AMERICAN UNIVERSITY OF BEIRUT

EXPLORING THE POTENTIAL OF TREATED WASTEWATER REUSE FOR IRRIGATION IN THE BEQAA UNDER CURRENT AND FUTURE CLIMATE SCENARIOS

by
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ABSTRACT
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Title: Exploring the Potential of Treated Wastewater Reuse for Irrigation in the Beqaa under Current and Future Climate Scenarios

The water resources in Lebanon are facing severe pressure due to the increase in the population, with the accompanying climatic changes that have exacerbated the water shortage problem. This study investigates the potential of treated wastewater reuse (TWWR) to supplement irrigation water needs to close the gap between supply and demand for crop production under climate change scenarios in the Beqaa Valley. A framework for the economic assessment of the (TWWR) for irrigation was provided as a solution for water shortages in the Beqaa. The Ablah region and its wastewater treatment plant (WWTP) in the Beqaa were identified as a case study because they have an operational and an irrigation network for local farmers that supplies TWW to their land. After calculating the water requirements of the Ablah crops under the business-as-usual conditions and under the two climate change scenarios, the results showed that continuing with the current scenario will lead to an increase in the water deficit in future years. As a solution, the study suggested an improved agricultural scenario (IAS) to reduce groundwater withdrawals and increase crop yields by increasing the proportion of TWW in the water balance and reallocating the land to different types of crops that are more suitable for the specific regional conditions. The results revealed that the (IAS) increased the TWW contribution to 28% instead of 12% in currunt scenario of irrigation water, compared to reducing the pressure the groundwater contribution to 72%. Also, IAS reduces the deficit in both climate scenarios, as SC.1 will remain positive after facing a deficit, while the deficit in SC.2 is reduced by 70%.
Additionally, an economic assessment of the costs associated with (TWWR) to replace groundwater, including energy costs and crop yield profits, was conducted. The cost estimate showed that replacing some groundwater with TWW for irrigation is less expensive than full irrigation with groundwater, at prices of \$0.18 and \$0.48, respectively. Using TWW gave the farmer economic feasibility for supplementary wheat and grapes irrigation. In comparison, supplementary irrigation of wheat with groundwater was not economically feasible, and the study recommended that wheat remain rainfed. Therefore, the price of TWW can be considered the most important factor that affects users' willingness to use TWW.
Most significant TWWR is an opportunity that must be exploited and developed to meet the demand for water and address the water shortage in Beqaa.
The framework of this study can be an important tool in facilitating the use of TWW and helping decision-makers and farmers manage and plan further.

TABLE OF CONTENTS

ILLUSTRATIONS

Figure

TABLES

Table

ABBREVIATIONS

AREC: Advancing Research, Enabling Communities Center, AUB's research and education center
°C: Degrees Celsius
CDR: Council for Development and Reconstruction
ESCWA: Economic and Social Commission for Western Asia
ETc Crop Evapotranspiration
ETo: Crop evapotranspiration
FAO: Food and Agriculture Organization of the United Nations
ha: hectare (10,000 square meters)
IAS: Improved Agriculture Scenario
IPCC: Intergovernmental Panel on Climate Change
IWMI: International Water Management Institute
GW: Ground water
Kc: Crop coefficient
m: meter
mm: millimeters
m^2: square meter
m^3: cubic meter
MENA: Middle East and North Africa
NGO: Non-governmental organization
NWSSU: National Water Sector Strategy Update
RICCAR: Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
Sc1: Climate change scenario 1
Sc2: Climate change scenario 2
TWW: Treated wastewater
UNFCC: United Nations Climate Change
%: percent
WEF: Water, Energy, and Food
WWTP: Wastewater Treatments Plants

CHAPTER 1

INTRODUCTION

Water resources in Lebanon are an issue of paramount importance. Lebanon is facing a shortage of water availability and frequent droughts (Shaban, 2020). The rapid growth of the population has contributed to the increase in water demand, the deterioration of water quality, and the increase in pollution due to unregulated use and discharge and unregulated consumption. The increasing water demand has caused an environmental problem that has affected surface and ground water resources throughout the country despite the diversity of surface water sources (rivers, springs, snow, lakes) and groundwater in Lebanon, which has led to a noticeable shortage of water. This imbalance between supply and demand created a national problem that remained unsolved for a long time (Shaaban 2019).

During the past four decades, estimates have shown a decrease in surface water resources ranging between 55% and 60%, accompanied by a drop in the groundwater table by tens of meters (Shaaban 2011). This decline has affected the sectors that use water, the most important of which are agriculture, energy, and food. The pressures on water resources in Lebanon dictates the need for improvement in water regulation as well as new investments in water supply and management to close the demand gap and the deficit in the water balance. Agriculture is the largest consumer of water in Lebanon where common estimates of water use for irrigation range from 62% up to 85% (Shaban A, Hamzé M 2017). Shaban (2020) reported that agriculture consumes 72% of water resources, although this percentage fluctuates yearly depending on the rainfall rate. Because of these restrictions and high demands, using TWW for irrigation, which has been shown to be a great opportunity for reducing pressure on freshwater sources and water extraction from surface and groundwater for irrigation (Hoekstra, 2015), should be considered as an alternative water source to support agriculture in the Beqaa.

Until now, Lebanon has a limited capacity to treat wastewater, with 98 wastewater treatment plants (WWTP) 41 of which are currently operational, 20 partially operation, and (36) not operational (Eid-Sabbagh et.al, 2022). More water scarcity is expected with the projections of climate change that are likely to result in a decrease or change in precipitation patterns, and an increase in temperature and evaporation. These climate-induced changes are expected to negatively affect food production and cause a reduction in crop yields; to maintain yields, more irrigation is going to be needed which will add an even heavier burden on water resources (Verner et al., 2013).

A large percentage (43%) of agriculture is focused on the Beqaa Valley (FAOstat, 2019), which is located in a semi-arid region with relatively low precipitation (400-450 mm), making it vulnerable to the effects of climate change. The frequency of droughts in the Beqaa make rainfed crops sensitive to climate change in most of the regions of the valley. The same is true for irrigated crops in the Beqaa, where their production is strongly linked to water availability (Verner et al., 2013). Consequently, an efficiently managed TWW system will contribute to achieving sustainable agriculture that is resilient and adaptive to climate change.

Some previous studies looked at irrigation water requirements and how to manage them in light of climate change. Most of the studies that evaluated the reuse of TWW in agriculture focused on the qualitative and social aspects of reuse such as the perspectives of farmers and acceptability of the use of this water. The importance of economic considerations when evaluating TWW reuse projects lies in the fact that it gives a guiding framework for integrated management and governance of wastewater resources. This guiding framework reconciles various objectives such as economic development, environmental protection, poverty alleviation, and food security enhancement. Considering the economic crises that has afflicted Lebanon since 2019, which led to an increase of more than 300 percent in food prices until the end of 2021 (CAS, 2021), there is an urgent need to invest and increase local production of high-nutrition and low-resource crops in drylands. Indeed, this is a critical issue because it directly affects all four pillars of food security namely, access, availability, use, and stability (Zurayk, 2020). Therefore, these strategies and policies must be coordinated with water, energy, and economic assessment to raise water use efficiency as well as food production.

In Lebanon, some farmers irrigate with TWW without any regulatory direction or strategies for using this water. In fact, some farmers tap into untreated wastewater to irrigate crops. Furthermore, end users of TWW need to know whether the economic costs, returns, and benefits associated with using this alternative water are more feasible than the cost of pumping groundwater for irrigation. I have toured a few wastewater treatment plants in the Beqaa Valley and witnessed firsthand some of the problems faced by farmers and managers of WWTP. Based on these observations, I was interested in assessing the impact of climate change on irrigation requirements and the role that TWW could play in bridging the gap between demand and availability of water for irrigation. Accordingly, in this study I developed a framework to assess the economic and social potential of using TWW as an alternative source to cover irrigation requirements. Then, this framework was applied in a case study in the town of Ablah in

Beqaa, where a WWTP is operating, using a secondary level treatment system, and there is an agricultural community using the TWW though a connected irrigation network. Currently, there is a part of this network on the public road that is not used, while the other part inside the real estate is used by farmers. As climate change is a challenge we face, we need to manage our water resources efficiently, know the volumes of water supply and the capacity of treated water as a complementary irrigation solution, and analyze the cost of using TWW water and compare it to the cost of pumping groundwater. The results of my study can be incorporated into the Water, Energy, and Food (WEF) studies. Also, this study can be considered as a model that can be applied to similar regional WWTPs in the Beqaa after site-specific data collection as relevant to each case study.

1.1. Objectives

The overall objective of this study is to assess the potential of TWW as a supplemental means for irrigation and sustainable food production under climate change scenarios in the Beqaa.

Based on my general goal, my study has three specific objectives:

- Identify and quantify the treated wastewater capacity, with respect to the quantity and the distribution to supplement irrigation water in Ablah, the Beqaa valley.
- Allocate and assess the potential of treated wastewater to augment the water shortage for irrigation under various climate change scenarios.
- Evaluate the economic feasibility of using treated wastewater for irrigation as one of the solutions in Ablah.

CHAPTER 2

LITERATURE REVIEW

2.1. The Importance of Reusing Treated Wastewater in Irrigation

2.1.1 Essential Need to Face Water Scarcity

Water is one of the essential natural resources for all life on this planet. Unfortunately, it has become increasingly inaccessible due to the increase in water demand, especially in arid and semi-arid regions, which consequently affects water quality. This has resulted in a rapidly growing water scarcity problem facing our world today (Kummu et al., 2016).

Determining the demand for water is difficult in Lebanon due to the lack of credible procedures and measures, and when available, there is usually contradiction between the procedures (Shaaban 2020). The greater part of the Lebanese territory suffers from water shortages, intermittent water supply, and water pollution. It is necessary to search for alternative water sources to fill the demand gaps and deficits in the regions where these options are available and feasible. In many cases, Lebanese farmers use untreated wastewater (or contaminated water) for irrigation. Therefore, reusing treated wastewater by farmers would be a good consideration to incorporate in their irrigation practices. Use of raw sewage or untreated wastewater is a detrimental practice for the environment, public health, and soil. Therefore, ensuring good levels of water quality is a main factor when considering TWW for reuse and the level of wastewater treatment determines its intended use. Based on the technical treatment level of wastewater the FAO has classified TWW irrigable crops into three categories that that specify which crops can be irrigated with primary, secondary, or tertiary treated wastewater; therefore, water quality must be monitored according to these standards and regulations (Cellamare et al., 2016). One of the most important reasons to practice irrigation with TWW is to reduce the withdrawal of freshwater, whether surface or groundwater (Hoekstra, 2015). For example, in China, estimates indicate that about 80% of all used extracted water is discharged as wastewater at the regional level and that 70% of the discharge can be recovered (Yi et al., 2011). Reusing TWW for irrigation is a great opportunity to reduce the quantities of water extracted for irrigation and reduce stress on freshwater sources.

Treated wastewater has played an essential role in supporting arid and semi-arid areas that suffer from water scarcity by being a major agricultural water source, (Corcoran et al., 2010). Thus, reducing the demand for freshwater through treated wastewater reuse for crop irrigation can ensure the sustainability of agriculture and water (Pedrero et al., 2010). For example, in the city of Ait Melloul in Morocco, the reuse of TWW for irrigation saved 4 Mm^3 of water annually that would have been otherwise extracted from freshwater sources to irrigate a forest area of 400 hectares (Benzene, 2012). A field study in Saudi Arabia showed a saving of 60% of groundwater when using TWW for irrigation (Balkhair et al., 2013). Also, in many arid and semi-arid countries such as China, the Palestinian occupied land, and Australia, treated wastewater is used as a basic source of irrigation water. (Angelakis and Snyder, 2015).

As for irrigation water demand, the National Water Sector Strategy Update NWSSU (2020) in Lebanon estimates the total demand is 879 Mm^3/year, most of which (595 Mm^3/year) is required to irrigate crops in the Beqaa Valley. As for the available irrigation water supply, it amounts to about 660 Mm^3/year (divided equally between ground and surface water) are currently being used in agriculture according to this estimate, and therefore there is a clear gap amount 25% between the current irrigation water demand and supply (Eid-Sabbagh, et.al., 2022).

2.1.2 Confronting Rapid Population Growth as well as Increasing Demand for Food.

The Earth's population reached seven billion in 2011 and growth projections indicate a rapid growth that will reach nine billion in 2030 World Bank (2017). The projections also indicate that most of the population growth will occur in developing countries, while the population of developed countries will remain constant at around one billion. (Jhansi, & Mishra, 2013).

In Lebanon, the population reached 3.7 million in 2003, with an average increase in population size of 1.2% to reach 4.3 million in 2013, according to the World Bank (2017). After the movement of Syrian refugees to Lebanon since the beginning of 2011 due to the war and political conflicts in Syria, which is estimated to be between 1.5 to 2.5 million refugees, the total population in Lebanon became 6.3 million in 2017. This population increase is directly reflected in the increased demand for water and food. The total water demand was about 829 Mm^3 in 2003 in Lebanon., which increased to 930 Mm^3 in 2013 when the population increased to 4.3 million (Shaaban, 2020). Water demand increased to 1390 Mm^3 after the influx of refugees, meaning that about 460 Mm^3 were added to the water demand (Shaaban, 2016). However, Lebanon does not yet have accurate population estimates therefore, it is difficult to accurately determine the volume of domestic water demand or wastewater production. While the most recent study in Lebanon published by the Central Administration of Statistics in 2019 estimated the population at 4.8 million, World Bank data estimated the number at 6.9 million, and the World Health Organization estimated the number at 6 million in

2016. It is worth noting that the greater the population and water demand, the greater the quantities of sewage produced, which requires the treatment of this wastewater that should ideally be reused where acceptable in order to achieve a balance between the increase in population and the demand for water and food.

2.1.3 Nutrient Recovery from Reclaimed Water as Fertilizer for Crops (Increase in Farm Expenditure and Income)

Reusing treated wastewater for irrigation not only has benefits as an alternative to freshwater but has also been shown to have positive effects on plant growth (Vergine et al., 2017a; Urbano et al., 2017). Significant improvement to crop yield and accelerated plant growth has been observed due to the provision of nutrients for plant uptake through the TWW (Aziz and Farisi, 2014). The growth of plants irrigated with TWW was reported to increase by 25.6%, 86.7%, and 63.0% in plant height, leaf area index, and biomass yield, respectively, compared to that irrigated with conventional irrigation water (Zema et al., 2012). In an experiment on the cultivation of two cycles of lettuce a significant difference in weight was reported between lettuce irrigated with fresh water and lettuce irrigated with TWW; lettuce irrigated with TWW had 48% and 100% greater weight than that irrigated with fresh water in the first and second cycles, respectively (Urbano et al., 2017).

As for economic benefits of using TWW for irrigation, there are many examples from different regions showing an increase in the income of farms using this practice due to savings in energy (pumping) and nutrients. For example, in the region of Tiznit (Morocco), TWW had a significant impact on improving the income and standard of living of farmers. Farmers have achieved an increase in crop productivity due to the fertilization effect of TWW in addition to savings in chemical fertilizers (Malki et al., 2017). The macronutrients (N, P, K) and micronutrients that are supplied to crops by TWW help farmers reduce fertilizer use and make savings in their cost of production. For example, irrigation with TWW was shown to reduce the use of chemical fertilizers by 45% and 94% in the cultivation of wheat and alfalfa, respectively (Balkhair et al., 2013). By evaluating and estimating the potential savings from TWW irrigation for tomato cultivation, Virgine et al. (2017a) found a potential savings of €280/ha. The benefits of TWW irrigation are not limited to direct income to farmers (sales from increased yields and fertilizer savings) but also provide non-market benefits to society, namely the preservation of freshwater resources (Ofori et al., 2021). Despite the benefits of nutrients present in TWW, the amount of these nutrients is highly variable and depends on the source and type of wastewater and the type of treatment (secondary or tertiary). Therefore, generalizations cannot be made, and care must be taken when estimating the benefits of using nutrients by considering the type of crops.

2.1.4 Environmental benefits: Reducing Pollution and Enhancing Water Quality

There is no doubt that the reuse of TWW for irrigation has many environmental benefits, the most important of which is maintaining and enhancing the quality of freshwater resources which is achieved through reducing water pollution by avoiding the discharge of effluents into water bodies (Becerra-Castro et al., 2015), and through allowing recycling of nutrients in the environment and reducing the risks of pollution resulting from the excessive use of mineral fertilizers in some places (Ungureanu et al., 2018), thus acting as a buffer against water pollution (Ofori et. al., 2021). Regardless, wastewater should be treated anyway, whether reused for irrigation or not.

Globally, about 5,500 BCM of water is polluted annually due to the discharge of untreated sewage (Zhang and Shen, 2019). Elevated levels of nitrates, micronutrients, phosphates, and heavy metals have been reported in water receiving sewage discharges, which negatively affects water quality, the ecosystem, and agricultural activities downstream of wastewater discharge. In addition to the environmental damage associated with the discharge of wastewater directly into rivers, there are other problems such as eutrophication, which is the depletion of oxygen from freshwater as a result of heavy nutrient load discharges, leading to the death of fish and other aquatic life forms (Ji, 2017).

In Lebanon, the Litani River is the largest water body and is used to support urban areas and develop the agricultural and industrial sectors in its vicinity. However, the river is heavily polluted from untreated sewage which is diverted directly into the river, industrial effluents, and agricultural runoff (Amacha et al., 2017). Despite the role of rivers in agriculture, and socioeconomic development in Lebanon, they are exposed to pollution, poor sewage management, and insufficient infrastructure (Daou, 2018). The use of contaminated water leads to many diseases, exacerbates infectious diseases, and increases food-borne diseases, especially among vulnerable and disadvantaged population groups (WHO, 2021). Therefore, additional to the importance of water quality monitoring and the prevention of surface and groundwater pollution, implementing wastewater treatment and reusing the TWW in irrigation and elsewhere can provide a sustainable approach to reducing river pollution.

2.1.5 The Impact of TWW Irrigation on Soil Quality

With the development of TWW irrigation projects it is important to ensure that there are no detrimental effects on soil quality. The effect of using TWW on soil was the focus of many research studies that have evaluated the effect of irrigation using TWW on soil productivity.

Perhaps the most negative effect associated with TWW is soil salinization. A study conducted in Jordan (Alkhaza'leh et al., 2023) showed that irrigation with TWW over long-term periods increases soil salinization compared to irrigation with groundwater. As for the effect of TWW on the physical-chemical properties and the potential accumulation of heavy metals in soil, several studies (Mohtar and Daher, 2019; Perulli et al., 2021) reported on the benefits of using treated wastewater on increasing soil fertility. Such studies show that there is a role of TWW in improving crop growth and yield, increasing soil fertility, and reducing fertilizer use. However, this depends on factors such as the treatment process and the quality of TWW (Baanu and Babu, 2023) which makes leaves uncertainties about the positive or negative effects of using TWW on the soil. Some studies (Serrano et al., 2014; Bedbabis et al., 2014) showed a negative effect of TWW on the soil due to microbial contamination and its transmission to crops through leaves, stems, or cracks, accumulation of heavy metals, increased soil salinization, and the resulting decrease in soil productivity. Several treatment methods have been developed (primary, secondary, tertiary treatment), and many chemical processes and reactions or microbial procedures are used to treat wastewater (Halakarni et al., 2021). Thus, the negative and positive effects of TWW irrigation on the soil vary depending on the source and quality of water, so these practices require more continuous local analysis and conclusions (Mohtar and Daher, 2019).

2.2 Climate Scenarios

2.2. 1 Climate Change Scenarios Developed for Lebanon

Water resources are among the most affected by climate variability. Therefore, the impact of climate change is one of the most important factors that contribute to determining the future water balance and food security in Lebanon. The Framework Convention on Climate Change (Ministry of Environment, 2011) presented the climate change scenarios developed for Lebanon through the application of the PRECIS model (Machayekhi et al., 2017). Based on the current climate and according to the model, this framework predicts the following scenarios for Lebanon:

- Increases in Tmax are projected to be between 1°C on the coast of Lebanon and 2°C inland by 2040, and between 3°C on the coast and 5°C inland by 2090
- Precipitation is expected to decrease by 10 to 20% by 2040 and may reach 25-45% by 2090 compared to 2017.

Based on these scenarios, this will increase the events of drought across the country that can be expected to increase by 9 days by 2040 and by 18 days by 2090. Because of the reduced amount of rain and the expected changes in the spatial and temporal distribution of rainfall, water resources will be greatly affected, along with an increase in evaporation and the occurrence of long droughts that may extend for an entire month. Already dry areas such as the Beqaa, Hermel, and the south Beqaa will be the most affected (Machayekhi et al., 2017). Drought significantly impacts agriculture in the Beqaa Valley, where two-thirds of the available water resources are used for irrigation (Yates 2014). Despite being relatively high, rainfall occurs between December and March, whereas the peak demand for water is from mid to late summer.

Strategic Environmental Assessment (SEA) of the National Water Sector Strategy (NWSS) 2010-2020 (ECODIT, 2015) predicts that a 6-8% decrease in the total volume of water resources is expected for a 1°C increase and 12-16% for a 2°C increase. It is estimated that a 2°C increase will reduce snow cover by 40%, which will lead to a significant change in snow patterns in Lebanon (MoE, 2011 and 2016). Under a more severe scenario, a 4°C increase would reduce snow cover by up to 70 percent (MoE 2011). Lebanon's specific contributions to addressing climate change highlight the need to adapt to water shortages and climate change. These predictions of climatic changes and the reduced precipitation require the pursuit of increasing and supporting water resources and rationalizing their better use (Government of Lebanon, 2015).

2.2.2 The Effects of Climate Change on Crop Water Requirements in The Beqaa

A few studies were conducted to assess crop yields under climate change scenarios in the Beqaa Valley, Lebanon. Recently observed increases in temperature in the Beqaa Valley damaged the peach, apple, cherry, and grape crops which was translated into a yield reduction from their current yields (Verner et al., 2013). Similarly, it was reported that wheat and barley, which are crops that cannot tolerate variations in temperatures (i.e. high temperatures), have experienced crop failures (Ober & Rajabi, 2010). The same applies for irrigated tomato and potato crops in the Beqaa where their production is highly related to water availability (Verner et al., 2013). Consequently, these study results confirm that the yields of the major crops grown in the Beqaa Valley will be decreased by climate change impacts.

Though Lebanon is going to be less affected in the temperature increase trends than other Arab countries (Eid-Sabbagh, et.al., 2022), it still falls within the scope of climate change and will be affected by an increase in evapotranspiration, which will be reflected in the quantity of water, water quality, productivity, and living standards (Farajalla, 2009). The agricultural sector is challenged to maintain current food production or produce more food using less water; this can be achieved by increasing crop water productivity CWP (Zwart & Bastiaanssen, 2004), which contributes to maintaining food and water security.

2.3 Crops which can be Irrigated with Treated Wastewater

2.3.1 Fruit Trees

Many studies have been conducted to evaluate the risks and benefits of TWW irrigation for different types of crops. In Italy, a study was conducted on using secondary TWW with drip irrigation in apples and nectarines monitoring the potential transport of chemical contaminants (i.e., heavy metals) and microbial contaminants (e.g., Escherichia coli) to reproductive plant tissues in both field and controlled conditions (Perulli et al., 2021). Apple and nectarine trees were selected as models for two different fruit growth behaviors. Five trees for each species were applied with either secondary treated wastewater or tap water. The study results indicate that TWW can be safely reused for irrigation without toxic effects on apples. In another study on olive trees irrigated in drip system with treated urban wastewater, Escherichia coli was not found in the vegetative and reproductive tissues of plants (Sofo et al., 2019). Although experimental findings generally showed that reclaimed water can be safely used for the environmental point of view, long-term studies need to be conducted to assess potential contamination of the fruits, and case-by-case assessments of the characteristics of soil and wastewater quality (Perulli et al., 2021).

2.3.2 Vegetables (Tomatoes, Broccoli)

A study was conducted in the Puglia region of southern Italy in an open field for one and a half years (Libutti et al., 2018) using treated water from an agricultural production operation where the crop rotation included tomato and broccoli. The results indicated that these crops were not negatively affected by secondary, or tertiary (ultrafiltration and ultraviolet rays) treated wastewater. Moreover, the tomato and broccoli crops, as well as the most important qualitative parameters of tomato fruits (soluble solid content, dry matter content, titratable acidity, pH) and broccoli heads (dry matter content, diameter), were not affected by irrigation with TWW. The study also reported that there was no difference in the microbiological quality of the tomato and broccoli edible portions between those irrigated with traditional water sources (groundwater) and TWW. The method of drip irrigation, and the death of fecal indicators in the soil, reduced direct contact between water and plant, and has reduced the potential contamination of crop products; the use of drip irrigation systems can therefore be recommended for use with wastewater (Libutti, et al., 2018).

In Lebanon in the Beqaa a study was carried out on vegetables (radishes, parsley, onions, and lettuce) over two seasons using irrigation water sources of TWW, groundwater, and river water and three irrigation methods (drip, sprinkler, and surface) (Abi Saab et al., 2022). Crop, soil, and water samples were analyzed for chemical and physical parameters, nutrients, and pathogens. The results of this study showed that no pathogens (Escherichia coli, Salmonella, parasite eggs) were detected in vegetables irrigated with water containing less than 2 log E. coli CFU/100 ml, irrespective of the irrigation method. The study also showed contamination with parasites: 8.33% of vegetables that were irrigated by sprinkler-and surface-irrigated, and 2.78% of root crops (radishes and onions) that were irrigated by a drip system. Thus, there was no negative effect on the quality of vegetables irrigated by TWW compared to vegetables irrigated with other water sources. Such studies in the Beqaa would support the use of the TWW and the development of efforts to update the standards that were proposed by the FAO for Lebanon.

2.3.3 Grapes with Treated Wastewater (Beqaa, Ablah)

Grapes which are grown in abundance in the village of Ablah in the Beqaa, in Lebanon were irrigated with secondary TWW produced by the Ablah wastewater treatment plant (Abi Saab et al., 2021) (the traditional treatment process through distillation filters + chlorination). In this study, the response of the grape crop during the 2017 growing season under drip irrigation was evaluated under three water systems (treated wastewater (TW), freshwater (FW), and alternating FW and TW (FW-TW). Bacterial analysis showed that grapes are safe for human consumption. The results also indicated that best agricultural practices, such as adopting drip irrigation, would ensure human health and safe agriculture concerning the risks of pathogens when using treated wastewater. The study results showed that grapes irrigated with TW and those irrigated alternately with FW and TW had higher yields by 19.57 and 14.95%, respectively, than plants irrigated with FW from local groundwater. These results are in agreement with those of Petousi et al. (2019) and Mendoza-Espinosa et al. (2008), who reported a 20% increase in grape yield per plant in fields irrigated with wastewater. The quality of the final product was not modified using TWW because the biochemical properties of grapes were equally good to grapes irrigated with fresh water. Petousi et al. (2019)

indicated that the use of TWW had no effect on the concentration of minerals in grape juice.

2.3.4 Common irrigated crops grown in the Beqaa

According to the comprehensive agricultural statistics of the Ministry of Agriculture (MOA, 2010), the cultivated areas used in Lebanon amounted to 2.3 million dunums (230,000 hectares) in 2010, 1.13 million of which were irrigated agricultural areas representing 49% of the total cultivated areas. The irrigated areas increase annually, as Figure 1 shows that the irrigated areas now represent more than half of the total cultivated areas in 2019. It should be noted that 65% of all the irrigated lands are fully irrigated, while 35% are partially irrigated (supplementary irrigation). The governorates of Baalbek-Hermel and Beqaa account for 28% and 27%, respectively, of the total exploited irrigated areas. The area of agricultural land in the Beqaa was 416,489 dunums, of which 298,663 dunums were irrigated lands according to the Comprehensive Agricultural Census 2010 i.e., approximately 72% of agricultural lands are irrigated lands, whether full irrigation or supplementary irrigation (MOA, 2010).

2.3.4.1 Seasonal crops

Cereals**:** The areas planted with cereals in Lebanon amounted to 449,242 dunums in 2010, representing 20% of the agricultural land (MOA, 2010). Wheat is at the forefront of the areas planted with grains and occupies about two-thirds of the land cultivated with grains and covers an area of 298,403 dunums in 2010 (comprehensive agricultural census 2010). While the areas occupied by wheat increased in 2019 to 317,070 dunums (FAOSTAT). The Beqaa Governorate ranks first in terms of the areas planted with wheat, amounting to 44%, or 123,476 dunums, of which 106,451 is irrigated wheat, representing 80 to 85% of the total wheat grown in the Beqaa.

Vegetables: It includes three large groups, leafy vegetables, fruit-bearing vegetables, and bulbs and tubers, all of which are irrigated. Leafy vegetables include lettuce, salad greens, cabbage, cauliflower, spinach, asparagus, mallow, parsley. These occupy 28,743 dunums of the agricultural area in Beqaa. Fruit-bearing vegetables include tomatoes, eggplant, cucumbers, peppers, zucchini, pumpkins, cantaloupe, and watermelons; these occupy an area of 21,861 dunums in the Beqaa Governorate, and all their cultivation is irrigated. Potatoes are grown, especially in the Beqaa and Akkar, where their cultivation occupies approximately 55,479 dunums in the Beqaa.

Legumes: include beans, kidney beans, fava beans, lentils, chickpeas, and peas, which occupy a total area of about 19,240 dunums, more than half of which are irrigated, or approximately 11,123 dunums.

2.3.4.2 Perennial crops

Apples: The Beqaa and Baalbek-Hermel occupy approximately 34% of the apple trees planted in Lebanon. The size of the irrigated and non-irrigated areas is about 14,551 dunums in the Beqaa (FAOSTAT), most of which are irrigated and occupy areas of approximately 13,169 dunums.

Grapes: The Beqaa Governorate accounts for 46% of the area planted with grapes in Lebanon, which amounts to 39,450 dunums, and the irrigated area is nearly half of that at 17,648 dunums.

Olives: 13% of the total cultivated areas in Lebanon are spread in the Beqaa and Baalbek-Hermel, which occupy about 26,285 dunums, the irrigated areas of which about 5,987 dunums

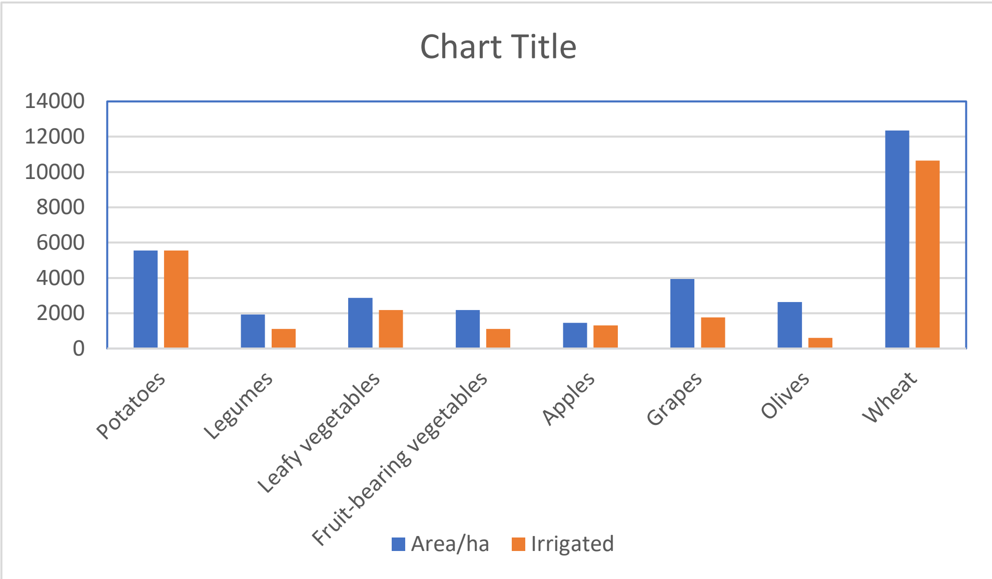

Figure 1 Common crops in the Beqaa total area, irrigated area (Source: FAOSTAT,2019).

2.4 Overview of Water in Lebanon

2.4.1. The Reality of Wastewater Treatment Plants in Lebanon

Based on the review and numbers reported in the previous sections, it can be said that carrying out the treatment of domestic sewage would be essential for augmenting irrigation with TWW and filling the existing deficit between supply and demand. Accordingly, serious support must be given to the issue of wastewater treatment and reuse in Lebanon. Only two-thirds of the population is connected to a sewage network. There is no pre-treatment of industrial wastewater, which is often discharged with urban wastewater into the sea, rivers, or land, or is unsafely used by farmers (FAO 2016).The wastewater master plan issued by the Ministry of Energy and

Water in 1994 and contained in the national strategy for the wastewater sector in 2012 stated that wastewater treatment plants are still insufficient. At the time of the 2012 report, of the 54 water treatment plants, only seven have been completed along the coast (out of 12 planned), and only two are operational (Ghadeer and Saida), while five (Tripoli, Chekka, Batroun, Jbeil, and Nabi Younes) lack a sewage network. Another is under construction (Tyre), three are under preparation (Al-Abda, Kesrouan, and Burj Hammoud), and one has not yet been funded (Sarfand) (FAO 2016). Two stations, Nabatiyeh, and West Beqaa, were completed, but they are not operational due to the absence of a sewage network. Although these two stations are somewhat close to the agricultural areas, they need an administrative decision and financial support to establish a sewage network. There are five stations that were recently established: Kafr Sir, Hummar, Zouter, Tibnin, and Zahle, and 14 stations are under design. The remaining 19 stations have not yet received funding. The report FAO (2016) listed 60 small wastewater processing plants, which were implemented in small municipalities, but their operational status remains unclear due to being managed by different local authorities. The wastewater treatment sector suffers from great overlap and lack of clarity in the distribution of responsibilities, in addition to the lack of coordination between officials managing the water sector. The Lebanese Council for Development and Reconstruction (CDR) is the only institution that can negotiate and implement projects financed through external loans. Still, it lacks staff, follow-up on projects, and coordination with municipalities. Municipalities still play a major role in the implementation, operation, and maintenance of water, sewage, and irrigation systems, but they do not have the sufficient technical capacity to decide on the design (Eid-Sabbagh et al., 2022). From the point of view of the Ministry of Energy and Water, municipalities and stakeholders play the role of opponents and a source of problems and may create obstacles when assessing environmental or social impact, so they are often excluded during planning and design (Eid-Sabbagh et al., 2022). Wastewater management still suffers from its historical exclusion from planning and implementation in both the Council for Development and Reconstruction and the Ministry of Electricity and Water; there appears to be a reluctance to involve municipalities substantially (Nassif, 2019).

2.4.2. Total Estimated Municipal Wastewater Production

The estimated total municipal wastewater production at the national level is 80% of domestic water consumption as well as commercial and industrial wastewater (Eid-Sabbagh et al., 2022). According to the National Water Sector Strategy Update (NWSSU) presented by the Ministry of Energy and Water in 2020, the total amounts of municipal wastewater produced are highly uncertain. Due to the lack of sustainable data over time, it is impossible to estimate the water volumes diverted for irrigation purposes. Furthermore, the current water volume assessment varies widely by region. According to NWSSU, water demand is calculated as 200 l/cap/day. Based on 200 liters/cap/day, they estimate sewage flow per capita at 80% of total needs (excluding physical losses) which is equal to 120 liters/capita/day. Since there is no confirmed population data, they considered the current population to be between 5 and 6 million. If these numbers reflect on the Beqaa, the situation may be more difficult due to the increased demand for water for agriculture and urban expansion. The Lebanese constitute 55% of the population in Beqaa and the rest of the population are refugees, which will increase the demand for water even more (UN, 2015b). Accordingly, the total volume of wastewater produced in Lebanon is estimated to be between 273.75 and 328.5 Mm^3 per year (NWSSU, 2020)

In 2012, the NWSS estimated that 310 $Mm^3$of wastewater were generated annually, of which 250 Mm^3were from domestic sources and 60 $Mm^3$from industrial sources, which is slightly higher than the above estimates given population estimates of about 4.4 million at that time.

Table 1 gives data on the wastewater treatment plants in the Beqaa. There are 14 plants, as shown in Figure 2 half of them are fully operational, while 5 of them are partially operational, and 2 of them have been established and not yet operational (Eid-Sabbagh et al., 2022). The actual average annual processing volume for the Beqaa wastewater treatment plants is 31,218,450 m^3, while the current design capacity in 2020 is 45,625,000 m^3 per year.

Table 1 Database of Existing WWTPs in Beqaa

Database of Existing WWTPs in Beqaa WWTP	operational status	Current Design capacity (m^3/day) (2019/2020)	Actual Average volume treated (m3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
Ablah	operational	2000	1300	Trickling Filters	Secondary	Secondary	Municipality	Domestic	
Aitanit / Machghara	operational	5000	1200	Sedimentation tanks Anaerobic digestion Sludge drying beds Trickling Filters Chlorination	Secondary	Secondary	Union of Municipalities of Lake Qaraoun	Domestic	Aitanit / Machghara
Deir El-Ahmar	partially operational	525	180	Extended Aeration	Secondary	Primary	Municipality	Domestic	Deir El-Ahmar
Fourzol	operational	0	1000	Trickling Filters Primary & final clarifiers Chlorination	Secondary	Municipality	Domestic	Fourzol	operational
Hasbaya	partially operational	0	Unknown	Municipality	Domestic	Conflicting operational status	Hasbaya	partially operational	0

Iaat	partially operational	24000	5000	Activated Sludge Chlorination Oxidation ditches	Tertiary	Secondary	BWE	Mixed	Iaat
Joubb Jannine	operational	10000	6000	Anaerobic Oxidation Disinfection Extended Aeration Activated Sludge	Tertiary	BWE	Mixed	Joubb Jannine	operational
Majdel Anjar / El Marj	under construction	45000	0	Activated Sludge Biological nitrogen removal Biological and chemical phosphorus removal	Tertiary	CDR	Mixed	Majdel Anjar / El Marj	under construction
Rachaiya	operational	600	0	Trickling Filters Aerobic treatment Extended aeration	Secondary	Municipality	Domestic	Rachaiya	operational
Saghbine	operational	560	100	Activated Sludge Extended aeration with anoxic zone	Secondary	Secondary	CDR	Domestic	Saghbine

Yammouneh	built not operational	800	50	Extended Aeration Activated Sludge	Secondary	BEW	Domestic	Yammouneh	built not operational
Yanta 1 (Northern)	partially operational	200	50	Activated Sludge Extended Aeration Trickling Filter	Secondary	Municipality	Domestic	Yanta 1 (Northern)	partially operational
Yanta 2 (Southern)	partially operational	300	50	Activated Sludge Extended Aeration Trickling Filter	Secondary	Municipality	Domestic	Yanta 2 (Southern)	partially operational
Zahleh	operational	35000	25000	Activated Sludge Trickling filters biological nitrogen removal UV Disinfection	Tertiary	Tertiary	CDR	Mixed	Zahleh

Source: *Eid-Sabbagh et al.*, 2022

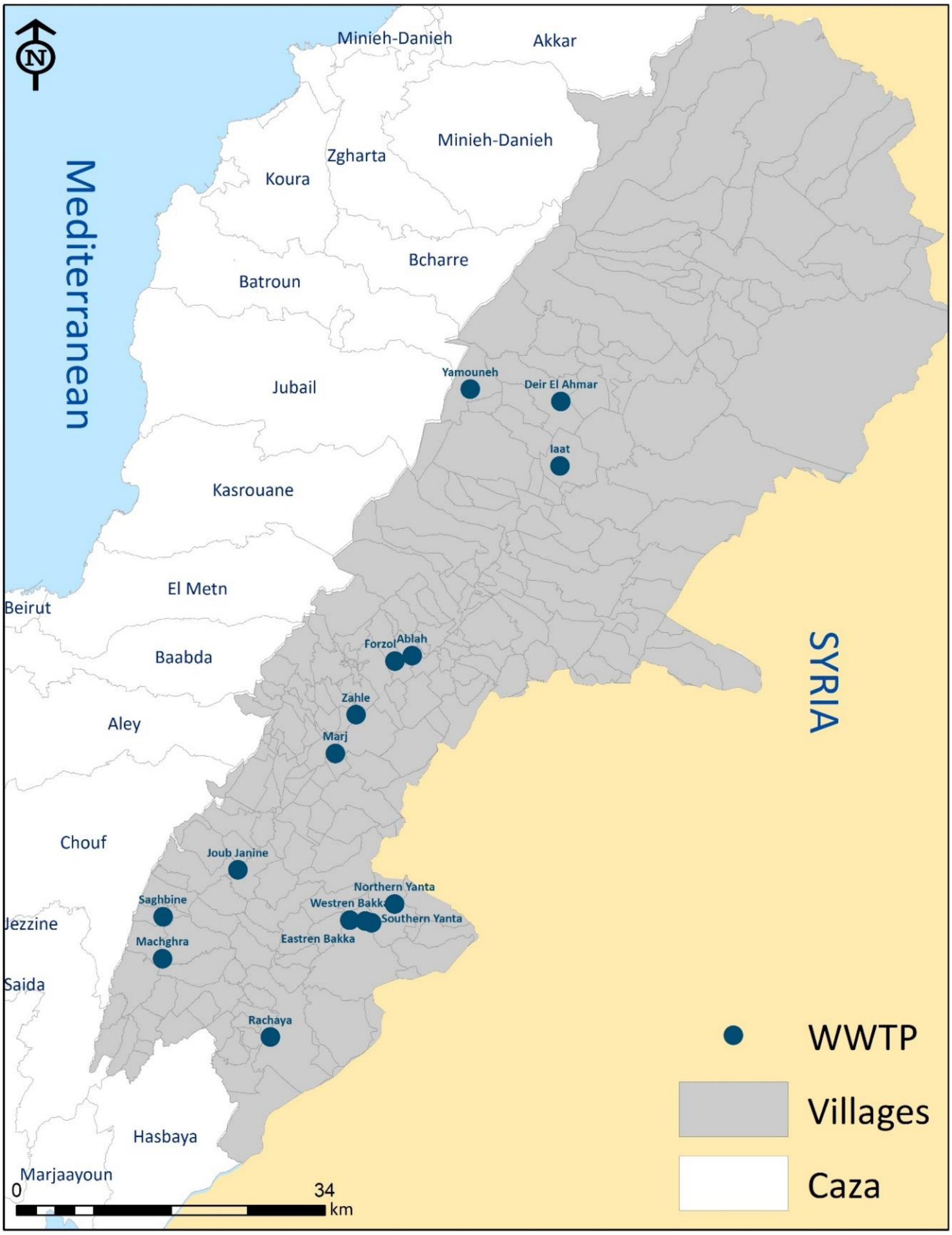

Figure 2 Distribution of wastewater treatment plants in the Beqaa

Source: CNRS (2017)

2.5 Economic Feasibility and Evaluation of Treated Wastewater

Unlike business and structural projects, treated wastewater reuse projects generally lack accurate economic analysis (Declercq et al., 2020). If this is done, the social and environmental benefits and costs are often incorrectly calculated in economic analysis of wastewater reuse projects. Like any other project, TWW reuse projects can adopt the method of cost-benefit analysis on a large scale, which shows the profitability of the project from the point of view of society as a whole. Perhaps the methodology is not a problem in itself, but rather the difficulties of evaluation and all the overlapping factors that affect the evaluation of feasibility studies make the evaluation process more complex; this makes the economic viability of TWW reuse projects inadequately studied (Molinos-Senante et al., 2011).

Several studies in Mediterranean countries have shown that when external benefits are correctly identified and incorporated into economic analysis, the number of reuse projects increases (Molinos-Senate et al., 2011; Condom et al., 2012). It is not sufficient for the success of water reuse projects to take into account and evaluate the main external factors if public opinion, risk analysis, evaluation of monetary benefits, willingness to pay the cost as well as the environmental impacts of reclaimed water are not included in these factors (Lazarova et al., 2001). In a study conducted by Massoud et al. (2019) to assess the perception of stakeholders and end users of TWW in Lebanon, farmers expressed their desire to obtain TWW as a supplement to irrigation for a reasonable price and fixed fees. Establishing a transparent financial vision, defining operating and maintenance costs, and a clear economic evaluation would encourage farmers to commit to paying the fees imposed for using TWW.

Literature on the economic feasibility of irrigation projects with TWW showed that the cost varies from one country to another according to the site conditions and the costs of treatment and pumping. In a study conducted in Morocco (Oubelkacem et al., 2020), it was found that freshwater costs are cheaper than TWW for farmers, which may require more pumping and energy costs for TWW, which also depends on the climatic and geographical nature of the region. In contrast in another study done in Iran (Deh-Haghi, et al. 2020), the groundwater cost was equal to that of TWW.

Calculating the cost of using TWW depends on several criteria. Some studies consider the water volume and the treatment type, some calculate the energy cost only and others still calculate the cost of operation, maintenance, and the project's total investment (Mateo-Sagasta et al., 2022). Therefore, there are no common standards that allow some comparisons to be made between different cases or regions (Murray et al., 2011). Studies of economic evaluation and cost of wastewater for agricultural and irrigation purposes are scarce in Lebanon. Perhaps the main reason for this is the lack of examples of the use of TWW irrigation except for the Ablah WWT plant in the Beqaa. Therefore, this research chose the Ablah WWT plant as a case study.

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CHAPTER 3

METHODOLOGY

3.1 The Framework for the Assessment of TWW Use in Agriculture

Reusing treated wastewater for irrigation is one of the solutions and alternative sources to address the water shortage challenges. As such, there is an urgent need to assess the ability of the TWW to reduce the gap between irrigation water supply and demand and assess the economic implications of its use in agriculture.

Before TWW can be reused for irrigation, several questions need to be answered to identify potential reuse options. The basic questions and information that are required to initiate an assessment include:

1. How much TWW is generated in a region, and how much fresh water is available? What are the sources of freshwater (wells, surface, storage basins) in the region.

2. What level of wastewater treatment is available in a given region? Is it compatible with the type of crops grown?

3. What are the costs of delivering fresh water and TWW to the intended users? Those costs need to be identified before an assessment is made. For our case study in the Beqaa region, these include freshwater pumping, water tariffs, wastewater treatment cost, infrastructure cost for the TWW distribution network, TWW pumping cost, and proximity of WWTP to intended users. The analysis will result in estimating the economic feasibility of fresh and TWW use from the farmer's point of view.

4. What are the main factors controlling the system of TWW reuse in irrigation in a given region?

Based on these questions, a framework has been established to assess the economic impact of TWW reuse. The different components of this framework have been classified into several layers of inputs, outputs, and outcomes according to various scenarios, as shown in Table (2). The scenarios consider many aspects. First, there are climate change scenarios considered in this framework which are overarching and outside the control of the farmers; in this study, two climate scenarios (based on RICCAR, 2017) are considered, including a moderate scenario, where a 10% decrease in rainfall and a 13% in evapotranspiration (ET0) is expected and an extreme scenario, where a 20% decrease in rainfall and a 26% increase in ET0 are expected. Second, regarding irrigation water sources, there are options for using groundwater or decreasing and replacing groundwater with different amounts of TWW. These are to be selected by farmers based on feasibility and availability. The third scenario is cropping systems that will dictate a change in crop water requirements. Thus, the usual cropping system may be continued, or alternative cropping systems suggested better to match the water availability within the climate change scenarios. The fourth is the economic scenario, which relates to the change in the exchange rate of the Lebanese pound against the dollar, which affects the market prices and farmers' profits.

Table 2 TWW reuse assessment framework.

Scenarios	**Input**	**Output**	**Outcomes**
Climate scenarios • **Moderate scenario**: 10% decrease in rainfall and a 13% increase in ET0 • **Extreme scenario**: 20% decrease in rainfall and a 26% increase in ET0.	**On-farm** • **Crop type** • **Area** (% of irrigation area and % of rainfed area) • **Water requirement** per crop by using the FAO56 approach • **% GW** • **% TW** • **Yield per crop** (By used the actual and maximum crops yields, actual and maximum evapotranspiration, the yield response factor Ky). • **Expected cost of production** (Without water) • **Decision maker** • **Irrigation system efficiency**	**On-farm** • **Expected yield** • **Water requirement** (Qty) by multiplying the crop area and then by the percentage of the irrigated area • **Expected revenue (without TWW** • **Expected revenue with TWW** • **Effective irrigation system**	• **Increased revenue** • **Increased water productivity** • **More resilience to climate change** • **Sustainable TWW management** • **Sustainability Livelihood** • **Sustainable food production**
Water source options • **TWW** • **GR** • **Non-irrigated (rainfed)**	**Outside farm** • **Water quality** (Level of treatment according to FAO guidelines • **Amount of TWW produced.** from the plant • **Cost of GW ($)** • **Cost of TWW ($)** • **Dependable services** • **Operational experience** • **Crop market price**	**Outside farm** • **Water cost (if no TWW is used)** • **Water cost (GW& TWW)** • **Eligibility** • **Affordability** • **Easy payment system** • **Reduced pumping** (saved GW) • **Revenue for TWW plant**	-
Cropping systems	**Externality** • **Climate change**	-	-

• **Current system** • **Alternative system**	(precipitation patterns, ET0, rainfall) • **Governance** • **Political, Economic factors**		
Economic: exchange rate	-	-	-

The inputs were divided based on inputs on the farm and outside the farm in addition to external inputs that are outside of the agriculture system.

3.1.1 Farm

These include a set of essential inputs such as options for types of crops and the area of each crop with the percentage of irrigated and non-irrigated crops. Calculating the water requirements for each crop is one of the most important inputs in this framework, as it depends on knowing the supply and demand for water; as it is calculated according to the FAO56 approach, the fresh and treated water supplies must be known.

It is necessary to know the amount of TWW generated from the wastewater treatment plant, which varies from one plant to another according to the capacity and type of the plant. Also, the available water used in irrigation must be known/estimated to know the amount of fresh water available for irrigation. When calculating available water volumes, climate change scenarios must be considered. These scenarios affect water availability and usually cause an increase in water demand. Another input to consider is the efficiency of the irrigation system which affects the amount of water available and reduces the demand for irrigation water. On the other hand, calculating the yield for each crop is important as one of the inputs; this is done by calculating the actual and maximum crop yields, the actual and maximum evapotranspiration, and the yield response factor Ky. After knowing the yield, expecting the cost of production without irrigation water is one of the inputs that help the farmer to make the decision, whether by changing the crop pattern or adding supplementary irrigation and irrigation system efficiency.

3.1.2 Inputs Outside the farm

These inputs relate to TWW quality and level of treatment in conjunction with the type of crops grown in the area that benefit from the TWW plant's water. Based on the guidelines set by the FAO for using TWW, specific crops can be grown under each level of treated water, so the crop type must match the treatment level. Furthermore, operational experience is essential to manage a wastewater treatment plant by ensuring TWW quality, disinfection operations, water distribution, crop irrigation schedules, and maintenance work. All these measures are important to facilitate the TWW reuse process and to make the TWW qualified, safe, and ready for use according to the appropriate crops.

As for the price of irrigation, water, whether from groundwater or treated, is one of the most essential inputs outside the farm. The cost per cubic meter of TWW and the pumping cost per cubic meter of groundwater should be calculated. Knowing the prices of irrigation water is one of the most important factors affecting the farmer's decision to choose between the two types of treated and freshwater because the water price will be reflected in the farmer's profit. Calculating the cost of water with crop yield and available land area will make clear which type of water is the most profitable and least burdensome for the farmer. Knowledge of the water price influences the farmer's decision to choose the most profitable crop and the least expensive water based on the crop's market price.

3.1.3 Outputs on farm and outside farm

They are outputs that include financial returns to the farmer, crop type, water requirements for each crop, yield forecasts for each crop, cost of irrigation water, and WWTP returns. These outputs depend on the crop chosen by the farmer and the resulting differences in net water requirements, type, and cost of water the farmer uses for irrigation. Outputs outside the farm are related to irrigation water conditions and choices, whether groundwater or TWW, regarding economy (cost), reliability for TWW (ensuring that the irrigation network is maintained and adheres to the specified irrigation schedule), and water quality.

3.1.4 Outcomes

1. Increased revenue: Determining the availability of water and the quantities of fresh and treated water and dividing them among crops will contribute to effective water management. Crop revenue calculations based on water price will create knowledge for farmers about which crops give more yield and revenue from supplemental irrigation than other crops, thus making the most of irrigation water to increase yields.

2. Water productivity: This framework contributes to increasing water productivity because when knowing the cost of water and calculating it with yield and crop revenue, the economic productivity of water will be reached, which is the value derived per unit of water used. Since water productivity aims to produce more food and income and

improve livelihoods, this framework leads to the same goals, thus increasing water productivity.

3. More resilience to climate change: One of the main reasons for reusing wastewater in irrigation is climate change, so this framework is resilient to climate change by relieving pressure on groundwater, reusing TWW as an alternative source, and mitigating the environmental impact of wastewater without treatment.

4. Sustainability of TWW Management: Operating following this framework is a means of managing the TWW reuse sector sustainably from an environmental, economic, and social point of view.

5. Sustainability Livelihood: Using an alternative, safe, and sustainable irrigation source improves farm returns, thus improving livelihoods and supporting food security for farmers.

6. Sustainable food production: Sustainably managing TWW will develop this sector to become a dependable source for increasing food production and improving food security.

In Figure (3) the color-coded arrows show how each element of the inputs and outputs relates to the scenarios. The inputs and outputs on farm are represented by unbroken arrows, and the inputs and outputs outside the farm are represented by dashed arrows. The arrow exiting from the inputs to the scenario and heading inside the box indicates that the inputs are affected by this option only and not by the entire scenario. But if the arrow is directed outside the box, this means that the inputs affect the scenario as a whole. On the other hand, the outputs reflect the farmer's performance in choosing the most feasible scenario, whether in terms of water type or crop.

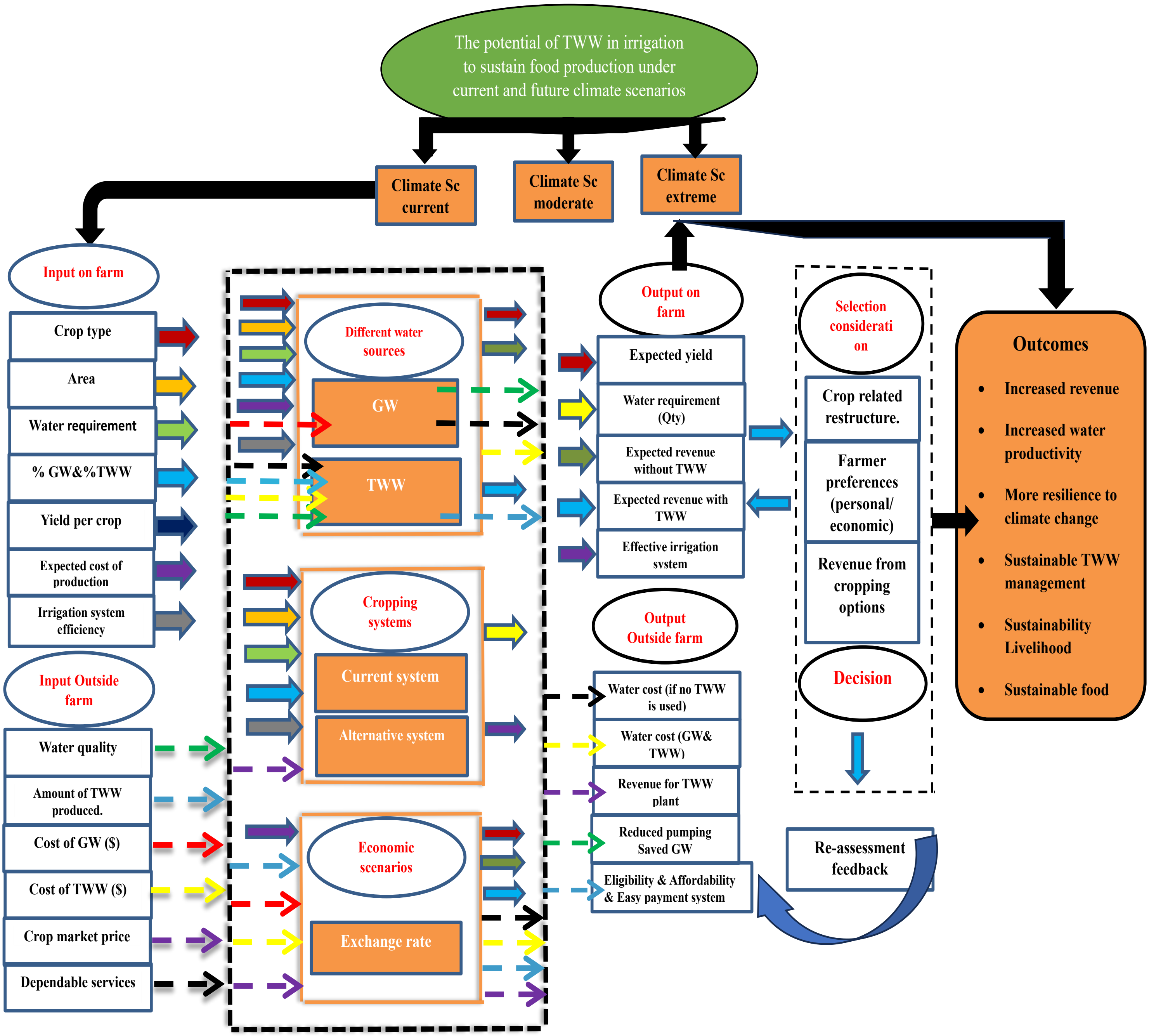


Figure 3 framework for the economic assessment of the TWW reused

3.2. Crop Water Requirements

Evapotranspiration (ET) is defined as the amount of water that evaporates and transpires from the soil and the plants and is equal to the crop water requirements (Allen et al.,1998).

To calculate the amount of water demand, the water requirements of the crops were calculated for each crop based on their specific growing season. Reference evapotranspiration (ET0) is calculated from weather data; ET0 was calculated using the Penman-Monteith equation (Allen et al., 1998, 2005). The actual evapotranspiration for each crop was calculated by using the crop coefficient (Kc) obtained from the FAO 56 PM method. Depending on the coefficient of Kc and the crop growing season, the actual evapotranspiration for each crop was obtained as follows:

$ETc = ET0 \times Kc$.

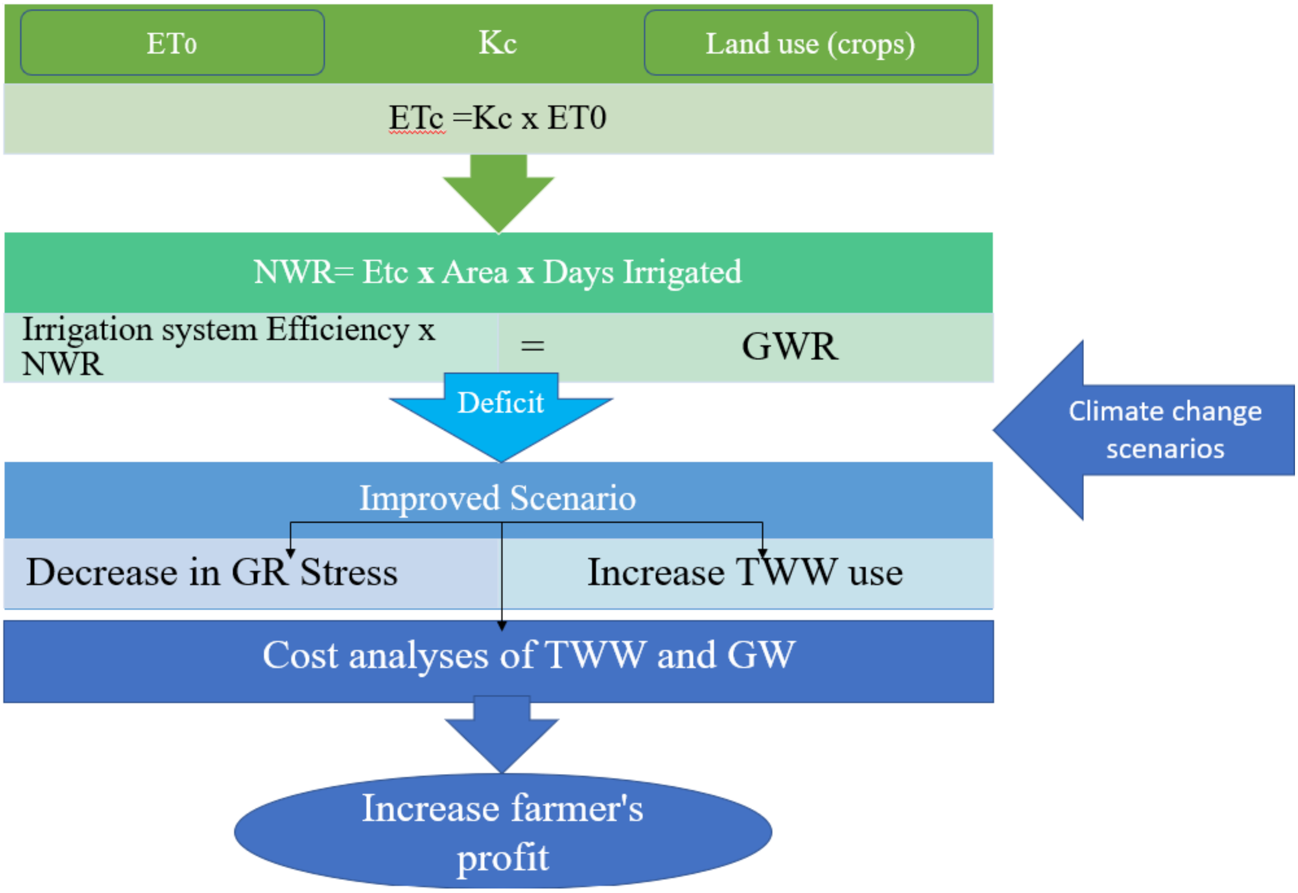
The calculated ETc was then used to calculate the net irrigation requirement (NIR) as follows:

$NIR = ETc - Peff$

Where Peff is the effective rainfall

The total water demand for the existing crop areas was calculated by dividing the net water requirement by efficiency, which depends on the irrigation system, the gross irrigation requirement was calculated as GIR = NIR / irrigation efficiency.

As shown in Figure 4, after obtaining the GIR and comparing it to the water supply, the deficit will be reduced through the improved scenario based on: 1 relieving pressure on the GW, 2 Increased uses of TWW. Finally, conduct a cost analysis of GW and TWW and use the option that increases profit for the farmer.



ET0: Reference evapotranspiration, Kc: Crop coefficient, ETc: Water requirements, NWR: Net irrigation requirement, GWR: Gross water requirement, GR: groundwater, TWW: Treated wastewater

Figure 4 Illustration of the methodology for TWW reuse and its role in farm income

3.3 Study Area

Ablah is located on the road leading to Tal Amara in the district of Zahle in the Beqaa Governorate (x =293,616.33, y = -33,637 .73). The Ablah wastewater treatment plant has been designed to serve several villages (Niha, Nabi Aila, Ablah, Fourzol) in the Beqaa, Lebanon (Table 3). The plant has a total design capacity of 2000 m^3 of domestic wastewater. The facility was established in 2007, and it uses a secondary treatment system designed according to the principle of the trickling filter. This system of filter works to remove organic matter from wastewater using microorganisms attached to the medium (aerobic, anaerobic, and facultative bacteria; fungi; algae; and protozoa) (EPA, U. 2000). The plant serves 14,650 people distributed over three villages (Ablah, Niha, Al-Nabi Ayla, and several buildings from Fourzol) as shown in Table 2, at a rate of 137 liters/person/day in 2022 through a wastewater network with a length of 13.07 km. According to Table 2, the operational capacity of the station (2000 m^3 /day) can continue to serve these villages until 2035.

Table 3 Estimated and projected population and generated wastewater flows in each village of the study area.

	Years 2013		**Years 2025**		**Years 2035**	
Town Name	**Estimated Population**	**Wastewater Generation Rate (m^3/d)**	**Projected Population**	**Wastewater Generation Rate (m^3/d)**	**Projected Population**	**Wastewater Generation Rate (m^3/d)**
Ablah	9,653	1,625	11,887	2,090	14,139	2,578
Niha	2,008	338	2,472	435	2,941	537
Nabi Ayla	1,585	٢٦٧	١,٩٥٢	٣٤٤	٢,٣٢١	٤٢٤
Fourzol	10,435	1,757	12,850	2,259	15,284	2,787

Source: KREDO/DAI and USAID 2015, WATER SUPPLY AND WASTEWATER SYSTEMS MASTER PLAN FOR THE BEKAA WATER ESTABLISHMENT

3.3.1 Descriptive analysis of the study area

To describe the study area, I have used ArcGIS 10.8 (LUC,2017) to create maps (Figures 3 and 4) of the topography, land cover, and land use. The maps were prepared based on the following data:

• Land cover in 2017 issued by the National Center for Scientific Research (CNRS).

• The road network was obtained from an open street map.

• Sewage networks and station sites from the Beqaa Water Establishment (BWE).

3.3.2 Topography

As shown in Figure (5), Ablah is the lowest elevation point of the areas where the wastewater is followed. In other words, the station was designed at a low elevation and close to the Litani River to facilitate water flow through the sewage networks. The slope between the highest and lowest points is about 49 degrees. It is noted that Ablah is a relatively flat area with slight slopes, which is what makes it suitable for agricultural production.

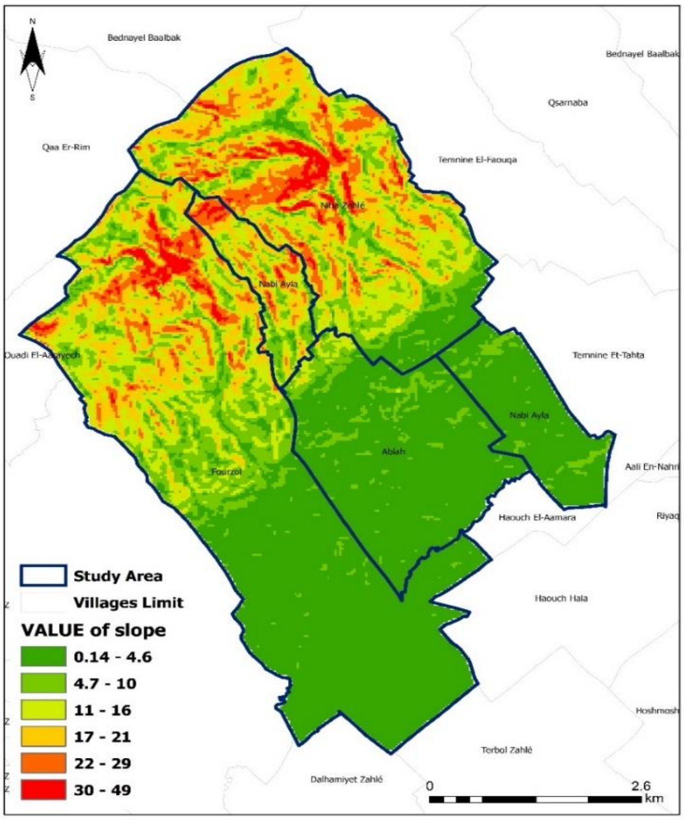


Figure 5 Slopes in the Ablah study area

After the treatment process is completed, a large part of the water is pumped into a pond which is located about a kilometer north of the plant, with a capacity of 15,000 m^3. The pond contains two types of filters: sand and disc filters. The water is then pumped through a 4.5 km extended network to the farmlands. Thirty farmers in Ablah received wastewater through the network. Since the operational capacity of the plant reaches 2000 m^3 per day, this treated water helps to irrigate the lands and farms of the Ablah area. It is insufficient to irrigate the crops of other regions from which the wastewater comes. As such, the focus will be on calculating land areas and crops water requirements in the Ablah area.

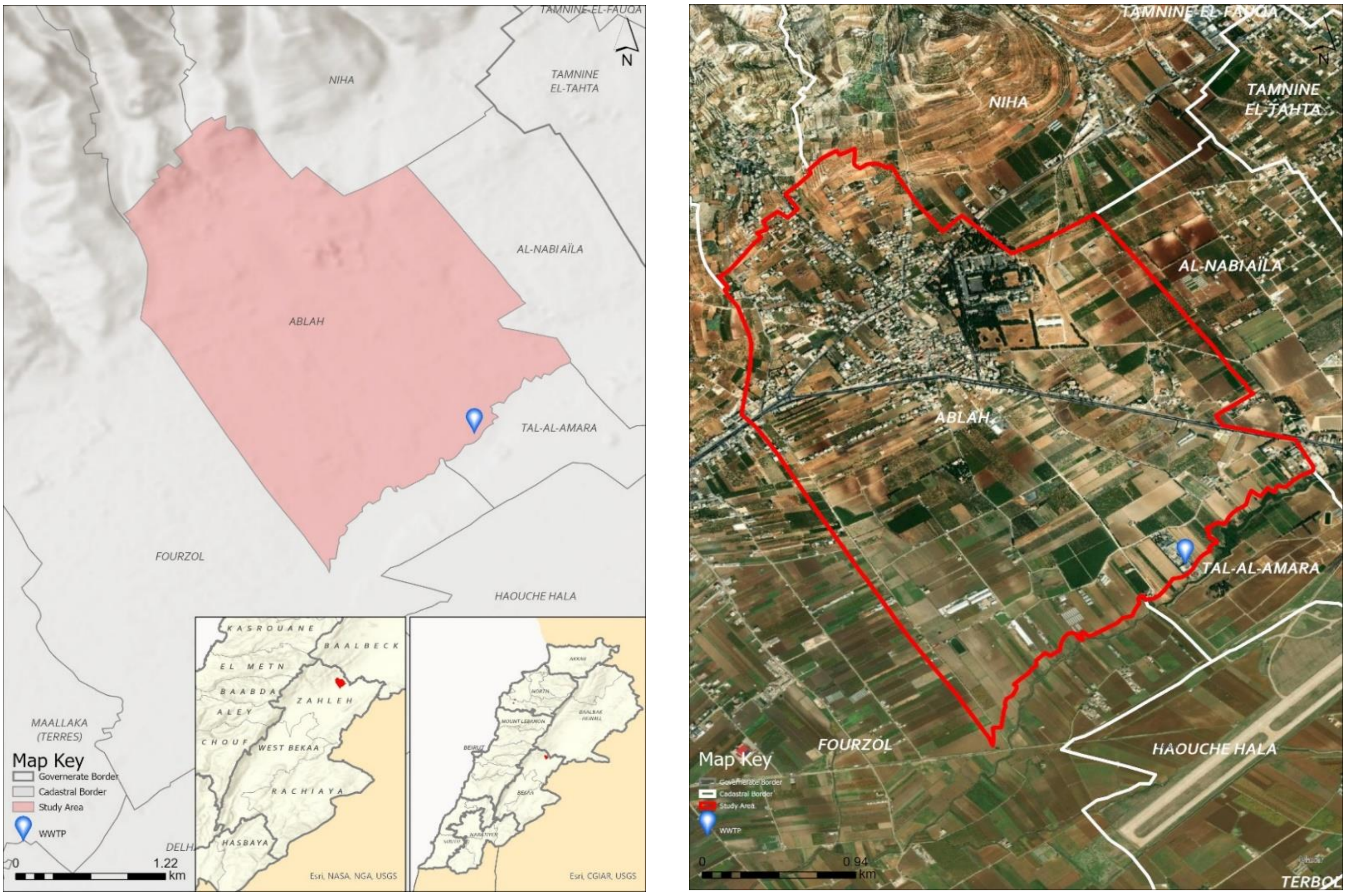


Figure 6 shows Ablah village location in Beqaa, Lebanon

Through the map of land used in Ablah (Figure 7), we see that the density of urban communities is in red north of the map, from which wastewater flows. Permanent crops and field crops cover most of the agricultural areas as shown in Table (4) (LUC,2017), except for some areas that are used for Intensive agriculture (Greenhouses).

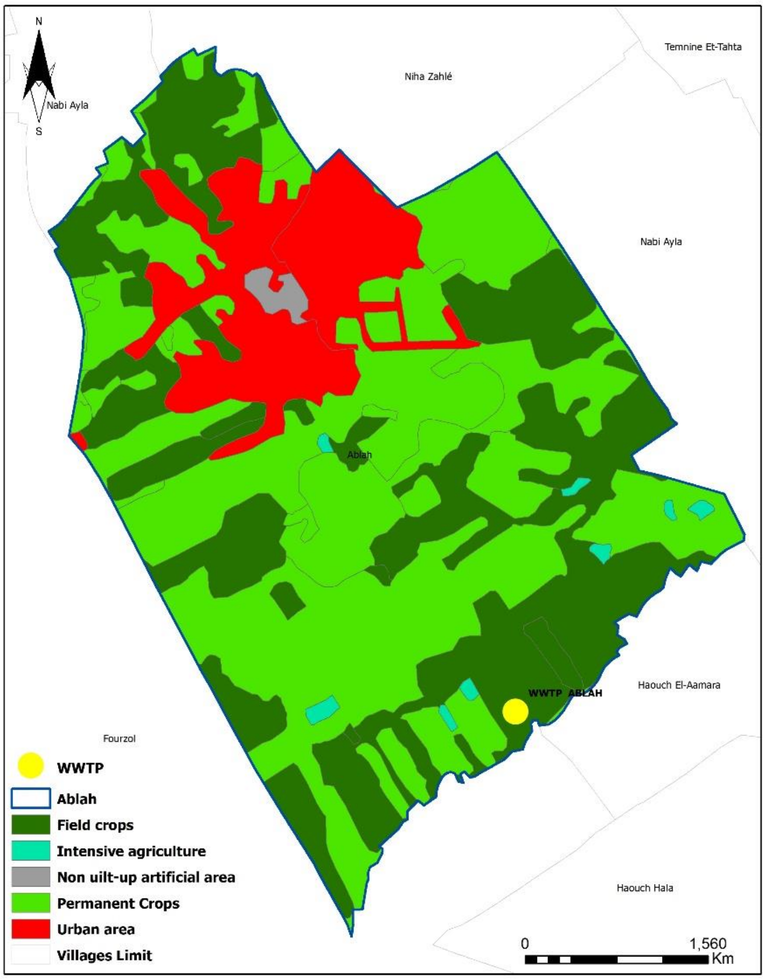


Figure 7 land cover land use in Ablah

Table 4 Area of each type of agriculture and urban area in Ablah.

Nomenclature	Total/ha
Field crops	210.39
Intensive agriculture	4.14
Non-built-up artificial area	3.66
Permanent Crops	296.24
Urban area	84.16
Grand Total	598.59

3.3.3 Weather data

Climatic data was collected from The Advancing Research Enabling Communities Center (AREC), for the years between 2011 and 2022 including temperature, wind speed, relative humidity, precipitation, and effective rainfall which is equal to the difference between total rainfall and actual evapotranspiration (Table 5).

Table 5 Monthly average of climatic data collected at AREC (average of 2011-2022)

Month	**Tmin (°C)**	**Tmax (°C)**	**Tmean/ (°C)**	**Average of RH**	**U2 The wind run in (km/day)**	**Avg Sunshine Hrs (hr/day)**	**Sum of Rain mm**	**Effective rainfall**	**ET0**
January	-6.65	16.45	4.67	76.96	139.27	5.3	127.3	101.4	1.55
February	-4.43	19.84	6.71	68.55	143.9	6.32	65.5	58.7	2.21
March	-1.90	23.59	9.83	61.45	160.3	6.92	47.6	44	3.28
April	1.25	28.96	13.81	51.83	152.6	8.78	18.8	18.2	4.69
May	5.34	33.14	18.65	43.51	157.32	9.99	9.3	9.2	5.9
June	8.31	36.16	22.11	39.06	166.03	11.6	2.1	2.1	6.91
July	11.79	37.45	24.92	36.38	156.25	11.72	2.2	2.2	6.99
August	12.47	37.23	24.68	38.77	148.91	11.11	0	0	6.51
September	9.46	35.91	22.16	42.00	143.22	9.75	0.5	0.4	5.46
October	5.57	30.56	17.45	48.92	129.5	8.24	21.1	20.3	3.82
November	1.36	24.52	11.62	61.88	118.11	6.05	37.8	35.5	2.35
December	-3.17	19.18	6.73	75.32	127.78	5.27	92.4	78.8	1.65
Totals	-	-	-	-	-	**-**	**424.6**	**370.8**	**4.28**

Table (5) describes averages of climatic data indicating that the coldest temperatures are recorded in January and the first half of February. As for the highest temperature, it may sometimes be recorded at 46°C in the months of July and August, while maintaining a high rate of between 36-37°C during the summer months. As for precipitation, it is generally described as low with the 11-year average of about 424 mm. The relative humidity generally increases from November to March and is accompanied by a decrease in evaporation. While evaporative demand increases from April to September with average temperature (>15°C) and minimum relative humidity (<60%).

3.3.4 Corp pattern and irrigation system used in Ablah

The area of Ablah village is approximately 600 ha, as shown in Table (4), 84 ha of which are urban areas, 440 ha are agricultural crops, and the remaining area is uncultivated. According to the land cover map of CNRS (2017), the types of all crops in Ablah were identified and the area occupied by each crop is shown in Table (6).

Table 6 Crops, area, and irrigation methods in Ablah

Crop details for Ablah	**Area (ha)**	**Irrigation type**
Barley	120	100% rainfed
Wheat	30.6	100% rainfed
Almond	28.2	100% rainfed
Apricot	20	50% drip irrigated, 50% surface irrigation
Peach	20	50% drip irrigated, 50% surface irrigation
Olives	2.28	33% surface irrigation, 67% rainfed
Cucumber	1.6	100% drip irrigation
Tomato	0.75	100% drip irrigation
Vineyards	216.6	33% surface irrigation, 33% drip irrigated, 34% rainfed
Total area	**440.03**	

Source: CNRS (2017)

Grapes occupy the first place in terms of area, followed by grains and fruit trees, while there are relatively small areas for vegetables such as cucumbers and tomatoes. Most of the crops in Ablah are irrigated and follow different irrigation systems.

3.4. Water Sources

Most of the irrigation water supply in Ablah comes from groundwater, which is the primary source that farmers depend on to irrigate their crops. Farmers who do not have private wells on their land tend to purchase water for irrigation from wells from neighboring farmers. After the establishment of the Ablah TWW plant, the TWW became an additional and important source of water supply that could contribute approximately 20% of the irrigation water supply in Ablah if all the operational capacity of the plant was used (personal communication).

Although the Ablah treatment plant is designed to treat 2000 m^3 per day as a full capacity of domestic sewage, it is not running at full capacity, and it is currently (at the time of this study in 2022) treating an average of about 1500 m^3 per day. This TWW goes to the Litani River most days of the year as it coincides outside of the crop growing season. For the use of TWW in irrigation, a water reservoir of 15,000 m^3 was designed with filters and an irrigation network installed to deliver the treated wastewater to about 30 farmers. Water is pumped from the reservoir through a 4.5 km irrigation network to irrigate mostly table grapes in Ablah.

According to the irrigation schedule followed in the Ablah WWTP, the reservoir is filled from mid-May to start pumping in June and continues until the end of the irrigation season in September. The treated wastewater was able to irrigate approximately 22 hectares of grapes in the stages before the current economic crisis in Lebanon. The network only worked for a year or two after its implementation, and then it stopped due to a local dispute, as one of the residents who lives next to the tank complained against the municipality, claiming that the tank caused damage to the foundations of the house. On the other hand, the current economic crisis in Lebanon affected the plant's ability to serve all previous farmers, which led to reducing their number by approximately half.

Table 7 Irrigation water supply in Ablah for both TWW and groundwater

<table>
<tr><th colspan="4">TWW Supply, m^3</th></tr>
<tr><th></th><th>Daily volume</th><th>In irrigation season</th><th>Annual</th></tr>
<tr><td>Design capacity</td><td>2,000</td><td>2,000</td><td>730,000</td></tr>
<tr><td>Actual average daily flow</td><td>1,200 – 1,500</td><td>1,200 – 1,500</td><td>547,500</td></tr>
<tr><td>Total water use in Irrigation</td><td>1,500</td><td>136,000</td><td>136,000</td></tr>
<tr><th colspan="4">Groundwater Supply, m^3</th></tr>
<tr><th>Total GWR m^3in Ablah</th><th colspan="2">TWW use in Irrigation</th><th>Groundwater pumping</th></tr>
<tr><td>1,124,608</td><td colspan="2">136,000</td><td>988,608</td></tr>
</table>

3.5 Economic Assessment of Using Groundwater and TWW in Irrigation

The economic evaluation of the use of TWW in Ablah will be based on integrating governance into economic feasibility. Without governance, there can be no economic feasibility and sustainability in using TWW for irrigation because the management of the water sector is the main determinant of wastewater reuse and the evaluation of its economic feasibility. The current economic crisis has created significant challenges for the operation of the WWT plant in Ablah and other plants in Lebanon, its technical operation, and its management. Therefore, in this study an economic assessment was conducted taking into consideration the impact of the developing economic situation in the country, to provide a clear vision and propose an action plan that contributes to the sustainability of the WWTP. The methodology is based on two main points:

- Calculation of the average cost of pumping from wells, including the cost of diesel
- Calculate the average production cost per cubic meter of TWW, which includes the cost of operating the plant, chemicals used in the treatment process, salaries of personnel, and the cost of the irrigation network and its maintenance, these values were adopted by a similar study in France conducted by (Declercq et al., 2020).

3.6 Yields and Water Productivity

Water productivity (WP) can be defined as crop yield per cubic meter of water consumption, including green water (actual rainfall) for rainfed crops and both blue and green water diverted from water systems for irrigated crops. In light of climate change and increased water stress, a yield decrease is expected. To calculate the decrease in yield due to the expected decrease in water supply and/or increase in ET, the following equation was used (Doorenbos and Kassam,1979):

$$\{1 - Y_a/Y_x\} = K_y\{1 - ET_a/ET_x\}$$

where, Y_a is actual crops yields, Y_x is maximum crop yields, ETa is actual evapotranspiration, ETx is maximum evapotranspiration, and Ky is the yield response factor. The Ky coefficient is related to low yield ($1 - Y_a/Y_x$) to water stress (1 - ETa/ETx) for a given environment and is widely used for all crops (Raes et al., 2006). On the other hand, the net profit for the farmer was calculated through the revenues per hectare and the prices of the crop in the local market obtained from (personal communications) as shown in Table 8.

Table 8 Crop yields and prices in hectare

Crops	Yield (ton /ha)	Precis $ (ton /ha)
Wheat, irrigated	8	٤50
Wheat, rainfed	5.35	٤50
Grapes, irrigated	25	256
Grapes, refined	12	256
Peach, irrigated	40	384

CHAPTER 4

RESULTS

4.1 Calculation of Net Water Requirement for Crops Currently Grown in Ablah

The climate data from the AREC weather station was used to compute the (ET0) because of the similarity in weather between the AREC and Ablah locations. To calculate the net water requirements of crops, ET0 is multiplied by the FAO standard crop coefficient (Kc), which is one of the most important parameters for assessing crop evapotranspiration and is often used when calculating water requirements. Table (9) shows an example of calculating the Kc of wheat for the different crop growth stages.

Table 9 Crop coefficient of wheat during the different growing stages in the Beqaa region.

Wheat	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.4	0.8	1.15	0.4	**0.75**
Length (days)	30	140	30	25	**225**

It should be noted that in Table (10), ETc is only shown for the growing season of wheat (November till June). The total water requirement for wheat is 5,592 m^3/ ha /season and if two supplementary irrigation events are carried out in April and May, this will amount to 2,149 $m^{3.}$

Table 10 Water requirements for wheat crop in Ablah where the season extends from November till June.

Month	Rainfall (mm/month)	ET0 (mm/day)	ETc (mm/month)	ETc (m^3/month)
January	101.4	1.55	35.98	359.8
February	58.7	2.21	46.34	463.4
March	44.0	3.28	76.15	761.5
April	18.2	4.69	105.37	1,053.7
May	9.2	5.90	136.97	1,369.7
June	2.1	6.91	67.27	672.7
July	2.2	6.99	-	-
August	0.0	6.51	-	-
September	0.4	5.46	-	-
October	20.3	3.82	-	-
November	35.5	2.35	52.80	528.0
December	78.8	1.65	38.31	383.1
Total	**370.8**	-	**559.2**	**5,591.9**
Total (mm/season)	**348.3**	-	-	-

In Ablah, table grapes are generally irrigated for three months, June, July, and August. To calculate the net water requirement in m^3/ha, the water requirements during the irrigation season (mm /year) is multiplied by the cultivated area and then by the percentage of the irrigated area. The volume of net water requirement is related to the length of the irrigation season. In (Table 11), the net crop water requirements for the irrigation season (90 days started from June) are 4,694 m^3/season minus rainfall (43 m^3) which amounts to 4,651 m^3/season.

Table 11 Water requirements for grapes in Ablah where the irrigation season extends from June till August.

Month	Rainfall (mm/month)	ET0 (mm/day)	ETc Grapes (m^3/month)
January	101.4	1.55	-
February	58.7	2.21	-
March	44.0	3.28	-
April	18.2	4.69	-
May	9.2	5.90	-
June	2.1	6.91	1,555
July	2.2	6.99	1,625
August	0.0	6.51	1,514
September	0.4	5.46	-
October	20.3	3.82	-
November	35.5	2.35	-
December	78.8	1.65	-
Total	**370.8**	**-**	**4,694**

4.2 Gross Water Requirement in Ablah for All Crops

The calculation of the total water needs is related to the irrigation system used for each crop because each system has a different efficiency. After knowing the net water requirements for each crop, it is necessary to know the percentage of efficiency in the irrigation system, so the sum of the net water requirements for each crop is divided by the efficiency of irrigation system to calculate the total gross water requirements (Table 12).

Table 12 Calculation of gross water requirements (m^3) for all crops currently grown in Ablah.

Crop	Net Water Requirement per season m^3/ha	Irrigated %	Irrigation Efficiency (%)	Gross Water Requirements (m^3/ha)	Total Area of crops (ha)	Total Gross Water Requirements (m^3)
Cereals	2,149	0% (rainfed)	-	-	150.6	-
Almond	4,025	0% (rainfed)	-	-	28.2	-
Apricot	5,276	100%	0.75	7,035	20	140,701
Peach	5,276	100%	0.75	7,035	20	140,701
Olives	4,050	33%	0.6	2,228	2.28	5,079
Cucumber	12,408	100%	0.9	13,787	1.6	22,059
Tomato	12,408	100%	0.9	13,787	0.75	10,340
Grapes	4,651	60%	0.75	3,720	216.57	805,727
Total	-	-	-	**-**	**440**	**1,124,608**

The areas and crops in Table (12) are a model that can change from year to year according to crop rotation or market requirements. However, the methodology that is presented in this research study allows flexibility to accommodate such crop changes. In case of crop pattern changes, the net water requirements for it can be easily calculated with the same methodology, or if the area of one crop is increased at the expense of other crops, the numbers can be changed without any impact on the methodology.

4.3 Water Requirements Under Different Climate Change Scenarios

The calculation shown in section (4.2) represents the current situation based on recent weather data, however, in this study we also present the situation and water requirements under two different scenarios of climate change, a moderate and an extreme one. These climate change scenarios are adopted based on the climate change study of RICCAR (2017) as part of Lebanon's Third National Communication to the UNFCC report. These scenarios were presented in the methodology, and they consider an increase of the reference ET0 by 10% for the moderate scenario, and 20% for the extreme scenario. As well as reducing rainfall by 13% and 26% for the two scenarios respectively in 2040. The net and gross water requirements were recalculated based on these updated ET and rainfall modelled data (Table13).

While recalculating the water requirements for climate change scenarios, the percentages of increase in ET0 and decrease in precipitation were considered but changing of irrigation period was not considered due to the high percentage of ET0 of crops. For example, the irrigation period is expected to increase to start from the end of May and extending to September.

On the other hand, these calculations show an increase in water demand by 146,199 m^3 (13%) according to the moderate scenario and 292,398 m^3 (27%) according to the severe scenario if we consider the same cropping pattern and the same irrigation system as the current practice (Table 13).

Table 13 Irrigation water deficit in Ablah under climate change scenarios (Sc 1 and Sc 2) compared to the current conditions for all the crops currently grown.

Irrigation for all crops	Total GWR (m^3) Current	GWR under Climate Sc 1 (m^3)	GWR under Climate Sc 2 (m^3)
Cereals	0	0	0
Almond	0	0	0
Apricot	140,701	158,993	177,284
Peach	140,701	158,993	177,284
Olives	5,079	5,739	6,399
Cucumber	22,059	24,927	27,794
Tomato	10,340	11,684	13,029
Grapes	805,727	910,472	1,015,216
Total Water demand (m^3)	1,124,608	1,270,807	1,417,006
Water Supply from TWW (m^3)	136,000	136,000	136,000
Groundwater pumping (m3)	988,608	988,608	988,608
Deficit (m^3)	0	-146,199	-292,398

Under both scenarios, the water balance and the amount of the water demand deficit were calculated in Tabel (13). Assuming a business-as-usual scenario, no change is expected in the water supply, whether fresh or treated, nor in crop patterns, there will likely be a shortage of fresh water to continue to irrigate the crops at the same capacity. Knowing that currently, water is only available for supplemental irrigation of some crops as farmers rely on surface river water and groundwater for irrigation. Table (13) shows that a water deficit from the current conditions under the moderate scenario is expected to be about 146,199 m^3 and 292,398 m^3 under the extreme scenario.

The current groundwater pumping is assumed to be the maximum capacity of groundwater pumping (now and in the future) and is 988,608 m^3 as it is not expected that there will be a capacity or management plans to increase recharge to replenish it.

Within this study, the assumption was that groundwater is more or less constant and did not consider the groundwater level decline under climate change scenarios as this goes outside the scope of this study. In such case, and to account for the water deficit, alternative sources must be found under climate change scenarios, or water requirements must be reduced when demand rises.

4.4 Proposed Climate Mitigation Measures

To mitigate the effect of climate change and cover the crop water requirements and the projected deficit, two practical solutions are proposed under an Improved Agriculture Scenario (IAS). The first suggested measure is related to better agricultural practices (improved irrigation efficiency) to reduce water demand as well as adding supplemental irrigation to improve productivity of certain crops, in this case cereals. The second mitigation measure is to increase the reuse of TWW as an alternative water source.

4.4.1 Impact of Improved Agricultural Scenario (IAS) on Current Scenario

This scenario aims to change current practices and assess what can be improved in the irrigation system to make it more efficient and add supplement irrigation to the cereals to increase yields (Table 14). Some of the crops that currently have a relatively low irrigation efficiency will be upgraded and cereals will get supplemental irrigation to boost yield. The selection of cereals for supplemental irrigation is based on the facts that 1) cereals are an important staple as a local food source and 2) they are currently 100% rainfed, which provides a good example of benefits from supplemental irrigation and increases the yield.

The proposed area for grains where crops can be provided with supplementary irrigation is 33% of the total grain production area in Al-Ablah (150.6 hectares, Table 12). 33% was determined by calculating the water requirements for this percentage and comparing it with the amount of treated water and available groundwater. Currently, the percentage of supplementary irrigation cannot be increased to more than 33% because this will lead to a deficit in the water balance in Ablah.

It should be noted that it is better to implement this IAS under current conditions because this will mitigate the impact of climate change scenarios by increasing supplementary irrigation to compensate for the high ET0 and decreased rainfall. The amount of supplementary irrigation will be increased through TWW, and the irrigation system's efficiency will be improved.

This suggested practice requires that TWW delivered to the farmers through the irrigation network is doubled. This in turn requires increasing the capacity of the existing irrigation network to be developed and expanded to reach more land while at the same time raising the irrigation system efficiency by using drip irrigation. Thus, more TWW from the Ablah WWT plant will be utilized rather than discharged into the Litani River.

Table 14 Suggested Improved Agricultural scenario for each crop in Ablah under current climate conditions.

Cereals	provide supplemental irrigation to 33% of the area (to increase productivity). Irrigation through sprinklers with 75% efficiency
Almond	Improve irrigation efficiency to 90%
Apricot	Improve irrigation efficiency to 90%
Peach	Improve irrigation efficiency to 90%
Olives	Business as usual (Small area and low irrigation percentage)
Cucumber	Business as usual (very small area)
Tomato	Business as usual (very small area)

By carrying out supplemental irrigation for 33% of the cereals and improving the irrigation system's efficiency (sprinkler for cereals and drip for all crops), the water requirements of crops in Ablah were reduced to 1,084,155 m^3 instead of 1,124,608 m^3 from the current conditions.

In this study, the area of grains that will be provided with supplementary irrigation was determined to be 33%. This percentage was calculated by calculating the water requirement for the season extending from November to June, which is 5,592 m^3/ha/season (Table 10). The IAS will add two supplementary irrigation events in April and May amounting to 2,149 m^3/ha (Table 15). Then, the amount of supplementary irrigation will be multiplied by only 33% of the total grain area due to the limited availability of water thus, the amount of water required for supplementary irrigation will be 142,428 m^3 (Table 15). This percentage can be increased if other water sources become available for supplementary irrigation.

The groundwater pumping capacity has been obtained by calculating the water requirements for the current scenario after subtracting the TWW capacity used for irrigation.; 1,124,608 - 136,000 (Table 7) = 988,608m^3 as shown in Table (15).

Table 15 Water requirement for Improved Agricultural Scenario (IAS) where irrigation efficiencies have been improved from the original (Table 12) and cereals were given supplemental irrigation under current conditions.

Crop	Net Water Requirement per season m^3/ha	Irrigated %	Irrigation Efficiency (%)	Gross Water Requirements (m^3/ha)	Total Area of crops (ha)	Total Gross Water Requirements (m^3)
Cereals	2,149	33%	0.75	946	150.6	142,428
Almond	4,025	0%	-	-	28.2	-
Apricot	5,276	100%	0.9	5,863	20	117,251
Peach	5,276	100%	0.9	5,863	20	117,251
Olives	4,050	33%	0.9	1,485	2.28	3,386
Cucumber	12,408	100%	0.9	13,787	1.6	22,059
Tomato	12,408	100%	0.9	13,787	0.75	10,340
Grapes	4,651	60%	0.9	3,100	216.57	671,439
-	-	-	-	**-**	**440**	**1,084,155**

4.4.2 Water balance under Improved Agricultural Scenario and climate change scenarios

The IAS will correspond to a proposal to improve some aspects of the management of the Ablah WWT plant, which will aim to raise the percentage of TWW contribution to irrigation from 136,000 m^3 to 300,000 m^3. Through discussions with the Ablah WWTP operator, an average of 1,500 m^3/ per day is treated. Annually, 547,500 m^3 are treated and discharged into the Litani River, and only 130,000 m3 are used to irrigate grapes. In other words, the amount of TWW that will be increased (300,000 m^3) exists, but it needs a network and pumping to be distributed, and this proposal will be discussed in detail later.

The effect of applying this scenario on the water balance under the climate change scenarios was calculated assuming there is no change in cropping patterns in Ablah. Table (16) shows that for the improved scenario, the stress on groundwater was minimized where less groundwater pumping is required, 784,155 m^3 instead of (988,608 m^3) (assuming a fixed capacity for groundwater pumping of 988,608 m^3). Thus, the improved scenario will lead to a reduction of groundwater depletion by 204,453 m^3/year.

As for the impact of the IAS on climate change scenarios, Table (16) shows that working with the IAS reduces the deficit in water demand in both climate scenarios. Climate change scenarios 1 and 2 have deficits of (146,199 m^3 and 292,398 m^3), respectively. When the difference between the water surplus from the IAS and the deficit in climate change scenario 1 is calculated, the water balance will be positive (58,254 m^3), while the deficit under climate change scenario 2, will be negative (87,945 m^3), as shown in Table (16). It must be noted that the amount of TWW that was increased in the IAS contributed significantly to improving the water balance under climate change scenarios.

Table 16 Water balance under improved scenario.

Water balance	Current Scenario	Climate Sc 1	Climate Sc 2	Improved Scenario
Water demand (m^3)	1,124,608	1,270,807	1,417,006	1,084,155
Water Supply from TWW (m^3)	136,000	136,000	136,000	300,000
Required Groundwater pumping	988,608	1,134,807	1,281,006	784,155
Groundwater maximum capacity	988,608			
Deficit from maximum groundwater availability (m^3)	**0**	**146,199**	**292,398**	**-204,453**
Impact of IAS on Climate Change Scenarios (Save Groundwater) (m^3)	**–**	**58,254**	**- 87,945**	**–**

4.5 Economic Assessment of Using Groundwater and TWW in Irrigation

To address the expected water shortages under the climate change scenarios, the amount of available water must be increased; this could come from TWW which needs to be increased from 136,000 m^3 to 300,000 m^3, as shown in Table (16). Though the Ablah WWTP can produce this amount 300,000 m^3 of water, it is currently not possible to exploit all of it because of two reasons. First the current network serves only 30 farmers with a capacity of 136,000 m^3 and needs to be expanded to accommodate 300,000 m^3. Second, Ablah plant suffers from operating problems due to lack of energy and the economic crisis.

As the results show, the amount of water that can be utilized to close the irrigation water gap warrants the proposal of a plan to improve the performance of the WWT plant. In terms of economics, the cost of pumping for both groundwater and TWW has been calculated, and the results, presented in section 4.5.1, show that TWW has the lowest cost for farmers. Working to increase the amount of TWW used in irrigation is more economical than increasing pumping from groundwater. Based on this finding, a suggested plan for the Ablah WWT plant is submitted, which enables it to implement the improved scenario, reduce the stress on groundwater and increase the farmer's profit through saving in irrigation costs.

4.5.1 The cost of TWW

WWT plants in Lebanon are classified according to their operation into several types. Donor institutions manage some stations, and some are awarded to private companies under contracts. Municipalities run a few of these plants. In the case of the Ablah plant, the municipality has managed and operated it since its establishment in 2012. Before the Lebanese economic crisis of 2019, TWW was pumped by the municipality to the grape farmers without taking any cost from them, but there was a plan to charge the farmers 250 LBP per m^3 of TWW. After the economic assessment and the new proposed action plan conducted in this study, the cost of TWW was reassessed through discussions with the manager of the Ablah WWTP, which amounted to about 7500 LBP per m^3. This cost includes the cost of operating the plant, chemicals used in the treatment, laboratory tests for water quality, workers' salaries, and the cost of maintaining the irrigation network. In other words, the farmer pays this cost without being responsible for pumping or extending the irrigation network or maintenance).

Since the capacity of TWW supply from the Ablah plant reached 30 farmers with a quantity of water of 136,000 m^3 before the economic crisis, and this quantity decreased due to the financial burdens on the plant, the action plan will increase the benefit of TWW to farmers.

Based on several discussions with the Ablah plant manager, through the current irrigation network, 136,000 m^3 will be pumped in the irrigation season through the current network, with a cost of 0.18$ (0.18$ = 7500 LBP at a rate of 39000 LBP for 1 $) per m^3 charged to the farmer. This will generate income for the plant that will enable it to cover its operational and maintenance costs. Thus, the plant will have enough money, and this could open an opportunity to the ability to gradually expand the irrigation network to reach more than 60 grape growers, with a TWW of about 300,000 m^3. After several seasons, the plant will be able to buy new land and build a reservoir with a capacity of 50,000 m^3, which will increase the utilization of TWW and increase the quantity of irrigated grapes to reach 76 ha. In fact, the Ablah WWT plant has a reservoir with a small capacity of 15,000 m^3, but this reservoir does not correspond to the plant's capacity. It would have been better to build a reservoir with a larger capacity since the establishment of Ablah WWT plant, but there was not enough land. On the other hand, there is a complaint from one of the neighbors because of the presence of the reservoir near his house. Which led to some problems regarding the use of the existing reservoir.

It should be noted here that I am talking about the cost of irrigation per m^3 of TWW and comparing it to the cost of irrigation with water from wells from the farmer's point of view because there is no official law for the sale of TWW. On the other hand, the Lebanese government is discussing a law that legalizes the sale of TWW to farmers according to certain specifications, but the law has not yet been approved during this study.

4.5.2 Calculation of The Cost of Pumping Water from Groundwater

The average depth of wells in the Beqaa region is about 150 m, which is considered the authorized depth as regulated by law. However, many unlicensed wells can be deeper than 150 m (Molle F. et al. 2017). Therefore, 150 m depth was taken as the average to calculate the cost of pumping. According to the FAO study (FAO, 2020), energy consumption for pumping water at 112 m Depth is 1.075 KWh/m^3. This rate was used to extrapolate the cost of pumping from 150 m well depth (Table 17).

Table 17 Energy consumption for pumping water on depth

Well depth (m)	112	150
Consumption for pumping water (KWh/m^3)	1.075	1.44

KWh: kilowatt-hour

Common pump designs in the literature show that the consumption is 0.333 Liter of diesel/KWhr (Choueiri et al., 2022). For the case of Ablah with an average of 150 m depth, the diesel consumption will be:

1.44 kWhr/m^3 * 0.333 Liter = 0.48 Liter of diesel/m^3 of water pumped from groundwater in Ablah. The diesel cost in Lebanon is 800,000 LBP (at the time of writing this thesis) for each tank (20 liter), which corresponds to 40,000 LBP/liter of diesel. The cost of pumping 1 m^3 of water from a 150 m depth well will then be:

0.48 liter/m^3 * 40,000 LBP = 19,200 LBP/m^3 = (0.48$ on rate of 39,000 LBP for 1$)

This is almost 2.5 times the cost of water from the treatment plant which is about 7,500 LBP/m^3. So, the farmers see the benefit of using treated wastewater compared to pumping from their wells.

4.6 Economic feasibility of doing supplemental irrigation for cereals using groundwater and TWW

In the improved scenarios, the use of supplemental irrigation for cereals to improve productivity was recommended. However, the farmers will only select this option if it is economical for them. So, the cost of pumping of the additional recommended supplemental irrigation was calculated to determine whether it is economically feasible, especially after knowing the difference between the cost of pumping groundwater and TWW.

On the other hand, an estimation of the potential increase in yield was calculated using Dorenbos and Kassam (1979) equation which describes the potential yield increase with additional water additions up to a maximum level. The potential yield (Table 18) is the maximum attainable yield which corresponds to a maximum ET (ETm).

Table 18 Potential yield of cereals with supplemental irrigation using groundwater.

	Potential Yield Ym (ton/ha)	**ETm m^3**	**ETa m^3**	**Ya (ton/ha)**
Irrigated	8.00	5,592	5,592	8.00
Rainfed	8.00	5,592	2,957	5.35
One supplemental irrigation event of 500 m^3/ha)	8.00	5,592	3,457	5.71
Two supplemental irrigations events of 500 m^3/ha each	8.00	5,592	3,957	6.12
Three supplemental irrigation events of 500 m^3/ha each	8.00	5,592	4,457	6.59

Ym: Potential Yield, ETm: Maximum water requirement, ETa: Actual water requirement, Ya: Actual yield

For supplementary irrigation of cereals using groundwater, Table (18) shows the increase in grain yields for each supplemental irrigation of groundwater. To determine whether this increase is economically feasible, the cost of irrigation was calculated to add to the returns by calculating the pumping cost for each supplemental irrigation event and calculating the return due to adding this supplemental irrigation. It is clear from Table (19) that supplemental irrigation of 500 m^3/ha is not profitable for farmers because the cost of pumping groundwater will be higher than the price of additional return. In the case of two or three supplemental irrigation events, the extra return will also be unprofitable to increase the cost of pumping. Therefore, supplementary irrigation of wheat with groundwater will be unprofitable for farmers. The more times supplemental irrigation increases, the more water costs will increase, which increases the losses to the farmer.

Table 19 Cost of irrigation extra yield/tons of supplement irrigation using groundwater.

	Cost of irrigation (groundwater) (USD)	**Extra Yield (tons)**	**Price/ton (USD)**	**Extra Revenue (from increased yield)**	**Net profit for farmers (USD)**
Rainfed wheat	0	0	450	0	0
Supplemental (1 irrigation of 500m^3/ha)	243.59	0.36	450	233.2	-82.2 Less profit
Supplemental (2irrigations of 500 m^3/ha each)	487.18	0.77	450	499.8	-141.2 Less profit
Supplemental (3 irrigation of 500m^3/ha each)	730.77	1.24	450	807.8	-171.6 Less profit

However, recalculating the cost of using TWW in supplement irrigation for extra cereal yield, Table (20), shows that the value of the profit that the farmer would earn from doing one supplemental irrigation would be much higher than the value of the profit that would be gained from performing three supplemental irrigations with groundwater (Table 19). If supplemental irrigation is conducted using TWW, the yield will be greater for the farmer, and more groundwater will be saved. Thus, groundwater will be preserved, and more profit will be made if the farmer conducts two or three supplemental irrigations using TWW.

Table 19 Cost of irrigation extra yield/tons of supplement irrigation using TWW.

	Cost of irrigation (TWW) (USD)	**Extra Yield (tons)**	**Price/ton (USD)**	**Extra Revenue (from increased yield)**	**Net profit for farmers (USD)**
Rainfed wheat	0	0	450	0	0
Supplemental (1 irrigation of 500m^3/ha)	96.15	0.36	450	233.2	65.3
Supplemental (2 irrigations of 500 m^3/ha each)	192.31	0.77	450	499.8	153.7
Supplemental (3 irrigation of 500m^3/ha each)	288.46	1.24	450	807.8	270.8

4.7 Comparison Cost of Irrigation Grapes with TWW and Groundwater

The proposed plan to improve some management aspects of the use of TWW as an alternative source not only contributes to alleviating stress on groundwater but also use of TWW in irrigation reduces the cost burden of pumping groundwater on the farmer who suffered from many challenges and difficulties since the outbreak of the economic crisis.

After calculating the cost of groundwater and TWW and conducting an economic assessment of the cost of supplementary wheat irrigation, a comparison was made to the cost of grape irrigation, especially since it is done using both groundwater and TWW in Ablah. Based on the cost of a cubic meter of TWW and groundwater, the profit was balanced between hectares of grapes irrigated with TWW and hectares of grapes irrigated with groundwater using the potential yield per hectare. Table (21) shows that using TWW instead of groundwater pumping to irrigate grapes will increase the profit of the farmers by about 1,371$/ ha. The profit difference (1,371$) between the hectare of grapes irrigated by TWW and the hectare irrigated by groundwater is an immense value considering the area of grapes that TWW can irrigate. It should be noted here that the yield was assumed to be the same regardless of the water source, however, this might not be necessarily correct; It is possible that the nutrient rich TWW could potentially increase yield or, if the quality of the water is low (e.g., high salinity) it could decrease yield. Therefore, this exercise assumes that the quality of the TWW is good enough not to impart a negative impact on yield.

As we mentioned before, the Ablah plant can irrigate about 76 ha of grapes after implementing the proposed plan that will correspond to the improved agriculture scenario. In other words, if we multiply the extra profit per hectare (1,371$) of TWW irrigated grapes by 76 ha, the result will be 105,000 $; this means extra profit due to the low cost of irrigation with TWW. Thus, increasing the amount of TWW and using it effectively according to the plan that has been suggested will increase the profit of the farmer, reduce the tension on groundwater, and improve food security.

Table 20 Comparison cost of irrigation grapes with TWW and groundwater water.

	Yield/ In tons	Price/ton (USD)	Revenue / ha (USD)	Price of irrigation /ha (USD)	Net profit for farmers /USD
Grapes irrigated (TWW)	25	256.41	6,410.3	894	5,515
Grapes irrigated (groundwater)	25	256.41	6,410.3	2,266	4,144
Extra profit if using TWW	-	-	-	-	1,371

3.8 Testing Economic Feasibility of The Updated Crop Pattern

In the improved agricultural scenario presented by this study, the water demand was reduced while maintaining the economic feasibility from the market point of view. However, there may be scenarios of crop patterns that demand less water but are not economically feasible and could lead to some farmer losses. If we assume that we will replace the peach and apricot crops with grape crops in the Ablah crop pattern because grapes have a smaller water demand, we will save more than 100,000 m^3 of water demand compared to the improved scenario.

However, such a change is not feasible for farmers; a calculation of the yield and economic viability of peaches showed that peaches will be more profitable, than grapes and replacing them with grapes will save water, but it will cause financial losses to the farmer. In Table (22), the financial yield of grapes and peaches per hectare was calculated, and it was found that peaches are more than twice as profitable as grapes. Also, it was calculated how much water could be saved by replacing peaches and apricots with grapes, along with the pumping cost of this water, which amounted to 304$/ha; this is a much lower value when compared to the profit that the farmer earns from apricot and peach cultivation. Accordingly, this scenario is not feasible although it is saving water because the farmer will lose 8,669 USD if they want to save 626 m^3/ha. Thus, economic feasibility must be considered when changing any cropping pattern, even if this scenario saves water.

Table 21 Testing economic feasibility on change crop pattern

	Yield	**Price/ton (USD)**	**Revenue / ha**
Grapes (irrigated)	25	256.4	6,410.3
Peach	40	384.6	15,384.6
Extra cost of irrigating peach compared to grapes (USD)			
Qty (m3)	626		
Cost USD / m3	0.49		
Saving cost of pumping	304.9		
Loss profit for farmers	8,669.5		

CHAPTER 5

DISCUSSION

5.1 Analysis of Water Supply and Water Demand in Ablah Under Different Scenarios

This study sought to assess the potential of treated wastewater as an alternative source for irrigation, relieving pressure on freshwater resources and improving crop productivity under IAS and climate change scenarios. The beginning was by building an evaluation of the current water supply, knowing its sources, and determining the capacity of groundwater and TWW in the Ablah agricultural plain.

The water requirements for crops currently grown in the Ablah area under the current scenario were calculated, which reached 1,124,608 m^3; this number presents two indications. First, determining the water requirements of crops serves as a key to calculating future water needs and planning for water resource management in light of climate change pathways with changing evapotranspiration (ET0) and temperatures. Second, groundwater represents 88% of the water supply, while TWW represents 12%, as shown in (Table 13), which means there is great pressure on groundwater and presents a potential for increasing the reuse of TWW for irrigation.

During a study conducted by the International Water Management Institute (IWMI) in Ablah (Eid-Sabbagh et al. 2022), it was shown that many farmers faced a decrease in the productivity of wells and a water shortage, especially during the irrigation season. Moreover, the farmers stated that the wells stop pumping at the beginning of August (Eid-Sabbagh et al. 2022), whereas the irrigation season for the grape crop, which is the prominent crop in Ablah, extends between June and end of August. This water stress is one of the most exacerbating problems in the Middle East

(Joffe, 2016) and is going to have a bigger impact as climate change effects set in. Most of the farmers in central Beqaa tend towards irrigated agriculture, with a percentage of 82% which has resulted in a drop in the groundwater level by more than 15 meters in the past five years alone (Jaafar and Ahmad 2020). However, under the climate change scenarios with a decrease in precipitation by (10%) and (20%) in the moderate and severe scenarios, respectively, farmers will inevitably face greater pressure and further decrease in the productivity of the wells in Ablah.

In general, many agricultural families in the Ablah region and the Beqaa are beginning to feel the negative effects of climate change on their livelihoods. This is consistent with Al Dirani et al. (2021) study to explore climate change adaptation practices and family food security in central Beqaa. Many farmers expressed their increasing concern about the depletion of groundwater and its inability to fill the gap in the water needs of their crops (Al Dirani et al., 2021), and this is also reflected in the agriculture situation in Ablah. Some farmers switched from growing grapes to seasonal crops that have shorter growing periods, such as vegetables and grains (personal communication with the operator of Ablah WWTP).

Therefore, during the preparation for this study and from several discussions with stakeholders in this field, it became clear that there was a need for some new measures to be taken in agricultural practices to reduce the water demand and improve irrigation efficiency which was explored in this study as the improved agricultural scenario. The IAS is based on the suggested plan prepared through this study to improve the management of the Ablah plant and increase the percentage of TWW in irrigation.

The suggested plan depends on several steps. The WWTP will benefit from the installation of a solar system for electricity generation to help reduce its operational costs. This solar system could possibly be donated or funded through NGOs that support community development in Lebanon. After that, the plant will pump water for irrigation with its originally designed operational capacity through the existing irrigation network. The amount of water that can be provided to farmers is 136,000 m^3 per season delivered to 30 farmers. A new price for the TWW will need to be set to enable the plant to cover its costs in the future. After discussions with the WWTP manager, who provided his estimates for a fair price based on costs of operation and maintenance, a value of 0.18$/$m^3$ for treated wastewater from Ablah was suggested and used for this analysis (section 4.6.1). During one season, the plant will earn 24,500$, enabling it to expand the network to a larger number of farmers.

Eventually after several seasons, the plant will be able to purchase new land to construct a new water storage tank with a capacity of greater than before. In the advanced stage, after expanding the network and expanding the water tank, 300,000 m^3 of treated water will be used instead of being discharged into the river without benefit, especially during the irrigation season. On the other hand, the flexibility of this methodology will be maintained so that this framework can be applied to other wastewater treatment plants that are similar to Ablah.

The proposed improved agricultural scenario resulted in reducing crop water requirements to 1,084,155 m^3, improving the water balance and pushing it positively to fill the water shortage gap. It presents an opportunity to reduce pressure on groundwater and increase the contribution of TWW to irrigation to 28% instead of 12% in the current scenario. If the IAS is followed, there will not be a water deficit in the climate change scenarios compared to the current water demand. In the moderate scenario, the water balance will remain positive while saving 204,453 - 146,199= 58,254 m^3. In the extreme scenario, we may face a deficit of about 204,453 - 292,398 = 87, 945 m^3, and this deficit can be met from the reservoir of TWW that will be built later based on the proposed plan. This means that by sustainably using TWW as a source of irrigation and improving the efficiency of the network, we can maintain food production without being affected by climate change conditions.

5.2 Economic Assessment as a Drive for The Reuse of Treated Wastewater in Irrigation

The financial analysis results in this study showed that the cost of a cubic meter of TWW was $0.18, compared to $0.48 for pumping one m^3 of groundwater. Although the cost of TWW is cheaper than groundwater, this result cannot be generalized due to higher energy cost in Lebanon. Contrary to this study, a study in the Souss Massa region of Morocco showed that the cost of groundwater is lower than that of TWW (0.15 Euro/m^3 and 0.23 Euro/m^3 for groundwater and TWW, respectively (Oubelkacem et al., 2020). Due to groundwater water availability in the study area (Souss Massa), the farmers did not have the motive to use TWW, but they may have to resort to using TWW in case of groundwater shortage or excessive effects of climate change.

On the other hand, a study in Jordan (Alfarra, A. et al., 2013) showed that farmers demand to use TWW due to the scarcity of groundwater, although its cost is more expensive than the cost of groundwater. Another study in western Iran found an equal cost of TWW and groundwater (Deh-Haghi, et al., 2020). Farmers prefer to reduce the cost of TWW as they consider the price of water as one of the most important factors that encourages them to use TWW. Therefore, the cost price of TWW varies from one case to another and from one region to another according to the type of treatment, the location of the plant in relation to agricultural lands and operating and maintenance costs and the availability of freshwater resources.

The case of farmers in the Iran study (Deh-Haghi, et al., 2020) can be taken as evidence that farmers are willing to pay a lower price for TWW than for fresh water. The price of TWW can be considered the most important factor that affects users' willingness to use TWW. Although many farmers have a perception of the scarcity of natural water sources, capital factors, and returns are the basis for the farmer. Therefore, switching to using and paying for TWW requires high service levels and reliability of the supply irrigation system.

Compared to these three cases from the literature, Ablah is more encouraging to use TWW for two reasons. The first is that TWW is less expensive and more profitable for the farmer. The second factor is water stress and the lack of groundwater. Assuming that the cost of pumping has changed, and groundwater has become less than TWW in the Ablah, farmers will tend to pay the cost and use TWW as an alternative source because of the lack of groundwater, as in the case scenario of Jordan.

Calculating the cost of irrigation and extra yield/ton of supplement irrigation of wheat using groundwater and performing supplemental irrigation over one, two, or three events was shown to be not economically feasible due to the high cost of pumping and the high energy prices that are no longer commensurate with wheat prices.

Other factors such as labor, cost of planting, and seeds were considered fixed in this study, and one variable was calculated: the cost of irrigation water. Therefore, it is advised not to carry out any supplemental irrigation of wheat using groundwater and to keep under rainfed cultivation. Otherwise, having access to TWW water offers value in using any number of supplement irrigation events which will be profitable for farmers to increase the yield with a low cost of irrigation.

As for the grapes, using TWW contributed to an increase in the farmer's profit by 1371$/ ha. This figure has important implications and is considered a driver for increasing the amount of TWW used in irrigation and expanding the network according to the plan proposed in this study. As I mentioned, the Ablah WWTP can support the irrigation of 76 hectares instead of the current coverage of 28 hectares, an increase of 48 hectares of grapes, after implementing the proposed plan.

The results obtained through the economic and financial assessment of using TWW in irrigation and comparing it with the cost of pumping groundwater had significant implications. After finding the water needs for current and future scenarios, it was necessary to integrate the economic and cost inputs for groundwater use and treatment. Combining agricultural data with economical cost and returns provided a clear vision that served as a driver for exploiting this water resource to support groundwater for irrigation. However, the environmental benefits cannot be overlooked although there are no straightforward methods to calculate or assess the economic benefits of the environmental effects. These environmental benefits would add to the value of saving fresh water through using TWW. The inclusion of an environmental assessment and other factors that account for interactions across sectors beyond agriculture can be assessed by a holistic assessment such as a WEF Nexus. Farmers might not be incentivized to use TWW just for its environmental benefits, but this could be a consideration for governmental plans to take into consideration when managing national water resources. Most of the new research directions should focus on using environmental efficiency analysis by integrating environmental and economic aspects which giving impetus to the sustainability performance of treated wastewater reuse projects (Canaj et al., 2021).

On the other hand, based on the Lebanese guidelines proposed in the FAO report (FAO, 2011) for the specifications of wastewater reused for irrigation, three classifications were developed, from most to least restrictive, based on the amount of chemical and biological contaminants allowed in each category. Cereals were placed in the third classification that meet the criteria: Secondary treatment plus a few days' storage or Oxidation Pond systems (Cellamare et al., 2016), regarding the quality of TWW that can be used for irrigation.

Based on the literature review, many studies tested the TWW quality in Ablah. Abi Saab (2021) tested the quality of Ablah TWW and placed it in the second category in 2020 when the Ablah WWTP was using chlorination to disinfect the treated water. Through an interview with the plant manager, it was found that due to the economic crisis, the plant can no longer carry out the disinfection process, so that the water quality may have decreased since then. However, cereal is in the third classification and can still be irrigated with this quality of TWW. To restart disinfection operations to raise water quality, the suggested plan must be implemented to improve the plant's management and obtain self-financing in light of the current economic and administrative conditions. Also, increasing the amount of TWW according to the suggested plan will contribute to improving the percentage of irrigated wheat to more than 33%, which will contribute to increasing the farmer's financial return.

5.3 Ablah Case Study as an example of the Framework application to Apply on another WWTPs

The results demonstrated that TWW has the potential to impact irrigation water supply and support groundwater to meet water needs. As previously mentioned, the improved agricultural scenario raised the TWW contribution from 12% to 28%, and the percentage could reach 35% in other WWTPs.

The ability of TWW to support groundwater for irrigation depends on several factors that can be inferred from the Ablah case study. These factors are, first, the presence of a dependable and reliable irrigation system. This reliability includes ensuring the maintenance of the irrigation network and adhering to the specific irrigation schedule and quantity agreed upon for each farmer. Secondly, water quality is one of the most critical factors determining the extent of expansion and sustainability of using TWW projects to irrigate crops. Third, the appropriate economic cost encourages farmers to use TWW and pay for it.

Based on the results of the framework followed in Ablah, it is possible to assume ranges for the percentage of TWW in irrigation water under the current and climate change scenarios. In Ablah, 12% was considered the minimum, and 30% was considered the maximum TWW in irrigation. As for the Zahle region and the WWT facility there, the ranges for the TWW percentage in irrigation are not necessarily similar to Ablah but may be more. This relates to the operational capacity of the station, which is larger in Zahle, the type of crops, and the irrigation networks.

The Ablah WWT plant is considered the only plant in the Beqaa whose treated water is reused in grape irrigation, while the rest of the WWTPs discharge their treated water into the Litani River. This situation gives great value to studying and assessing the economic feasibility of using TWW in Ablah. Applying the framework proposed by the study to the rest of WWTP achieves a type of sustainable irrigation management (TWW) and is more resistant to climate change.

For example, the Zahle plant operates a tertiary treatment system with a capacity of 25,000 to 28,000 m^3/day with a potential irrigation capacity of 572 ha (Eid-Sabbagh, et al .2022). However, until now, this treated water has not been used for irrigation in Zahle due to difficulties in management, governance, and some political issues and considerations. Thus, political, economic, and administrative factors are among the most important reasons for the success of treated wastewater reuse projects in Lebanon. Unfortunately, governmental laws and regulations are currently not available to guide the management and reuse of TWW in irrigation.

Although the Ablah WWTP needs to be restructured in management through the suggested plan, it was considered one of the successful TWW projects. The case of Ablah and the methodology adopted in this study represent research that can be expanded as it can be an example and a framework that can be applied and improved to other studies in the Beqaa Valley. Based on the economic benefits of the wastewater reuse system and the lack of fresh irrigation water in Ablah and generally in the Beqaa Valley, there is an urgent need to implement the improved scenario and plan which is proposed in this study for the development and rehabilitation of the WWTP project. Taking these measures will lead to the sustainable utilization of this vital resource and support the agricultural community of Ablah in response to the repercussions of climate change, whose impact on freshwater resources is evident.

CHAPTER 6

CONCLUSION

This study sought to evaluate the ability of treated wastewater to be a supportive source of fresh irrigation water and an alternative solution under climate change scenarios. Through a case study of Ablah, the results proved that TWW is an important source and a significant opportunity that must be exploited and developed to meet the demand for water and address the problems of irrigation water shortage in Beqaa.

Calculating the water requirements of crops through the crop coefficient (Kc) and crop evaporation (ET0) is one of the essential tools and foundations for planning and managing irrigation water. Determining the demand and water supplies for crops in Ablah in terms of quantity and source of water was the primary data needed to manage water resources, identify shortages and gaps, and build future scenarios for water requirements in light of climate changes. The improved scenario pushed the water balance towards equilibrium by relieving pressure on withdrawals from groundwater and raising the capacity of the TWW to share a more significant percentage of the irrigation water. In addition to improving the water balance in Ablah, it was necessary to introduce financial aspects and economic assessment to calculate the cost of using treated groundwater from the farmer's point of view.

The study provided evidence that planning in the qualitative and quantitative aspects of TWW reuse in irrigation will not be accurate unless the economic and cost factors are introduced to the farms. Studies based on linking water prices and costs to farmers with quantity and quality are among the scarce studies in Lebanon. Therefore, end users of this water resource must be provided with knowledge and understanding of the cost, benefits, and harms associated with using TWW for irrigation.

The study proved that wheat irrigated with groundwater has become unprofitable because of the high pumping costs and the lack of government support for farmers. On the other hand, supplementary irrigation of wheat with TWW water can be profitable. This is considered an important factor in pushing stakeholders to improve and support projects for reusing treated water and encouraging farmers to plant this strategic crop in light of the economic crisis. Irrigating grapes with TWW water is more profitable for the farmer, and this is an additional incentive to expand TWW irrigation networks and introduce new farmers in Ablah.

The results of this study reflect the implications for the role of governance and local politics in making water resources sustainable. Implementing the improved scenario and the proposed plan to restructure the plant management and expand the irrigation network in Ablah requires an administrative, political, and economical approach by those concerned; this approach makes TWW easier and according to standards that are in the interest of farmers in the first place without other considerations.

As for some of the challenges and issues related to this research, there were very few studies conducted in this region on improving the water balance and required data was sometimes unavailable, especially on the subject of investment in infrastructure and irrigation systems.

Regarding the economic feasibility, the study was limited to calculating the cost of water without a comprehensive economic feasibility procedure, including investment and project processing costs. It should be noted that the data on water cost and crop prices used in the economic assessment was calculated based on current market prices in Lebanon. Consequently, the results and numbers may change according to several circumstances, including political ones at the governmental and administrative level and economic ones regarding the dollar exchange rate against the Lebanese pound.

On the other hand, the research can be expanded to address the study of treated wastewater reuse by including economic, environmental, and social analysis and their interactions. Such studies can be challenging but give important results for the sustainability of treated wastewater projects and the development of food production in Beqaa. Also, we must not forget the importance of governance and water resource management in such studies. It was clear from restructuring the management of Ablah WWT plant the significant impact of governance on the success and reliability of treated wastewater reuse projects and their sustainability. Still, due to time constraints and the difficulty of obtaining such data, these aspects were not widely included in this research. As a final note, the study provided some recommendations:

1. Conducting more studies that include a full assessment of the economic, environmental, and social aspects of treated wastewater reuse projects is the best approach for the sustainability of these projects.
2. Reusing TWW in irrigation needs permanent monitoring of water quality and measuring the impact on irrigated crops to ensure food quality.
3. The data availability would be one of the most important things that need to be developed in the future if similar studies are to be of value and effective.

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