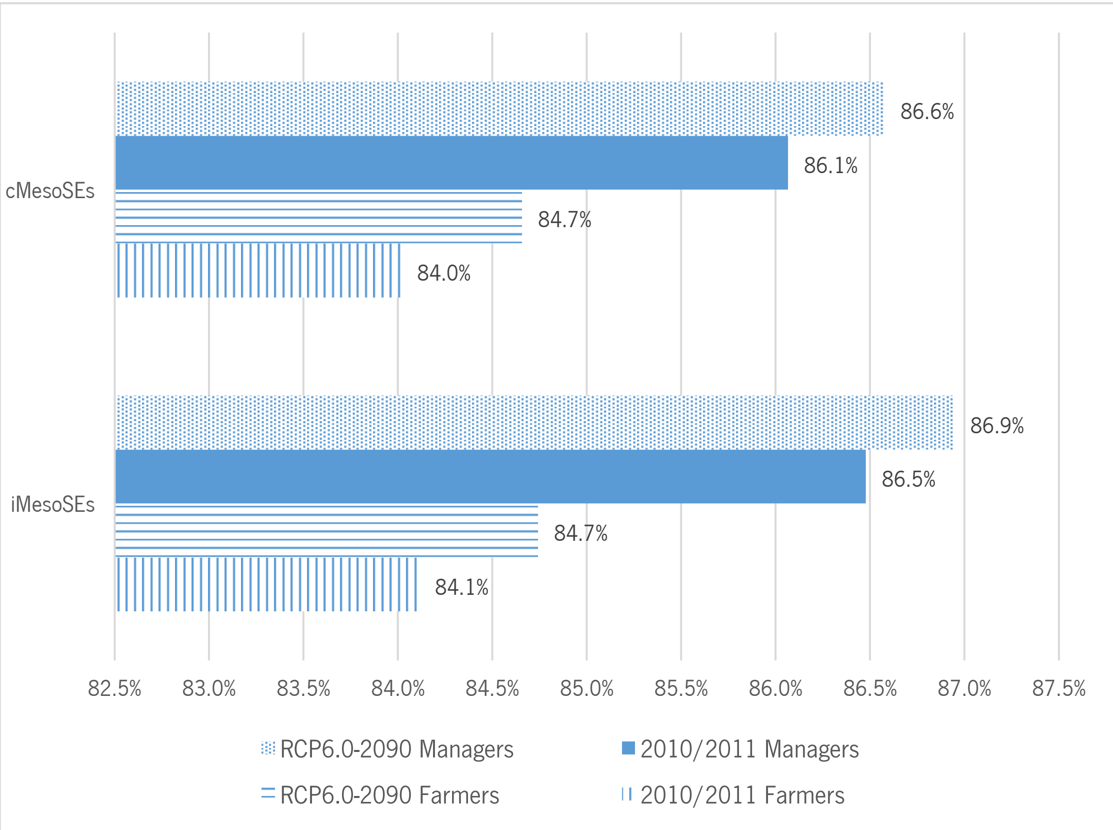


Figure 6.7: Sefficiency results under RCP6.0-2090

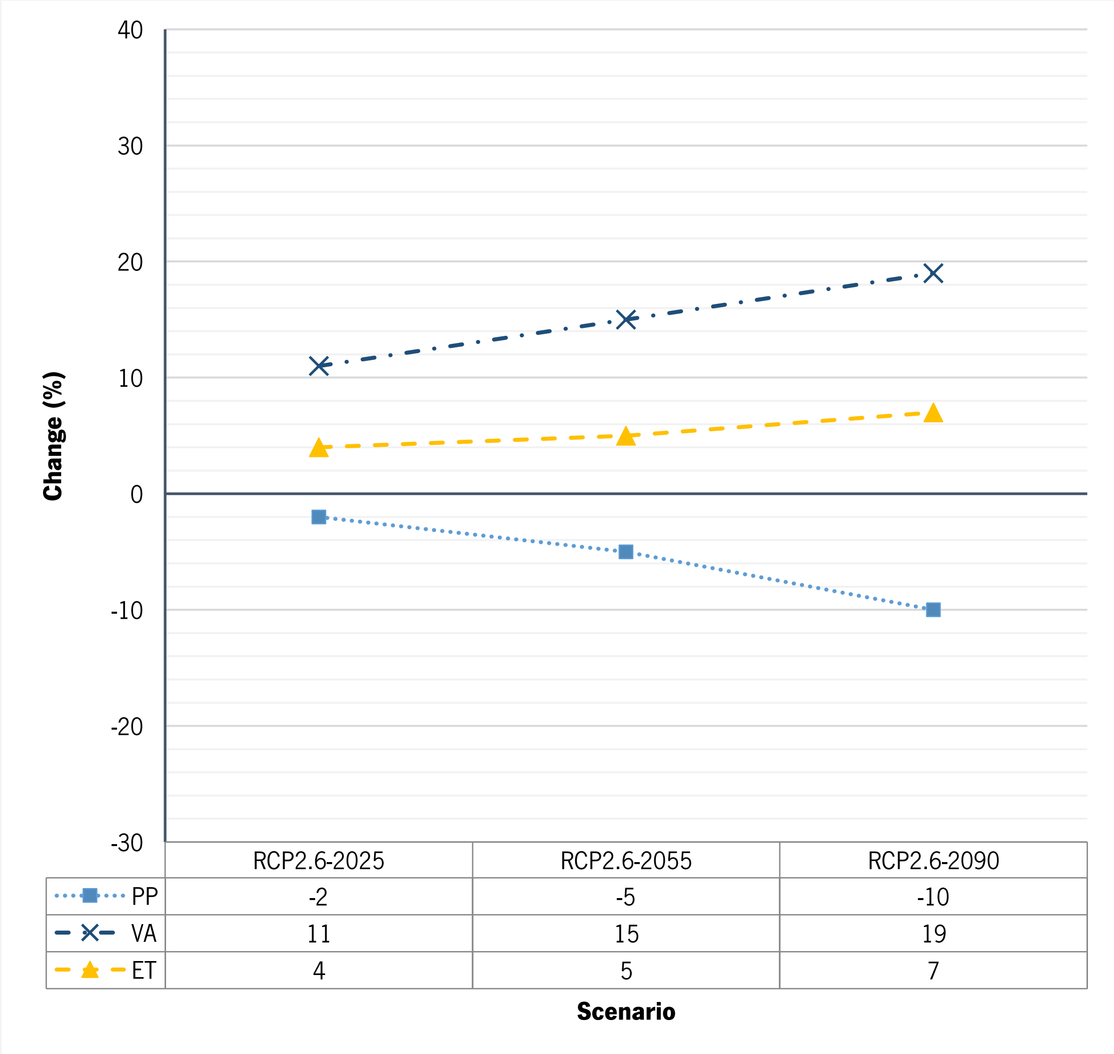
Similar to RCP2.6 pathway, the overall results of the three intervals' scenarios under RCP6.0 pathway indicate a minor impact on the Sefficiency results, meaning that the WUS will maintain a similar performance at the meso level considering the projected climatic changes under this pathway.

Once more, the results clearly show that the increased ET value under such sizeable changes in climatic conditions would not impact the WUS's performance if it was accompanied by a proportionate increase in groundwater withdrawals. As mentioned earlier, this is expected in a region under water shortage, where higher quantities of withdrawals above the demand are not expected.

Nevertheless, the main concern that comes out of our scenario analyses is the sustainability of the main source, the Eastern Aquifer Basin (EAB). Under both pathways, there were substantial increases in abstractions over the consecutive years paralleled with a continuous decrease in precipitation rates. As shown in Figures 6.8 and 6.9, the gap between the increased abstractions from the main source and precipitation, which is the aquifer's main replenishment source, kept increasing moving forward in time under both RCPs. More importantly, assuming sustaining the same level of agricultural activities, the gap between the main consumptive water use, ET, and the aquifer's main replenishment source also kept increasing.

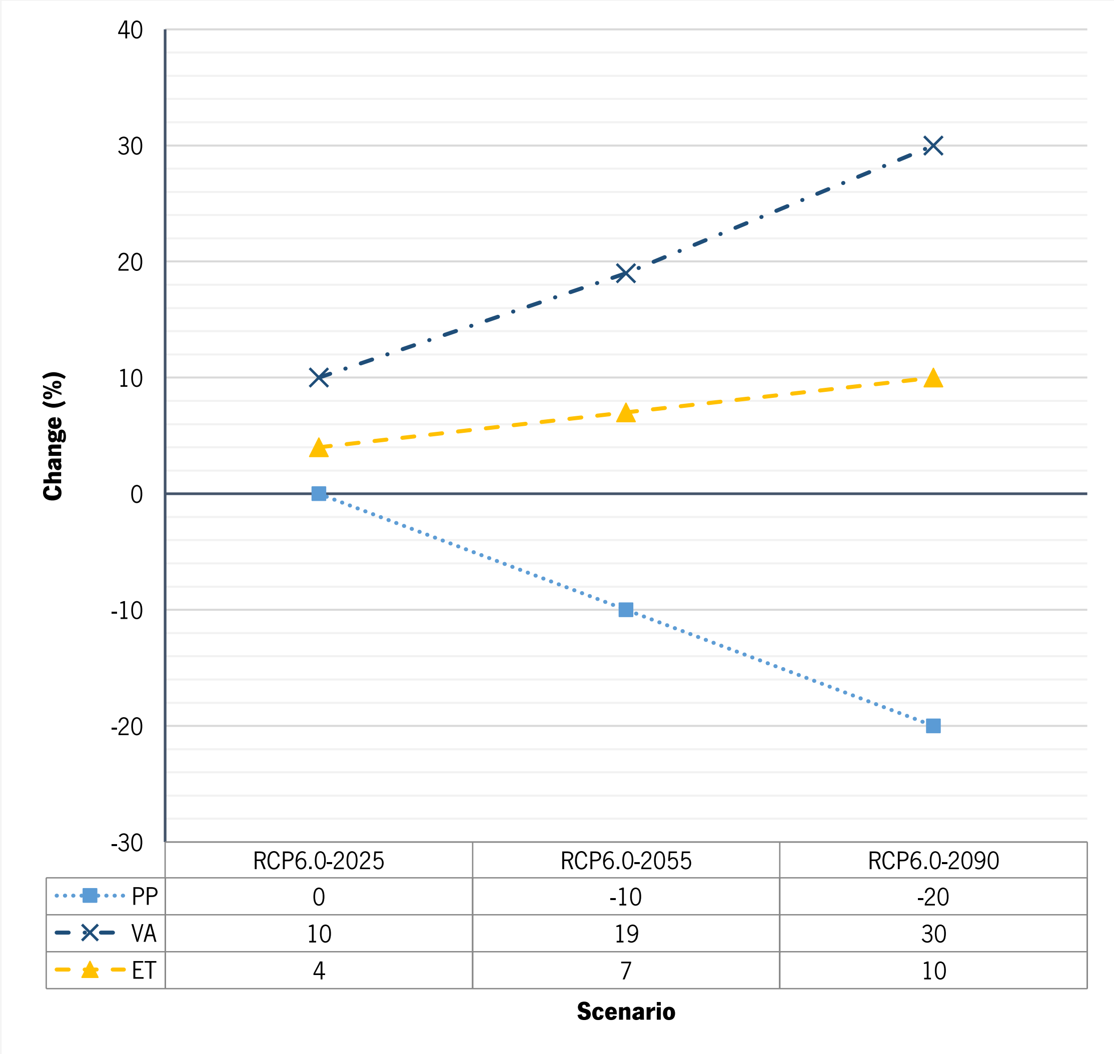
This combination of changes is substantially damaging for the aquifer's sustainability. Since $MesoSE$ relates to the interaction between the useful outflow and total flow, such as the WUS's impact on the downstream users and the effects of its return instances, it will not reflect the WUS's impact on main source's sustainability. This is what Macro-Sefficiency ($MacroSE$) is meant to assess. $MacroSE$ would require measures of water table levels at the beginning and end of the analysis period.

Furthermore, the gaps illustrated in Figures 6.8 and 6.9 deliver a message that the region needs a larger (transboundary) scale assessment. The sustainability of EAB would crucially require joint managerial efforts to assess the efficiencies and impacts of the regional WUSs on EAB. Hence, the scale of such an assessment should be wide enough to include other water uses systems that depend on EAB as their main source.



	RCP2.6-2025	RCP2.6-2055	RCP2.6-2090
PP	-2	-5	-10
VA	11	15	19
ET	4	5	7

Figure 6.8: Percentage change of PP, VA, and ET under RCP2.6 pathway scenarios



	RCP6.0-2025	RCP6.0-2055	RCP6.0-2090
PP	0	-10	-20
VA	10	19	30
ET	4	7	10

Figure 6.9: Percentage change of PP, VA, and ET under RCP6.0 pathway scenarios

CHAPTER SEVEN. CONCLUSIONS AND FUTURE WORKS

We will discuss in the final two sections of this thesis the remarks and findings that we can conclude from this study in addition to the recommended future works. This is of a high significance as we consider this research work as a link in the chain of knowledge within the fields of water resources and irrigation management in Palestine rather than a discrete piece.

7.1. Conclusions

In regions such as Palestine, the question of water scarcity expands beyond the availability or accessibility of water. Water use systems and the assessment of their efficiency are complex due to the nature of their variables' dynamics. After applying Sefficiency at meso level ($MesoSE_S$) in this study, we have reached conclusions that can change, at least, the mindset of the water resources stakeholders in Palestine, especially in irrigation management.

The overall results of $MesoSE_S$, from the managers' and farmers' perspectives considering the inflow and consumption models, have not fallen below 80%. To describe or classify the result into a certain category (e.g. good, satisfactory, poor, and so on) is a management decision based on predefined criteria and objectives. Nevertheless, in a water-scarce region, improvements and efficient water use enhancements are always in need. Additionally, in a future study that includes MacroSE results, we may find out low values at the macro level that demonstrates the need for some fundamental changes in managing water in that part of the world.

This study proved that some changes in the three pillars of water management could lead to great impacts on the overall WUS's performance. To elaborate, improving the quality of return flows for instance, as examined in scenario SC1, has led to substantial changes in the WUS. To begin with, such an improvement can take place through one or a combination of activities such as reducing the use of chemical substances in agriculture and reusing the agricultural wastewater. Each of these actions is, at minimum, a collective effort that encompasses a lot of resources and managerial interventions. Sefficiency results under this scenario indicated how significant an improvement of W_{qRF} can be on the overall performance of our WUS. From the managers' perspective, in both inflow and consumption models, $MesoSE_S$ jumped by more than

10 percentage points (pp), and from the farmers' perspective, it jumped by more than 3 pp in both models as well. Although we do not account for the Israeli side's use in the scope of this study, which is reportedly higher, the meso level and sensitivity analysis results of SC1 demonstrated the impact of chemical substances use on the basin.

One of the greatest advantages of adopting Sefficiency is to underline the WUS's weak points. The number of unreported abstractions is a critical point, which is also a problem in many parts of the world. Despite the PWA's awareness and acknowledgement of the issue as was confirmed in our interview with Eng. Deeb Abdulghafour, Director-General of Water Resources Management at the Palestinian Water Authority (PWA), and despite the great sensitivity of the issue as he described, we demonstrated how significant it could influence the understanding of the WUS's performance.

In fact, any underestimation of VA_{Unr} values affects Sefficiency results. In all of our hypothesised scenarios, including the six climate change projections, we assumed that the number of unreported abstractions would be as much to satisfy the existing ET values to maintain water balance. Nevertheless, while VA_{Unr} values are unlikely to be lower given the demonstrated analyses, they may well be higher than presented throughout this study, in which case return flows and potential returns maintain water balance. Consequently, the dynamics of the entire system would change, including the usefulness criterion. In order to illustrate that, let us assume that we underestimated the value of VA_{Unr} by 10%, which is the equivalent to the amount of VA_{PWA} increase we hypothesised in SC2. Our analysis of this scenario showed that several consequences will be encountered in the WUS, including a 42% increase in RF_{Eq} to maintain water balance accompanied by a change in its W_q to 0.5. More importantly, it showed that $MesoSE_s$ results dropped down by nearly 4 pp from the farmers' perspective in both inflow and consumption models, which is a significant drop. It has also slightly dropped from the managers' perspective in both models despite the improvement in W_{qRF}.

The remarkable contrast of W_{qRF} improvement's impact on $MesoSE_s$ results between scenarios SC1 and SC2, depending on the reason causing that improvement, is a clear demonstration that the relationship between the different WUS's variables is not linear, especially when considering the quality and beneficence dimensions of those variables. Furthermore, contrary to what we found in SC2 results, scenario SC3's analysis proves that an increase in precipitation, which is another form of inflow, could have a noticeable positive impact on

$MesoSE_s$ results. While a 10% increase in VA_{PWA} led to a drop in $MesoSE_s$, we found that a 48% increase in PP (to match the long-term average) improved it by more than 2 pp from the managers' perspective and by more than 1 pp from the farmers' perspective in both models. This is yet another clear example of the nonlinearity in the systems' dynamics.

Another great advantage of adopting Sefficiency is to highlight the opportunities to enhance the WUS's sustainability and maximise the benefits according to the defined objectives. For example, scenario SC4 demonstrated the considerable benefit of reducing the unwanted crops (weed) in our WUS (using eco-friendly methods), the selection of high socio-economic value crops, or a combination of both. In our analysis of SC4, we hypothesised that such actions would lead to a 7% increase in W_{bET}, a change that resulted in improving $MesoSE_s$ considerably by more than 6 pp from both stakeholders' perspectives in both inflow and consumption models.

This last conclusion in particular distinguishes Sefficiency with a unique feature. No other water use efficiency assessment approach can translate policy decisions, field actions, environmental considerations, and socio-economic measures the way Sefficiency does. It facilitates for both stakeholders and WUS's users a tool and, more importantly, a mindset that helps them achieve the most efficient utilisation of EAB, the main source under consideration.

In regards to the potential climate change impacts on temperature and precipitation in the region, our analysis showed a minor effect of those projected changes on $MesoSE_s$ results under the six different hypothesised scenarios. For instance, the most sizeable changes are expected to take place within the RCP6.0-2090 scenario, where projections expect the temperature to increase by 3.0°C and precipitation to decrease by 20%. These projections will have dramatic impacts on the different water path instances, such as a 30% increase in VA and a 10% increase in ET consumption. Yet, $MesoSE_s$ results from both stakeholders' perspectives in both inflow and consumption models changed by less than 1 pp.

The Sefficiency results of the climate change potential impacts' within our WUS highlights that the performance at $MesoSE_s$ level can be maintained as long as we were able to provide the system with additional abstractions enough to compensate for the increase in ET due to the increase in temperature and decrease in precipitation, and assuming that W_{sX} values remain the same. This necessarily means that in order to maintain the same level of agricultural activities and yield production, additional abstractions will be needed, other flows paths are better controlled, or W_{sX} values are better adjusted.

Correspondingly, supplying additional resources in order to maintain the same yield production in spite of the climate change impacts, if it was possible, would result in possible negative impacts in relation to the basin's sustainability. However, this does not appear in $MesoSE_S$ results because this level of Sefficiency does not reflect the WUS's impact on the main source. This is $MacroSE$'s job.

7.2. Recommendations for Future Works

As we consider this work as a link in the chain of knowledge in this field rather than a discrete piece, the conclusions that we came across highlight a number of future works that can further complement our efforts. To begin with, the following points explain the areas in which we struggled and what can be done to mitigate that:

1. Agricultural Data in Palestine

   We selected 2010/2011 season in particular because it is the most recent season for which the Palestinian official sources provide a complete data set that fits the purpose of this study. As we reached the year 2020, a lack of agricultural data is clearly evident in the different Palestinian sources. At the same time as we acknowledge the great efforts of the Palestinian Central Bureau of Statistics, the Palestinian Water Authority, and the Ministry of Agriculture, we can state that the need for additional data collected from the field significantly surpasses these efforts.

2. Water Quality Weights

   As explained in section 3.3, there are several methods to quantify or score water quality. Besides, we found in this study how significant can the influence of water quality weights be on $MesoSE_S$ results (e.g. SC1 scenario results). The application of the previously explained water quality scoring method would require a lot of field quality tests based on the adopted method. Unfortunately, the funding allocated to this research is well below the capacity to perform such tests, and thus we would highly recommend further investigations in this domain.

3. Public Participation

   Since transparency is the core benefit of adopting Sefficiency as a mindset besides being an efficiency assessment method, public participation is a key element in its application. We attempted to reach as many as 40 farmers after spending a lot of time and effort in order to achieve a representable sample of farmers. Yet, there is room to expand this research to include more farmers and other workers in the field of agriculture. Similarly, we managed to interview the Director-General of Water Resources Management at the PWA after a long coordination process, nevertheless, future works can include additional decision-makers, legislators, water resources managers at the local, national, and regional levels.

On a different note, any underestimation of the abstracted volumes from EAB, which is a likely situation in our study area, would have a vivid impact on the Sefficiency results and the overall understanding of the water use system. National collective efforts should involve the governmental decision-makers, nongovernmental organisations, researchers and research centres, and the civic community members in order to tackle the unreported abstractions issue. We recommend having these efforts aiming to raise awareness among farmers, improve the technological infrastructure, and enhance public participation in the decision-making process would be a worthy investment.

The results of our climate change scenario analysis have highlighted the potential increase in the gap between abstractions, evapotranspiration and precipitation rates under the anticipated climatic changes in the region. Furthermore, during our interview, Eng. Abdulghafour had stressed, more than once, about the negative consequences of the ongoing over-pumping practices and the recently experienced low replenishment rates due to decreased precipitation rates. Therefore addressing the Eastern Aquifer Basin's sustainability through analysing the relevant water use system(s) on the macro level is extremely needed. We have focused this study only on the agricultural sector in Jericho, which is, by far, the largest use sector among the Eastern Aquifer Basin's users. Nevertheless, we would recommend a wider analysis that encompasses the different water instances that are flowing in and out of EAB, in addition to its water level at the beginning of the analysis period (VU) and at the end of it (VD), in order to perform macro-level Sefficiency analysis. Such analysis would enable the relevant stakeholders and decision-makers to touch the points where actions are needed.

In conclusion, Sefficiency champions transparency. A water balance-based assessment approach is fundamental to reach a thorough understanding of the system's nature and conclusion about its performance. Additionally, the active participation of all stakeholders involved within the WUS's boundaries, which constructs a clear definition of water use objectives, enhances the sustainability of our available resources. Joint managerial efforts to assess the performance and impact of the regional water use systems on EAB are crucially important in order to advance its sustainable performance.

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APPENDICES

Appendix I: Farmers Survey

In an attempt to achieve the objective of public participation, better understand the reality on the ground, and estimate several variables and weights in this study, we surveyed the opinion and perspective of 40 local farmers in Jericho governorate. The survey could not be conducted without the generous support of Eng. Abdul-Rahim Barqawi, who runs a local business for supplying agricultural materials and supplements in the area under consideration. Engineer Barqawi helped us reach and contact the surveyed farmers through his widespread network of connections in the region.

Survey Design

As depicted in Figure I.1, we designed the survey to be short and concise by including only questions of direct relevance to this study. At the same time, we avoided including questions that may be considered as sensitive for some farmers, such as the use of unauthorised wells. The survey was written in the local language, Arabic, and a translated version to English is made available in this thesis (Figure I.2).

The questions in the survey are in the forms of factual, multiple-choice, polar (yes/no), and Likert scale questions. These questions aim to collect from each farmer information about the nature and size of their agricultural activities, self-assessment of their irrigation equipment, and their perspective about the return flows and reclaimed wastewater reuse.

Survey Data

Between July and December of 2016, we conducted a study visit to the study area under consideration in order to organise the surveying approach, establish our connections in the region, and introduce the research topic to the potential surveyed farmers. Additionally, during that period, we gathered the contact details of those farmers, where Eng. Barqawi became our focal local point of contact. Later, during the second half of 2018 and the first half of 2019, we performed the surveys via phone calls with each farmers. That process was very challenging due to several reasons, including (but not limited to):

- Logistical difficulties such as the travelling arrangements with limited financial resources, security measures (especially in areas C), farmers' availability, and the poor telecommunication infrastructure in the region.
- Sensitivity of the water topic to many of these farmers despite the survey was conducted on an anonymous basis.
- Lack of trust. Although our identities, the institution we are representing, and the research topic and objectives were all clearly identified, yet many farmers do not trust such research activities due to previous unfortunate misleading experiences in the region of covered missions.
- Gap in knowledge and lack of awareness about several concepts and terms in the survey's questions. As many of those farmers are non-college-educated, most questions needed to be explained in non-academic terms, which prolonged the estimated time of each survey.

To ensure representability, we did not limit our survey to large-scale farmers, instead, we extended our reach to include small-scale farm owners. In addition, we highly considered the geographic distribution as shown in Figure I.3. To clarify, 30% of the farmers were from Jericho city, which is the area of highest population and farming density, another 30% from the northern villages, which have a high rate of agricultural activities, and the remaining 40% were from the remaining villages across the governorate. On the other hand, the survey was anonymous with no consideration for the gender, age group, level of education, or any of the social and economic conditions.

Survey Results

The figures starting from Figure I.4 until Figure I.12 summarise the answers of our surveyed farmers. Figure I.4 presents the number of farmers grouped according to their answers about their farm's area in Dunums. Similarly, Figure I.5 shows the number of farmers grouped according to their answers about the quantity of water they monthly use for irrigation, while Figure I.6 group them according to their answers about their use of artificial fertilisers and pesticides.

Figure I.7 comes across the number of farmers according to their own assessment of the weeds percentage among their crops. It is worth noting that the farmers, who answered 0% of weeds among their crops, have all mentioned in a way or another that they proactively treat the unwanted plants.

Then, Figure I.8 presents the percentage of surveyed farmers based on the method of irrigation they use, and Figure I.9 explains the farmers' first and second sources of irrigation water. Later, Figure I.10 shows the percentage of surveyed farmers based on their position of reclaimed wastewater use in irrigation, while Figure I.11 shows the percentage based on the highest price they agree to pay for reclaimed wastewater. Finally, Figure I.12 details the farmers' answers to the six different polar (yes/no) questions.

استبيان

1. **اسم المجلس القروي/البلدي حيث تقع المزرعة الخاصة بك:** ______________________
2. **عدد الدنومات المزروعة:** ______________________
3. **كمية مياه الري التي تستخدمها شهريا (بالمتر المكعب أو بالشيكل):** ______________________
4. **كمية الأسمدة المصنعة أو المبيدات التي تستخدمها شهريا (بالكيلو):** ______________________
5. **بتقديرك، كم نسبة النباتات والحشائش غير المنتجة وغير المرغوب بين مزروعاتك:** ______________________
6. **نوع الري المستخدم (يمكنك اختيار أكثر من إجابة):**

☐ التنقيط ☐ الرشاشات ☐ الري السطحي باستخدام القنوات ☐ وسيلة أخرى (أذكرها) ______________________

7. **ضع دائرة حول رقم الإجابة الانسب من فضلك:**

- أكبر مصدر استخدمه لمياه الري يأتي من:

1. المجلس/البلدية 2. مكروت 3. بئر خاص 4. شراء 5. مصدر آخر (أذكره)______________________

- ثاني أكبر مصدر استخدمه لمياه الري يأتي من (لا تجب عن السؤال إن لم يكن هناك مصدر ثاني):

1. المجلس/البلدية 2. مكروت 3. بئر خاص 4. شراء 5. مصدر آخر (أذكره)______________________

- معدات الري التي استخدمها هي:

1. أفضل المتاح في السوق 2. تحتاج للتحسين والصيانة 3. سيئة وتحتاج للاستبدال

- هل توافق على استخدام مياه مكررة في ري محاصيلك:

1. أوافق وبشدة 2. أوافق بتحفظ 3. أرفض مبدأيا 4. أرفض وبشدة

- أكبر سعر مستعد لدفعه مقابل المتر المكعب من المياه المكررة:

1. أرفض استخدامها 2. شيكلين 3. من شيكلين إلى 5 4. من 5 إلى 10 شيكل

8. **أجب بنعم أو لا من فضلك (بوضع دائرة حول نعم/لا):**

اهتم بالمياه الراجعة بعد عملية الري	نعم	لا		وسيلة الري التي استخدمها هي الأنسب وأفضل المتاح	نعم	لا
مياه الأمطار مهمة لري مزروعاتي	نعم	لا		امتلك وحدة معالجة مياه عادمة خاصة بي	نعم	لا
الحصول على مياه تكفي احتياجاتي للري مهمة شاقة	نعم	لا		انتاجي سيزيد إذا زادت كمية المياه المتاحة لي	نعم	لا

9. **عدد أسماء أهم المحاصيل تنتجها من فضلك مع تقدير مساحة الأرض المزروعة والأشهر التي تزرع فيها هذه المحاصيل خلال السنة:**

رقم	اسم المحصول	الدونمات المزروعة	كم تستهلك مياه بتقديرك (ضع دائرة)			تزرعها من شهر	حتى شهر
1			كثير	متوسط	قليل		
2			كثير	متوسط	قليل		
3			كثير	متوسط	قليل		
4			كثير	متوسط	قليل		
5			كثير	متوسط	قليل		
7			كثير	متوسط	قليل		
8			كثير	متوسط	قليل		
9			كثير	متوسط	قليل		
10			كثير	متوسط	قليل		

شكرا جزيلا جدا

Figure I.1: Arabic version of the survey

Survey (English Translation)

1. **Name of municipality or village council where your farm is located: ______________________________**

2. **Area of farmlands you own (in dunums): ______________________________**

3. **Quantity of monthly used irrigation water (in cubic meters or Shekels (NIS)): ______________________________**

4. **Quantity of monthly used pesticides and artificial fertilizers (in kg): ______________________________**

5. **How much is your estimate of the weeds' percentage among your plants: ______________________________**

6. **Method of irrigation you use (you can select multiple):**

   ☐ Drip ☐ Sprinklers ☐ Surface open channel ☐ Other (please specify) _____________________

7. **Select the most accurate answer, please:**

   - The first source of water you depend on the most:

     1. Municipality 2. Mekorot 3. Private well 4. Purchasing 5. Other (please specify) _______________

   - The second source of water you depend on the most:

     1. Municipality 2. Mekorot 3. Private well 4. Purchasing 5. Other (please specify) _______________

   - The irrigation equipment I use is:

     1. The best in the local market 2. Needs improvement 3. Needs replacement

   - Do you agree to use reclaimed wastewater in irrigating your crops?

     1. Strongly agree 2. Conservatively agree 3. Somewhat disagree 4. Strongly disagree

   - The highest price you agree to pay for a cubic meter of reclaimed wastewater:

     1. I disagree to use it 2. 2 NIS 3. Between 2 and 5 NIS 4. Between 5 and 10 NIS

8. **Answer with Yes or No, please (encircle your choice):**

The irrigation method I use is the most suitable and available	Yes	No		I consider returned water after irrigation important	Yes	No
I own a household wastewater treatment plant	Yes	No		I depend on precipitation for my crops	Yes	No
My yield will increase if my water share increases	Yes	No		It is difficult to get my need of water resources for irrigation	Yes	No

9. **List the most predominant crops you grow with an estimate of the area and growing period, please:**

No.	Name of Crop	Area in Dunums	Estimation of Used Water Quantity (encircle your choice)			Planted From Month	Until Month
1			High	Medium	Low		
2			High	Medium	Low		
3			High	Medium	Low		
4			High	Medium	Low		
5			High	Medium	Low		
7			High	Medium	Low		
8			High	Medium	Low		
9			High	Medium	Low		
10			High	Medium	Low		

Thank You

Figure I.2: English version of the survey

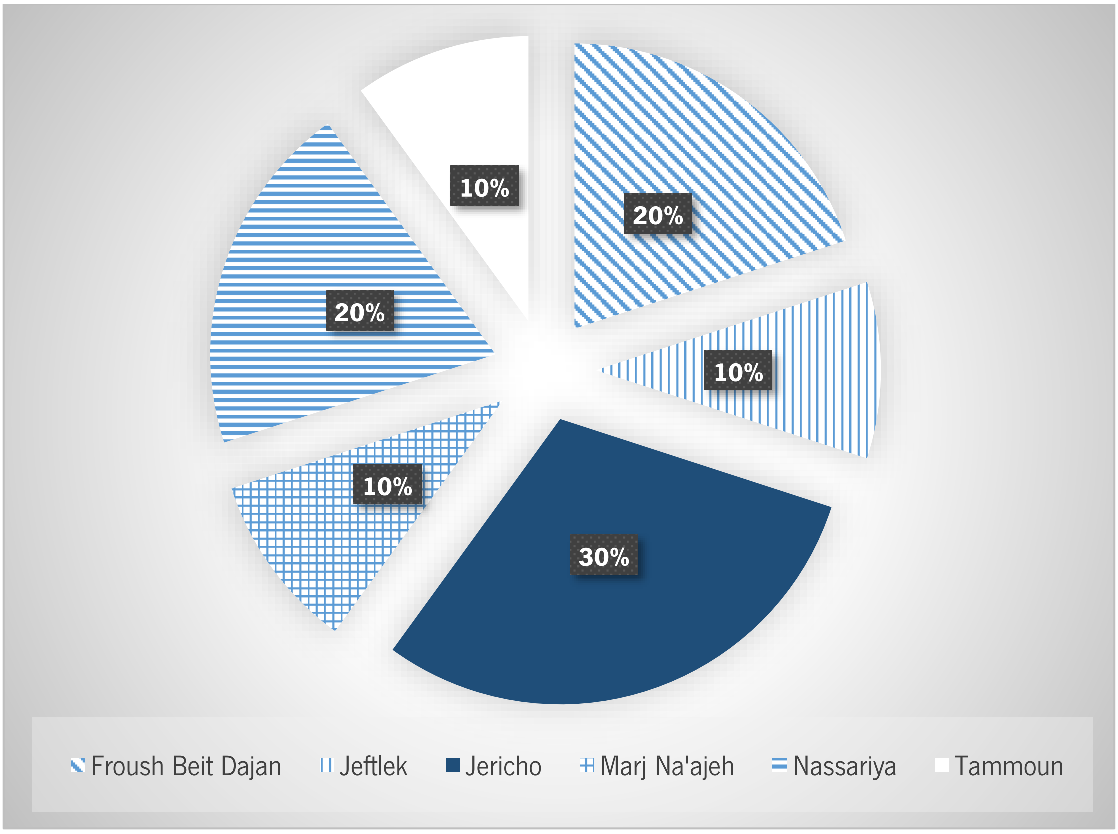


Figure I.3: Geographic distribution of surveyed farmers by village or city

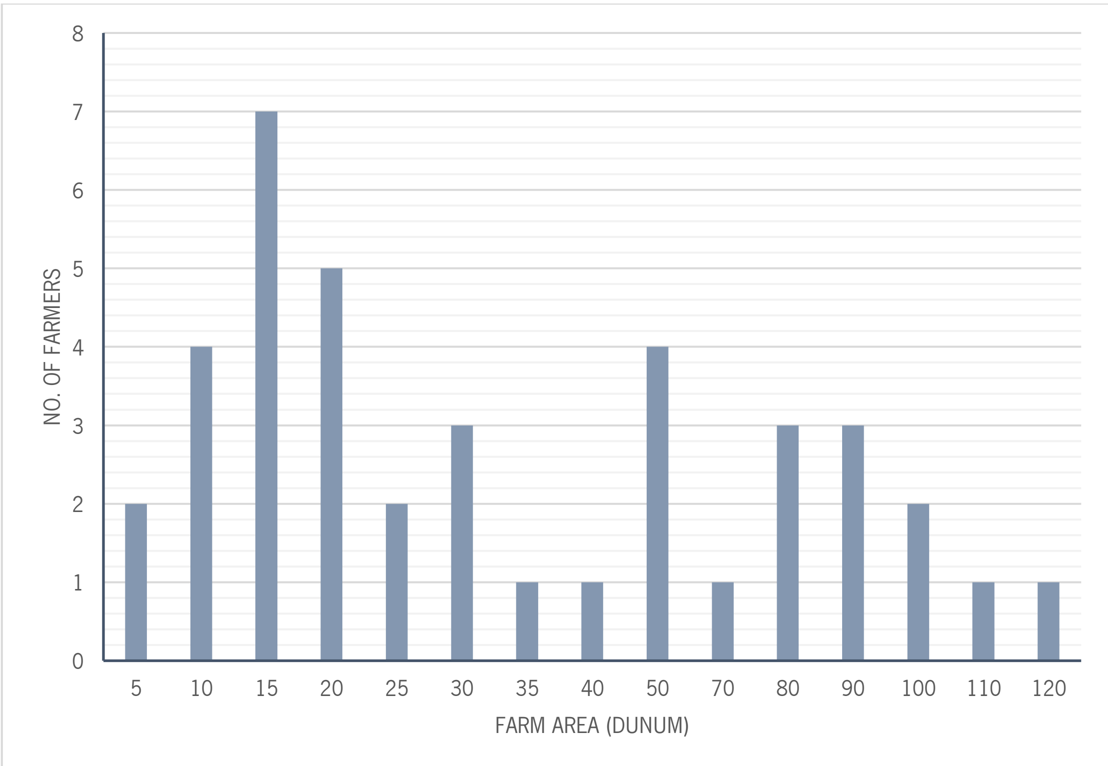


Figure I.4: Number of farmers according to their answers about their farm's area in Dunums

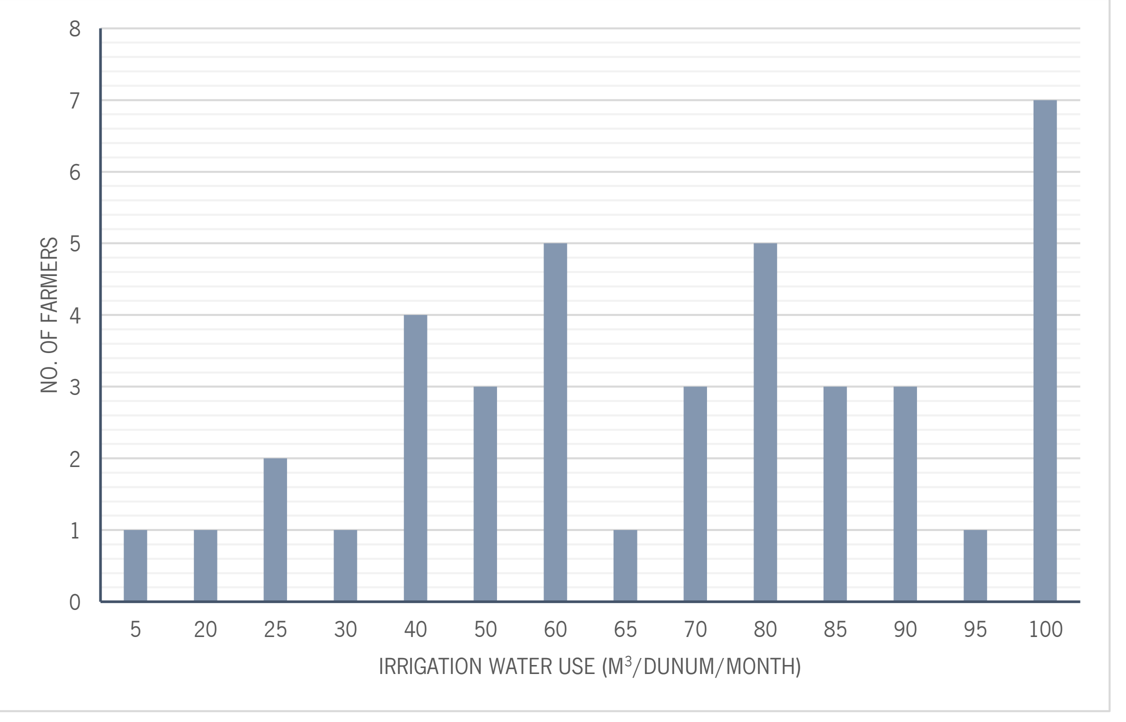


Figure I.5: Number of farmers according to their answers about the quantity of water they monthly use for irrigation

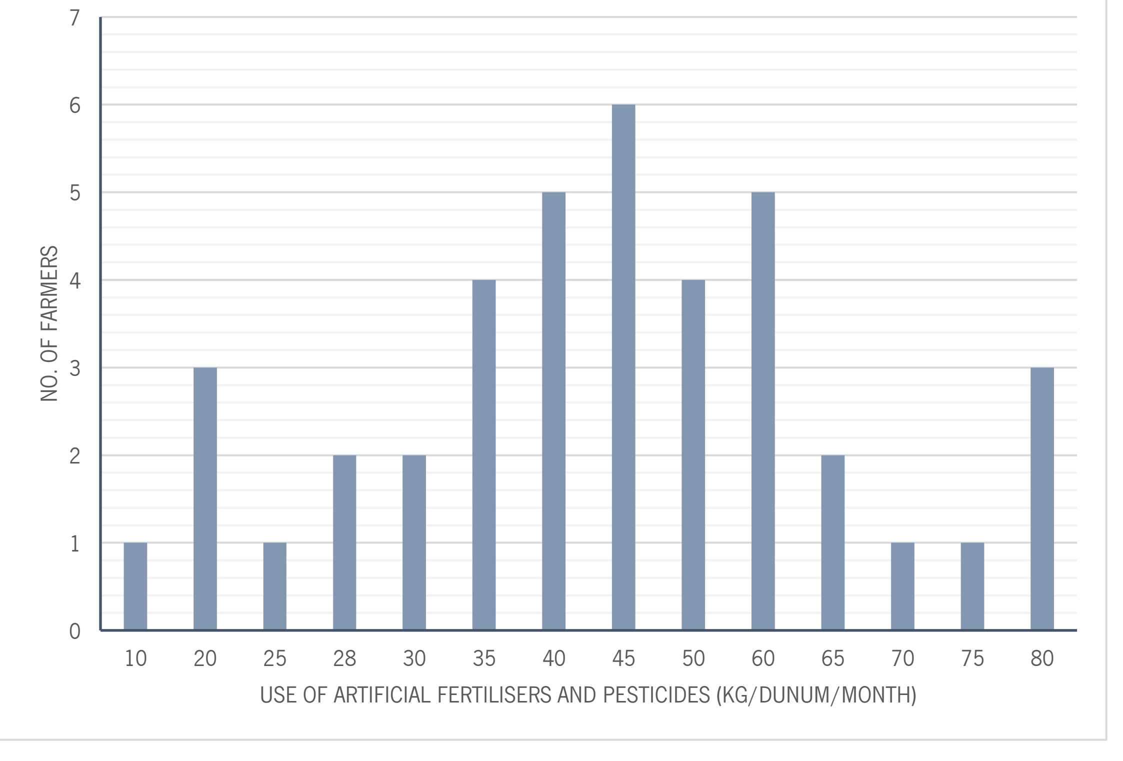


Figure I.6: Number of farmers according to their answers about their use of artificial fertilisers and pesticides

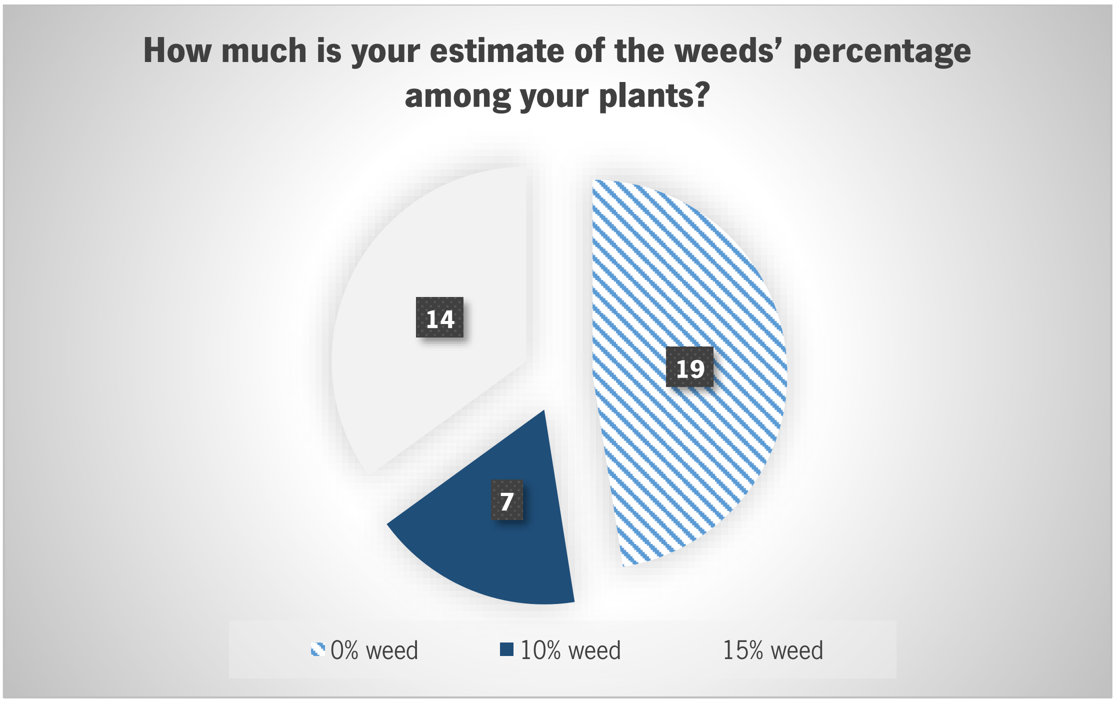


Figure I.7: Number of farmers according to their answers about their assessment of the weeds percentage among their crops
Those 19 farmers, who answered 0%, have all mentioned in a way or another that they proactively treat the unwanted plants.

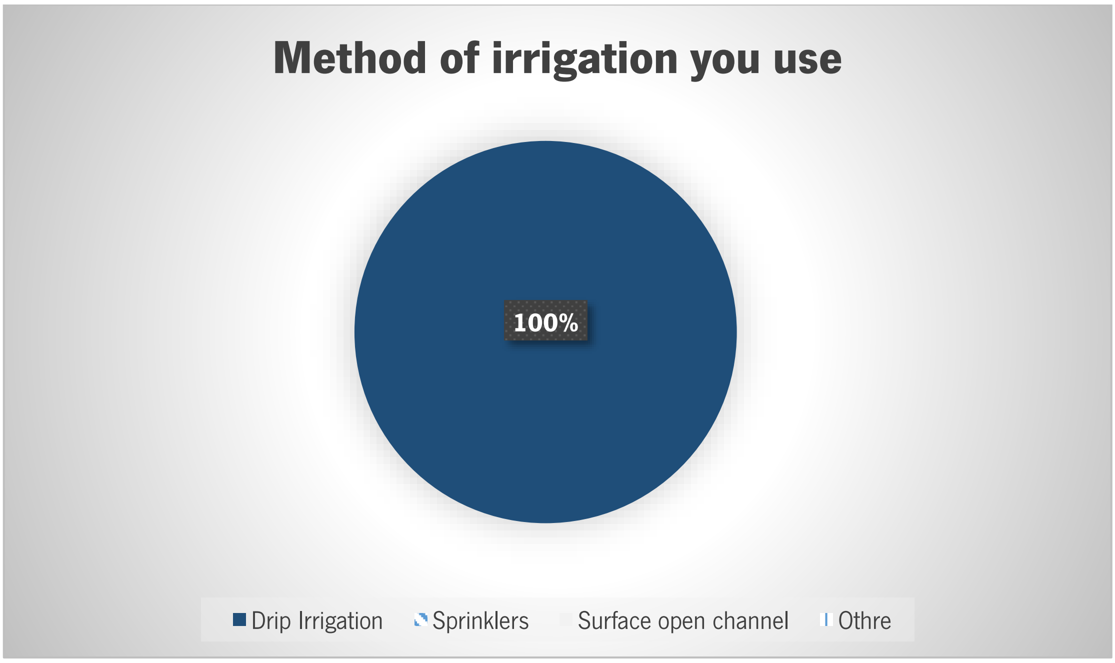
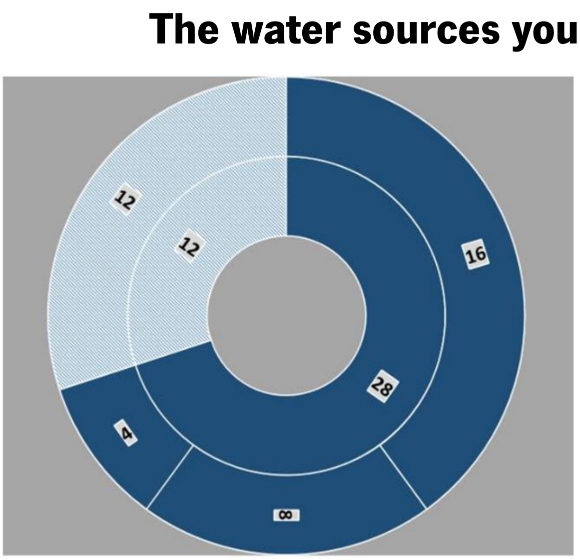


Figure I.8: Percentage of surveyed farmers based on the method of irrigation they use



First Source	Second Source	No. of Farmers
Private well	Mekorot	4
	Purchasing	8
	None	16
Purchasing	None	12

Figure I.9: Number of farmers according to their answers about their first and second sources of irrigation water
Note: the inner circle of the pie chart corresponds with the first source and the outer circle represents the second source.

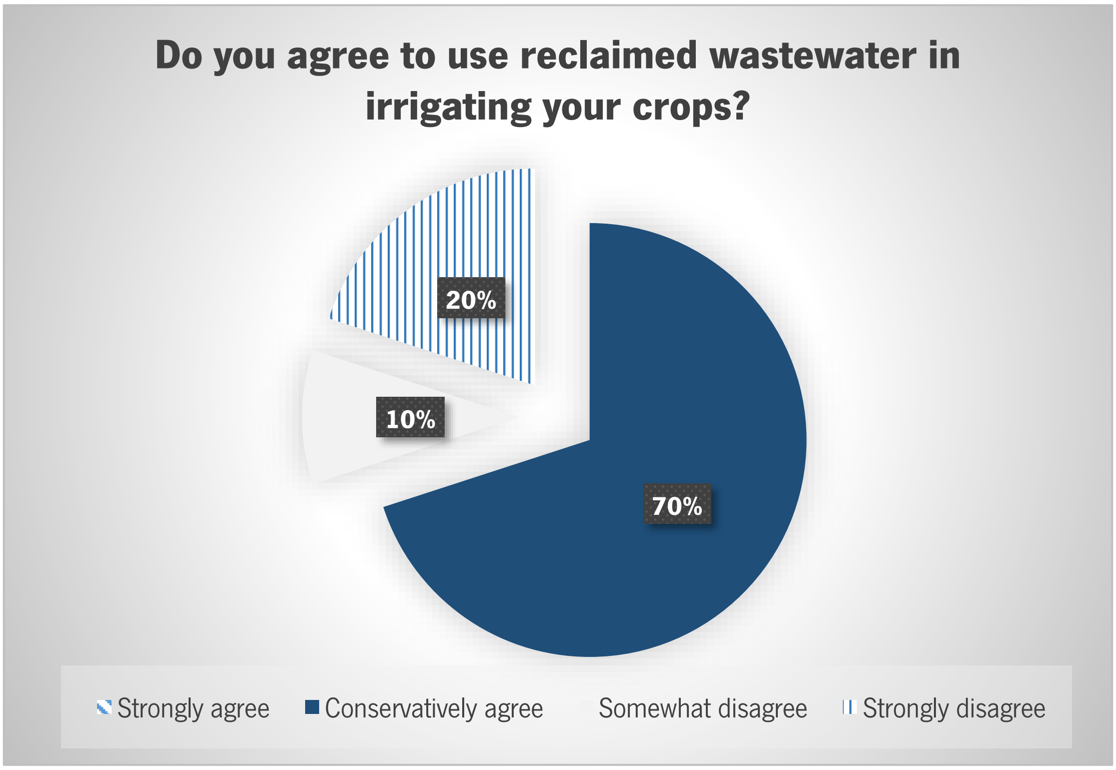


Figure I.10: Percentage of surveyed farmers based on their position of reclaimed wastewater use in irrigation

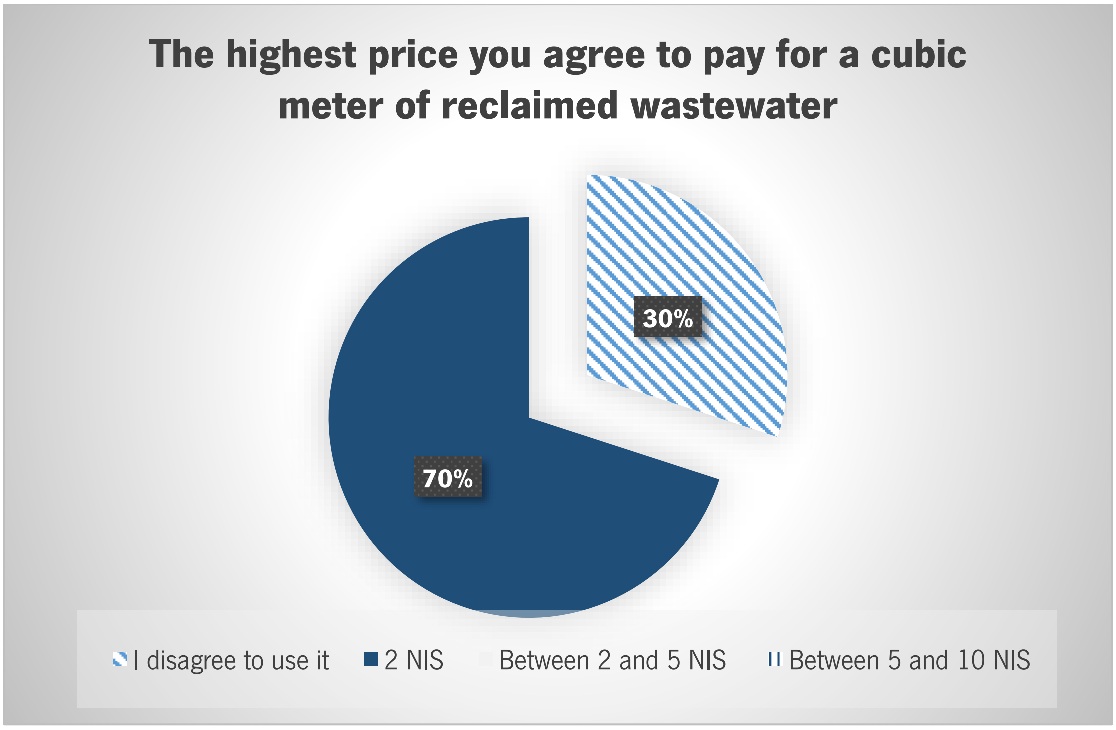


Figure I.11: Percentage of surveyed farmers based on the highest price they agree to pay for reclaimed wastewater

NIS: New Israeli Shekel

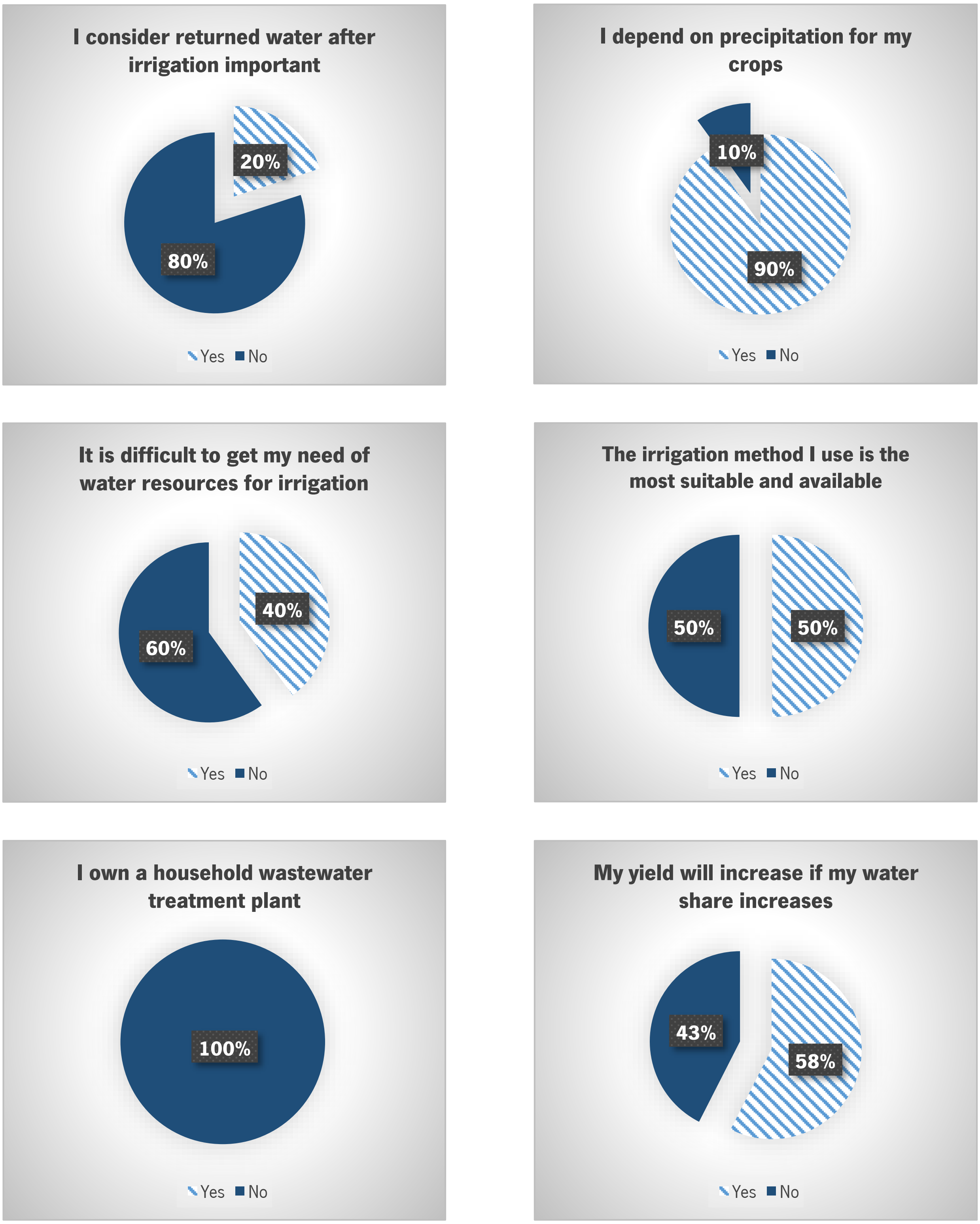


Figure I.12: Farmers' answers to the polar questions

Appendix II: Engineer Deeb Abdulghafour's Interview Transcript Summary

On Tuesday, the 8th of October 2019, we had the opportunity to interview the Director-General of Water Resources Management at the Palestinian Water Authority (PWA), Eng. Deeb Abdulghafour. The objective of this interview is to acquire the perspective of the water resources managerial and decision-making level in Palestine. Besides, we benefited from the interview to confirm our understanding of the conditions on the ground, and to obtain additional data and information.

Eng. Abdulghafour joined the PWA around the year 2000, and since then, he worked in different decision-making positions within the organisation, including leading the Projects Development Unit, until he reached his current position as the Director-General of Water Resources Management. He is the author and co-author of a great number of the PWA official publications and is considered as one of the most knowledgeable figures in this organisation.

We conducted the interview remotely via a phone call in Arabic. The location of the interviewer, Nasser Tuqan, was in Braga, Portugal, while Eng. Abdulghafour was in Ramallah, Palestine. The following pages will present a written transcript summary translated to English that includes only the relevant information for this research work.

Start of the interview.

Tuqan, N.:

"Greetings Eng. Abdulghafour. First, on behalf of Professor Naim Haie and myself, I would like to thank you very much for accepting our invitation to participate in this interview."

Q. "Could you walk us through the agricultural water resources in the Jordan Valley and the role that the PWA plays there, please?"

Eng. Abdulghafour:

"Agriculture in the Jordan Valley depends on groundwater wells of the Eastern Aquifer Basin since the Jordanian era[1]. All of those wells are private. Later, when the Israeli occupation occurred in 1967, the Israelis surveyed all of those wells and specified, for each well, an ID number and an annually renewed withdrawal permit that includes what we call an "extraction quota", which is a limited amount that the well owner can annually withdraw. Any extra withdrawals above that quota would be a violation that is subjected to a fine. These private wells are registered for individual citizens and their heirs. The PWA does not control what type of use the abstracted quantities from these wells are for. Our role is limited to the abstractions' monitoring, conducting the water budgeting, and issuing the annual renewals of the withdrawal permits."

"The wells we are discussing are old wells predate the Israeli occupation in 1967, and hence, in my personal opinion, many of them are expired, should be closed and replaced with new wells. However, due to the current circumstance under the Israeli occupation, any well that requires a substitute or a rehabilitation process, regardless of whether it was a hydrological or mechanical rehabilitation, would require the approval of the Joint Water Committee (JWC) as per Oslo agreement. Now, for instance, when well owners approach the PWA to get a permit for drilling a substitute well, with the justification that their well is too old or due to a backfill incident, we assess the request from a hydrological perspective. If we approve it after the hydrological assessment, we forward it to the JWC for the final approval. This approval process does not influence the annual quota that was specified earlier."

"Our role in the PWA does not extend beyond the moment when the water is withdrawn from a well, whereas the Palestinian Ministry of Agriculture (MOA) oversees the agricultural water use,

[1] Between the years 1948 and 1967, the West Bank was annexed to the Hashemite Kingdom of Jordan and both regions were considered as one country. Locally, Palestinians refer to this period as the Jordanian era.

including matters such as the method of irrigation, crops feasibility and selection, community farming, number of beneficiaries, etc. In some instances, the PWA coordinates with the MOA in their efforts of creating cooperative societies or associations incorporating a group of farmers or a group of adjacent wells' beneficiaries. The objective of those associations is to ensure expanding water use for the largest possible number of farmers, especially because not all farmers, families, nor landowners own wells. Upon agreed terms with the MOA, being a member of a water association secures a share of water for those individuals and families who do not own wells. The agreed terms are to ensure maximising the number of beneficiaries, equity between the beneficiaries, and protection of the well owner's rights."

Tuqan, N.:

Q. "What about the water quality testing and control?"

Eng. Abdulghafour:

"Quality testing is our job. The well itself is our responsibility in terms of quality and quantity. We have a certain monitoring programme to measure the water level and pumping rate of more than 200 wells in the Jordan Valley every 3 months."

Tuqan, N.:

Q. "Most of the 200 wells are agricultural wells, right?"

Eng. Abdulghafour:

"All of them."

"Put the Israeli wells in that region aside, there are a handful of PWA wells for drinking water in Jericho city only."

Tuqan, N.:

Q. "Is this because Jericho is classified as area A?"

Eng. Abdulghafour:

"The only two areas A in the entire governorate are Jericho and Al-Auja. The rest, including Al-Jiftlik, Fasayil, Bardala, and so on are all classified as area C, which are difficult to manage. On the contrary, inside Jericho city, we sometimes do not wait for the JWC's approval for small projects such as wells' rehabilitation."

“Note that we have a mutual understanding with the MOA stating that the rehabilitation of the agricultural wells is in their scope, yet in coordination with us. To elaborate, it is their responsibility to secure funds to rehabilitate agricultural wells, and when the fund is available, they discuss with us the rehabilitation process plan in regards to the technical and hydrological aspects. Such aspects include the drilling depth, structural casing, what pumping test is the best fit for purpose after rehabilitation, hydraulic operational values for an optimal output, and so on. As you know, farmers lack knowledge in these issues and variables such as the static water level, dynamic water level, water head, etc. For instance, imagine there is a well with a 200 m depth and a static level of 50 m. Instead of abstracting 50 cubic meters out of it, we could increase the pump’s depth with the appropriate pumping test and monitor the well’s drawdown leading to potentially doubling the abstractions without affecting the well itself, surrounding wells, nor the aquifer’s water budget. These dynamics vary from an area to another because, in the Joran Valley region, from a geological and hydrogeological perspective, the aquifer’s geological setting varies. Most of our aquifers there are shallow.”

Tuqan, N.:

Q. “Is the water brackish there?”

Eng. Abdulghafour:

“Yes. This is the problem of shallow aquifers. They do not get enough replenishment, especially due to a drought that the entire region is suffering from in the last 10-15 years. As you know, there is a significant fluctuation and variation in the annual precipitation rates. In addition, the number of wells is increasing. Furthermore, the farmers are pumping in quantities that exceed their quotas and this is a very sensitive topic. When we demand the farmers to abide by their quotas, they use the argument that {*these rules were set up by an occupying force on our national resources, why would the PWA side with the occupier?*}”

Tuqan, N.:

Q. “To clarify, are these quotas equal to the Palestinian share of the aquifer that was agreed upon in Oslo Accords?”

Eng. Abdulghafour:

“No. We refer to that share as allocation. Please note that the allocation, according to Oslo Accords, is a temporary arrangement. Palestinians and Israelis agreed on this allocation for a transition phase of 5 years ending in 1999 when the "final negotiations" were supposed to proceed. Nevertheless, as you know, the so-called "final negotiations" reached nowhere."

"The allocation is a more inclusive term that refers to the total water share for the Palestinian. The Jordan Valley is part of the Eastern Basin, which has two major aquifer types. First, there is the mountain aquifer, which is a carbonate-rock aquifer, and the second is composed of alluvium deposits and sand formations. For the second type, in several areas in the Jordan Valley, the aquifer is too shallow to have suitable water. Most of the water in the alluvium deposits and sand formations exist within the area of Jericho city, while between Jericho and Al-Auja it is an aquitard instead. The aquifer within Al-Auja area has some potentials, but much fewer quantities than Jericho. Then, around Fasayil, there are 1 or 2 wells tapping the shallow aquifer of the alluvium deposit."

"As for Al-Jiftlik area, the aquifer composition is different because the gravel there has a complex structure, where you can find alluvium deposits mixed with Eocene, marl, and other bed formations. A mix of different geological formation, hence you can find wells tapping each of the aforementioned soil formations. Move out of Al-Jiftlik heading to Marj Na'ja and Marj Ghazal until you reach Kardala and Bardala, also you will find there is a mixture of Eocene and other bed formations. The wells are tapping a variety of geological settings within the same area."

"Concerning the potential water quantity, it depends on the geological settings and the depth of the well itself. However, generally speaking, there is a trend of salinity increase in the region. As mentioned earlier, the brackish water is increasing due to the over-pumping combined with the decreased levels of replenishments."

Tuqan, N.:

Q. "Could you confirm the Palestinian allocation from the Easter Aquifer Basin, please?"

Eng. Abdulghafour:

"54 Mm^3 per year. Our annual allocation from the Northeastern Basin is 42 Mm^3 and from the Western Basin is 22 Mm^3. Hence, the total is 118 Mm^3. This is the total temporary allocation for the Palestinian side according to the Oslo agreement. In addition to those 118 Mm^3, Oslo Accords stated that there would be an additional 78 Mm^3 available in the Eastern Basin for future development and needs. It is not acceptable that we are in 2019 and our allocation remains without an increase for more than 24 years. We decline to discuss the Israeli proposal to sell us additional water through the national Israeli water company, Mekorot, as we deem the reconsideration of our water allocation from our national water resources as a human right."

"Moreover, it is preposterous that, since 1967, we have no access to the Palestinian-Jordanian annual share of the Jordan River, which is estimated in the Johnston Plan[2] around 257-300 Mm^3. In addition, in regards to those additional 78 Mm^3 available in the Dead Sea springs, we previously proposed a project concept to the JWC to develop at least 30-35 Mm^3 of the agreed 78 Mm^3, considering that the long-term annual average recharge there is around 80 to 100 Mm^3 that are mostly brackish. Note that the agreement was later amended to state that the 78 Mm^3 can be developed from the Eastern Basin or "any other agree resources", referring by the "other agreed resources" to water desalination, nevertheless, we demand to develop half of the 78 Mm^3 from the Dead Sea springs. Our project proposed, in its first stage, developing wells in the upper stream region, namely Marsaba area, in order to catch the flow while it is fresh before mixing with the high-salinity layers adjacent to the Dead Sea. This first stage is designed to get 11-12 Mm^3. In the project's second stage, we proposed developing a desalination plant with a capacity of around 20 Mm^3. Then, we planned to mix the abstracted water from the first stage with the effluent of the second stage and supply them to Hebron and Bethlehem governorates, which are the 2 most water-critical governorates in the West Bank. However, the JWC declined the proposal with the justifications that such a plan should be only discussed within the "final negotiations" phase and that such a proposal will have negative ecological impacts, especially on the natural reserves in the Dead Sea area."

Tuqan, N.:

Q. "What about wastewater treatment?"

Eng. Abdulghafour:

"Concerning the wastewater treatment, the Palestinian side kept waiting for the JWC's approval to build wastewater treatment plants (WWTPs) for more than 15 years. This is a major challenge. Besides, when we were planning to develop reuse-scheme projects, we faced many obstacles getting JWC and Israeli civic administration's approvals since most of those projects are located

[2] "Johnston Plan" is the common name for the Jordan Valley Unified Water Plan. It was a plan negotiated and developed by US ambassador Eric Johnston between 1953 and 1955 in order to ensure equitable water sharing between the riparian countries of the Jordan River.

in areas C[3]. For instance, in the case of the WWTP in Western Nablus, we barely got the necessary approvals after a long struggle to use its effluent only in a limited number of dunums in areas C."

"WWTPs as well as desalination plants project are associated with a heavy investment cost compared to our financial capabilities. The smallest project would cost up to 30 to 40 million USD. Raising funds from potential donors is not an easy task, and thus it is important to ensure the feasibility of those plants through the reuse-scheme projects."

Tuqan, N.:

"That is it for now. We cannot thank you enough for all of the valuable information and details. We would be glad if you considered the results of our research when they are published and look forward to future collaboration."

Eng. Abdulghafour:

"Thank you for your efforts and if you need any further information, we will be happy to assist"

Tuqan, N.:

"Your offer is greatly appreciated. Goodbye."

End of the interview.

[3] The reason why the WWTP projects are located in areas C is that these projects, for hydraulic purposes, have to be located in the city edges. Typically speaking, in the West Bank, areas inside the cities are classified as areas A, while areas starting from the city boundaries outward are classified as areas C

Appendix III: Evapotranspiration Data

The most significant variable in our water use system (WUS) and any other agricultural WUS is evapotranspiration. This appendix provides the complete dataset that was used in order to estimate ET.

Data Collection

As explained in subsection 3.2.4, we adopted the baseline of the Palestinian Central Bureau of Statistics in their 2010 agricultural census (PCBS, 2012) in terms of crops' cataloguing and classification. In addition, we acquired the areas of irrigated farmland in Jericho Governorate for each crop from the same census.

We used the CROPWAT modelling tool (Figure III.1) and the metrological data from the Jericho metrological station (Table 4.1) to estimate the reference crop evapotranspiration (ET_o), which was adjusted later per each growing period.

Monthly ETo Penman-Monteith - C:\Users\TuqanN\Desktop\Last mile\CROPWAT\PhD.PEM

Country: Palestine — Station: Jericho

Altitude: 0 m. — Latitude: 31.85 °N — Longitude: 35.45 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m²/day	mm/day
January	7.4	19.1	70	1.3	5.5	10.5	1.67
February	8.3	20.9	65	1.4	5.9	12.9	2.24
March	10.5	24.3	57	1.8	7.7	17.8	3.52
April	14.2	29.3	45	2.3	9.3	22.4	5.45
May	17.6	33.7	38	2.2	9.4	23.8	6.54
June	20.4	36.7	38	2.1	11.8	27.7	7.47
July	22.1	37.8	40	2.2	11.7	27.2	7.68
August	22.4	37.6	44	2.1	11.6	26.0	7.18
September	21.2	36.1	47	1.8	10.5	22.2	5.89
October	17.9	32.3	51	1.3	8.7	16.9	3.98
November	12.9	26.4	60	1.1	6.5	11.9	2.46
December	9.0	20.5	70	1.1	5.6	10.0	1.64
Average	**15.3**	**29.6**	**52**	**1.7**	**8.7**	**19.1**	**4.64**

Figure III.1: CROPWAT model using the metrological data from Jericho station

The growing period and the crop coefficient (K_c) for each of the different crop types was estimated based on the extensive local research work in this field conducted by the Applied Research Institute—Jerusalem (ARIJ) in 1998 (J. Isaac & Sabbah, 1998). We verified the growing periods in ARIJ's book for each crop by comparing them with those listed by the surveyed farmers in the last question of the survey, and with the opinion of local agricultural engineers.

Then, we utilised K_c in order to estimate the actual crop evapotranspiration (ET_c) per the growing period of each crop. Finally, the value of ET in volumetric unit (e.g. m^3) resulted from multiplying the value of ET_c for a given crop by its respective area.

ET Results

Based on the collected data and after taking into consideration the differences in units, Table III.1 presents the complete ET details and results.

Table III.1: ET details and results

Type	Crop Name (Arabic)	Crop Name (English)	Area (Dunum)	K_c	ET_o (mm)	ET_c (mm)	ET (m^3)
Vegetables	جرجير	Arugula	23	0.832	669	557	12,812
	فول أخضر	Broad Bean (green)	1,096	0.736	1,207	889	974,284
	قرنبيط	Cauliflower	1,055	0.842	699	588	620,679
	لوبياء (خضراء)	Cowpea	14	0.795	835	664	9,301
	خيار	Cucumber	1,103	0.891	616	549	605,614
	باذنجان	Eggplant	3,880	0.751	1,504	1,130	4,382,909
	شومر	Fennen	28	0.751	780	586	16,163
	ثوم أخضر	Garlic (green)	0.55	0.751	780	586	322
	قرع	Gourd	78	0.904	1,294	1,170	91,239
	فلفل حار	Hot Pepper	743	0.795	780	620	460,980
	ورق لسان	Jew's Mallow	706	0.832	1,445	1,203	848,698
	فاصولياء خضراء	Kidney Bean (green)	1,117	0.715	886	633	707,217
	خس	Lettuce	46	0.832	699	582	26,780
	ذرة صفراء	Maize	3,830	0.720	806	580	2,220,233
	فطر	Mushroom	5	0.842	983	827	4,135
	شمام	Muskmelon	588	0.746	1,294	966	567,731
	بامية	Okra	314	0.973	1,229	1,196	375,100
	بصل أخضر	Onion (green)	115	0.832	669	557	64,245
	خضراوات أخرى	Other Vegetables	19	0.751	1,668	1,253	23,810
	فلفل حلو	Paprika	712	0.795	780	620	441,692
	بقدونس	Parsley	9.46	0.832	1,668	1,388	13,135

	بازيلاء (خضراء)	Peas (green)	10	0.795	1,207	960	9,602
	بطاطا عادية	Potato	34	0.832	780	648	22,146
	يقطين	Pumpkin	30	0.746	1,668	1,245	37,351
	فجل	Radish	0.42	0.751	1,445	1,086	456
	ملفوف أحمر	Red Cabbage	7	0.842	699	588	4,116
	فقوس	Snake cucumber	99	0.891	1,207	1,075	106,357
	سبانخ	Spinach	31	0.751	1,668	1,253	38,660
	كوسا	Squash	7,603	0.904	983	888	6,751,736
	بندورة	Tomato	2,376	0.832	806	670	1,592,496
	بطيخ	Water Melon	138	0.746	1,294	966	133,311
	ملفوف أبيض	White Cabbage	462	0.842	699	588	271,424
	حويرنة	White Wall-rocket	26	0.832	669	557	14,693
Trees	صبر	Aloe	1.20	0.935	1,668	1,559	1,871
	تفاح	Apple	0.24	0.751	1,668	1,253	301
	المشمش	Apricot	0.10	0.751	1,668	1,253	125
	برتقال بلدي	Balady Orange	5	0.678	1,668	1,132	6,111
	موز	Banana	1,111	0.872	1,332	1,161	1,290,290
	توت عادي	Berry	0.39	0.751	1,668	1,253	489
	بوملي	Bomaly	58	0.795	1,668	1,327	77,373
	باباي	Carica papaya	5.50	0.751	1,668	1,253	6,892
	كرز	Cherry	0.42	0.751	1,668	1,253	526
	كلمنتينا	Clement	15	0.795	1,668	1,327	19,868
	قشطة	Custard apple	2.57	0.715	1,668	1,192	3,064
	بلح	Date	4,794	0.935	1,668	1,559	7,474,434
	تين	Fig	10	0.751	1,668	1,253	12,193

	عنب	Grape	253	0.509	1,668	850	215,281
	جريبفروت	Grapefruit	3.86	0.678	1,668	1,132	4,368
	جوافة	Guava	6.35	0.872	1,668	1,455	9,241
	ليمون	Lemon	249	0.795	1,668	1,327	330,595
	أسكدنيا	Loquat	0.76	0.751	1,668	1,253	952
	مندلينا	Mandarin	7.07	0.795	1,668	1,327	9,383
	مانجا	Mango	0.06	0.751	1,668	1,253	75
	برتقال أبوصرة	Navel Orange	0.40	0.678	1,668	1,132	453
	زيتون	Olive	75	0.666	1,668	1,110	83,442
	برتقال	Valencia Orange	141	0.678	1,668	1,132	159,338
	حمضيات أخرى	Other Citrus	143	0.678	1,668	1,132	161,952
	أشجار بستنة أخرى	Other Trees	3.59	0.751	1,668	1,253	4,499
	كمثرى	Pears	0.02	0.751	1,668	1,253	25
	رمان	Pomegranate	119	0.621	1,668	1,037	123,765
	برتقال شموطي	Shammoty Orange	0.30	0.678	1,668	1,132	339
	جوز	Walnut	0.07	0.751	1,668	1,253	88
Field Crops	يانسون	Anise	20	0.842	669	563	11,256
	شعير	Barley	286	0.715	242	173	49,510
	فول (يابس)	Broad Bean	5.30	0.752	1,207	908	4,810
	بابونج	Chamomile	0.40	0.842	669	563	225
	هندباء	Cichorium	4.55	0.842	669	563	2,561
	برسيم	Clover	30	0.751	1,504	1,130	33,890
	ثوم يابس	Dry Garlic	0.70	0.916	907	831	581
	بصل يابس	Dry Onion	100	0.916	1,145	1,049	104,887
	فاصولياء (يابس)	Kidney Bean	5.00	0.752	1,192	897	4,483

نعناع	Mint	36	0.832	1,668	1,388	49,985
ميرمية	Meramieh	43	0.751	669	502	21,600
زعتر فارسي/حصا البان	Other Beverage Crops	163	0.832	669	557	90,443
محاصيل حقلية أخرى	Other Field Crops	400	0.751	1,668	1,253	501,268
عصفر	Safflower	1.50	0.832	669	557	835
بيقيا	Sern	7	0.840	669	562	3,932
ذرة بيضاء	Sorghum	1,180	0.720	242	174	205,628
زعتر	Thyme	31	0.751	669	502	15,623
قمح	Wheat	659	0.840	983	825	543,532
Total		**36,278**				**33,091,811**

Climate Change Impact on ET Values

As explained in section 3.5, scenarios of both RCP2.6 and RCP6.0 pathways predict changes in temperature. The most likely scenarios under RCP2.6 is a temperature increase of 0.5°C in 2025, 1.0°C in 2055, and 1.5°C in 2090. Similarly, the most likely scenarios under RCP6.0 is a temperature increase of 0.5°C in 2025, 1.5°C in 2055, and 3.0°C in 2090. Therefore, we used CROPWAT to estimate the changes in ET values under temperature increases of 0.5°C, 1.0°C, 1.5°C, and 3.0°C. The tables from Table III.2 to Table III.5 present the detailed impact of these changes on each crop and the total value of ET.

Table III.2: ET details and results under 0.5°C increase

Type	Crop Name (Arabic)	Crop Name (English)	Area (Dunum)	K_c	ET_o (mm)	ET_c (mm)	ET (m^3)
Vegetables	جرجير	Arugula	23	0.832	709	590	13,576
	فول أخضر	Broad Bean (green)	1,096	0.736	1,254	923	1,011,808
	قرنبيط	Cauliflower	1,055	0.842	707	595	628,043
	لوبياء (خضراء)	Cowpea	14	0.795	844	672	9,404
	خيار	Cucumber	1,103	0.891	655	584	644,145
	باذنجان	Eggplant	3,880	0.751	1,553	1,167	4,525,886
	شومر	Fennen	28	0.751	821	617	17,019
	ثوم أخضر	Garlic (green)	0.55	0.751	821	617	339
	قرع	Gourd	78	0.904	1,342	1,213	94,609
	فلفل حار	Hot Pepper	743	0.795	821	653	485,400
	ورق لسان	Jew's Mallow	706	0.832	1,495	1,244	877,633
	فاصولياء خضراء	Kidney Bean (green)	1,117	0.715	896	640	715,322
	خس	Lettuce	46	0.832	707	588	27,098
	ذرة صفراء	Maize	3,830	0.720	848	610	2,337,601
	فطر	Mushroom	5	0.842	1,027	864	4,321
	شمام	Muskmelon	588	0.746	1,342	1,002	588,700
	بامية	Okra	314	0.973	1,243	1,210	379,391
	بصل أخضر	Onion (green)	115	0.832	709	590	68,072
	خضراوات أخرى	Other Vegetables	19	0.751	1,720	1,292	24,549
	فلفل حلو	Paprika	712	0.795	821	653	465,091
	بقدونس	Parsley	9.46	0.832	1,720	1,432	13,542

	بازيلاء (خضراء)	Peas (green)	10	0.795	1,254	997	9,972
	بطاطا عادية	Potato	34	0.832	821	683	23,319
	يقطين	Pumpkin	30	0.746	1,720	1,284	38,510
	فجل	Radish	0.42	0.751	1,495	1,123	472
	ملفوف أحمر	Red Cabbage	7	0.842	707	595	4,165
	فقوس	Snake cucumber	99	0.891	1,254	1,117	110,453
	سبانخ	Spinach	31	0.751	1,720	1,292	39,860
	كوسا	Squash	7,603	0.904	1,027	928	7,054,670
	بندورة	Tomato	2,376	0.832	848	706	1,676,680
	بطيخ	Water Melon	138	0.746	1,342	1,002	138,235
	ملفوف أبيض	White Cabbage	462	0.842	707	595	274,644
	حويرنة	White Wall-rocket	26	0.832	709	590	15,569
Trees	صبر	Aloe	1.20	0.935	1,720	1,607	1,929
	تفاح	Apple	0.24	0.751	1,720	1,292	310
	المشمش	Apricot	0.10	0.751	1,720	1,292	129
	برتقال بلدي	Balady Orange	5	0.678	1,720	1,167	6,300
	موز	Banana	1,111	0.872	1,379	1,203	1,336,327
	توت عادي	Berry	0.39	0.751	1,720	1,292	504
	بوملي	Bomaly	58	0.795	1,720	1,368	79,774
	باباي	Carica papaya	5.50	0.751	1,720	1,292	7,106
	كرز	Cherry	0.42	0.751	1,720	1,292	543
	كلمنتينا	Clement	15	0.795	1,720	1,368	20,484
	قشطة	Custard apple	2.57	0.715	1,720	1,229	3,159
	بلح	Date	4,794	0.935	1,720	1,607	7,706,325
	تين	Fig	10	0.751	1,720	1,292	12,572

	عنب	Grape	253	0.509	1,720	876	221,960
	جريبفروت	Grapefruit	3.86	0.678	1,720	1,167	4,503
	جوافة	Guava	6.35	0.872	1,720	1,500	9,527
	ليمون	Lemon	249	0.795	1,720	1,368	340,851
	أسكدنيا	Loquat	0.76	0.751	1,720	1,292	982
	مندلينا	Mandarin	7.07	0.795	1,720	1,368	9,674
	مانجا	Mango	0.06	0.751	1,720	1,292	78
	برتقال أبوصرة	Navel Orange	0.40	0.678	1,720	1,167	467
	زيتون	Olive	75	0.666	1,720	1,145	86,030
	برتقال	Valencia Orange	141	0.678	1,720	1,167	164,281
	حمضيات أخرى	Other Citrus	143	0.678	1,720	1,167	166,976
	أشجار بستنة أخرى	Other Trees	3.59	0.751	1,720	1,292	4,638
	كمثرى	Pears	0.02	0.751	1,720	1,292	26
	رمان	Pomegranate	119	0.621	1,720	1,069	127,605
	برتقال شموطي	Shammoty Orange	0.30	0.678	1,720	1,167	350
	جوز	Walnut	0.07	0.751	1,720	1,292	90
Field Crops	يانسون	Anise	20	0.842	709	596	11,927
	شعير	Barley	286	0.715	277	198	56,715
	فول (يابس)	Broad Bean	5.30	0.752	1,254	943	4,995
	بابونج	Chamomile	0.40	0.842	709	596	239
	هندباء	Cichorium	4.55	0.842	709	596	2,713
	برسيم	Clover	30	0.751	1,553	1,167	34,995
	ثوم يابس	Dry Garlic	0.70	0.916	950	870	609
	بصل يابس	Dry Onion	100	0.916	1,191	1,091	109,121
	فاصولياء (يابس)	Kidney Bean	5.00	0.752	1,238	931	4,656

نعناع	Mint	36	0.832	1,720	1,432	51,536
ميرمية	Meramieh	43	0.751	709	532	22,887
زعتر فارسي/حصا البان	Other Beverage Crops	163	0.832	709	590	95,831
محاصيل حقلية أخرى	Other Field Crops	400	0.751	1,720	1,292	516,819
عصفر	Safflower	1.50	0.832	709	590	885
بيقيا	Sern	7	0.840	709	595	4,166
ذرة بيضاء	Sorghum	1,180	0.720	277	200	235,551
زعتر	Thyme	31	0.751	709	532	16,553
قمح	Wheat	659	0.840	1,027	862	567,919
Total		**36,278**				**34,369,716**

Table III.3: ET details and results under 1.0°C increase

Type	Crop Name (Arabic)	Crop Name (English)	Area (Dunum)	K_c	ET_o (mm)	ET_c (mm)	ET (m^3)
Vegetables	جرجير	Arugula	23	0.832	717	597	13,739
	فول أخضر	Broad Bean (green)	1,096	0.736	1,270	935	1,025,239
	قرنبيط	Cauliflower	1,055	0.842	717	603	636,739
	لوبياء (خضراء)	Cowpea	14	0.795	855	680	9,523
	خيار	Cucumber	1,103	0.891	665	592	653,650
	باذنجان	Eggplant	3,880	0.751	1,572	1,181	4,581,957
	شومر	Fennen	28	0.751	833	625	17,263
	ثوم أخضر	Garlic (green)	0.55	0.751	833	625	344
	قرع	Gourd	78	0.904	1,359	1,228	95,769
	فلفل حار	Hot Pepper	743	0.795	833	662	492,359
	ورق لسان	Jew's Mallow	706	0.832	1,514	1,260	888,859
	فاصولياء خضراء	Kidney Bean (green)	1,117	0.715	907	648	724,377
	خس	Lettuce	46	0.832	717	597	27,473
	ذرة صفراء	Maize	3,830	0.720	860	619	2,369,402
	فطر	Mushroom	5	0.842	1,041	876	4,379
	شمام	Muskmelon	588	0.746	1,359	1,014	595,919
	بامية	Okra	314	0.973	1,258	1,224	383,858
	بصل أخضر	Onion (green)	115	0.832	717	597	68,891
	خضراوات أخرى	Other Vegetables	19	0.751	1,742	1,309	24,862
	فلفل حلو	Paprika	712	0.795	833	662	471,759
	بقدونس	Parsley	9.46	0.832	1,742	1,450	13,715

	بازيلاء (خضراء)	Peas (green)	10	0.795	1,270	1,010	10,104
	بطاطا عادية	Potato	34	0.832	833	693	23,654
	يقطين	Pumpkin	30	0.746	1,742	1,300	39,000
	فجل	Radish	0.42	0.751	1,514	1,137	478
	ملفوف أحمر	Red Cabbage	7	0.842	717	603	4,223
	فقوس	Snake cucumber	99	0.891	1,270	1,132	111,919
	سبانخ	Spinach	31	0.751	1,742	1,309	40,367
	كوسا	Squash	7,603	0.904	1,041	940	7,150,449
	بندورة	Tomato	2,376	0.832	860	715	1,699,490
	بطيخ	Water Melon	138	0.746	1,359	1,014	139,930
	ملفوف أبيض	White Cabbage	462	0.842	717	603	278,447
	حويرنة	White Wall-rocket	26	0.832	717	597	15,756
	صبر	Aloe	1.20	0.935	1,742	1,628	1,954
	تفاح	Apple	0.24	0.751	1,742	1,309	314
	المشمش	Apricot	0.10	0.751	1,742	1,309	131
	برتقال بلدي	Balady Orange	5	0.678	1,742	1,182	6,380
	موز	Banana	1,111	0.872	1,396	1,218	1,352,868
	توت عادي	Berry	0.39	0.751	1,742	1,309	510
Trees	بوملي	Bomaly	58	0.795	1,742	1,386	80,790
	باباي	Carica papaya	5.50	0.751	1,742	1,309	7,197
	كرز	Cherry	0.42	0.751	1,742	1,309	550
	كلمنتينا	Clement	15	0.795	1,742	1,386	20,745
	قشطة	Custard apple	2.57	0.715	1,742	1,245	3,199
	بلح	Date	4,794	0.935	1,742	1,628	7,804,485
	تين	Fig	10	0.751	1,742	1,309	12,732

	عنب	Grape	253	0.509	1,742	887	224,788
	جريبفروت	Grapefruit	3.86	0.678	1,742	1,182	4,561
	جوافة	Guava	6.35	0.872	1,742	1,519	9,649
	ليمون	Lemon	249	0.795	1,742	1,386	345,193
	أسكدنيا	Loquat	0.76	0.751	1,742	1,309	994
	مندلينا	Mandarin	7.07	0.795	1,742	1,386	9,797
	مانجا	Mango	0.06	0.751	1,742	1,309	79
	برتقال أبوصرة	Navel Orange	0.40	0.678	1,742	1,182	473
	زيتون	Olive	75	0.666	1,742	1,159	87,126
	برتقال	Valencia Orange	141	0.678	1,742	1,182	166,374
	حمضيات أخرى	Other Citrus	143	0.678	1,742	1,182	169,103
	أشجار بستنة أخرى	Other Trees	3.59	0.751	1,742	1,309	4,698
	كمثرى	Pears	0.02	0.751	1,742	1,309	26
	رمان	Pomegranate	119	0.621	1,742	1,082	129,230
	برتقال شموطي	Shammoty Orange	0.30	0.678	1,742	1,182	354
	جوز	Walnut	0.07	0.751	1,742	1,309	92
Field Crops	يانسون	Anise	20	0.842	717	604	12,070
	شعير	Barley	286	0.715	282	201	57,577
	فول (يابس)	Broad Bean	5.30	0.752	1,270	955	5,062
	بابونج	Chamomile	0.40	0.842	717	604	241
	هندباء	Cichorium	4.55	0.842	717	604	2,746
	برسيم	Clover	30	0.751	1,572	1,181	35,429
	ثوم يابس	Dry Garlic	0.70	0.916	963	882	617
	بصل يابس	Dry Onion	100	0.916	1,206	1,105	110,511
	فاصولياء (يابس)	Kidney Bean	5.00	0.752	1,253	942	4,712

نعناع	Mint	36	0.832	1,742	1,450	52,192
ميرمية	Meramieh	43	0.751	717	539	23,162
زعتر فارسي/حصا البان	Other Beverage Crops	163	0.832	717	597	96,983
محاصيل حقلية أخرى	Other Field Crops	400	0.751	1,742	1,309	523,402
عصفر	Safflower	1.50	0.832	717	597	895
بيقيا	Sern	7	0.840	717	602	4,216
ذرة بيضاء	Sorghum	1,180	0.720	282	203	239,133
زعتر	Thyme	31	0.751	717	539	16,752
قمح	Wheat	659	0.840	1,041	874	575,630
Total		**36,278**				**34,819,617**

Table III.4: ET details and results under 1.5°C increase

Type	Crop Name (Arabic)	Crop Name (English)	Area (Dunum)	K_c	ET_o (mm)	ET_c (mm)	ET (m^3)
Vegetables	جرجير	Arugula	23	0.832	725	604	13,896
	فول أخضر	Broad Bean (green)	1,096	0.736	1,289	949	1,040,139
	قرنبيط	Cauliflower	1,055	0.842	729	614	647,842
	لوبياء (خضراء)	Cowpea	14	0.795	868	690	9,666
	خيار	Cucumber	1,103	0.891	677	603	665,239
	باذنجان	Eggplant	3,880	0.751	1,593	1,197	4,643,245
	شومر	Fennen	28	0.751	847	636	17,551
	ثوم أخضر	Garlic (green)	0.55	0.751	847	636	350
	قرع	Gourd	78	0.904	1,376	1,243	96,954
	فلفل حار	Hot Pepper	743	0.795	847	673	500,572
	ورق لسان	Jew's Mallow	706	0.832	1,535	1,277	901,154
	فاصولياء خضراء	Kidney Bean (green)	1,117	0.715	922	659	735,843
	خس	Lettuce	46	0.832	729	607	27,952
	ذرة صفراء	Maize	3,830	0.720	874	629	2,407,872
	فطر	Mushroom	5	0.842	1,057	889	4,447
	شمام	Muskmelon	588	0.746	1,376	1,027	603,292
	بامية	Okra	314	0.973	1,272	1,238	388,237
	بصل أخضر	Onion (green)	115	0.832	725	604	69,680
	خضراوات أخرى	Other Vegetables	19	0.751	1,766	1,327	25,205
	فلفل حلو	Paprika	712	0.795	847	673	479,628
	بقدونس	Parsley	9.46	0.832	1,766	1,470	13,904

	بازيلاء (خضراء)	Peas (green)	10	0.795	1,289	1,025	10,251
	بطاطا عادية	Potato	34	0.832	847	704	24,048
	يقطين	Pumpkin	30	0.746	1,766	1,318	39,539
	فجل	Radish	0.42	0.751	1,535	1,153	484
	ملفوف أحمر	Red Cabbage	7	0.842	729	614	4,297
	فقوس	Snake cucumber	99	0.891	1,289	1,148	113,546
	سبانخ	Spinach	31	0.751	1,766	1,327	40,925
	كوسا	Squash	7,603	0.904	1,057	955	7,260,794
	بندورة	Tomato	2,376	0.832	874	727	1,727,083
	بطيخ	Water Melon	138	0.746	1,376	1,027	141,661
	ملفوف أبيض	White Cabbage	462	0.842	729	614	283,302
	حويرنة	White Wall-rocket	26	0.832	725	604	15,937
Trees	صبر	Aloe	1.20	0.935	1,766	1,650	1,981
	تفاح	Apple	0.24	0.751	1,766	1,327	318
	المشمش	Apricot	0.10	0.751	1,766	1,327	133
	برتقال بلدي	Balady Orange	5	0.678	1,766	1,198	6,468
	موز	Banana	1,111	0.872	1,416	1,235	1,371,745
	توت عادي	Berry	0.39	0.751	1,766	1,327	517
	بوملي	Bomaly	58	0.795	1,766	1,405	81,905
	باباي	Carica papaya	5.50	0.751	1,766	1,327	7,296
	كرز	Cherry	0.42	0.751	1,766	1,327	557
	كلمنتينا	Clement	15	0.795	1,766	1,405	21,031
	قشطة	Custard apple	2.57	0.715	1,766	1,262	3,244
	بلح	Date	4,794	0.935	1,766	1,650	7,912,188
	تين	Fig	10	0.751	1,766	1,327	12,907

	عنب	Grape	253	0.509	1,766	900	227,890
	جريبفروت	Grapefruit	3.86	0.678	1,766	1,198	4,624
	جوافة	Guava	6.35	0.872	1,766	1,540	9,782
	ليمون	Lemon	249	0.795	1,766	1,405	349,956
	أسكدنيا	Loquat	0.76	0.751	1,766	1,327	1,008
	مندلينا	Mandarin	7.07	0.795	1,766	1,405	9,933
	مانجا	Mango	0.06	0.751	1,766	1,327	80
	برتقال أبوصرة	Navel Orange	0.40	0.678	1,766	1,198	479
	زيتون	Olive	75	0.666	1,766	1,175	88,329
	برتقال	Valencia Orange	141	0.678	1,766	1,198	168,670
	حمضيات أخرى	Other Citrus	143	0.678	1,766	1,198	171,437
	أشجار بستنة أخرى	Other Trees	3.59	0.751	1,766	1,327	4,762
	كمثرى	Pears	0.02	0.751	1,766	1,327	27
	رمان	Pomegranate	119	0.621	1,766	1,097	131,014
	برتقال شموطي	Shammoty Orange	0.30	0.678	1,766	1,198	359
	جوز	Walnut	0.07	0.751	1,766	1,327	93
Field Crops	يانسون	Anise	20	0.842	725	610	12,209
	شعير	Barley	286	0.715	286	205	58,509
	فول (يابس)	Broad Bean	5.30	0.752	1,289	969	5,135
	بابونج	Chamomile	0.40	0.842	725	610	244
	هندباء	Cichorium	4.55	0.842	725	610	2,778
	برسيم	Clover	30	0.751	1,593	1,197	35,903
	ثوم يابس	Dry Garlic	0.70	0.916	978	896	627
	بصل يابس	Dry Onion	100	0.916	1,224	1,122	112,151
	فاصولياء (يابس)	Kidney Bean	5.00	0.752	1,268	953	4,767

نعناع	Mint	36	0.832	1,766	1,470	52,912
ميرمية	Meramieh	43	0.751	725	545	23,428
زعتر فارسي/حصا البان	Other Beverage Crops	163	0.832	725	604	98,095
محاصيل حقلية أخرى	Other Field Crops	400	0.751	1,766	1,327	530,625
عصفر	Safflower	1.50	0.832	725	604	905
بيقيا	Sern	7	0.840	725	609	4,265
ذرة بيضاء	Sorghum	1,180	0.720	286	206	243,004
زعتر	Thyme	31	0.751	725	545	16,944
قمح	Wheat	659	0.840	1,057	888	584,513
Total		**36,278**				**35,330,282**

Table III.5: ET details and results under 3.0°C increase

Type	Crop Name (Arabic)	Crop Name (English)	Area (Dunum)	K_c	ET_o (mm)	ET_c (mm)	ET (m^3)
Vegetables	جرجير	Arugula	23	0.832	751	625	14,386
	فول أخضر	Broad Bean (green)	1,096	0.736	1,333	981	1,075,888
	قرنبيط	Cauliflower	1,055	0.842	751	632	667,499
	لوبياء (خضراء)	Cowpea	14	0.795	893	710	9,943
	خيار	Cucumber	1,103	0.891	701	624	688,800
	باذنجان	Eggplant	3,880	0.751	1,644	1,235	4,790,448
	شومر	Fennen	28	0.751	877	659	18,185
	ثوم أخضر	Garlic (green)	0.55	0.751	877	659	362
	قرع	Gourd	78	0.904	1,423	1,286	100,286
	فلفل حار	Hot Pepper	743	0.795	877	698	518,648
	ورق لسان	Jew's Mallow	706	0.832	1,587	1,320	931,527
	فاصولياء خضراء	Kidney Bean (green)	1,117	0.715	948	678	757,227
	خس	Lettuce	46	0.832	751	625	28,800
	ذرة صفراء	Maize	3,830	0.720	905	651	2,494,376
	فطر	Mushroom	5	0.842	1,094	921	4,604
	شمام	Muskmelon	588	0.746	1,423	1,062	624,023
	بامية	Okra	314	0.973	1,313	1,277	400,526
	بصل أخضر	Onion (green)	115	0.832	751	625	72,139
	خضراوات أخرى	Other Vegetables	19	0.751	1,824	1,370	26,036
	فلفل حلو	Paprika	712	0.795	877	698	496,948
	بقدونس	Parsley	9.46	0.832	1,824	1,518	14,363

	بازيلاء (خضراء)	Peas (green)	10	0.795	1,333	1,060	10,603
	بطاطا عادية	Potato	34	0.832	877	730	24,917
	يقطين	Pumpkin	30	0.746	1,824	1,361	40,843
	فجل	Radish	0.42	0.751	1,587	1,192	501
	ملفوف أحمر	Red Cabbage	7	0.842	751	632	4,427
	فقوس	Snake cucumber	99	0.891	1,333	1,188	117,448
	سبانخ	Spinach	31	0.751	1,824	1,370	42,274
	كوسا	Squash	7,603	0.904	1,094	989	7,517,693
	بندورة	Tomato	2,376	0.832	905	753	1,789,129
	بطيخ	Water Melon	138	0.746	1,423	1,062	146,529
	ملفوف أبيض	White Cabbage	462	0.842	751	632	291,898
	حويرنة	White Wall-rocket	26	0.832	751	625	16,499
Trees	صبر	Aloe	1.20	0.935	1,824	1,705	2,046
	تفاح	Apple	0.24	0.751	1,824	1,370	329
	المشمش	Apricot	0.10	0.751	1,824	1,370	137
	برتقال بلدي	Balady Orange	5	0.678	1,824	1,237	6,682
	موز	Banana	1,111	0.872	1,461	1,275	1,416,183
	توت عادي	Berry	0.39	0.751	1,824	1,370	534
	بوملي	Bomaly	58	0.795	1,824	1,451	84,606
	باباي	Carica papaya	5.50	0.751	1,824	1,370	7,537
	كرز	Cherry	0.42	0.751	1,824	1,370	576
	كلمنتينا	Clement	15	0.795	1,824	1,451	21,725
	قشطة	Custard apple	2.57	0.715	1,824	1,304	3,351
	بلح	Date	4,794	0.935	1,824	1,705	8,173,111
	تين	Fig	10	0.751	1,824	1,370	13,333

	عنب	Grape	253	0.509	1,824	929	235,405
	جريبفروت	Grapefruit	3.86	0.678	1,824	1,237	4,776
	جوافة	Guava	6.35	0.872	1,824	1,591	10,104
	ليمون	Lemon	249	0.795	1,824	1,451	361,497
	أسكدنيا	Loquat	0.76	0.751	1,824	1,370	1,041
	مندلينا	Mandarin	7.07	0.795	1,824	1,451	10,260
	مانجا	Mango	0.06	0.751	1,824	1,370	82
	برتقال أبوصرة	Navel Orange	0.40	0.678	1,824	1,237	495
	زيتون	Olive	75	0.666	1,824	1,214	91,241
	برتقال	Valencia Orange	141	0.678	1,824	1,237	174,232
	حمضيات أخرى	Other Citrus	143	0.678	1,824	1,237	177,090
	أشجار بستنة أخرى	Other Trees	3.59	0.751	1,824	1,370	4,919
	كمثرى	Pears	0.02	0.751	1,824	1,370	27
	رمان	Pomegranate	119	0.621	1,824	1,134	135,334
	برتقال شموطي	Shammoty Orange	0.30	0.678	1,824	1,237	371
	جوز	Walnut	0.07	0.751	1,824	1,370	96
Field Crops	يانسون	Anise	20	0.842	751	632	12,640
	شعير	Barley	286	0.715	299	214	61,166
	فول (يابس)	Broad Bean	5.30	0.752	1,333	1,002	5,312
	بابونج	Chamomile	0.40	0.842	751	632	253
	هندباء	Cichorium	4.55	0.842	751	632	2,875
	برسيم	Clover	30	0.751	1,644	1,235	37,041
	ثوم يابس	Dry Garlic	0.70	0.916	1,011	926	648
	بصل يابس	Dry Onion	100	0.916	1,265	1,159	115,857
	فاصولياء (يابس)	Kidney Bean	5.00	0.752	1,311	985	4,927

نعناع	Mint	36	0.832	1,824	1,518	54,657
ميرمية	Meramieh	43	0.751	751	564	24,254
زعتر فارسي/حصا البان	Other Beverage Crops	163	0.832	751	625	101,555
محاصيل حقلية أخرى	Other Field Crops	400	0.751	1,824	1,370	548,124
عصفر	Safflower	1.50	0.832	751	625	937
بيقيا	Sern	7	0.840	751	631	4,415
ذرة بيضاء	Sorghum	1,180	0.720	299	215	254,039
زعتر	Thyme	31	0.751	751	564	17,542
قمح	Wheat	659	0.840	1,094	919	605,194
Total		**36,278**				**36,526,336**