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TREATED WASTEWATER REUSE FOR IRRIGATION IN BEKAA, LEBANON: QUALITY ASSESSMENT AND PUBLIC PERCEPTION

by
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ABSTRACT
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In Lebanon, agriculture consumes 61% of the freshwater resources. In this sector, an estimated water supply-demand gap of 25% in 2020 is predicted to increase with the elevated and unmet water demand and the exacerbating pressure on the water supply. Despite having negligible, unregulated, and challenging water reuse practices, treated wastewater (TWW) is among the alternative water sources for irrigation to increase water availability and reduce the pressure on freshwater resources. However, its safe quality is of utmost concern and a prerequisite for water reuse, including farmers' and consumers' acceptability of this safe practice. Therefore, this study aims to determine the willingness of farmers in Zahle and Ablah, located in two water-scarce agricultural villages in the Bekaa governorate of Lebanon, and consumers from the general Lebanese communities toward safe TWW reuse in agriculture. It further characterizes the quality of TWW effluent from the Ablah and Zahle wastewater treatment plants (WWTPs) for reuse in irrigation to evaluate their environmental and public health risks.

The results revealed that farmers in Zahle and Ablah, potential beneficiaries of the Zahle and Ablah WWTPs, and consumers from the general Lebanese population aged 18 years and above have a very high willingness to safely use (32/34 farmers) and accept the safe usage (245/256 consumers) of TWW for irrigation. Farmers' acceptance was incentivized by the economic benefits of safe reuse, while the consumers mostly care about the environmental benefits of this safe practice. Statistical analysis showed that the economic incentive to increase agricultural yield and environmental incentive to reduce water scarcity in Lebanon significantly increased the willingness of consumers to accept the irrigation of crops that have the lowest health risk category (WTU1) with safe TWW. Their perception of the lack of sustainable access to sufficient freshwater significantly increased the consumers' acceptance of the irrigation of crops with an increased health risk (WTU2). As for their willingness to accept safe reuse for the highest health risk crops (WTU3), it was significantly correlated with their knowledge that safe TWW conserves fresh potable water.

The main barrier hindering safe water reuse among farmers and consumers is their lack of trust in the authorities in Lebanon to ensure safe quality effluents. This perception matches the reality due to the very restrictive and inconsistent quality effluent of the Zahle and Ablah WWTPs. Based on a 6-month monitoring period (Jan-March and June-August 2022), the quality was found to be only suitable to irrigate Category III crops with the highest degree of restriction. This restriction and variability are mainly influenced by

chronic poor governance and the national economic crisis. Despite this severe restriction, some farmers in Zahle and Ablah are irrigating their crops with these water outlets irrespective of the guidelines. Farmers in Bekaa and across Lebanon are also indirect users of wastewater from the 70 to 75% of the national generated WW discharged untreated into water bodies. Hence, some farmers are not fully aware of the actual risks of irrigating with unsafe TWW or even WW (whether direct or indirect irrigation), but they also might not have another alternative because of the worsened water security issues. A major implementation barrier for safe water reuse in Lebanon identified in this study is the gap between the reality, in terms of the unsafe quality of TWW for reuse, the lack of trust in the authorities in ensuring its safety for irrigation, and weak law enforcement for safe discharge of TWW in surface water bodies, and the goal of an integrated WW treatment and safe reuse practices in agriculture.

On the other hand, TWW remains a sustainable alternative that can contribute to bridging the water gap in agriculture, among other interventions. The Zahle and Ablah effluents can be improved in quality to match the intended design abilities and capacities of the treatment plants upon improvement of the general economic and financial situation in the country or through donor support to allow normal operation and maintenance. Some technical recommendations are also proposed in this thesis, to be decided on upon further monitoring and investigation, complemented by some suggested recommendations at the irrigation level to mitigate the risks of a restrictive TWW quality based on the improved quality of the effluent. Most importantly, water reuse projects need to be regulated and enforced by a national policy and standards for TWWR. The Lebanese Standards Institution (LIBNOR) is currently developing those standards based on the FAO draft Lebanese guidelines. A water strategy addressing water reuse management and quality control is fundamental, along with developing effective and appropriate communication mechanisms. To strengthen the trust in the authorities, these initiatives should be based on a transparent and accountable participatory approach from the earliest stages and throughout the entire decision-making process. Lastly, customized awareness raising can further promote safe water reuse in agriculture. This thesis established the groundwork for a more in-depth investigation of water reuse management and implementation and shed some light on current problems of wastewater reuse in irrigation.

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ABBREVIATIONS

APHA – American Public Health Association
BOD5 – Biological Oxygen Demand
CFU – Colony Forming Unit
COD – Chemical Oxygen Demand
dS/m – Deci-Siemen per meter
EC – Electric Conductivity
FAO – Food and Agriculture Organization
IRB – Institutional Review Board
IWRM – Integrated Water Resource Management
LARI – Lebanese Agricultural Research Institute
LIBNOR – Lebanese Standards Institution
LL – Lebanese Lira
MENA – Middle East and North Africa
NWSSU – National Water Sector Strategy Update
OR – Odd Ratio
SAR – Sodium Adsorption Ratio
TDS – Total Dissolved Solids
TSS – Total Suspended Solids
TWW – Treated Wastewater
TWWR – Treated Wastewater Reuse
VIF – Variance Inflation Factor
WHO – World Health Organization
WTU – Willingness to Use (for WTU1, WTU2, and WTU3 check Appendix I)
WW – Wastewater
WWTP – Wastewater Treatment Plant
μS/cm – Micro Siemen per centimeter

CHAPTER I

INTRODUCTION

Globally, water scarcity is worsening as the world's population grows, the economy develops, technology advances, per capita consumption rises, and urbanization rapidly expands (Massoud et al., 2018). In addition to the increase in water demand, the available water supply is under further pressure from climate change impacts and inadequate water management, including the deteriorating water quality and overexploitation of the available freshwater resources, especially in areas of fragility, conflict, and violence (IWMI, 2021b). According to the United Nations (UN) - Water (2021), water-stressed countries inhabit 2.3 billion people, with 733 million living in severely critical water-stressed areas. Similarly, the United Nations International Children's Emergency Fund (UNICEF) estimates that 1.42 billion people, including 450 million children, reside in high or extremely high-water vulnerability conditions (UNICEF, 2021a). The agricultural sector is the largest consumer of freshwater resources, where an average of 72% of global water withdrawals are dedicated to irrigation (UN-Water, 2021). Agricultural water consumption is predicted to increase due to several factors, including drought, agricultural intensification, and expansion of irrigated lands (Michetti et al., 2019). The Food and Agriculture Organization (FAO) estimates that 3.2 billion people live in high to extremely high-water scarce agriculture areas, of whom 1.2 billion reside in heavily water-restricted agricultural regions, nearly one-sixth of the global population (FAO, 2020). From the 50% projected increase in irrigated food production by 2050, only a 10% increase in water can be further withdrawn by agriculture, assuming that irrigation efficiencies improve and yields rise (FAO, 2017). Consequently, proper integrated water resource management (IWRM) is required to manage our water resources effectively and sustainably (Hamdan et al., 2021). In particular, treated wastewater reuse (TWWR) (also referred to as water reuse or wastewater reuse) is suggested among the alternative water sources, along with other interventions (such as increasing irrigation efficiency), to achieve a sustainable, climate-smart, and resilient agricultural system. The use of treated wastewater (TWW) increases water availability and reduces the pressure on freshwater resources used for irrigation, while decreasing the amount of wastewater discharged into the environment (Hamdan et al., 2021).

The Middle East and North Africa (MENA) region is widely acknowledged as the most water-scarce region in the world. Despite accounting for 5% of the global population, its total renewable water supply is only 1% of the water available globally (Antonelli et al., 2017). In Lebanon, our case study in the MENA region, water availability is under stress from inadequate management, exacerbated by the projected climate change-induced hydrological changes (ICRC, 2021). Climate projections anticipate the prevailing of longer and geographically expanded drought periods, mostly affecting Bekaa, Hermel, and the South (INDC, 2015). Over 71% of Lebanese residents, equivalent to more than four million people, including one million refugees, are at risk of losing access to a sufficient and safe water source (UNICEF, 2021b). Additionally, the water crisis is exacerbated by the escalating economic crisis along with the lack of funding, fuel, infrastructure, and needed supplies (such as maintenance equipment, including chlorine and spare parts) (UNICEF, 2021b).

Agriculture in Lebanon consumes, on average, around 61% of the total water usage (FAO, 2020), which is hindering the domestic use of freshwater (30%) (FAO, 2016). In 2020, the National Water Sector Strategy Update (NWSSU) estimated the total irrigation water demand at 879 million m^3/year, with 595 million m^3/year in the Bekaa, 215 million m^3/year in the North, 37 million m^3/year in Mount Lebanon, and 31 million m^3 in the South. The report also identifies a 25% gap between irrigation water demand and current use. According to this estimate, only 660 million m^3/year are currently used in agriculture, equally divided between groundwater and surface water (IWMI, 2021a). This gap is not only caused by water availability issues. It is also associated with conflicts over water use and rights, competition between domestic and agricultural use, intensive well drilling for irrigation, poor irrigation infrastructure, and degradation of water quality (IWMI, 2021a). This supply-demand gap is predicted to increase with the unmet and elevated water demand and the exacerbating pressure on the freshwater supply (IWMI, 2021a).

In the Middle East, water scarcity has necessitated water reuse for agricultural irrigation in many countries (Craddock et al., 2021), where integrated wastewater treatment and reuse programs are lacking. In Lebanon, the total volume of wastewater generated ranges between 273.75 and 328.5 million m^3 per year, assuming that the current population is around 5 to 6 million inhabitants (IWMI, 2021a). In contrast, only 25% to 30% of the national generated wastewater is treated (81.2 million m^3/year) (IWMI, 2021a). In 2012, the National Strategy for the Wastewater Sector reported that the majority of the existent 166 WWTPs in Lebanon are either non-operational or not working efficiently. Among the 166 plants, 60 small WWTPs are managed by local municipalities with an unclear operation status (FAO, 2016). Given the lack of enough functional wastewater treatment plants (WWTPs) and adequate wastewater discharge infrastructure, untreated sewage infiltrates groundwater aquifers and reaches surface water bodies to be indirectly used for agriculture. Farmers, unable to meet their water demand, also tend to directly, sometimes unrestrictedly, irrigate with raw wastewater in central Bekaa and other Lebanese agricultural areas without any consideration to its harmful environmental and human health implications (Karam et al., 2013). In 2020, total direct water reuse for irrigation (i.e., TWW used directly for agriculture without an environmental buffer) was negligible (IWMI, 2021a). In addition to the low levels of safe effluent for reuse, national legal/institutional frameworks and standards for TWW reuse are still absent, along with insufficient law enforcement to prevent the discharge of untreated or poorly TWW in water bodies (FAO, 2016). However, Lebanon drafted a reformed decree based on the FAO guidelines for wastewater reuse in its report titled, Wastewater Reuse and Sludge Valorization and Reuse: Proposition for Lebanese Wastewater Reuse Guidelines, 2010. Those guidelines do not allow the irrigation of fresh crops with TWW for raw consumption (LWP/USAID, 2019). Recently, the Lebanese Standards Institution (LIBNOR) has resumed working on developing standards for TWWR based on the FAO recommended guidelines for Lebanon after stopping for a while due to the COVID-19 pandemic.

Despite negligible direct TWW reuse in Lebanon and its numerous challenges, this non-conventional water source can be a sustainable option for water management. Unlike freshwater, farmers could have continuous access to TWW even during drought periods, considering wastewater is increasing with population growth and enhanced living standards, making it economically attractive (Dare, 2014; IWMI, 2021b). Furthermore, TWWR mitigates the environmental, public health, and economic implications of untreated wastewater discharge into surface water bodies or its application for agriculture (Massoud et al., 2018; Hamdan et al., 2021). Several studies have emphasized its benefits in agriculture, such as adequate nutrient provision, a fertilizer alternative, greater energy efficiency, higher food production, and others (Akpan et al., 2020). TWWR for irrigation might also contribute to job creation, hunger alleviation, poverty reduction, and sustainable development (Kwabla, 2017).

The quality of the water effluent is one of the crucial factors affecting the success of sustainable wastewater treatment and reuse projects. While the benefits of water reuse are numerous, failing to ensure safe effluent leads to environmental (such as soil salinization and plant toxicity) and public health risks (occupational and environmental) (Massoud et al., 2018). Hence, attention must be paid to TWW composition to ensure clean and safe use for irrigation (LWP/USAID, 2019). In Lebanon, the Bekaa Valley is the primary agricultural area producing most of the irrigated crops in the country (FAO, 2016). The Bekaa also has several existing and operational WWTPs, including Joubb Jannine, Ablah, Fourzol, and others, with negligible TWWR (KREDO, 2015). However, insufficient studies are available about their updated operational status, treatment efficacy, and water reuse potential for irrigation in terms of the safety of the effluent quality.

Furthermore, in most cases, water reuse projects are designed and implemented based on their technical and financial feasibility (Massoud et al., 2019). However, successful projects significantly depend on the support of farmers (Deh-Haghi et al., 2020) and the public acceptance of TWWR in any given community, along with the factors associated with their decision (Adewumi et al., 2014). Because numerous reuse projects have failed from public opposition, perception studies are necessary to understand people’s willingness to use (WTU) of TWW to promote its safe reuse in agriculture (Adewumi et al., 2014). Unfortunately, the perceived need for water reuse and its level of acceptance is frequently overlooked (Massoud et al., 2019), with only a few in-depth studies in developing countries, including Lebanon (Massoud et al., 2018). Therefore, this study aims to:

(1) Determine the willingness of farmers in the Bekaa governorate of Lebanon, with Zahle and Ablah as case studies, and consumers from the general Lebanese communities toward safe TWWR in agriculture.

(2) Characterize the physical, chemical, and microbiological quality of TWW effluent from the Ablah and Zahle wastewater treatment plants in the Bekaa for reuse in irrigation to evaluate their environmental and public health risks.

CHAPTER II

TREATED WASTEWATER REUSE IN BEKAA, LEBANON, PUBLIC PERCEPTION

A. Introduction

In the Middle East and North Africa (MENA) region, agriculture is the most water-intensive sector, accounting for more than 80% of the average water consumption (UNICEF, 2021). Therefore, many MENA countries, including Lebanon, have increased their efforts to assess and adopt treated wastewater (TWW) reuse to deal with water-related problems in irrigation, where integrated wastewater treatment and reuse programs are lacking. Perceptions and public acceptance of water reuse are recognized as critical elements for the successful implementation of wastewater reuse programs, despite the depth of the scientific evidence supporting this practice (Michetti et al., 2019). However, social and cultural acceptance is often disregarded in the region and, specifically, in Lebanon (Massoud et al., 2019). Therefore, this paper investigates the willingness of (i) farmers in Zahle and Ablah, who are potential beneficiaries of the Zahle and Ablah WWTPs located in two water-scarce agricultural villages in the Bekaa governorate, and (ii) consumers from the general Lebanese communities toward safe TWWR in agriculture. This research aims to identify the factors behind farmers and consumers' acceptance or rejection of the reuse of TWW for irrigating agricultural crops. It also highlights some recommendations that might encourage their acceptance. After providing insights on contributions from the literature on public acceptance of water reuse for irrigation among farmers and consumers (Section B), the method is described (Section C). The results are then presented and discussed in Section D.

Section F provides a conclusion, while section G proposes recommendations, and section H identifies some limitations.

B. Literature Review

The literature of previous studies on public perceptions of TWWR for irrigation shows varying results (Akpan et al., 2020). Numerous studies demonstrated a high WTU of TWW for irrigation. Saliba et al. (2018) revealed that 59% of the farmers and 87% of the residents in the southeastern region of Italy are inclined to apply TWW for agricultural purposes. Similarly, farmers in the West Bank of Palestine stated a high WTU of 75% (Hamdan et al., 2021). According to Abu-Madi et al. (2008a), consumers in Tunisia and Jordan accepted the application of reclaimed wastewater for food products at high levels, 81.7% and 71.5%, respectively. High acceptance was evident among the participants in a study in Ghana, with a rate of 95% in the town of Ashaiman and 92.6% at the University of Ghana (Kwabla, 2017). On the other hand, Dare (2014) and Dare & Mohtar (2018) demonstrated the existence of insufficient economic, environmental, and health-related incentives to reuse TWW in Qatar, the West Bank, and Tunisia among farmers. The acceptance of safe TWWR by farmers and consumers is influenced by various factors: their knowledge, perceived economic costs and benefits, perceived environmental benefits, ethical considerations, perceived availability and accessibility of freshwater, and types of crops that can be irrigated with TWW from a public health perspective (Table 1).

Table 1: Influencing Factors of Farmers and Consumers' Willingness to Use of safe TWW for Irrigation

Influencing Factors	**Farmers and Consumers**	**References**
Knowledge	1. Knowledge about TWW and its reuse in agriculture, the benefits and need for this practice, and its potential impacts. 2. The understanding of wastewater treatment processes and effluent quality.	Hamdan et al., (2021) and Kwabla (2017)
	Perceived knowledge about TWWR.	Menegaki et al., (2007)
Economic Incentives (mainly for farmers)	The price of TWW compared to freshwater.	Dare & Mohtar (2018) and Hamdan et al., (2021)
	The demand for crops irrigated with TWW, determined by the willingness of consumers to buy and consume such crops.	Hamdan et al., (2021)
	The perceived benefit of TWWR in reducing irrigation and fertilizer costs.	Saliba et al., (2018), Dare & Mohtar (2018), and Hamdan et al., (2021)
	The perceived benefit of TWWR in increasing agricultural yield of better quality, thus higher sales.	Mahjoub et al., (2018) and Deh-Haghi et al., (2020)
Environmental Incentives	The perceived benefit of TWWR in reducing the national water scarcity problem.	Mahjoub et al., (2018), Menegaki et al., (2007), and Saliba et al., (2018)
	The perceived benefit of TWWR in reducing synthetic fertilizer inputs.	Dare & Mohtar (2018) and Mahjoub et al., (2018)
	The perceived benefit of TWWR in ensuring pollution reduction and environmental protection.	Dare & Mohtar (2018) and Saliba et al., (2018)
Ethical Considerations	The trust in the local authorities (ministers, agencies, governmental levels, private organizations, etc.) to effectively operate, monitor, and manage WWTPs and deliver a safe TWW effluent for agriculture.	Dare & Mohtar (2018) and Terkawi (2016)
	The fairness of TWW distribution to farmers without biases and discrimination.	Terkawi (2016)

Perceived Availability and Accessibility of Freshwater	The perception of whether access to safe freshwater is sufficient and sustainable for the farmers.	Menegaki et al., (2007), Saliba et al., (2018), Mahjoub et al., (2018), and Adewumi et al., (2010)
Types of crops from a public health perspective	From a public health perspective, farmers and consumers mostly prefer irrigating crops of category 1 with the lowest health risk, followed by category 2 with an increased risk, then category 3 with the highest risk.	Michetti et al., (2019), Saliba et al., (2018), Kwabla (2017), and Deh-Haghi et al., (2021).

1. Knowledge of Farmers and Consumers

Results from quantitative studies found a positive association between the level of awareness of farmers and the general public, in terms of environmental knowledge and actions, and their WTU of TWW (Abu-Madi et al., 2008b; Deh-Haghi et al., 2020; Saliba et al., 2018). In Palestine, Hamdan et al. (2021) found that farmers were highly interested in and affected by scientific information originating from professional reports and studies (83.1%), direct communication of experts through seminars, lectures, and workshops (82.8%), and the media (such as radio, television, and newspapers) (81.5%). These variables showed a significant relation ($p < 0.05$) with farmers' WTU considering their important role in communicating environmental information, raising awareness about TWW, and promoting freshwater conservation. More specifically, the probability of accepting water reuse is higher when producers exhibit knowledge and understanding of the concept of TWW, its benefits, and its need for irrigation, along with its regulatory framework (Hamdan et al., 2021). Similarly, in Greece, the enhanced environmental consciousness of farmers from engaging in environmentally beneficial actions made them more accepting of irrigating their tomatoes with tertiary TWW. Environmentally responsible citizens, who perceive themselves as more informed about and involved in environmental matters and consider water shortage a highly significant environmental problem, were generally inclined to buy and consume those tomatoes (Menegaki et al., 2007). Lastly, in Ghana, public knowledge and awareness of the wastewater treatment process and effluent quality was a significant positive determinant of the public's willingness to allow the irrigation of crops with TWW. The latter was manifested in most participants, 80.8% at the University of Ghana and 60.9% in Ashaiman (Kwabla, 2017).

2. *Economic Factors*

Economic benefits are the main reasons driving water reuse in agriculture among producers (Terkawi, 2016). Mahjoub et al. (2018) reported that Tunisian farmers perceived financial gain as the first determinant of success in encouraging future water reuse projects. Farmers were motivated to use TWW due to the reduction of their irrigation costs and extraction and pumping costs (47% and 73% in Italy, respectively) and their fertilization costs (41% in Italy, 38.5% in Tunisia, and 81% in the West Bank) (Saliba et al., 2018; Dare & Mohtar, 2018; Hamdan et al., 2021). Similarly, the price of TWW compared to freshwater was significantly correlated (86.2%) with the willingness to reuse among farmers in the West Bank, Palestine (Hamdan et al., 2021). Farmers are reportedly more likely to irrigate with TWW when its price is lower than the price of freshwater (10% in the West Bank and around 8% in Tunisia) (Dare & Mohtar, 2018). This finding is partly caused by farmers' beliefs that treated water effluent is of inferior quality and hence should be less expensive than freshwater (Deh-Haghi et al., 2020). Moreover, the low price is listed among the advantages of TWW and the reasons for continuing to use this water source instead of returning to conventional water among 78% of the interviewed farmers in Tunisia (Mahjoub et al., 2018).

Other financial incentives can result from the high acceptance of consumers to buy crops irrigated with TWW, stated by 75.4% of the producers in Palestine (Hamdan et al., 2021). In addition, TWW irrigation was mentioned by farmers to produce a greater agricultural yield of better quality, thus, higher sales (Mahjoub et al., 2018; Deh-Haghi et al., 2020). TWW is rich in organic matter and nutrients, which enhance soil productivity and fertility, nutrient crop uptake, plant growth, and crop yield (Leonel &

Tonetti, 2021; Mohammad & Ayadi, 2004). This increase in agricultural productivity was acknowledged by 8/13 farmers in Tunisia and 2/20 in the West Bank (Dare, 2014). Thus, those overall benefits generate more revenues and increase farmers' income (Dare & Mohtar, 2018).

3. *Environmental Factors*

Some farmers and consumers were motivated by the environmental benefits of TWWR in agriculture. This alternative water source was perceived to contribute to reducing the water scarcity problem exacerbated by climate change, which is negatively affecting agricultural activities in dry periods (Mahjoub et al., 2018). In Greece, the majority of the farmers are aware of the water shortages in their country. Freshwater shortage seems to be the sole reason that pushes farmers to accept to use secondary TWW to irrigate their olive trees (Menegaki et al., 2007). Additionally, decreasing freshwater resource exploitation has motivated 54% of the farmers and 92% of the interviewed general population in Italy (Saliba et al., 2018).

Another environmental incentive of water reuse is reducing synthetic fertilizer inputs. The richness of TWW with nutrients motivates farmers to apply it as a source of water and fertilizers (67% in Tunisia) (Mahjoub et al., 2018). In a study conducted by Dare & Mohtar (2018), Tunisian farmers (5/13) were mainly positive about reducing their need for fertilizers because they had practical experience with TWW. Lastly, TWW for irrigation was valued because it ensures pollution reduction (72% of consumers in Italy) and environmental protection (2/13 farmers in Tunisia and 1/20 in the West Bank) (Saliba et al., 2018; Dare & Mohtar, 2018).

4. Ethical Considerations

Trust in the authorities has always been identified as a major obstacle in gaining acceptance of TWWR projects. Local authorities in charge of water and sanitation (ministers, agencies, governmental levels, private organizations, etc.) are not trusted to effectively monitor and manage WWTPs and deliver a safe TWW effluent for agriculture (Dare & Mohtar, 2018; Terkawi, 2016). For instance, in the city of Cape Town in South Africa, users of TWW, based on their experiences, reported a poor trust level of 48% in the service providers to supply the appropriate TWW quality (Adewumi et al., 2010). This concern appears to be more common in states under military control or countries with new or transitional governments because of the future uncertainties and the significant disturbances from the norm. The latter applies to citizens and farmers in the West Bank due to the lack of state authority and in Tunisia, which was under a transitional government (Dare & Mohtar, 2018). Furthermore, in developing countries, including Palestine, Jordan, and South Africa, some people seem to be worried about political parties controlling the reuse projects. This control results in unfair distribution of the water effluent to benefit communities with specific political support (Terkawi, 2016).

In contrast, other studies show a different view. In Italy, Saliba et al. (2018) demonstrated that consumers had a modest level of confidence in the responsible authorities of wastewater (WW) treatment and control. Hence, trust has not hindered nor favored reuse. Additionally, Craddock et al. (2021) reported that the willingness to serve cooked produce was significantly associated with the Palestinians' trust in the local utility to monitor the TWW effluent (62.5%; *p*-value = 0.01). Additionally, their willingness to serve fresh crops irrigated with TWW was significantly correlated with

Palestinians' trust in the private sector to monitor the treated effluent (52.6%; *p*-value = 0.03).

5. *Perceived Availability and Accessibility of Freshwater*

The decision to irrigate with treated sewage effluent is affected by the perceived availability and accessibility of safe freshwater. In Greece, the perceived unavailability of freshwater among consumers was significant for irrigating tomatoes with tertiary treated WW, indicating their willingness to consume high-risk products to address the serious water scarcity issue (Menegaki et al., 2007). This was also the case in Italy, where the on-farm lack of freshwater has driven about 50% of the farmers to use TWW for irrigation (Saliba et al., 2018). Similarly, in Tunisia, farmers (33%) were reluctant to rely on conventional water resources due to their low and less frequent supply (Mahjoub et al., 2018). Therefore, arid communities are most likely to approve the reuse of TWW due to limited freshwater availability, accessibility, and restrictions (Adewumi et al., 2010).

In contrast, Hamdan et al. (2021) reported that accessibility to freshwater from wells and springs at a very low average price (US\$0.43/m^3) prevented 43% of the West Bank farmers from using TWW for irrigation. However, 66% of those farmers acknowledged the existence of freshwater shortages in their country. The authors identified two scenarios in their study. The first scenario includes 9% of the farmers who refuse to use TWW because they consider freshwater availability to be enough to meet their irrigation needs. As for the second scenario, around 91% of the producers preferred reducing the irrigated agricultural areas due to insufficient amount of freshwater to cover their needs. In this case, reclaimed wastewater might allow them to cultivate all of their lands.

6. Types of Crops

Crops irrigated with TWW are classified into three categories based on their public health risks to consumers, field workers, and handlers (Appendix I) (Jurdi, 2017). Published research results generally indicated that farmers and consumers preferred irrigating crops with TWW if they belong to the lowest public health risk category to consumers with the protection of field workers (i.e., category 1). They both favor crops not meant for direct human consumption, such as biodiesel, animal feed, and ornamental (Michetti et al., 2019; Saliba et al., 2018). In the same category, farmers also choose to irrigate crops for processing (Saliba et al., 2018). Similarly, consumers were more willing to accept the irrigation of crops processed before consumption (category 1) compared to crops eaten raw (i.e., highest risk category or category 3) because of public health concerns (Kwabla, 2017). Moreover, the interviewed citizens of Khorramabad in Iran did not accept irrigating non-processed corn with partially TWW (i.e., physical treatment and aeration). This correlation between WTU and product type was significantly negative (Deh-Haghi et al., 2021).

C. Methodology

Farmers and consumers were the two stakeholder groups targeted for the assessment of the social acceptance of the safe reuse[1] of treated wastewater for

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[1] Note that this social assessment is about safe TWWR. Hence, the farmers and consumers were interviewed/surveyed about this safe practice abiding by international guidelines for water reuse for irrigation.

irrigation in Bekaa and Lebanon, respectively. The farmers are from Zahle and Ablah, potential beneficiaries of the Zahle and Ablah WWTPs, considering this thesis also assesses the quality of the TWW effluent from these two plants. However, this methodology can target farmers in the Bekaa region, given the similar context and restrictions. As for the consumers, they are from the general Lebanese population aged 18 years and above.

1. Farmers

a. Study Areas

Zahle is the fourth-largest city in Lebanon, located in the Bekaa Governorate between 900 and 1,450 m above sea level. It is characterized by its Mediterranean climate, with an annual air temperature ranging between 2 °C and 29 °C and average precipitation of 600 mm. A population of around 72,000-80,000 people resides in Zahle, with an urban cluster of about 157,000 people extending way beyond its municipal boundaries. Moreover, the number of Syrian refugees currently living there exceeds 160,000. Zahle district is composed of 29 municipalities and 3 municipal unions: The Union of Zahle District, the Union of East (or Charqui) Zahle, and the Union of Central Bekaa (or Al Bekaa Al Awsat) (Figure 1) (Abunnasr & Mhawej, 2021; Farah et al., 2019). This study focuses on the city of Zahle (number 20 in Figure 2). Its total agricultural area is approximately 4,400 hectares (MoA, 2021).

Ablah (number 40 in Figure 2) is a village located in the Zahle District of the Central Bekaa valley of Lebanon (33.8669°N, 35.9594°E) with an elevation of 975 m (Chalak et al., 2007, and Romanos et al., 2019). The area's climate is Mediterranean, with a hot and dry season from April to October and yearly precipitation of 615 mm (Chalak et al., 2007; Mcheik et al., 2017). Its total agricultural area is approximately 400 to 450 hectares (MoA, 2021).

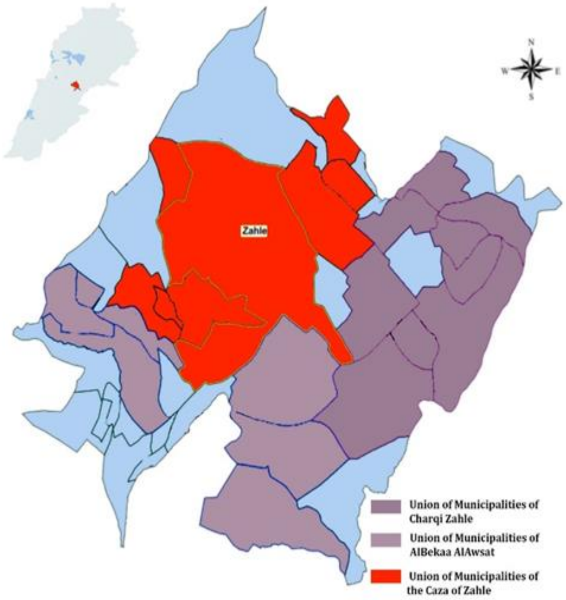


Figure 1: Zahle District and its Union of Municipalities (Farah et al., 2019)

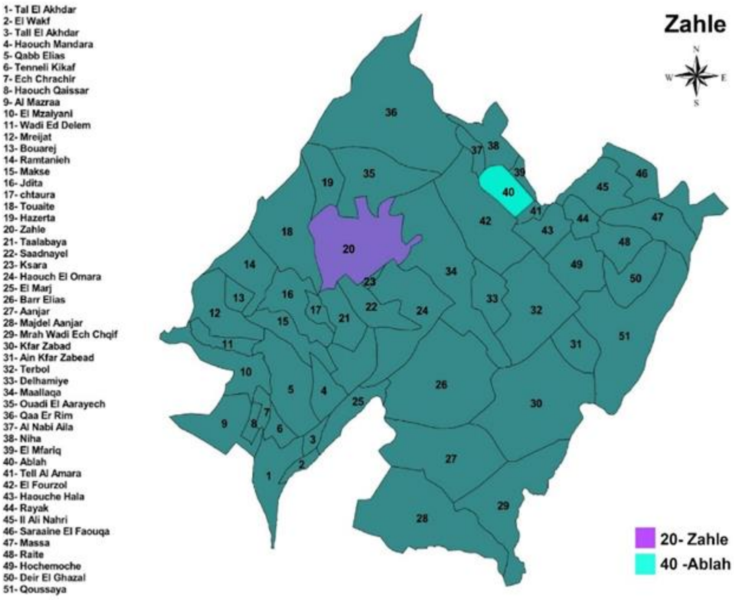


Figure 2: Zahle and Ablah in the Zahle District (Localiban, 2015)

b. Sample Size

The sample size consists of 33 farmers, who are potential beneficiaries of Zahle and Ablah WWTPs, based on a statistical sample size calculator (Equation 1) with an accessible farmer-beneficiaries population in the two study areas of 59 farmers, a margin of error of 5%, a confidence level of 95% (critical value 1.96), and a response distribution of 95% (Raosoft Inc., 2004). The distribution of the agricultural lands, which can potentially benefit from the two plants, was accounted for to identify our sample size in each area. The total surface area of the land is 10,107 dunum (du) (equivalent to 100%), divided into 10,000 dunum (equivalent to 98.94%) in Zahle and 107 dunum (equivalent to 1.06%) in Ablah. Based on this distribution, 32 farmers were interviewed from Zahle (≈ 98.94% x 28) and 1 farmer from Ablah (≈ 1.06% x 28). One more farmer was interviewed from Ablah, increasing our sample size to 34 farmers (Table 2).

Equation 1: Sample Size Formula of Farmers

$n = N*X / (X + N - 1)$,

Where:

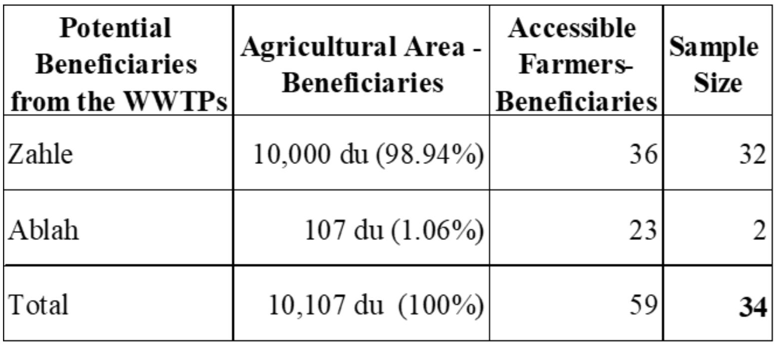
n: sample size

N: population size

$X = Z_{\alpha/2}^2 *p*(1-p) / MOE^2$

Where: $Z_{\alpha/2}$: Critical value; p: Probability of success (response distribution); 1 - p: Probability of failure; and MOE: Margin of error

Table 2: Sample Size Calculations



Potential Beneficiaries from the WWTPs	Agricultural Area - Beneficiaries	Accessible Farmers-Beneficiaries	Sample Size
Zahle	10,000 du (98.94%)	36	32
Ablah	107 du (1.06%)	23	2
Total	10,107 du (100%)	59	**34**

c. Data Collection Plan

A simple random sampling technique was employed to select our calculated sample size from the two accessible, but incomplete lists of farmers collected by the research team based on their connections, as shown in Table 2. One-on-one interviews with 25 farmers were conducted in Arabic face-to-face in Zahle, adhering to the COVID-19 precautionary measures. The farmers were contacted on the phone beforehand and invited to participate in the study. Their consent was taken according to the consent form on the day of the interview. Moreover, 9 farmers from Zahle were interviewed by phone after taking their consent.

d. Questionnaire Structure

The Institutional Review Board (IRB)-approved questionnaire (IRB ID: SBS-2021-0265) consists of an introduction and four main sections (Appendix II):

i. Section 1: Farmers' Background

- Their current source of water for irrigation,
- Average cost of irrigation per month (in LL/dunum),
- Area of irrigated land (in hectares),

- Whether they irrigate their entire agricultural field and crops,
- Types of crops irrigated,
- Irrigation methods,
- The challenges faced in irrigation.

ii. Section 2: Knowledge about Wastewater Reuse

- Awareness of the term “treated wastewater” (TWW) effluent and its reuse for irrigation.
- Their perceived risks of the safe reuse of TWW for irrigation.
- Their perceived benefits of the safe reuse of TWW for irrigation.

iii. Section 3: WTU

It assesses the respondents’ willingness to safely use TWW for agricultural purposes and the underlying reasons behind their decision. If they accept this practice, they are further asked to choose the types of crops they are willing to safely irrigate with TWW from a public health perspective and their willingness to pay. However, if they refuse this practice, they are requested to identify resources, if any, which might help them make an informed decision about the use of TWW in agricultural irrigation.

iv. Section 4: Socio-economic and Demographic

Questions include age, attained education level, family size, and monthly household income from all sources after deduction of taxes.

e. Data Analysis

The collected data was cleaned, merged, and numerically coded in Excel, followed by statistical analysis using the Software for Statistics and Data Science (STATA 16). Descriptive statistics of the different variables using tables and graphs were first presented (frequencies and percentages) to gain a better sense of the data distribution and the overall trends in the responses. The dependent variable of this study is the willingness of participants to safely use TWW for irrigation (WTU) (Q.11 - Appendix II). This variable is categorical, with yes and no as potential responses (binary outcome). Three additional binary outcomes are 1) WTU1 for the lowest health risk category to consumers (i.e., non-consumable crops, fodder crops, sun-dried and harvested animal feed, and crops for canning or processed by heat or drying before human consumption), 2) WTU2 for the increased health risk category to consumers and handlers (crops for human consumption normally eaten only after cooking or after peeling), 3) WTU3 for the highest health risk category to consumers, field workers, and handlers (crops eaten uncooked) (Q.12 - Appendix II). The remaining independent variables are also categorical, merged into two or more options. Therefore, a Logistic Regression Univariate Analysis was conducted to find correlations between each independent variable and the outcome WTU. The significant variables from the bivariate analysis were further analyzed using a multivariate Logistic Regression Model adjusting for confounders. Odds ratios (OR), which represent the relationship between the variables and the likelihood of occurrence, were interpreted to understand the direction and strength of the associations between the independent and dependent variables (OR=1 means no variability (or the independent variables do not affect the odds of the outcome), OR>1 indicates a positive relationship, while OR<1 shows a negative relationship). P-values were also assessed for significance (if p-value < 0.05). To detect multi-collinearity, the variance inflation factor (VIF) was generated, which measures the correlation and strength of correlation between the explanatory variables in a regression model. A value greater than 5 indicates a potentially severe correlation between a given explanatory variable and another in the model. In this case, the coefficient estimates and p-values in the regression output are likely unreliable. However, considering the regression procedures for a categorical outcome do not have collinearity diagnostics, the linear regression procedure was used with the same predictors and dependent variable in the logistic regression. Lastly, for each outcome, the strongest predictor was identified using the TEST command in STATA (i.e., Test linear hypotheses after estimation) when the difference between the coefficients/ORs of the significant variables in the multivariate models is significant (p-value < 0.05).

f. Limitations of the Farmers' Analysis

- Most of the respondents pay a lot more than 100,000 LL on average to get water for irrigation per month (Appendix II, Q2). The very high irrigation cost is mainly attributed to the rising fuel costs in Lebanon. Some farmers reported paying more than 1,000,000 LL. The proposed ranges in this question were suggested (in July 2021) before the rise in fuel prices and the further deterioration of the exchange rate of the Lebanese Lira.
- Some farmers (26.5%) refused to respond to the question on monthly household income. These farmers were removed from the analysis of the income variable. Thus, they could have influenced the correlation between the

income variable and the different WTU outcomes, and hence the overall findings. However, the model does account for missing data.

- In an attempt to impress the interviewers, farmers may have given inaccurate information about their perceptions, attitudes, and practices (known as participant bias or response bias). This bias acts as a confounder, influencing the outcome instead of the independent variables. However, the interviewers minimized this bias by practicing objectivity and reminding the farmers that this study has no desired results and that their personal opinions matter.
- The study did not compare/contrast interviews conducted face-to-face versus telephone interviews.
- The research team was only able to reach 59 farmers-potential beneficiaries of the Zahle and Ablah WWTPs, which was assumed to be the total population of farmers. Hence, the calculated sample size could be relatively small.
- The study assumes that TWW abiding by international guidelines for water reuse for agriculture with no degree of restriction is safe. Those guidelines are the draft-Lebanese guideline for water reuse (FAO, 2010), the World Health Organization (WHO) guideline for water reuse for irrigation (WHO, 2006), and the FAO guidelines for conventional water quality for irrigation (Ayers & Westcot, 1985). However, it does not account for the presence of contaminants beyond those guidelines (Appendix IV, V, and VI, and heavy metals), such as contaminants of emerging concern (CEC).

2. Consumers

a. Sample Size

The sample consists of 246 participants from the general Lebanese population, aged 18 years and above, based on a statistical sample size calculator (Equation 2), assuming a population size of 80,000, a margin of error of 5%, a confidence level of 95% (critical value 1.96), and an expected response rate of 80% (based on previous studies). Note that the sample size doesn't change for populations larger than 80,000. The survey was filled by 256 participants, exceeding the targeted sample size.

Equation 2: Sample Size Formula of Consumers

$n = [(Z_{\alpha/2})2 * p * (1 - p)]/MOE\ 2$

Where: n: sample size; $Z_{\alpha/2}$: Critical value; p: Probability of success (response distribution); 1 - p: Probability of failure; and MOE: Margin of error

b. Data Collection Plan

An online survey targeting the entire Lebanese residential population aged 18 years and above was conducted through social media. The questionnaire was created on Google Forms and posted on several media channels, including WhatsApp, LinkedIn, Twitter, Instagram, and Facebook. The number of respondents and their socio-economic and demographic characteristics were tracked throughout the data collection phase to ensure a somehow diverse sample. This data collection design was chosen to ensure the health and safety of the participants considering the COVID-19 pandemic. In addition, self-completed questionnaires reduce interviewer bias since the respondents are not influenced by the interviewers. Furthermore, a relatively higher number of participants was reached through online platforms, which increased our sample size.

c. Questionnaire Structure

The IRB-approved questionnaire (IRB ID: SBS-2021-0265) consists of an introduction and three main sections (Appendix III). Section 1, knowledge about TWWR, and section 2, consumers' WTU and their justifications, are respectively the same as sections 2 and 3 in the farmers' questionnaire, but without the willingness to pay question. In section 3, consumers are asked about their socio-economic and demographic background, which include sex, age, attained education level, employment level, monthly household income from all sources after tax-deduction, context (rural or urban), and status (farmers or consumers).

d. Data Analysis

The analysis was the same as for the farmers. The dependent variable is the willingness of consumers to safely use (if they are farmers) or accept the safe usage of TWW for irrigation (WTU) (Q.4 - Appendix III). This variable is categorical, with yes and no as potential responses (binary outcome). Three additional binary outcomes are 1) WTU for the lowest health risk category to consumers (WTU1), 2) WTU for the increased health risk category to consumers and handlers (WTU2), 3) WTU for the highest health risk category to consumers, field workers, and handlers (WTU3) (Q.5 - Appendix III).

e. Limitations of the Consumers' Analysis

- The sample was not diverse in all its socio-economic and demographic variables. It was biased toward young consumers between 18 and 25 years old, university-educated (first and higher degrees), and with an urban status.
- Some respondents (27.3%) refused to respond to the question on monthly household income. These consumers were removed from the analysis of the income variable. Thus, they could have influenced the correlation between the income variable and the different WTU outcomes, and hence the overall findings. However, the model does account for missing data.
- The study assumes that TWW abiding by international guidelines for water reuse for agriculture with no degree of restriction is safe. Those guidelines are the draft-Lebanese guideline for water reuse (FAO, 2010), the WHO guideline for water reuse for irrigation (WHO, 2006), and the FAO guidelines for conventional water quality for irrigation (Ayers & Westcot, 1985). However, it does not account for the presence of contaminants beyond those guidelines (Appendix IV, V, and VI, and heavy metals), such as contaminants of emerging concern (CEC).

D. Results and Discussion - Perception of Farmers

1. Descriptive Statistics

a. Farmers' Demographic and Socio-Economic Characteristics

The interviews were conducted with a diverse sample of 32 farmers from Zahle and two from Ablah. Their demographic and socioeconomic characteristics are summarized below (and in Appendix II). The age distribution (Q18) varies, with 44.1% of the farmers falling between 26 and 49 years old (one of them from Ablah) and 55.9% farmers above 50 (one from Ablah) (Figure 3). Of the respondents, 26.5% have attained their first university degree (8 from Zahle and 1 from Ablah), 26.5% reached high school (9 from Zahle), 14.7%, equivalent to 5 farmers, have a higher university degree (Masters/Ph.D.), and another 14.7% are non-educated (from Zahle). As for the remaining farmers, 8.8% attended technical schools, 5.9% (one from Ablah) reached an intermediate level, and 2.9% an elementary level (Q19) (Figure 4). The families of 61.8% of the farmers (20 from Zahle and one from Ablah) consist of five or more members in their households (somehow biased) (Q20) (Figure 5). As for the average monthly household income after tax deduction (Q21), 11 farmers (32.3%) reported less than 6,000,000 Lebanese Lira (LL) (the two Ablah farmers included), and 14 farmers (41.2%) more than 6,001,000 LL. In contrast, 9 farmers (26.5%) refused to disclose their income. Thus, they were removed from the analysis of the income variable (Figure 6).

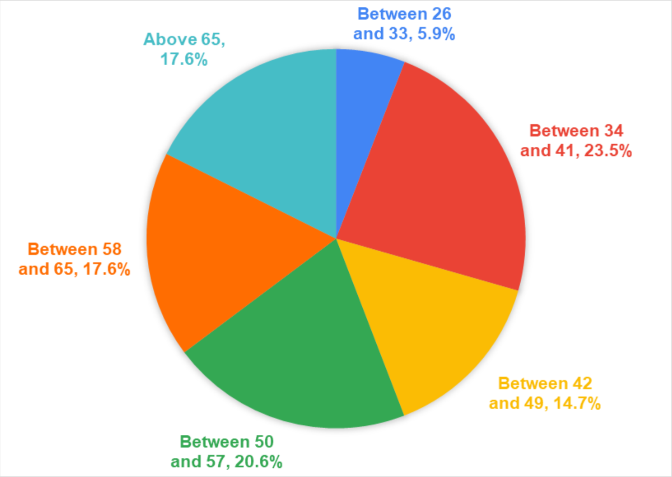


Figure 3: Age Distribution of Farmers

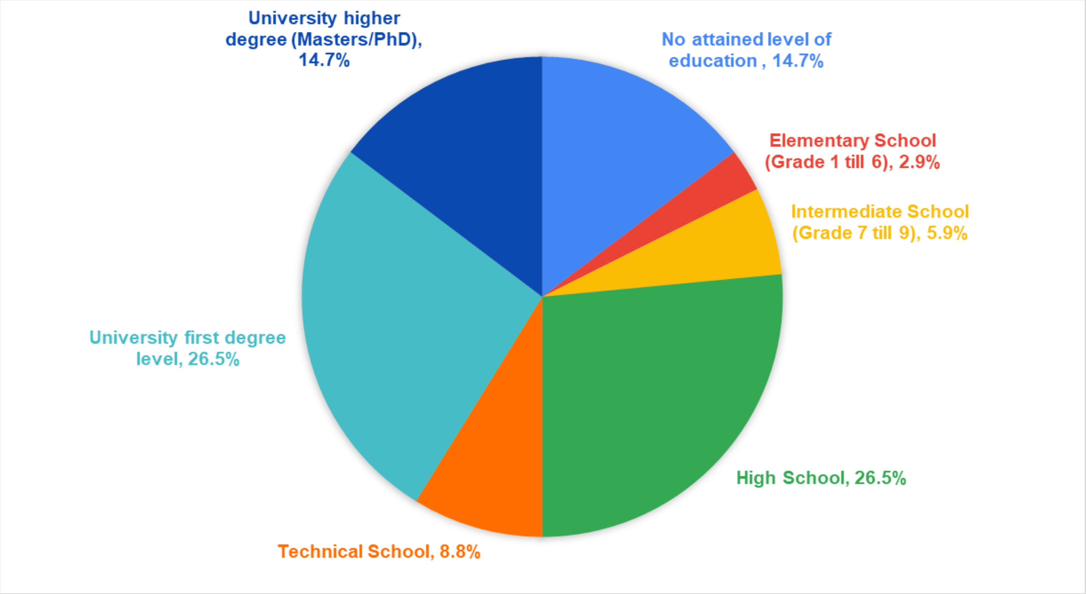


Figure 4: Attained Education level of Farmers

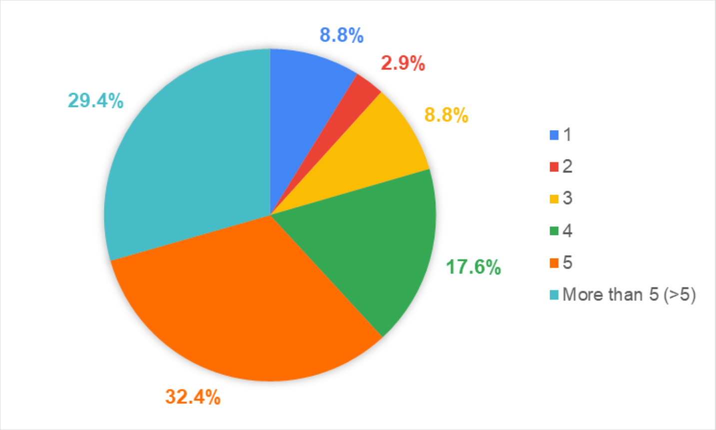


Figure 5: Family Size of Farmers

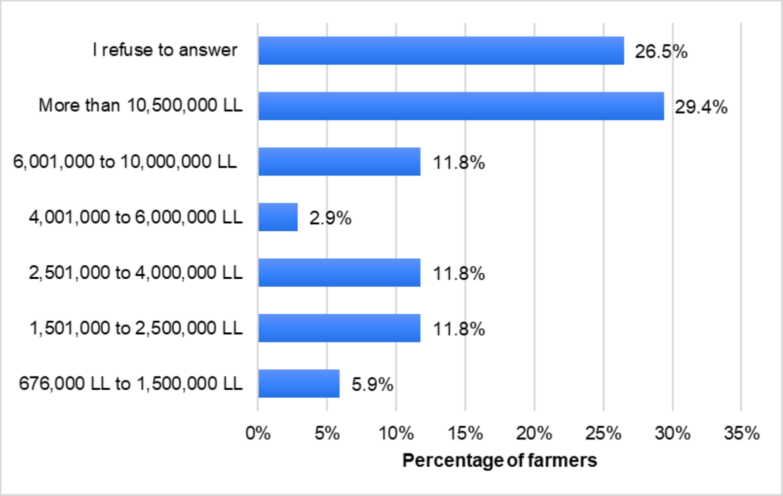


Figure 6: The Average Monthly Household Income of Farmers after Tax Deduction in Lebanese Lira (LL)

b. Farmers' Water Use

Background information was collected about the farmers' source of water, average monthly irrigation cost, total irrigated area per farmer, irrigation status, irrigation methods, and irrigation challenges (Appendix II). Most farmers use groundwater and river water (from the Litani or Berdawni river) for irrigation, 91.2% and 88.2%, respectively (3 farmers use only river water, 3 farmers only rely on groundwater, and 27 farmers depend on both sources simultaneously). Only two farmers (5.9%) use tap water from the municipality in addition to groundwater and river water. Two farmers (5.9%), one from Ablah and the other from Zahle[2], reported using treated wastewater to complement other water sources, groundwater and river water, respectively (Q1) (Figure 7). Considering that most farmers rely on groundwater, TWW, as an alternative water source, might reduce the overexploitation of aquifers.

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[2] Unlike the case of Ablah, the Zahle farmer is using the TWW from the Zahle WWTP at his own risk considering that the plant has not given out any rights to use the effluent.

A big proportion of the farmers (79.4%, equivalent to 27) pay more than 100,000 LL per month on average to get water for irrigation (including the farmers from Ablah), mainly attributed to the pumping cost of groundwater (Q2) (Figure 8). At the time of the interviews, 100,000 LL was equivalent to around $4 (1$ = 24,000 LL). The Lebanese Lira value is further deteriorating, along with the rise in fuel costs. The area (ha) of land irrigated per farmer (Figure 9) is mostly lower medium (i.e., between 2 and 30 ha) for 21 farmers (61.8%) from Zahle (Q3). The two Ablah farmers irrigate a small area of land between 0.5 and 1 ha. However, some of the interviewed farmers are relatives with common land ownership. Only 29.4% of the farmers (all from Zahle) do not entirely irrigate their lands, which might be caused by water availability and/or accessibility issues (Q4) (Figure 10).

Different irrigation methods are used separately or in combination (Q6). Figure 11 reflects that most farmers use more than one irrigation method on their farms. Overall, 67.6% of the farmers rely on sprinkler irrigation, 58.8% on surface irrigation, and 50% on drip irrigation. As for the direct current users of TWW, the Ablah farmer uses drip and sprinkler systems to irrigate grapes, onions, and potatoes; and the Zahle farmer uses surface and sprinkler methods to irrigate onions, potatoes, wheat, and vegetables. The remaining farmers (31 from Zahle, non-direct users of TWW) irrigate potatoes (64.7%), corn (20.6%), grapes (20.6%, including the other Ablah farmer), and onions (35.3%). Additionally, farmers in Zahle irrigate different types of vegetables (such as lettuce, cucumbers, etc.), grains (wheat, oat, green beans, etc.), and fruit trees (apple, cherry, peach, apricot, and others) (Q5). All the farmers might be indirect users of TWW, or even wastewater diluted with freshwater. When asked about the challenges faced regarding irrigation (Q7), the top two challenges were the Lebanese economic crisis causing an increase in the prices of USD versus LL among 88.2% of the farmers and reduced river flow or drought periods among 82.4% (Figure 12). Hence, farmers are majorly impacted by physical water scarcity, especially in the dry season, and the economic situation in the country.

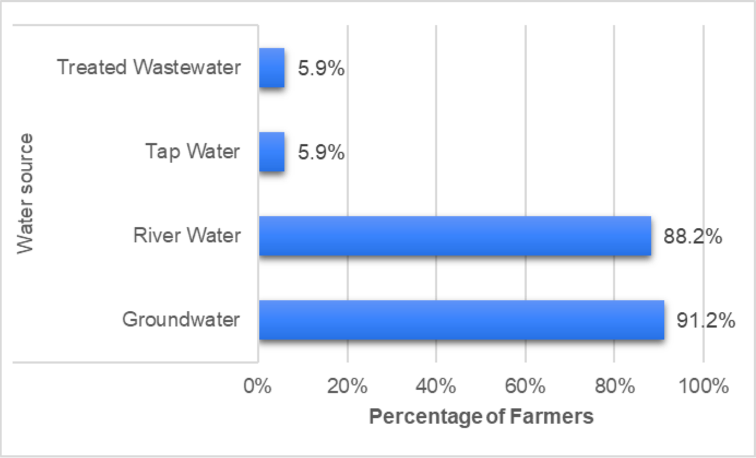

Figure 7: The distribution of the Farmers by Water Source

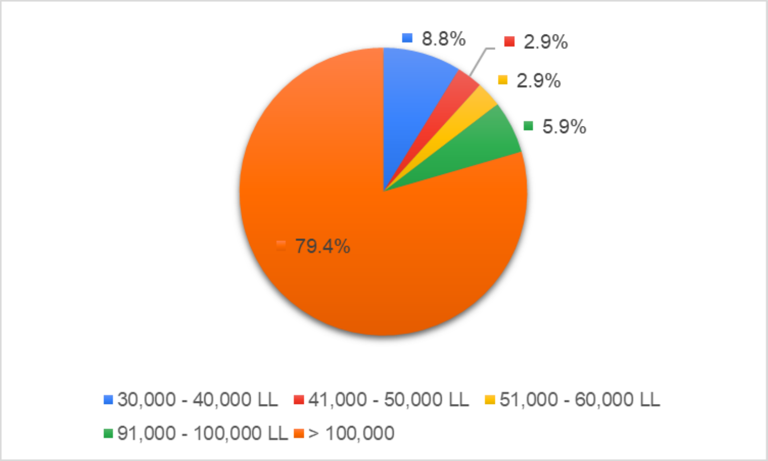

Figure 8: Monthly Irrigation Cost of Farmer

Figure 9: Total Irrigated Area (ha) per Farmer

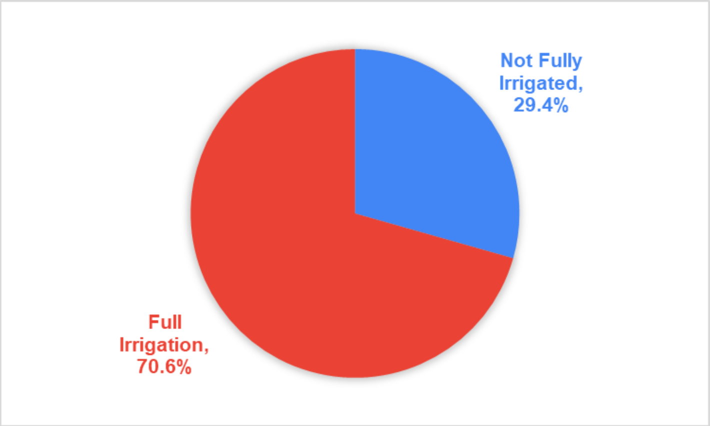

Figure 10: Irrigation Status of Farmers

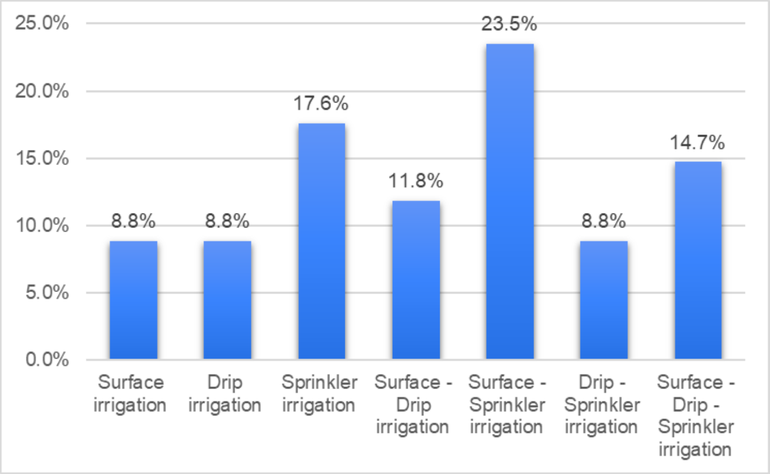

Figure 11: Irrigation Method(s) Used by Farmers in Zahle and Ablah

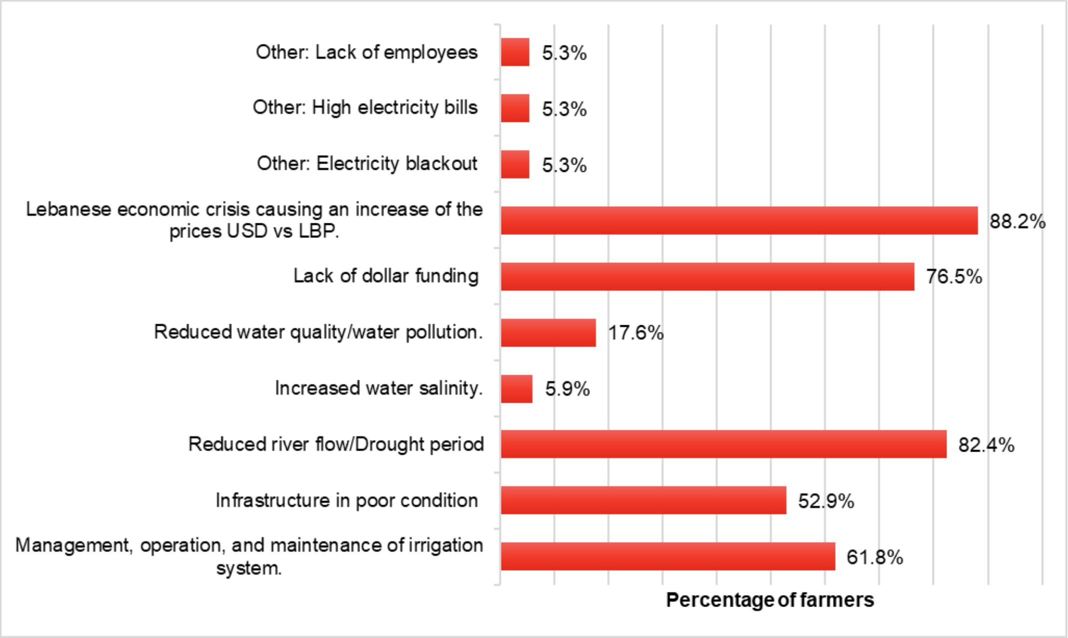

Figure 12: Irrigation Challenges of Farmers

c. Knowledge about Water Reuse among Farmers

Knowledge is crucial to evaluating the perception of farmers toward the use of treated wastewater (Appendix II). The findings reveal that 58.8% of the farmers have heard about TWW and its reuse for irrigation and know what it means (including the farmers from Ablah). In contrast, 38.2% have heard about it but do not know what it means (i.e., insufficient knowledge), and 2.9% did not hear about this practice (Q8) (Figure 13). A strong significant positive correlation (OR = 14.66, p-value = 0.038) was found between the university-educated farmers and their perceived knowledge of TWW and its reuse for agriculture (i.e., heard and know) compared to non-educated respondents with no attained level of education.

The questionnaire also tested farmers' actual knowledge of the risks and benefits of safe reuse (abiding by international guidelines) through Q9 and Q10. 73.5% of the respondents, equivalent to 25 farmers, are aware that the safe reuse of TWW has no risks (including one farmer from Ablah). On the other hand, the remaining 9 farmers (26.5%) reported the following risks: safe reuse (abiding by the international standards for water reuse for irrigation) increases health concerns and disease outbreaks (3 farmers, 8.8%), attracts disease vectors to the irrigation ponds and fields (4 farmers, 11.8%), causes environmental impacts (2 farmers, 5.9%), and it is not clean and safe enough for irrigation compared to freshwater (8 farmers, 23.5%) (Q9) (Figure 14). The benefits of safe reuse are also well-known by farmers (Q10). The most mentioned benefits are that farmers could have continuous access to TWW for crop irrigation even during drought periods (73.5%), and safe reuse promotes sustainability in agriculture and water resource use (70.6%) (Figure 15).

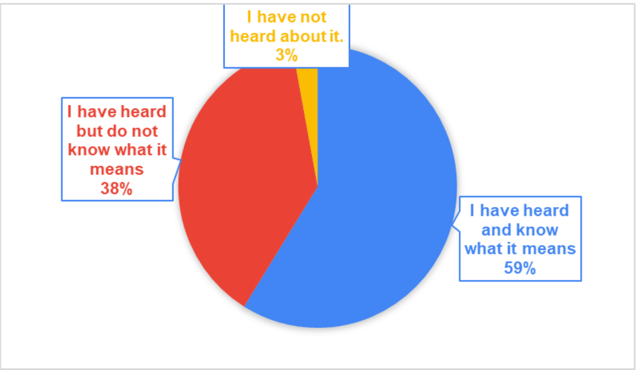

Figure 13: Perceived TWWR Awareness among Farmers

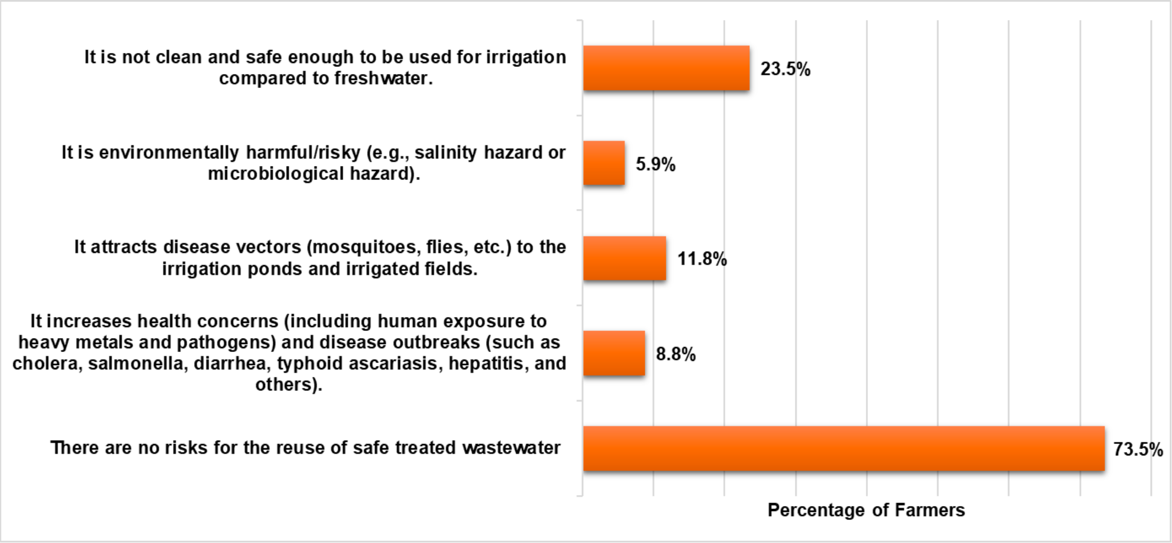

Figure 14: Perceived Risks of TWW Reuse among Farmers

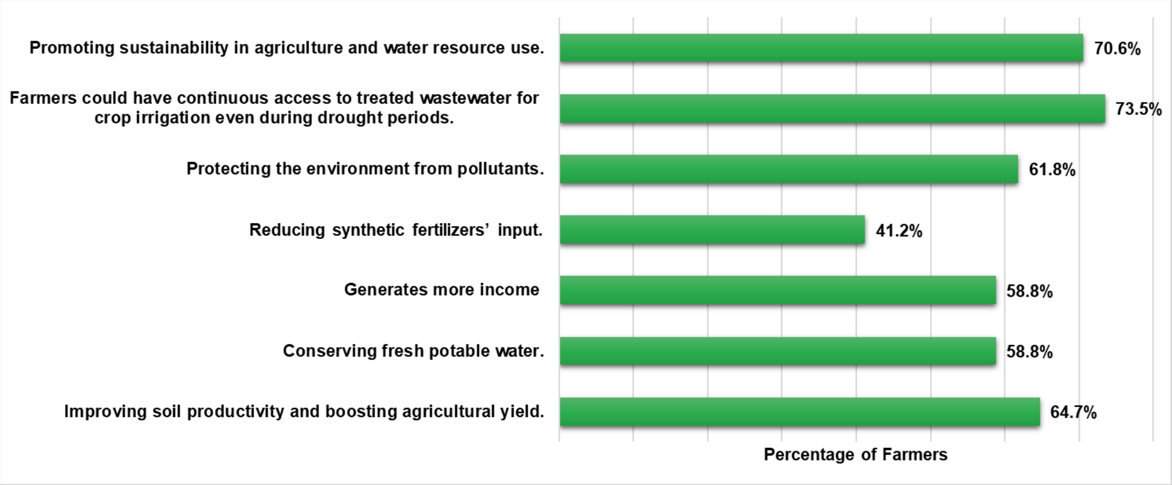

Figure 15: Perceived Benefits of TWW Reuse among Farmers

d. Willingness to Use and Willingness to Pay among Farmers

When asked about their willingness to use (Figure 16), 32 interviewees (94.1%, two from Ablah and 30 from Zahle) accept the safe use of treated wastewater for agriculture (Q11). This finding meets our expectation of a response distribution of 95% (32 farmers) and is one of the highly reported WTU figures among farmers in the literature. From a public health perspective, the highest acceptance is for crops eaten only after cooking (such as potatoes), which is unexpected considering this category has an increased risk to consumers and handlers (among 31 farmers, 96.9%). The second-highest acceptance is for fiber and fodder/animal feed crops, which have the lowest risks to consumers, but field worker protection is needed (26 farmers, 81.3%). The least accepted is the irrigation of uncooked crops (such as fresh vegetables) (14 farmers, 43.8%), considering this category has the highest risk to consumers, field workers, and handlers (Q12) (Figure 17). On average, farmers mostly accept the irrigation of crops with the increased risks (WTU 2) (81.25%), followed by the lowest risks (WTU1) (76.6%), and lastly, the highest risks (WTU 3) (27.3%).

Out of the 32 farmers, 25 (78.1%) are willing to pay less than their current irrigation costs, while 4 (12.5%) are willing to pay the same amount, and only 3 (9.4%) are willing to pay more (Q14) (Figure 18). Similarly, 78% of the Tunisian farmers indicated that the lower cost of TWW is a prerequisite for its application over conventional water (Mahjoub et al., 2018). However, future studies should investigate farmers' WTP and its influencing factors, considering the price of TWW might be cheaper than groundwater with the increasing fuel price for pumping, or it might become expensive with the increase in water demand for irrigation.

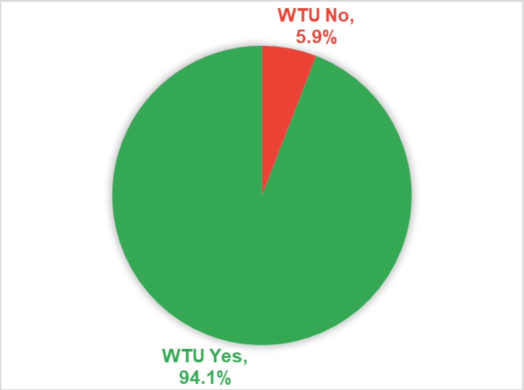

Figure 16: WTU among Farmers

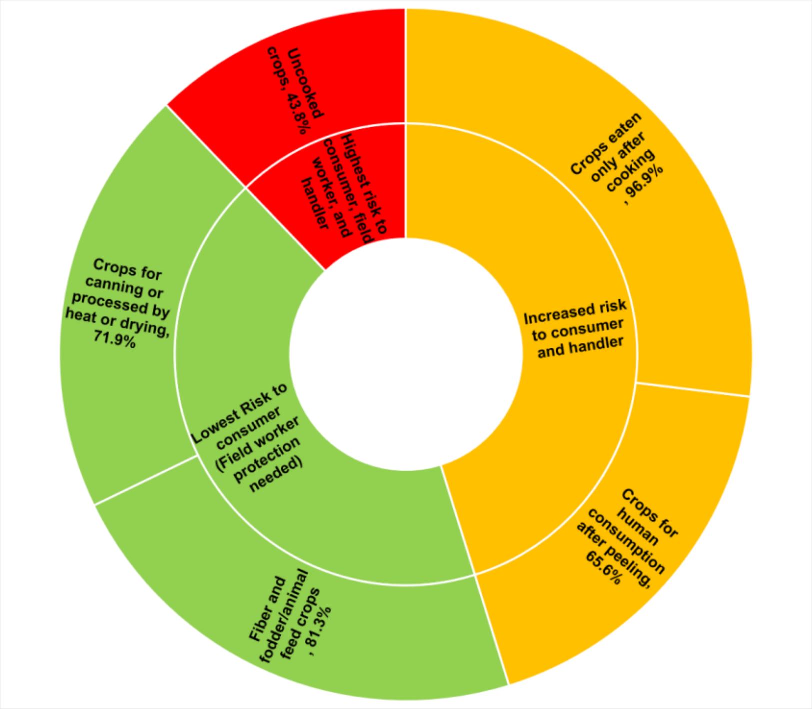

Figure 17: WTU based on Crops Category among Farmers

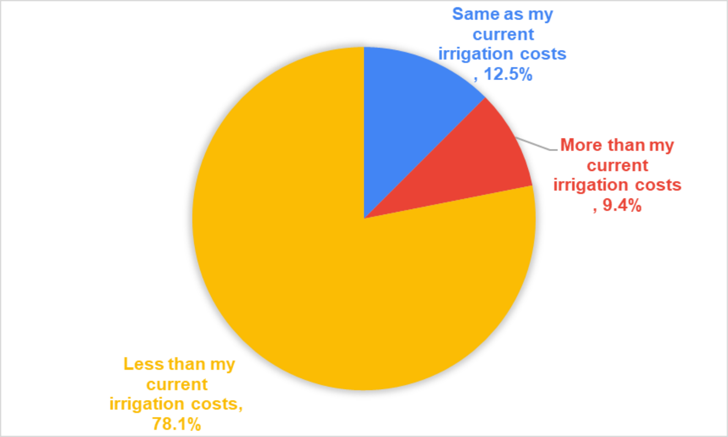

Figure 18: Willingness to pay (WTP) among Farmers

e. Willingness to Use Justifications

i. The Reasons Behind Farmers' Acceptance

Farmers mainly attributed their WTU of safe TWW for irrigation to its economic benefits (Q13) (Figure 19). Economic benefits are among the top reasons and determinants of success driving water reuse in agriculture among producers in the literature (Terkawi, 2016; Mahjoub et al., 2018). The main three reasons are the ability of this water source to increase the agricultural yield (78.1%), save energy (78.1%), and generate more revenues (68.8%). They also justified their acceptance because of environmental reasons, mainly that TWW helps reduce the water scarcity problem in Lebanon (68.8%). However, only 7/32 farmers (21.9%) reported that they trust the authorities to ensure a safe quality of treated wastewater. Therefore, the lack of trust seems to be a barrier that might hinder their acceptance in practice.

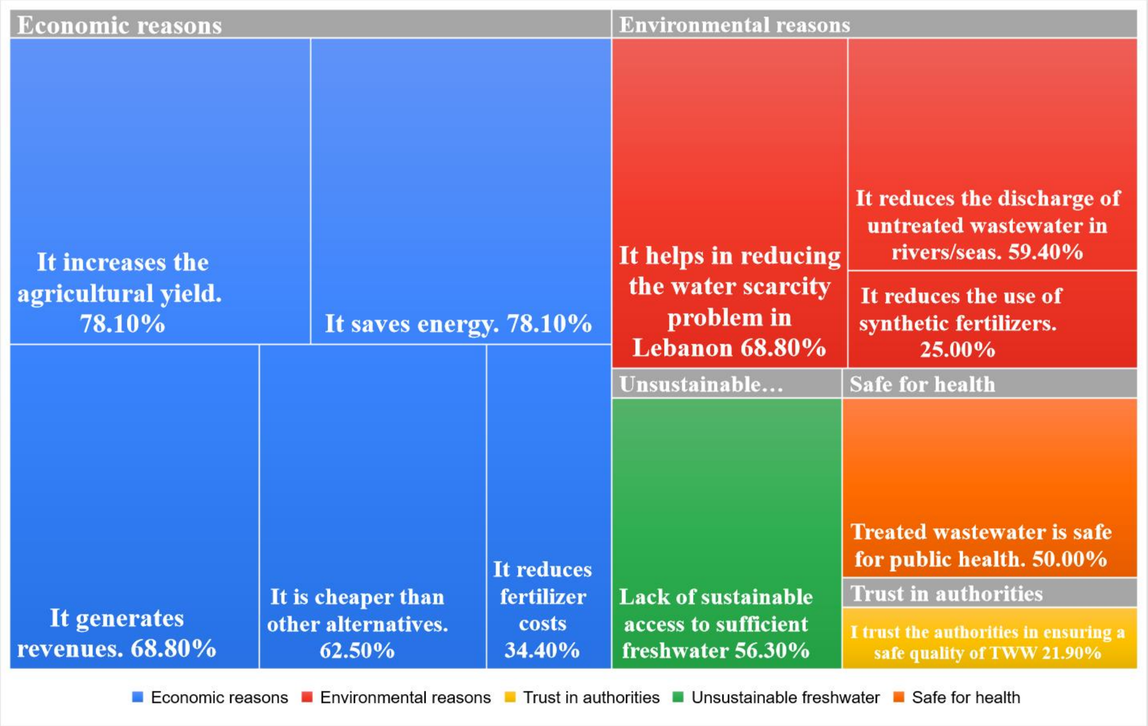

Figure 19: Justifications for Accepting the Safe Use of TWW among Farmers

ii. The Reasons Behind Farmers’ Rejection

As for the two farmers from Zahle who refuse the safe reuse of TWW (Q15) (Figure 20), their common reason is the lack of trust in the municipal authorities to adequately operate, monitor, and maintain the wastewater treatment plants (i.e., distrusted water quality). One of them (farmer 1) added insufficient coordination, while the other (farmer 2) reported that it is environmentally risky. The latter reason for farmer 2 is attributed to his lack of knowledge about TWW, considering he did not hear about it before (in Q8). He further perceives that safe reuse has risks with minimal benefits (in Q9 and 10). As for the first farmer, he perceives himself as knowledgeable about TWW reuse (in Q8), did not report any risks for safe reuse (in Q9), and selected 5 out of the 7 benefits of this water source (in Q10). Hence, his reasoning is considered more valid than the other farmer.

To help them make an informed decision about the use of TWW for irrigation (Q16), the second farmer (farmer 2) is interested in learning about and/or visiting a WWTP facility. As for the first farmer (farmer 1), he wants to expand his knowledge about TWWR by understanding the involved treatment processes and reading studies documenting the safety and benefits of using TWW in agricultural irrigation. Additionally, he cares about professional endorsements and approvals of the TWW reuse process and, most importantly, being involved in water reuse projects considering his lack of trust in the authorities to ensure the safety of the effluent for irrigation in Lebanon.

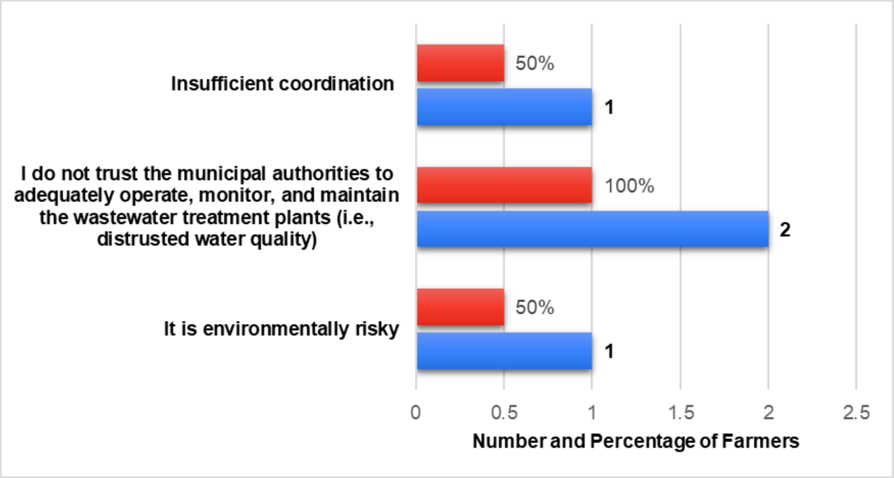

Figure 20: Justifications for refusing the Safe Use of TWW among Farmers

2. *Analytical Statistics*

a. Logistic Regression Model Analysis of WTU among Farmers

Logistic regression was adopted to find the factors affecting farmers' willingness to use safe TWW for irrigation. However, the associations between the outcome WTU and the independent variables in our questionnaire were either insignificant (p-value > 0.05) or with no variability (OR = 1). With no significant variables resulting from the univariate logistic regression models, a multivariate logistic regression analysis could not be performed. The insignificance might be caused by the small sample size of the farmers and/or the similar opinions among the farmers. Some farmers are relatives with common land ownership, experiences, and share similar norms and practices.

b. Logistic Regression Model Analysis of WTU per Crop Category among Farmers

Based on the results about the general acceptance of wastewater reuse and given that there were indications that the type of crop irrigated is a factor in the decision, the WTU per crop category from a public health perspective was analyzed (Q12).

i. Univariate Analysis

❖ WTU1 of Crops with the Lowest Health Risk to Consumers (Field worker protection is needed) among Farmers:

Univariate logistic regression was adopted to find the factors affecting farmers' willingness to use safe TWW for the irrigation of fiber and fodder/animal feed crops and/or crops for canning or processed by heat or drying (such as grains). The significant associations between the binary outcome WTU1 and the independent variables in our questionnaire ($p\text{-value} < 0.05$) are the following:

- Knowledge:

- Types of perceived risks - Safe TWW is not clean and not safe enough to be used for irrigation compared to freshwater (OR=0.13, p-value = 0.03): Farmers who perceive that safe TWW is not clean and safe enough to be used for irrigation compared to freshwater are significantly 0.13 times less willing to irrigate with safe TWW than the respondents who do not perceive such a risk. The perception of risks for safe reuse (abiding by international guidelines for water reuse and irrigation) is linked to insufficient knowledge about this practice.

- Perceived benefit - Protecting the environment from pollutants (OR=17.14, p-value = 0.015): Farmers who perceive that safe TWW protects the environment from pollutants are significantly 17.14 times more willing to irrigate with safe TWW than the ones who don't perceive this benefit. This perceived benefit of safe reuse is associated with sufficient knowledge about this practice because treating wastewater for safe reuse prevents the discharge of raw sewage into the environment, which has severe environmental and public health implications.

  Farmers perceiving greater benefits and lower risks for safe reuse are considered more knowledgeable. Higher knowledge and information raise their acceptability level, which thus increases openness to embracing water reuse (Michetti et al., 2019). This finding agrees with several studies. For instance, Hamdan et al. (2021) showed that farmers in Palestine have a higher probability of accepting water reuse when they exhibit knowledge and understanding of this concept and its benefits. However, Massoud et al., (2019) found that farmers in Lebanon with minimal knowledge about water reuse accept this practice to deal with water scarcity.

- WTU Justification: TWW generates revenues (OR=7.14, p-value = 0.037): Farmers who are willing to use safe TWW because it generates more income are significantly 7.14 times more willing to irrigate with safe TWW than the ones who did not have this economic reason behind their decision. According to the literature, one of the primary motivations for farmers to reuse TWW for agriculture is economic gain (Dare & Mohtar, 2018; Terkawi, 2016).

- WTU2 of Crops with an Increased Health Risk to Consumers and Handlers among Farmers:

Univariate logistic regression was used to identify the factors affecting farmers' willingness to apply safe TWW for the irrigation of crops eaten only after cooking (such as potatoes) and/or crops for human consumption after peeling (e.g.: bananas, melons, nuts, etc.). However, the associations between the outcome WTU2 and the independent variables were not significant (p-value > 0.05), thus, explainable by chance alone.

- WTU3 of Crops with the Highest Health Risk to Consumers, Field workers, and Handlers among Farmers:

Univariate logistic regression was employed to find the factors influencing farmers' willingness to use safe TWW for the irrigation of uncooked crops (e.g.: fresh vegetables). Significant variables at the 95% confidence interval are discussed below:

- Irrigation challenges: Reduced water quality/water pollution (OR=10.55, p-value = 0.044): Farmers facing irrigation challenges due to reduced water quality and water pollution are significantly 10.55 times more willing to irrigate with safe TWW than the ones who don't face this resource challenge. Water pollution reduces water availability for irrigation, leading to physical and economic water scarcity. Hence, farmers with polluted water sources tend to search for an alternative water source for irrigation to meet their water demand.

- Knowledge: A good understanding of this practice is necessary for the benefits of safe reuse to be perceived. Same interpretation as in WTU1.

    - Perceived benefit - Safe TWW generates more income (OR=9, p-value = 0.014): Farmers who perceive that safe TWW generates more income are significantly 9 times more willing to irrigate with safe TWW than the ones who don't perceive this benefit. Safe TWW tends to increase farmers' revenue since it boosts their agricultural yield and reduces fertilization costs, among other reasons (Mahjoub et al., 2018; Deh-Haghi et al., 2020).
    - Perceived benefit - Protecting the environment from pollutants (OR=17.14, p-value = 0.015): Farmers who perceive that safe TWW protects the environment from pollutants are significantly 7.33 times more willing to irrigate with safe TWW than the ones who don't perceive this benefit.

- WTU Justification:
    - Safe TWW generates revenues (OR=15.89, p-value = 0.014): Farmers who are willing to use safe TWW because it generates more income are significantly 15.89 times more willing to irrigate with safe TWW than the ones who did not have this economic reason behind their decision. As previously mentioned, farmers tend to be highly motivated by the financial gain added to their revenues by applying TWW for irrigation (Dare & Mohtar, 2018; Terkawi, 2016). This finding agrees with studies in the literature, where farmers claimed that TWW irrigation would result in increased agricultural yields of better quality, which would lead to higher sales and income (Mahjoub et al., 2018; Deh-Haghi et al., 2020).

    - Safe TWW helps in reducing the water scarcity problem in Lebanon (OR=15.89, p-value = 0.014): Farmers who are willing to use safe TWW because it helps in reducing the water scarcity problem in Lebanon are significantly 15.89 times more willing to irrigate with safe TWW than the ones who did not have this environmental reason behind their decision. The latter also applies in Tunisia, where farmers perceive that TWW can help lessen the water scarcity issue, which severely impacts their agricultural activity, especially during dry seasons (Mahjoub et al., 2018). This perception makes them more likely to approve of the safe reuse of TWW for agriculture.

- Lack of sustainable access to sufficient freshwater (OR=6.81, p-value = 0.017): Farmers who are willing to use safe TWW because of the lack of sustainable access to sufficient freshwater are significantly 6.81 times more willing to irrigate with safe TWW than the ones who did not have this reason behind their decision. In Greece, farmers' acceptance of using secondary treated WW to irrigate their olive trees appears to be solely motivated by the freshwater shortage (Menegaki et al., 2007). Similarly, due to the scarcity of freshwater and the barriers to its accessibility, communities in dry regions are most likely to support the reuse of treated wastewater (Adewumi et al., 2010). In contrast, despite the water shortage in the West Bank, 43% of the farmers with access to wells and springs at a very low average price refuse to use TWW for irrigation (Hamdan et al., 2021).
- TWW abiding by the international standards for water reuse for irrigation is safe for public health (no or minimum health risks) (OR=24, p-value = 0.001): Farmers who are willing to use safe TWW because it is safe for

public health (with no or minimal health risks) are significantly 24 times more willing to irrigate with safe TWW than the ones who did not have this reason behind their decision. This perception is associated with adequate knowledge about this practice and confidence in international standards to ensure a safe effluent quality if appropriately adopted.

ii. Multivariate Analysis

Significant variables resulting from the univariate binary logistic regression models were subjected to multivariate logistic regression analysis. In contrast, all the predictor variables found to be significant at the univariate analysis level were insignificant (p-value > 0.05) at the multivariate analysis level for both WTU1 (Table 3) and WTU3 (Table 4) when accounting for the combined effect of variables on farmers' willingness to use safe TWW for specific categories of crops. A variable that is significant at the univariate level but insignificant at the multivariate level is probably only predictive of the outcome because of its associations with other predictors and due to the small sample size of the farmers. After testing for the collinearity, the independent variables have indeed a moderate correlation with each other due to their VIF between 1 and 5 (Tables 3 and 4).

Table 3: The significant variables tested for their association with WTU1 in a Multivariate Logistic Regression Model.

WTU1	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]	VIF
Q9.2_4_types_of_perceived_risks_unfit-for-irrigation	0.391	0.444	-0.830	0.408	0.042	3.609	1.37
Q10_perceived_benefits_environmental protection	9.314	11.598	1.790	0.073	0.811	106.926	1.33
Q13_why_yes_economic3_generates income	2.429	2.778	0.780	0.438	0.258	22.844	1.39
_cons	1.313	1.279	0.280	0.780	0.194	8.864	
Mean VIF							1.37

Table 4: The significant variables tested for their association with WTU3 in a Multivariate Logistic Regression Model

WTU3	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]	VIF
Q7_7_env_waterpollution	3.066	4.784	0.720	0.473	0.144	65.280	1.48
Q10_perceived_benefits_more income	2.083	3.105	0.490	0.623	0.112	38.696	1.88
Q10_perceived_benefits_environmental protection	0.249	0.485	-0.710	0.476	0.005	11.369	1.91
Q13_why_yes_economic3_generates income	6.024	10.206	1.060	0.289	0.218	166.734	1.92
Q13_why_yes_env3_less water scarcity	1.31E+08	5.34E+11	0	0.996	0	.	2.63
Q13_why_yes_unsustainable_FW	1.72E-15	1.17E-11	-0.01	0.996	0	.	3.25
Q13_why_yes_safe_health	9.54E+14	6.49E+18	0.01	0.996	0	.	3.7
_cons	3.23E-09	0.0000132	0	0.996	0	.	
Mean VIF						2.4	

E. Results and Discussion – Perception of Consumers

1. *Descriptive Statistics*

a. Consumers' Demographic and Socio-economic Characteristics

A total number of 256 consumers filled out the online survey from the general Lebanese population, aged 18 years and above, in January and February 2022 (Figures 21 and 22, and in Appendix III). The sample consists of 49.2% females (N= 126) and 50.8% males (N= 130) (Q10). The majority of the respondents fall in the range of 18-25 years old (47.3%) (Q11). About 79.7% of the respondents have attained university degrees, while 8.2% have reached high school, 4.3% intermediate education, 2% elementary, 3.5% technical degrees, and 2.3% are non-educated (Q12). About 56.25% of the participants were employed at the time when this survey was conducted (102 employed and 42 self-employed), along with 33.6% students and 10.2% unemployed (Q13). As for the average monthly household income after tax deductions (Q14), 78 consumers (30.5%) reported less than 4,000,000 LL, while 108 respondents (42.2%) have an income of more than 4,001,000 LL. In contrast, 70 people (27.3%) refused to report their income, due to privacy reasons. Thus, they were removed from the analysis of the income variable Among the 256 participants, 197 (77%) consider themselves urban, compared to 59 (23%) who identify themselves as rural (Q15). Lastly, 38 farmers (15.2%) answered this survey versus 217 (84.8%) consumers (general public) (Q16).

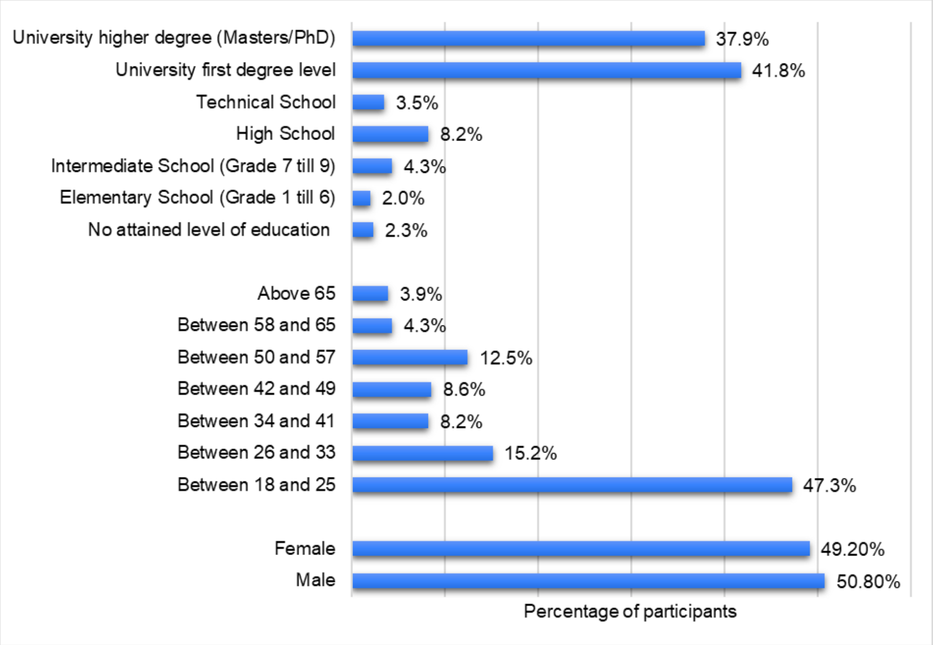

Figure 21: Attained Education Level, Age, and Sex of Consumers

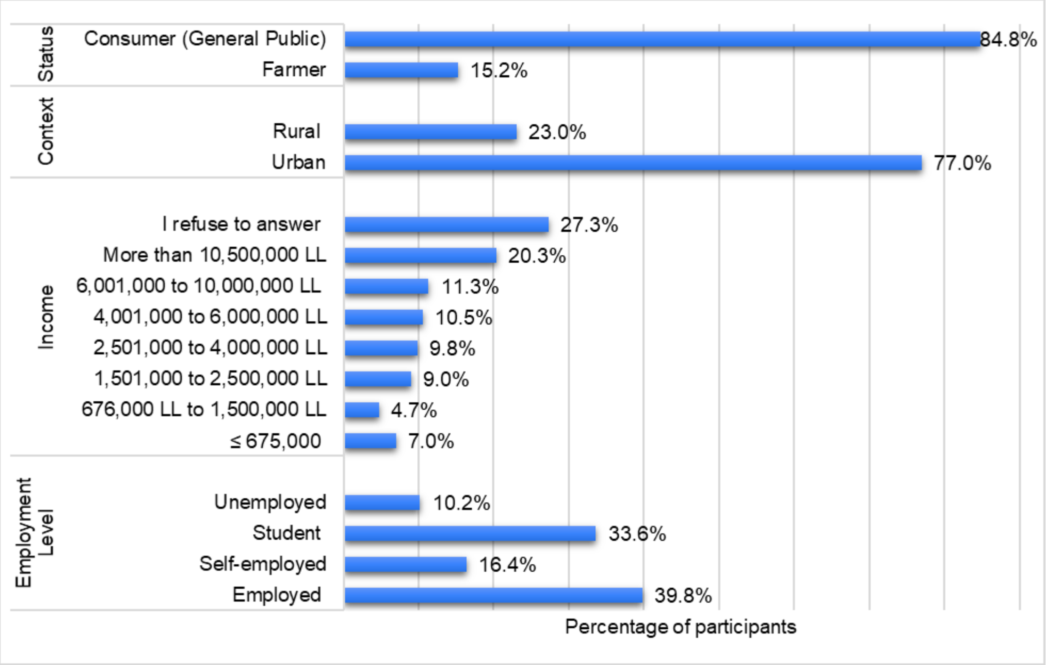

Figure 22: Status, Context, Average Monthly Household Income, and Employment Level of Consumers

b. <u>Knowledge about Water Reuse among Consumers</u>

Knowledge about water reuse is evident among the majority of the respondents (Appendix III). The results reveal that 60.9% of the consumers have heard about TWW and its reuse for irrigation and know what it means and 25% have heard but do not know what it means (i.e., insufficient knowledge), while only 14.1% did not hear about it (Q1) (Figure 23). The questionnaire also tested consumers' actual knowledge of the risks and benefits of safe reuse (abiding by international guidelines) through Q2 and 3. 62.5% of the participants (equivalent to 160) are aware that the safe reuse of TWW has no risks. On the other hand, the remaining 96 (37.5%) consumers reported the following risks: safe reuse (abiding by the international standards for water reuse for irrigation) increases health concerns and disease outbreaks (48 responses, 18.8%), attracts disease vectors to the irrigation ponds and fields (20 responses, 7.8%), causes environmental impacts (20 responses, 7.8%), and it is not clean and safe enough for irrigation compared to freshwater (47 responses, 18.4%) (Q2) (Figure 24). The benefits of safe reuse are also well-known by consumers (Q3). The most mentioned benefits are that farmers could have continuous access to treated wastewater for crop irrigation even during drought periods (66.8%), safe reuse promotes sustainability in agriculture and water resource use (63.7%), and this practice conserves fresh potable water (63.3%) (Figure 25).

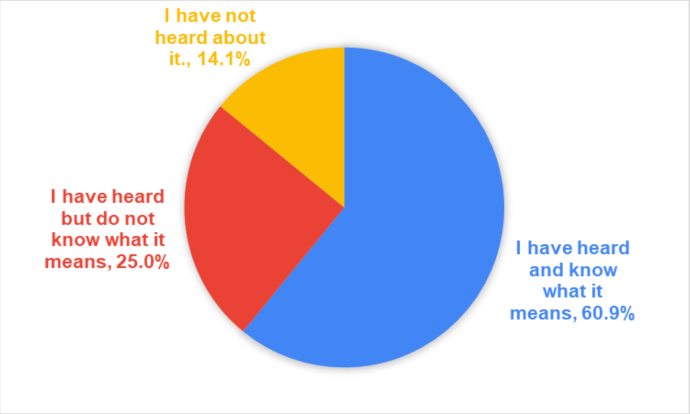

Figure 23: Perceived TWWR Awareness among Consumers

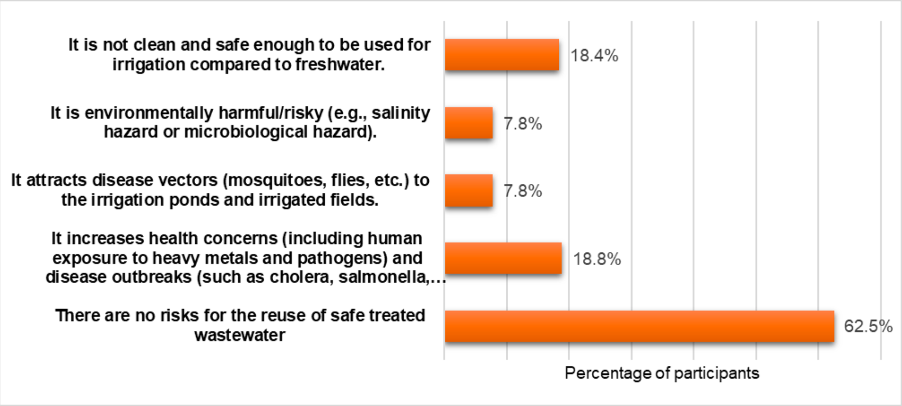

Figure 24: Perceived Risks of TWW Reuse among Consumers

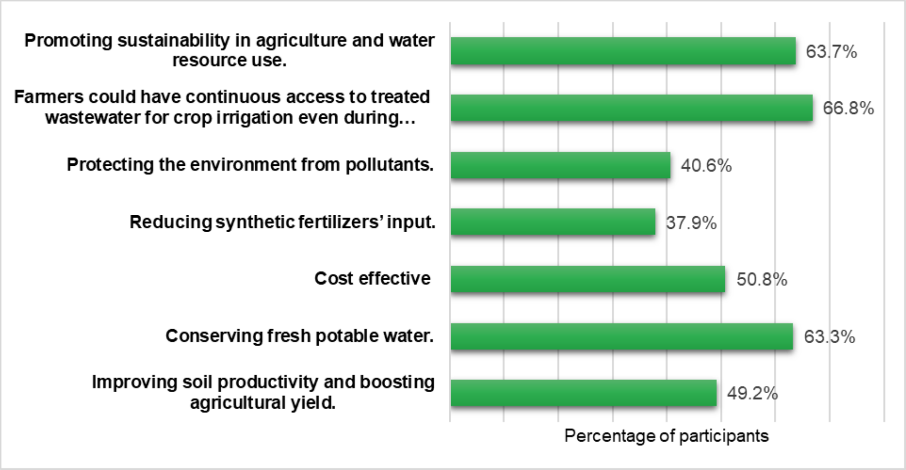

Figure 25: Perceived Benefits of TWW Reuse among Consumers

c. Willingness to Use among Consumers

The willingness to use or accept the safe use of TWW is very high among the participants. In fact, 245 respondents (95.7%) accept the safe use of this non-conventional water source for agriculture (Q4) (Figure 26). This finding exceeds our expectation of a response distribution of 80%. Similar to the farmers, the highest acceptance is for the crops eaten only after cooking (such as potatoes), which is unexpected considering this category has an increased risk to consumers and handlers (181 responses, 73.9%). The second-highest acceptance is for fiber and fodder/animal feed crops, with the lowest risk to consumers (field worker protection needed) (175 consumers, 71.4%). The least accepted is the irrigation of uncooked crops (such as fresh vegetables) (67 consumers, 27.3%), considering this category has the highest risk to the consumers, field workers, and handlers (Q5) (Figure 27). On average, consumers mostly accept the irrigation of crops with the lowest risk (WTU1) (65.1%), followed by the increased risk (WTU 2) (56.5%), and lastly, the highest risk (WTU 3) (27.3%). When asked to rate their willingness to use (Figure 28), 72/245 (or 29.4%) are 100%

sure of their decision, while the second-highest rating is 80% among 52 consumers (Q7).

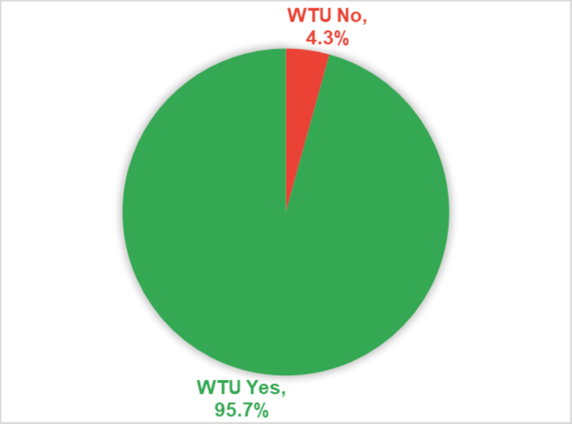

Figure 26: Willingness to Use among Consumers

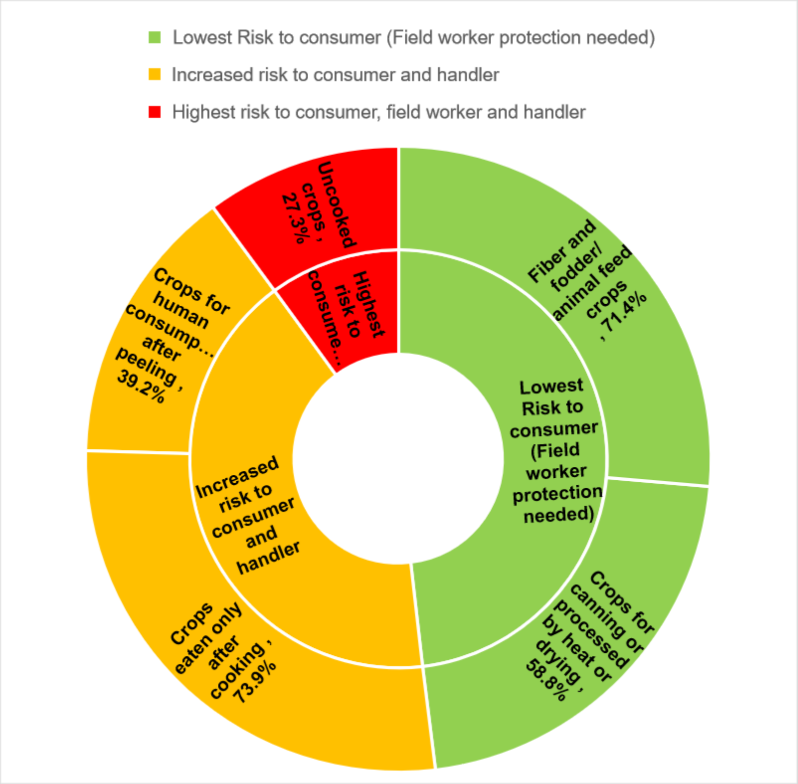

Figure 27: WTU based on Crops Category among Consumers

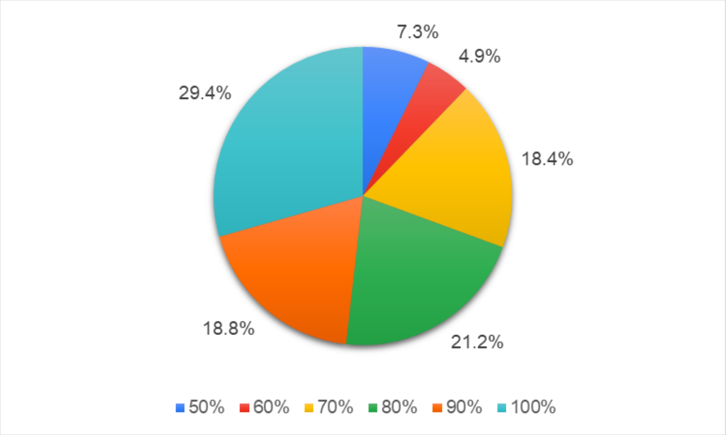

Figure 28: WTU Ratings among Consumers

d. Willingness to Use Justifications among Consumers

i. The Reasons Behind Consumers' Acceptance

Consumers mainly attributed their WTU of safe TWW for irrigation to its environmental benefits (Q6) (Figure 29). The two main reasons are that this practice reduces the discharge of untreated wastewater in rivers or seas (70.2%) and helps in reducing the water scarcity problem in Lebanon (65.3%). The third-highest reason for their acceptance is the ability of this water source to increase farmers' agricultural yield (54.7%) (i.e., an economic benefit). However, only 14 respondents (5.7%) reported that they trust the authorities to ensure the safe quality of treated wastewater. Therefore, the lack of trust seems to be a barrier that might hinder their acceptance in practice.

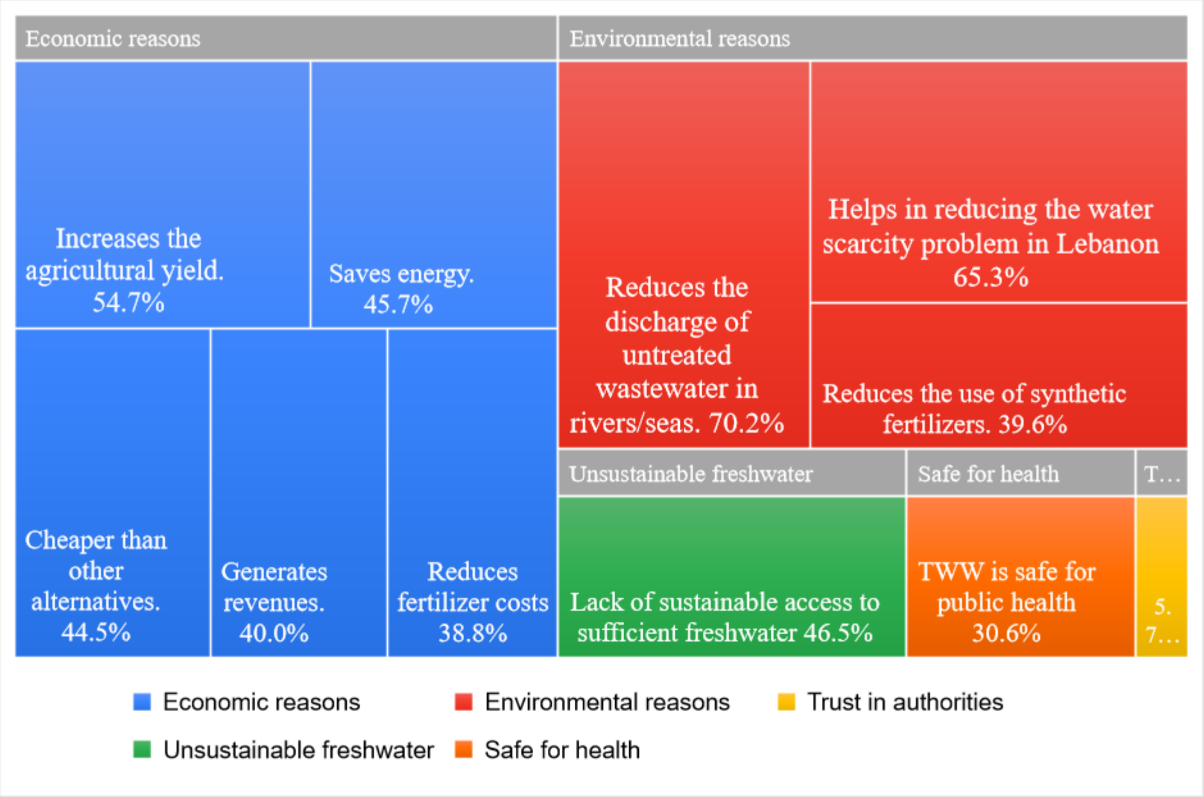

Figure 29: Justifications for Accepting the Safe Use of TWW among Consumers

ii. The Reasons Behind Consumers' Rejection

Among the 11 consumers who refuse the safe reuse of TWW (Q8) (Figure 30), 9 (81.8%) reported a lack of trust in the municipal authorities to adequately operate, monitor, and maintain the wastewater treatment plants (i.e., distrusted water quality). Their rejection was also attributed to their perception of TWW as dirty (among 5 consumers, 45.5%). A few others justified their decision by linking it to the fear of public criticism, insufficient knowledge, and the possibility that TWW might interfere with the sprinkler and drip irrigation systems (3 participants or 27.3% each). The latter responses with the technical concern came surprisingly from consumers, not farmers. Two consumers (18.2%) were concerned that the service will be unequally distributed over areas at various topographies, while one (9.1%) considers water reuse as religiously unacceptable. As for the consumers who perceive that safe reuse causes public health problems (3 responses, 27.3%) and environmental impacts (1 response, 9.1%), their justification is less valid. Their reasons might be attributed to their lack of knowledge about TWW, considering they perceive that safe reuse has risks with minimal benefits (in Q2 and 3).

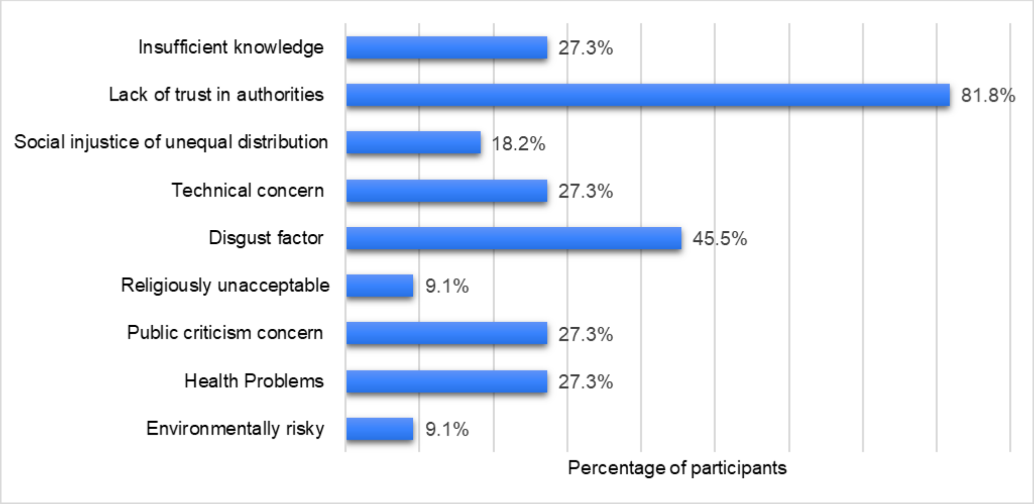

Figure 30: Justifications for Refusing the Safe Use of TWW among Consumers

To help them make an informed decision (Q9), the top three resources are a clear TWW policy from the Ministry of Agriculture and Ministry of Water and Energy (81.8%), studies documenting the safety and benefits of using TWW in agricultural irrigation (54.5%), and to understand the involved treatment processes (45.5%) (Figure 31).

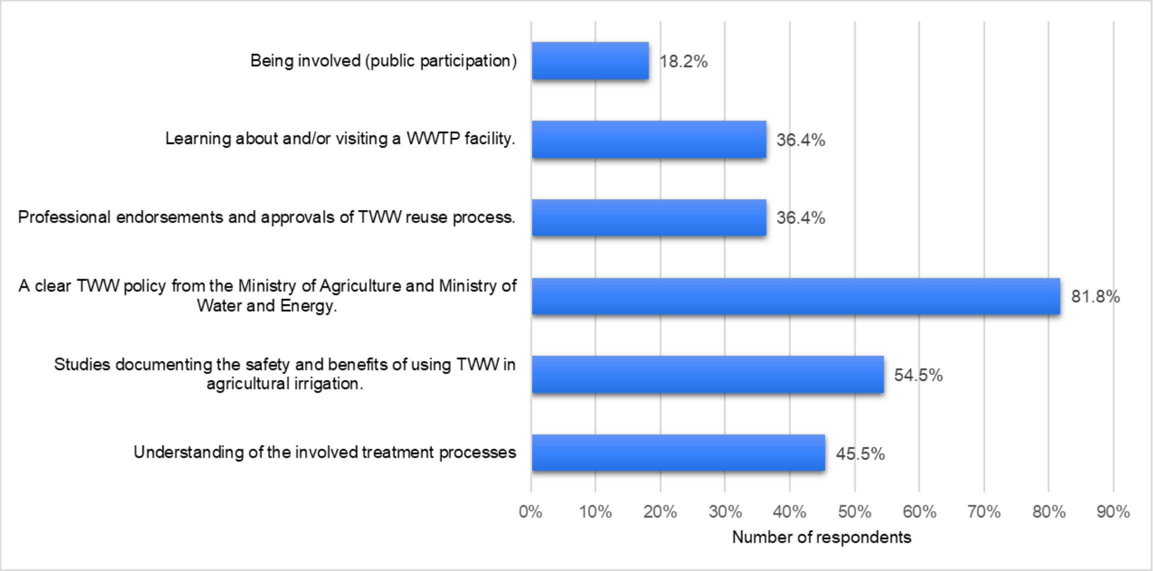

Figure 31: Resources for an Informed Decision

2. *Analytical Statistics*

a. Logistic Regression Model Analysis of WTU among Consumers

i. Univariate Analysis

Univariate logistic regression was employed to find the variables affecting consumers' willingness to safely use (if they identified themselves as farmers) or allow safe usage of treated wastewater for agricultural purposes. The significant associations between the binary outcome WTU and the independent variables in our questionnaire (p-value < 0.05) are the following:

- Knowledge

- Perceived risks of safe reuse (OR= 0.12, p-value = 0.01): Consumers who perceive risks for safe reuse are significantly 0.12 less willing to allow irrigation with safe TWW than those who do not perceive risks for this safe practice.

- Types of perceived risks - Safe TWW increases health concerns (including human exposure to heavy metals and pathogens) and disease outbreaks (such as cholera, salmonella, diarrhea, typhoid ascariasis, hepatitis, and others) (OR=0.25, p-value = 0.03): Consumers who perceive increases in health concerns and disease outbreaks for safe reuse are significantly 0.25 less willing to allow the irrigation with TWW than the participants who do not perceive such risks.
- Types of perceived risks - Safe TWW is not clean and safe enough to be used for irrigation compared to freshwater (OR= 0.25, p-value = 0.03): Consumers who perceive that safe TWW is not clean and safe enough to be used for irrigation compared to freshwater are significantly 0.25 less willing to allow the irrigation with safe TWW than the respondents who do not perceive such a risk.

The perception of risks for safe reuse, abiding by international guidelines, is correlated with insufficient knowledge about this practice. Thus, this perception is significantly associated with lower acceptance among consumers. These results are similar in Ghana and Kuwait, where knowledge was a significant positive indicator of the public's willingness to approve TWW for irrigation and the consumption of irrigated crops (Kwabla, 2017; Alhumoud & Madzikanda, 2010).

ii. Multivariate Analysis

Significant variables resulting from the univariate logistic regression models were then subject to multivariate logistic regression analysis. In contrast, all the significant predictor variables at the univariate analysis level were insignificant at the multivariate analysis level (p-value > 0.05) when accounting for confounders, as if all of the other predictors were constant (Table 5). The VIF for all independent variables is less than 5 (Table 5), indicating a moderate correlation between a given explanatory variable and the other, which might have caused this insignificance.

Table 5: The significant variables tested for their association with WTU in a Multivariate Logistic Regression Model

Q4_WTU	**Odds Ratio**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**	**VIF**
Q2.1_perceived_risksYESvsNo	0.220	0.246	-1.360	0.175	0.025	1.963	3.56
Q2.2_1_types_of_perceived_risks_health concerns	0.579	0.477	-0.660	0.507	0.115	2.910	2.23
Q2.2_4_types_of_perceived_risks_unfir for irrigati	0.562	0.463	-0.700	0.484	0.112	2.823	2.2
_cons	79.000	56.214	6.140	0.000	19.586	318.651	
Mean VIF							2.66

b. Logistic Regression Model Analysis of WTU per Crop Category among Consumers

The WTU per crop category from a public health perspective was further analyzed based on the findings about the general acceptance of wastewater reuse and given that there were indications that the type of crop irrigated is a factor in the decision (Q5).

i. WTU1 of Crops with the Lowest Risk to Consumers (Field worker protection is needed) among Consumers

❖ Univariate Analysis

Univariate logistic regression was adopted to find the factors affecting consumers' willingness to safely use (if they are farmers) or allow safe usage of treated wastewater for the irrigation of fiber and fodder/animal feed crops and/or crops for canning or processed by heat or drying (such as grains). The significant associations between the binary outcome WTU1 and the independent variables in our questionnaire (p-value < 0.05) are the following:

- Knowledge:
  - Awareness of TWW and its reuse for irrigation (OR=3.93, p-value = 0.001): Consumers who heard and know about TWW and its reuse for irrigation are significantly 3.93 times more willing to accept safe TWW irrigation than the ones who don't know. This variable is an indicator of their perceived knowledge.

  - Perceived risks of safe reuse (OR=0.37, p-value = 0.001): Consumers who perceive risks for safe reuse are significantly 0.37 times less likely to allow irrigation with safe TWW than those who do not perceive any risks for its safe reuse.

  - Types of perceived risks - Safe TWW increases health concerns (including human exposure to heavy metals and pathogens) and disease outbreaks (such as cholera, salmonella, diarrhea, typhoid ascariasis, hepatitis, and others) (OR=0.36, p-value = 0.003): Consumers who perceive increases in health concerns and disease outbreaks for safe reuse are significantly 0.36 less willing to allow the irrigation with TWW than the participants who do not perceive such risks.

  - Perceived benefits: Consumers, who perceive the following benefits, are significantly more willing to allow irrigation with safe TWW than the ones who don't perceive them.

→ Improving soil productivity and boosting agricultural yield (OR=2.65, p-value = 0.003): significantly 2.65 times

→ Conserving fresh potable water (OR=5.19, p-value = 0): significantly 5.19 times more willing.

→ Protecting the environment from pollutants (OR=2.67, p-value = 0.005): significantly 2.67 times more willing.

These variables are indicators of consumers’ actual knowledge, where the perception of benefits is associated with adequate knowledge considering all the options in this question are benefits of safe reuse, and vice versa for the perception of risks.

- Level of Education (OR=3.5, p-value = 0.411): University-educated consumers are significantly 3.5 times more willing to allow irrigation with safe TWW than school-educated participants. Likewise, in Kuwait, people with higher levels of education demonstrated a greater willingness to accept treated wastewater compared to other groups. These results might be explained by their increased familiarity with the practice (Alhumoud & Madzikanda, 2010). University graduates are usually more familiar with success stories and benefits of safe TWWR in other nations because they use a wider variety of information sources for environmental news (Kazarian, 2016; Massoud et al., 2018).

- WTU Justification:

- Economic Reasons: Consumers, with the below economic incentives, are significantly more willing to accept the irrigation with safe TWW than the ones who did not have these economic reasons behind their decision.

→ Safe TWW increases the agricultural yield (OR=4.89, p-value = 0): significantly 4.89 times more willing.

→ It saves energy (OR=3.55, p-value = 0): significantly 3.55 times more willing.

→ It generates revenues (OR=4.76, p-value = 0): significantly 4.76 times more willing.

→ It is cheaper than other alternatives (OR=4.37, p-value = 0): significantly 4.37 times more willing.

→ It reduces fertilizer costs (OR=4.48, p-value = 0): significantly 4.48 times more willing.

- Environmental Reasons: Consumers with the below environmental incentives are significantly more willing to accept the irrigation with safe TWW than the ones who did not have these environmental reasons behind their decision.

→ Safe TWW reduces the use of synthetic fertilizers (OR=2.99, p-value = 0.003): significantly 2.99 times more willing.

→ It reduces the discharge of untreated wastewater in rivers or seas (OR=8.45, p-value = 0): significantly 8.45 times more willing.

→ It helps in reducing the water scarcity problem in Lebanon (OR=13.23, p-value = 0): significantly 13.23 times more willing.

- Lack of sustainable access to sufficient freshwater (OR=9.48, p-value = 0): Consumers who are willing to accept the safe use of TWW because of the lack of sustainable access to sufficient freshwater are significantly 9.48 times more willing to allow irrigation with safe TWW than the ones who did not have this reason behind their decision.
- TWW abiding by the international standards for water reuse for irrigation is safe for public health (no or minimum health risks) (OR=15.11, p-value = 0): Consumers who are willing to allow the use of safe TWW because it is safe for public health (with no or minimal health risks) are significantly 15.11 times more willing to accept this safe practice for irrigation than the ones who did not have this health incentive behind their decision.

❖ Multivariate Analysis

Significant variables resulting from the univariate models were subjected to multivariate logistic regression analysis (Table 6). The predictor variables found to be significant, independently of their associations with the other variables, are:

- WTU Justification - Safe TWW increases the agricultural yield (OR=2.58, p-value = 0.038): Consumers, who are willing to allow the safe use of TWW because it increases the agricultural yield, are significantly 2.58 times more willing to accept the irrigation with safe TWW than the ones who did not have this economic incentive behind their decision. In agriculture, treated wastewater is an attractive water source since it can produce a greater agricultural yield of better quality due to the supply of nutrients for crop growth and consequently boost the economy (Mahjoub et al., 2018; and Deh-Haghi et al., 2020).

- WTU Justification - Safe TWW helps in reducing the water scarcity problem in Lebanon (OR=3.26, p-value = 0.026): Consumers who are willing to accept the safe use of TWW because it helps in reducing the water scarcity problem in Lebanon are significantly 3.26 times more willing to allow irrigation with safe TWW than the ones who did not have this reason behind their decision. Similarly, 92% of the interviewed general population in Italy were motivated by the environmental benefit of TWW to decrease the exploitation of their freshwater resources (Saliba et al., 2018). Furthermore, residents in the West Bank are encouraged to use TWW, as an alternative source to freshwater, due to the region's exacerbating water shortage (McNeill et al., 2009).

A moderate correlation between one explanatory variable and another is indicated by the VIF being less than 5 for all independent variables, but this is frequently not significant enough to warrant attention (Table 6). Furthermore, the difference between the coefficients/ORs of those two significant variables was insignificant (p-value = 0.7253). Hence, the strongest predictor for WTU1 cannot be determined.

Table 6: The significant variables tested for their association with WTU1 in a Multivariate Logistic Regression Model

WTU1	**Odds Ratio**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**	**VIF**
Q2.1_perceived_risksYESvsNo	0.967	0.494	-0.070	0.947	0.355	2.631	1.92
Q2.2_1_types_of_perceived_risks_health concerns	0.588	0.342	-0.910	0.361	0.188	1.838	1.71
Q3_perceived_benefits_Improving productivity	1.688	0.779	1.130	0.257	0.683	4.172	1.5
Q3_perceived_benefits_conserve FW	2.035	0.929	1.560	0.120	0.831	4.981	1.45
Q3_perceived_benefits_env. protection	0.702	0.375	-0.660	0.509	0.246	2.002	1.53
Q6_why_yes_economic1_increases yield	2.577	1.176	2.070	0.038*	1.054	6.304	1.43
Q6_why_yes_economic2_saves energy	1.118	0.538	0.230	0.817	0.435	2.871	1.5
Q6_why_yes_economic3_generates revenues	1.835	0.993	1.120	0.262	0.635	5.302	1.43
Q6_why_yes_economic4_cheaper	2.265	1.079	1.720	0.086	0.890	5.762	1.31
Q6_why_yes_economic5_reduces fertilizers costs	2.171	1.249	1.350	0.178	0.703	6.703	1.96
Q6_why_yes_env1_less fertilizer	0.794	0.453	-0.400	0.686	0.260	2.427	1.83
Q6_why_yes_env2_less discharge	2.321	1.098	1.780	0.075	0.918	5.868	1.82
Q6_why_yes_env3_less water scarcity	3.262	1.737	2.220	0.026*	1.148	9.265	2.11
Q6_why_yes_unsustainable_FW	1.519	0.910	0.700	0.485	0.470	4.912	1.71
Q6_why_yes_safe_health	3.446	2.869	1.490	0.137	0.674	17.622	1.6
awar1 (heard and know)	1.246	0.527	0.520	0.603	0.544	2.856	1.15
educ1 (university level)	0.789	0.384	-0.490	0.625	0.304	2.046	1.2
_cons	0.320	0.169	-2.150	0.031	0.113	0.903	
Mean VIF							1.59

* Significant

ii. WTU2 of Crops with an Increased Risk to Consumers and Handlers among Consumers

❖ Univariate Analysis

Univariate logistic regression was adopted to find the factors affecting consumers' willingness to safely use (if they are farmers) or allow safe usage of treated wastewater for the irrigation of crops eaten only after cooking (such as potatoes) and/or crops for human consumption after peeling (e.g.: bananas, melons, nuts, etc.). The significant associations between the outcome WTU2 and the independent variables (p-value < 0.05) are the following:

- Knowledge: Perceived benefits - Conserving fresh potable water (OR=1.98, p-value = 0.022): Consumers, who perceive that safe TWW conserves fresh potable water, are significantly 5.19 times more willing to allow the irrigation with safe TWW than the ones who don't perceive this benefit.

- WTU Justifications:

- Economic Reasons: Consumers, with the below economic incentives, are significantly more willing to accept the irrigation with safe TWW than the ones who did not have these economic reasons behind their decision.

→ Safe TWW increases the agricultural yield (OR=2.88, p-value = 0.001): significantly 2.88 times more willing.

→ It saves energy (OR=2.01, p-value = 0.024): significantly 2.01 times more willing.

→ It generates revenues (OR=3.66, p-value = 0): significantly 3.66 times more willing.

→ It is cheaper than other alternatives (OR=1.89, p-value = 0.04): significantly 1.89 times more willing.

- Environmental Reasons: Consumers, with the below environmental incentives, are significantly more willing to accept the irrigation with safe TWW than the ones who did not have these environmental reasons behind their decision.

→ Safe TWW reduces the use of synthetic fertilizers (OR=2.22, p-value = 0.016): significantly 2.22 times more willing.

→ It reduces the discharge of untreated wastewater in rivers or seas (OR=5.91, p-value = 0): significantly 5.91 times more willing.

→ It helps in reducing the water scarcity problem in Lebanon (OR=4.29, p-value = 0): significantly 4.29 times more willing.

- Lack of sustainable access to sufficient freshwater (OR=5.83, p-value = 0): Consumers who are willing to accept the safe use of TWW because of the lack of sustainable access to sufficient freshwater are significantly 5.83 times more willing to allow irrigation with safe TWW than the ones who did not have this reason behind their decision.
- TWW abiding by the international standards for water reuse for irrigation is safe for public health (no or minimum health risks) (OR=3.47, p-value = 0.002): Consumers who are willing to accept the use of safe TWW because it is safe for public health (with no or minimal health risks) are significantly 3.47 times more willing to accept this safe practice for irrigation than the ones who did not have this reason behind their decision.

- Context (OR=0.51, p-value = 0.04): Rural consumers are significantly 0.51 times less willing to accept this safe practice for irrigation than urban participants.

- Level of Education (OR=2.05, p-value = 0.042): University-educated consumers are significantly 2.05 times more willing to allow irrigation with safe TWW than school-educated participants.

- Income (OR=2.07, p-value = 0.035): Consumers with a monthly household income of more than 4,001,000 LL are significantly 2,07 more willing to allow irrigation with safe TWW than the ones with a monthly household income of less than 4,000,000 LL. This finding agrees with studies in the literature, where people with high incomes showed a higher willingness to use TWW (Garcia-Cuerva et al., 2016).

- Multivariate Analysis

Multivariate logistic regression analysis followed the univariate logistic regression models for the significant variables (Table 7). The factors which remained significant when all of the other predictors were constant are:

- WTU Justification - Lack of sustainable access to sufficient freshwater (OR=3.05, p-value = 0.042): Consumers who are willing to accept the safe use of TWW because of the lack of sustainable access to sufficient freshwater are significantly 3.05 times more willing to allow irrigation with safe TWW than the ones who did not have this reason behind their decision. In Greece, the perceived freshwater unavailability was significantly correlated with consumers' acceptance to irrigate tomatoes with tertiary TWW, indicating their willingness to consume high-risk products to address the serious water scarcity issue (Menegaki et al., 2007).

- Context (OR=0.42, p-value = 0.04): Rural consumers (19 farmers and 40 non-users/only consumers) are significantly 0.42 times less willing to accept this safe practice for irrigation than urban participants. Similarly, Alataway et al. (2011) showed a difference in attitudes between rural and urban communities in Saudi

Arabia. Residents of rural areas, where wastewater reuse is practiced, were more sensitive than residents of urban areas, where TWWR is very limited. In Lebanon, some farmers are irrigating their crops with TWW (like the two interviewed farmers in this study). Hence, rural consumers, who might be witnessing and experiencing this practice, especially since it is not legally regulated in Lebanon, are less willing to accept it and trust its safety. On the other hand, rural consumers tend to be more aware of and witness more farmers' inability to meet their water demand for irrigation and the irrigation challenges, which might increase their WTU compared to urban consumers.

The VIF for all independent variables is less than 5, indicating a moderate non-severe correlation between a given explanatory variable and the other (Table 7). Additionally, the difference between the coefficients/ORs of the two significant variables was significant (p-value = 0.0045). Hence, the strongest predictor of WTU2 with the biggest OR is the WTU Justification - Lack of sustainable access to sufficient freshwater.

Table 7: The significant variables tested for their association with WTU2 in a Multivariate Logistic Regression Model

WTU2	**Odds Ratio**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**	**VIF**
Q14_income	1.483	0.617	0.950	0.343	0.656	3.351	1.21
educ1	1.236	0.590	0.440	0.657	0.485	3.148	1.32
Q3_perceived_benefits_conservef	0.744	0.352	-0.630	0.532	0.294	1.881	1.43
Q6_why_yes_economic1_increases	1.271	0.565	0.540	0.589	0.532	3.040	1.39
Q6_why_yes_economic2_savesenerg	1.076	0.503	0.160	0.875	0.431	2.689	1.42
Q6_why_yes_economic3_generatesr	2.326	1.110	1.770	0.077	0.913	5.927	1.38
Q6_why_yes_economic4_cheaper	1.043	0.446	0.100	0.921	0.451	2.413	1.24
Q6_why_yes_env1_lessfertilizer	0.747	0.347	-0.630	0.530	0.300	1.859	1.28
Q6_why_yes_env2_lessdischargeo	2.169	1.146	1.470	0.143	0.770	6.111	2.02
Q6_why_yes_env3_lesswaterscarc	1.181	0.651	0.300	0.763	0.401	3.477	2.09
Q6_why_yes_unsustainable_fw	3.048	1.668	2.040	0.042*	1.043	8.910	1.75
Q6_why_yes_safe_health	1.050	0.572	0.090	0.928	0.361	3.053	1.43
Q16_urbanorrural	0.420	0.178	-2.050	0.04*	0.183	0.962	1.04
_cons	0.918	0.407	-0.190	0.847	0.385	2.190	
Mean VIF							1.46

* Significant

iii. WTU3 of Crops with the Highest Health Risk to Consumers, Field workers, and Handlers among Consumers

❖ Univariate Analysis

Univariate logistic regression was adopted to find the factors affecting consumers' willingness to safely use (if they are farmers) or allow safe usage of treated wastewater for the irrigation of uncooked crops (e.g.: fresh vegetables). Significant variables at the 95% confidence interval are discussed below:

- Knowledge:
    - Perceived risks of safe reuse (OR=0.31, p-value = 0.001): Consumers who perceive risks for safe reuse are significantly 0.31 times less willing to allow irrigation with safe TWW than those who do not perceive any risks for its safe reuse.

- Types of perceived risks: Consumers who perceive the below risks for safe reuse are significantly less willing to allow irrigation with TWW than the participants who do not perceive such risks.

→ Safe TWW increases health concerns (including human exposure to heavy metals and pathogens) and disease outbreaks (such as cholera, salmonella, diarrhea, typhoid ascariasis, hepatitis, and others) (OR=0.42, p-value = 0.048): significantly 0.42 less willing.

→ Safe TWW is not clean and safe enough to be used for irrigation compared to freshwater (OR=0.28, p-value = 0.011): significantly 0.28 times less willing.

- Perceived benefit - Conserving fresh potable water (OR=3.99, p-value = 0): Consumers, who perceive that safe TWW conserves fresh potable water, are significantly 3.99 times more willing to allow the irrigation with safe TWW than the ones who don't perceive this benefit.

- WTU justification
  - Safe TWW generates revenues (OR=1.85, p-value = 0.033): Consumers, who are willing to allow the safe use of TWW because it generates more income for the farmers, are significantly 1.85 times more willing to accept the irrigation with safe TWW than the ones who did not have this economic reason behind their decision.
  - Environmental Incentives: Irrigation with safe TWW is significantly more acceptable to consumers who have the following environmental incentives than the ones who do not.

→ Safe TWW reduces the discharge of untreated wastewater in rivers or seas (OR=2.82, p-value = 0.003): significantly 2.82 times more willing.

→ It helps in reducing the water scarcity problem in Lebanon (OR=3.67, p-value = 0): significantly 3.67 times more willing.

- Lack of sustainable access to sufficient freshwater (OR=2.3, p-value = 0.004): Consumers who are willing to accept the safe use of TWW because of the lack of sustainable access to sufficient freshwater are significantly 2.3 times more willing to allow irrigation with safe TWW than the ones who did not have this reason behind their decision.

- TWW abiding by the international standards for water reuse for irrigation is safe for public health (no or minimum health risks) (OR=3.72, p-value = 0): Consumers who are willing to allow the use of safe TWW because it is safe for public health are significantly 3.72 times more willing to accept this safe practice for irrigation than the ones who did not have this reason behind their decision.

❖ Multivariate Analysis

Multivariate logistic regression analysis was then performed on the significant factors identified by the univariate logistic regression models. Similar to previous models, all independent variables have a VIF less than 5, indicating a moderate non-severe correlation between one explanatory variable and the other (Table 8). The only significant variable is Knowledge: Perceived benefits - Conserving fresh potable water (OR=2.49, p-value = 0.024): Consumers, who perceive that safe TWW conserves fresh potable water, are significantly 2.49 times more willing to allow the irrigation with safe TWW than the ones who don't perceive this benefit. Knowledge in the form of perceived benefits tends to increase people’s WTU. These results are similar in Italy, where knowledge about the advantages of safe reuse positively influenced consumers’ attitudes and acceptance (Saliba et al., 2018).

Table 8: The significant variables tested for their association with WTU3 in a Multivariate Logistic Regression Model

WTU3	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]	VIF
Q2.1_perceived_risksYESvsNo	0.670	0.457	-0.590	0.556	0.176	2.547	3.83
Q2.2_1_types_of_perceived_risks_health concerns	0.908	0.633	-0.140	0.889	0.231	3.561	2.28
Q2.2_4_types_of_perceived_risks_not clean and safe	0.519	0.368	-0.920	0.355	0.129	2.084	2.23
Q3_perceived_benefits_conserve FW	2.482	1.000	2.260	0.024*	1.127	5.465	1.32
Q6_why_yes_economic3_generates revenues	0.967	0.323	-0.100	0.920	0.502	1.862	1.2
Q6_why_yes_env2_less discharge	1.029	0.486	0.060	0.953	0.407	2.597	1.65
Q6_why_yes_env3_less water scarcity	1.838	0.905	1.240	0.216	0.701	4.823	2.04
Q6_why_yes_unsustainable_FW	0.975	0.378	-0.070	0.948	0.456	2.085	1.66
Q6_why_yes_safe_health	2.080	0.781	1.950	0.051	0.997	4.341	1.49
_cons	0.118	0.052	-4.810	0.000	0.049	0.282	
Mean VIF							1.97

* Significant

F. Conclusion

To assess and promote direct treated wastewater reuse in Lebanon, where it is currently nearly nonexistent, an analysis of acceptance of this practice was carried out to add to the limited research in the literature about this topic. Although this study was conducted in Lebanon, the identified influencing factors impacting the willingness to use safe TWW in agriculture, along with the actions and strategies that will be suggested to encourage this practice, may serve as a guide for water resources planning decisions in other countries with a similar socio-cultural and natural context.

The findings reveal that farmers in Zahle and Ablah elicited good knowledge about safe water reuse. They also reported a very high willingness to safely use treated wastewater for agricultural purposes (94.10%), mainly because of its economic benefits. Indeed, the decision of farmers to use TWW is highly influenced by financial considerations that affect their net earnings (Alfarra et al., 2013). Furthermore, respondents prefer, on average, to irrigate crops with an increased health risk to consumers and handlers (WTU2) (i.e., crops eaten only after cooking and crops for human consumption after peeling) (81.25%). When assessing for correlations, the acceptance to irrigate crops with the lowest health risk to consumers (field worker protection is needed) (WTU1) is significantly and strongly correlated with their knowledge that TWWR protects the environment from pollutants (OR=17.14) and farmers' economic incentive to generate higher revenue (OR=7.14). On the other hand, this acceptance is significantly hindered by their misjudgment that safe TWW is not clean and not safe enough to be used for irrigation compared to freshwater (OR=0.13). As for WTU3 for crops with the highest health risk, this willingness is significantly and highly associated with the reduced quality of farmers' current water sources (OR=10.55), their knowledge of the benefits of safe reuse of environmental protection (OR=17.14) and higher income generation (OR=9), the perceived lack of sustainable access to sufficient freshwater (OR=6.81), and their economic (OR=15.89), environmental (OR=15.89), and health incentives (OR=24) for safe TWWR. In contrast, these significant variables at the univariate level but insignificant at the multivariate level are probably only predictive of the outcome because of their association with other predictors/confounders, indicated by the moderate collinearity between the independent variables in the multivariate models ($1 < VIF < 5$), and due to the small sample size of the farmers.

As for the consumers, the results reveal that the participants from the general Lebanese population, aged 18 years and above, elicited good knowledge about safe water reuse and its benefits. They also reported a very high willingness to allow the safe use of treated wastewater for agriculture (95.7%), mainly because of its environmental benefits. The acceptance rate is even 100% among 29.4% of the respondents. Furthermore, respondents prefer, on average, to irrigate crops with the lowest health risk to consumers with field worker protection is needed (WTU1) (i.e., fiber and fodder/animal feed crops and crops for canning or processed by heat or drying) (65.1%). This acceptance (or WTU) is significantly and negatively correlated with consumers' insufficient knowledge about the risks of safe reuse (only at the univariate level). Thus, these associations might only predict the outcome because they correlate with other predictors (moderate collinearity). Three additional binary outcomes were examined using univariate logistic regression and then multivariate analysis for the significant variables. At the multivariate level, the acceptance of crops with the lowest health risk to consumers (field worker protection is needed) (WTU1) is significantly correlated with consumers' economic incentive to increase farmers' agricultural yield (OR=2.58) and environmental incentive to reduce the water scarcity problem in Lebanon (OR=3.26). However, the difference between the coefficients/ORs of those two significant variables was insignificant (p-value = 0.7253). Hence, the strongest predictor for this outcome cannot be determined. As for WTU2 (crops with an increased risk), this willingness is significantly and strongly influenced by consumers' perception of the lack of sustainable access to sufficient freshwater (OR=3.05) followed by their rural identity (OR=0.42), considering that the difference between their coefficients/ORs was significant (p-value = 0.0045). Lastly, WTU3 (for crops with the highest health risk) is only significantly associated with participants' knowledge that safe TWW conserves fresh potable water (OR=2.49). In all the multivariate models, the VIF for the independent variables is less than 5, indicating a moderate correlation between a given explanatory variable and the other, but this is often not severe enough to require attention.

From both analyses, the main identified barrier is the lack of trust in the authorities to adequately operate, monitor, and maintain the wastewater treatment plants and ensure a safe effluent among the two farmers and 9 consumers who refuse safe reuse and 25 farmers and 231 consumers who accept this practice. This ethical barrier appeared in other perception studies conducted in Lebanon (Terkawi, 2016), South Africa (Adewumi et al., 2010), Tunisia, and West Bank (Dare & Mohtar, 2018). To help them make an informed decision, the farmers who refused safe reuse are interested in learning about and/or visiting a WWTP facility, understanding the involved treatment processes, reading studies documenting the safety and benefits of using TWW in agricultural irrigation, caring about professional endorsements and approvals of the TWW reuse process, and be involved in water reuse projects. The 11 consumers who refused safe reuse are mostly interested in a clear TWW policy from the Ministry of Agriculture and Ministry of Water and Energy (81.8%), studies documenting the safety and benefits of using TWW in agricultural irrigation (54.5%), and to understand the involved treatment processes (45.5%). Chapter III will characterize the TWW quality from the Ablah and Zahle wastewater treatment plants (WWTPs) in Bekaa for reuse in irrigation to link the willingness to use of farmers and consumers to the quality of TWW of these two plants in chapter IV.

CHAPTER III

TREATED WASTEWATER REUSE IN BEKAA, LEBANON: QUALITY ASSESSMENT

A. Introduction

The Water-Energy-Food-Health nexus Renewable Resources Initiative (WEFRAH) is one of the most important challenges for the sustainability of life on Earth. Wastewater is becoming part of the solution to mitigate global water scarcity, along with preventing inappropriate raw wastewater usage for farming and irrigation with serious health hazards and unregulated sewage flow into water bodies aggravating already-existing environmental issues (Abi Saab et al., 2021; Cellamare et al., 2016). The primary criterion determining whether a water reuse project for irrigation would be appropriate and successful for communities and countries is TWW quality. Poor water quality can lead to environmental and public health risks, which can set-back public opinion of this practice (Dare, 2014). The Bekaa valley is Lebanon's primary agricultural region, providing the majority of the country's irrigated crops (FAO, 2016). The region also has numerous functional WWTPs with negligible TWWR (KREDO, 2015). However, there is not enough research about their updated operational state, treatment effectiveness, and water reuse potential for irrigation in terms of the safety and quality of the effluent. Thus, this paper targets two WWTPs in the Bekaa, namely the Zahle (tertiary) and Ablah (secondary) WWTPs, and aims to determine the physical, chemical, and microbiological quality of their effluent over the wet and dry seasons and evaluate their environmental and public health risks. After providing insights from the literature on the potential environmental and public health risks of irrigating with unsafe treated wastewater (Section B), the method is described in detail (Section C). The results are presented in Section D and discussed in Section E. Section F provides a conclusion, Section G proposes some recommendations, and Section H identifies some limitations of the study. Chapter IV will link the outcomes from this chapter to the perception and willingness to use of farmers and consumers about irrigation with safe TWW.

B. Literature Review

1. Environmental Risks on Soil and Crops

a. Salinity

The salinity of irrigation water often dictates soil salinization or the accumulation of inorganic water-soluble salts in the soil, whether cations (sodium, magnesium, iron, calcium) or anions (chloride) (Ofori et al., 2021; Pescod, 1992). Salinity is measured by the electrical conductivity of water (EC_w in deci-Siemen per meter (dS/m) at 25°C) and the concentration of total dissolved solids (TDS in mg/L) (Pescod, 1992; Shakir et al., 2017). High irrigation water salinity increases the total osmotic potential of soil water, which requires crops to exert more energy per water unit to extract their water demand from the soil. As a result, plant water and nutrient uptakes are reduced, while respiration rises, leading to significant and prolonged water stress periods. Furthermore, high salinity is proven to lower microbial diversity and biomass, including fungal and bacterial populations, increase microbial stress levels, and lower their metabolic efficiency (Becerra-Castro et al., 2015; Leonel & Tonetti, 2021). Moreover, carbon and nitrogen mineralization are negatively influenced, along with the retardation of nitrification in the soil (Becerra-Castro et al., 2015). Consequently, hyper-osmosis (or increased osmotic pressure preventing the absorption of water by the crops) and microbial change limit plant growth and productivity (quantity and quality of crops) (Ayers & Westcot, 1985; Becerra-Castro et al., 2015; Ofori et al., 2021; Pescod, 1992). Plant symptoms include wilting, a darker bluish-green tint, and sometimes thicker and waxier leaves, similar to drought symptoms. The severity of the symptoms varies depending on the stage of plant growth, with the early growth phases being the most vulnerable. The plant shows signs of stunting, leaf damage, necrosis, or apparent injury only after extended exposure to moderately high salinity. However, plants respond differently to salinity with certain crops generating acceptable yields at far higher salinity levels than others. This tolerance is due to the higher ability of some plants to make the necessary osmotic changes, allowing them to absorb more water from saline soil (Ayers & Westcot, 1985).

Many authors have documented higher soil salinity after irrigating with treated wastewater (Ofori et al., 2021; Shakir et al., 2017). In most studies, it is even the most commonly observed impact on soil properties from TWW irrigation (Leonel & Tonetti, 2021). For instance, in Apulia (Italy), Vergine et al. (2017) reported that a tomato-growing farm irrigated with treated wastewater underwent transient salinization during the summer but returned to previous normal levels by the end of the winter season. This temporal increase was attributed to a high irrigation regime and a lack of rainfall, which accumulated salts from treated wastewater. Similarly, Erel et al. (2019) conducted a long-term study in Israel that revealed a seasonal rise in soil salinity during the irrigation season, which was mitigated each year by leaching during the rainy season. Thus, salt accumulation is more prevalent in arid and semi-arid regions, with high evaporation and limited precipitation (Muyen et al., 2011). In general, as the salinity of TWW rises, the likelihood of soil, water, and crop problems increases especially for non-salt tolerant plants (Pedrero et al., 2010). Maestre-Valero et al. (2019) observed a 23% yield reduction in peaches (Prunus persica) after irrigating with TWW of electrical conductivity of more than 1.1 dS/m in Murcia, Spain. In contrast, in Texas, USA, the increased soil salinity from TWW irrigation did not negatively impact sorghum biomass yield (Chaganti et al., 2020). Therefore, understanding the characteristics of effluent, soil, and crops is required for sustainable water reuse practices (Leonel & Tonetti, 2021).

b. Reduced Water Infiltration Rate

i. Sodium Absorption Ratio and Electric Conductivity

The sodium level is an essential factor for assessing the suitability of the water quality for irrigation (Shakir et al., 2017). Sodium hazard is measured by the sodium ion concentration relative to calcium and magnesium ion concentrations, known as the Sodium Adsorption Ratio (SAR) (Equation 3) (Pescod, 1992; Shakir et al., 2017).

Equation 3: SAR Formula

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}{2}}}$$

The SAR and the electrical conductivity of irrigation water (EC_w) can estimate the effect of treated wastewater on soil permeability (Pedrero et al., 2010; Shakir et al., 2017). For a given EC_w, high SAR decreases soil permeability. For a given SAR, low salinity water decreases soil permeability. Therefore, a low salinity and/or high SAR water decreases the water infiltration rate into the soil (Ayers & Westcot, 1985; Pescod, 1992).

Excessive sodium from irrigation water increases soil sodicity and alkalinity. It also produces changes to the soil's physicochemical properties, notably its structure (Becerra-Castro et al., 2015; Ofori et al., 2021; Pescod, 1992; Shakir et al., 2017). When present over a particular threshold value compared to the concentration of the total dissolved salts (i.e., an elevated SAR), sodium has the capacity to disperse the soil by clay deflocculation and movement, negatively affecting the stability of the soil aggregates and increasing soil compaction (Becerra-Castro et al., 2015; Ofori et al., 2021; Pescod, 1992). Consequently, the water and air infiltration rates into the soil, i.e., the rate at which water and air enter the soil, are diminished (Becerra-Castro et al., 2015; Ofori et al., 2021; Pedrero et al., 2010; Pescod, 1992). When the penetration rate of the applied water is significantly reduced, water remains on the soil surface for too long or infiltrates too poorly to provide sufficient water to the crops' root zone to sustain their growth and produce acceptable yields (Ayers & Westcot, 1985; Pedrero et al., 2010). Soils with low infiltration rates are also highly susceptible to runoff and erosion problems, which create a hazard to surrounding areas. In summary, crop water supply is reduced, similar to the reduction due to salinity, but for a different reason. Water infiltration reduces the amount of water into the soil to be used by the crop, whereas salinity reduces the water uptaken by the crop (Ayers & Westcot, 1985). Furthermore, saturated and temporarily flooded soil even for a few days without enough aeration allows for the fast denitrification of nitrate-nitrogen (NO_3-N) to end up lost from the soil to the atmosphere as nitrogen (N_2O/N_2) gas. Nitrogen deficiency becomes evident in the yellowed areas of the crops (Ayers & Westcot, 1985). When dispersed soil dries, it produces surface crusts that are difficult to till and obstruct germination and seedling emergence (Pescod, 1992). If irrigation must be extended to ensure enough infiltration, secondary difficulties may arise. They include crusting of seedbeds, abundant weeds, nutritional problems, crop drowning, seeds rotting, and poor crop stands in low-lying wet locations. A serious consequence is the risk of diseases and vector concerns (Ayers & Westcot, 1985).

These problems are a concern in planning TWWR projects since TWW might have a relatively high sodium level (Pedrero et al., 2010). In their study, Zema et al. (2012) reported a 113.6% elevation in the SAR of the soil irrigated with TWW compared to conventional water. On the other hand, in addition to the TWW composition and quality, a reduced infiltration rate and its negative effects are also influenced by the type of irrigation and frequency, soil characteristics, including soil structure, texture, type of clay minerals, degree of compaction, organic matter content, chemical make-up, plant uptake characteristics, and agricultural management practices (Ayers & Westcot, 1985; Ofori et al., 2021).

ii. Suspended Material

TWW irrigation might supply high levels of suspended organic and inorganic sediments to the soil, measured in terms of the water’s total suspended solids (TSS). With time, these sediments tend to clog the pores of the soil, slowing down the water infiltration rate and increasing soil runoff, especially for slowly permeable soil (Ayers & Westcot, 1985; Ofori et al., 2021). However, soil pores are difficult to clog unless the water is poorly treated. Furthermore, suspended material causes clogging problems in the sprinkler and drip irrigation systems (i.e., clogging of gates, sprinkler heads, and drippers, along with damaging pumps) (Ayers & Westcot, 1985).

c. Increased Sodium Absorption Ratio

In addition to lowering the water infiltration rate, high SAR significantly hinders the sorption of dissolved organic carbon in the soil, impeding soil fertility and agriculture productivity (Mavi et al., 2012; Ofori et al., 2021). Furthermore, in the case of high SAR and/or low salinity, the calcium level might be relatively low in the applied water (Ayers & Westcot, 1985; Ofori et al., 2021). Very low calcium content is highly correlated with a permeability problem (Pedrero et al., 2010). Additionally, calcium deficiency (below 2 milliequivalents per Liter (meq/L)) may occur in plants, reducing the crop yield (Ayers & Westcot, 1985; Ofori et al., 2021). This deficiency is exacerbated in magnesium-dominated water (ratio of Ca/Mg < 1). High magnesium levels create antagonistic effects or compete with calcium on the cation adsorption sites, reducing calcium absorption and transport from soil water to the growing crop. Additionally, the effects of sodium on the soil become more damaging for a given SAR if the Ca/Mg ratio is less than 1. The lower the ratio, the higher the effects of SAR. However, low productivity might still occur, such as lower barley, wheat, maize, and sugar beets yields, with a low Ca/Mg ratio even if infiltration issues aren't immediately apparent (Ayers & Westcot, 1985). Water with a high sodium adsorption ratio (SAR > 6) can also induce iron chlorosis in vulnerable crops (maize, sorghum, Sudan grass, and a few others). Similarly, sodic soils are associated with zinc deficiency in paddy rice (Ayers & Westcot, 1985).

d. Specific Ion Toxicity

The concentration of phytotoxic ions must be assessed to determine the acceptability of treated wastewater quality for agricultural application. Boron (B), chloride (Cl), and sodium (Na) are the most common ions that, if present above threshold values, can induce plant toxicity (Pescod, 1992). These specific ions of most concern can be absorbed by the plant roots and gradually accumulate in the leaves during water transpiration in amounts large enough to cause harm (Pedrero et al., 2010), individually or in combination (Ayers & Westcot, 1985). Toxicity can be accelerated with overhead sprinklers, allowing the fast absorption of hazardous ions directly through the wetted leaves. Plant symptoms include chlorosis, bronzing, and burn (necrosis) mainly at the leaf top and leaf edges (Ayers & Westcot, 1985). This harm leads to impaired growth, a reduction in yield, changes in plant morphology, defoliation, and even death (Pescod, 1992). The degree of damage is influenced by the level of uptake of toxic ions, duration of exposure, crop sensitivity, transpiration rate, stage of development, climate (exacerbated by hot climates (high temperature and low humidity)), soil conditions, and others (Ayers & Westcot, 1985; Pedrero et al., 2010; Pescod, 1992). Toxicity is difficult to prevent without changing the crop or the water source for sensitive crops (Pedrero et al., 2010). The majority of tree crops and woody perennial-type plants fall into this sensitive category. Sensitivity depends on climate, irrigation management, leaching fraction, drainage, crop growth stage, and crop maturity date. Toxicity frequently occurs in conjunction with and complicates a salinity or water infiltration problem, but it can also occur with low salinity (Ayers & Westcot, 1985).

i. Chloride

Chloride is not adsorbed to soil particles. Hence, it flows freely with the soil-water to be absorbed by the crop, then circulated via the transpiration stream, and concentrated in the leaves. If chloride concentration in the leaves exceeds crops' tolerance, injury symptoms, such as leaf burn or drying, appear. Plant harm usually starts at the leaf tips and spreads down the edges as the severity increases. Early leaves drop or defoliation is frequently accompanied by excessive necrosis (dead tissue). In addition to the irrigated water quality, chloride toxicity is influenced by soil chlorides, controlled by leaching, and the crops' ability to exclude chloride (Ayers & Westcot, 1985; Shakir et al., 2017).

ii. Sodium

Sodium toxicity is linked to elevated sodium concentrations in the water (high Na or SAR). Accumulation of sodium in the crops requires several days and weeks to reach toxic levels. Symptoms first emerge on older leaves from the outer edges and progress inside between the veins toward the leaf core as severity intensifies. Leaf burns and dead tissues around the exterior edges are the usual symptoms. A few examples of sensitive crops are deciduous fruits, nuts, citrus, avocados, beans, and many others. Poor water infiltration may be causing or complicating sodium-induced toxicity. Lastly, enough calcium in the soil generally diminishes it (Ayers & Westcot, 1985).

iii. Boron

Unlike sodium, boron is an essential nutrient for plant growth in relatively small amounts but can become hazardous in concentrations higher than required. Boron toxicity can impact all crops, but with a wide range of tolerance affected by climate, soil conditions, and crop varieties. The tips and edges of older leaves are firstly affected as their leaf tissues become spotted, yellow, or dry. With increased boron accumulation over time, drying and chlorosis tend to reach the interveinal area (i.e., the center between the veins). Some crops do not show typical leaf symptoms. Instead, gum or exudate appears on the limbs or trunk of severely damaged trees, such as almonds. Boron-induced leaf necrosis can occasionally be severe enough to significantly limit the total leaf surface available for photosynthesis (Ayers & Westcot, 1985). Besides its toxicity to plants, boron may affect microbial communities by diminishing the soil's bacterial diversity and dehydrogenase activity (Becerra-Castro et al., 2015).

e. Miscellaneous Effects

i. Excess Organic Matter and Nutrients

TWW effluent improves the organic matter content of the soil (measured indirectly by the biological oxygen demand (BOD5) and chemical oxygen demand (COD) levels in the water) (Leonel & Tonetti, 2021). Because of its high adsorptive ability, organic material can immobilize metals from reclaimed wastewater, lowering their accessibility for plant absorption. It can further hold essential plant nutrients and release them as the material is degraded over time, increasing soil fertility (Becerra-Castro et al., 2015; Pedrero et al., 2020). Organic matter also adds to the capacity of soil structure to hold water by forming and stabilizing aggregates, impacting drainage characteristics and compaction resistance (Becerra-Castro et al., 2015). In contrast, excess organic matter and nutrients stimulate, based on their type, specific microbial biomass, and enzymatic activities in the soil (Leonel & Tonetti, 2021). In extreme cases, this increasing microbial growth and activity might result in the formation of biofilms, clogging porous spaces between soil particles, thus reducing the water infiltration rate of the soil while promoting its hydrophobicity and water repellency (Becerra-Castro et al., 2015; Leonel & Tonetti, 2021). Intensive TWW irrigation may also result in the leaching of organic xenobiotics and nutrients into groundwater and their runoff to surface water bodies, deteriorating the water quality (e.g.: eutrophication of surface water and nitrates contamination of groundwater) and impacting aquatic ecosystems (Ofori et al., 2021).

Nitrogen is a beneficial nutrient for plants that promotes crop growth. Nitrate and ammonium are the most commonly available types of nitrogen, while nitrate-nitrogen (NO_3-N) is the most common in irrigation water. Irrigation with treated wastewater may contain excess nitrogen beyond the crop requirement. This excessive level in the water, similar to an excessive fertilizer application, may disrupt the production of various crops due to over-stimulation of growth, lodging, delayed or uneven maturity, and poor quality (Ayers & Westcot, 1985). Musazura et al. (2019) linked the delayed and unpredictable flowering in a banana (Musa paradisiaca) plantation to surplus nitrogen after irrigating with TWW. Nitrogen concentrations exceeding 5 mg/l may impact sensitive crops, such as apricots, grapes, sugar beets, and cotton. Most other crops are relatively unaffected until nitrogen levels in water surpass 30 mg/l. Crop tolerance is highly influenced by the growth stage. High nitrogen levels may be favorable during the early stages of growth, but they may result in crop failure during the later flowering and fruiting stages. Early in the season, high nitrogen TWW can substitute or complement fertilizers. In other words, these nitrogen water levels are equivalent to fertilizer nitrogen for most crops, to be accounted for in the total nitrogen application strategy. In contrast, as the crop's nitrogen requirements decrease later in the growing season, the nitrogen supplied to the crop must be significantly reduced by changing the water supply or blending it with freshwater (Ayers & Westcot, 1985). Blending TWW with freshwater can manage the nutrient and water demand of crops such that irrigation supplies an acceptable water quantity without exceeding the safe nutrient level (Leonel & Tonetti, 2021). Another approach is to cultivate fewer sensitive crops (e.g., maize), which can more effectively use the nitrogen from TWW irrigation. Farmers can also plan crop rotations to benefit from the residual nitrogen in the soil during the non-irrigation season (Ayers & Westcot, 1985).

In addition to nitrogen, reclaimed wastewater contains other nutrients in significant levels, mainly phosphorus and, to a lesser extent, potassium, zinc, boron, sulfur, calcium, magnesium, manganese, and iron. Those nutrients are essential for crop development, replacing or reducing the use of synthetic fertilizers (Becerra-Castro et al., 2015; Pedrero et al., 2010). However, they must be monitored regularly to avoid uneven nutrient supply (Pedrero et al., 2010). Furthermore, the risk of nutrient oversupply from TWW is higher than in conventional water. The latter is caused by the higher concentration of nutrients in reclaimed wastewater than in conventional water sources, considering irrigation rates are proportional to the water content (i.e., irrigation based on water demand, not the nutrients supplied in the water) (Leonel & Tonetti, 2021). Phosphorus is a vital nutrient for crop development and its scarcity may limit agricultural productivity. However, excessive amounts in the soil might generate an ecological imbalance (Zohar et al., 2010). Phosphorus also inhibits zinc uptake, leading to zinc deficiency (Ofori et al., 2021). Laurenson et al. (2012) reported that TWW irrigation supplies more nitrogen and phosphorus than the nutritional needs of grapevines, which may foster vigorous vegetative growth generating dense canopies and shades of growing fruit. Lastly, excess potassium causes magnesium deficiency by lowering its uptake (Mccauley et al., 2011). It can further reduce nitrogen absorption and carbon assimilation of leaves, along with hindering the transportation of photosynthetic products from leaves to roots (Xu et al., 2020). However, potassium is always added as a fertilizer in our Lebanese soils. Therefore, the consideration of excessive or restrictive levels of potassium in irrigation TWW is to be assessed based on the existing levels of potassium in the soil, which is to be determined by a soil test.

ii. Scale Deposits

When overhead sprinklers are used, TWW irrigation with a high proportion of calcium, bicarbonate (HCO_3), iron (Fe), sulfate (SO_4^{2-}), and unusual pH causes the formation of white scales on leaves or fruits. During very low humidity seasons (less than 30 percent), deposits form even at very low concentrations due to the high evaporation rate. The evaporation of water droplets from the leaves causes the less soluble salts, such as lime ($CaCO_3$) and gypsum ($CaSO_4$), to precipitate. Once precipitated, they will be difficult to re-dissolve during repeated wettings as the sprinkler rotates. Thus, deposits will start to accumulate. Although there is no toxicity, the accumulation of deposits is especially problematic when flowers, vegetables, or fruits are cultivated for the fresh market because it decreases their marketability. Fruits, such as apples and pears, necessitate an expensive acid wash treatment before marketing (Ayers & Westcot, 1985).

iii. Abnormal pH

The pH range for irrigation water is usually between 6.5 and 8.4. Irrigation water with a pH outside the typical range may produce nutritional imbalances or contain hazardous ions (Ayers & Westcot, 1985; Pescod, 1992). It also influences nutrient and metal availability and solubility, cation exchange capacity, and organic matter mineralization (Becerra-Castro et al., 2015). For instance, a high soil pH ($pH > 8.5$) is associated with zinc deficiency in paddy rice (Ayers & Westcot, 1985). This parameter appears to be a major driver of soil bacterial richness (number of different species) and diversity (types of microorganisms) (Becerra-Castro et al., 2015). Bacterial diversity and richness were similar in different ecosystems with identical pH regardless of climatic conditions or soil properties (Fierer and Jackson, 2006). In general, soil habitats with neutral pH have more bacterial diversity than those with more acidic or alkaline pH values (Becerra-Castro et al., 2015; Fierer and Jackson, 2006). On the other hand, fungal populations might be less susceptible to pH changes (Rousk et al., 2010). Abnormal pH also corrodes irrigation equipment, including pipelines, sprinklers, and control equipment (Ayers & Westcot, 1985).

TWW irrigation has been associated with pH changes in the soil (Leonel & Tonetti, 2021). The increase in the availability and mobility of free metals in treated wastewater-irrigated soil was correlated with a drop in soil pH (Rattan et al., 2005). Mohammad and Mazahreh (2003) reported a considerable drop in soil pH with TWW application. The authors attributed this decline to the high ammonium content of the secondary effluent, whose nitrification is a source of hydrogen ions, increasing the acidity of the soil. A reduction in soil pH may improve the solubility and availability of macro and micronutrients, such as P, Fe, Mn, Zn, and Cu, hence improving soil fertility

(Mohammad and Mazahreh, 2003). In contrast, Adrover et al. (2012) and Zolti et al. (2019) observed a pH increase, attributed to the high levels of exchangeable cations, primarily sodium, from irrigation water. This pH raise may reduce the availability of essential nutrients and impact soil structure, limiting crop growth (Kamran et al., 2020). In contrast, because the soil is highly buffered and resists alteration, any change in soil pH produced by irrigation water will be gradual (Ayers & Westcot, 1985).

iv. Trace Elements and Heavy Metals

Trace elements are found in relatively low concentrations, generally less than a few mg/l, in conventional irrigation water (Pescod, 1992). However, they may be added to irrigated soil when TWW, originating from industrial wastewater, is used for irrigation without sufficient treatment (Leonel & Tonetti, 2021). Trace elements include Iron (Fe), Manganese (Mn), Aluminum (Al), and others. Heavy metals are a subgroup of trace elements (such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), and Zinc (Zn)) (Pescod, 1992). Several elements are required for plant growth in small quantities (Fe, Mn, and Zn) (Ayers & Westcot, 1985; Ofori et al., 2021). In contrast, their repeated application with TWW in excessive amounts could irreversibly contaminate the soil due to their abilities to readily fix and accumulate in soils (i.e., high retention rate), making it unproductive (Ayers & Westcot, 1985). The most commonly accumulated elements are copper, cadmium, lead, nickel, zinc, chromium, and iron (Becerra-Castro et al., 2015). Their excessive presence above threshold values may thus lead to phytotoxicity from their long-term build-up in plant tissues (Ayers & Westcot, 1985; Leonel & Tonetti, 2021; Pescod, 1992). They can additionally cause crop growth retardations by influencing plant metabolism, photosynthesis, and stomatal opening (Parveen et al., 2015). For instance, excess zinc uptake results in poor germination, leaf chlorosis, and wilting of older leaves (Ofori et al., 2021). Moreover, heavy metals can influence soil microbial populations (Becerra-Castro et al., 2015). This disruption can reduce microbial biomass and/or change community structure. Metal contamination can further impair some microbial processes, such as carbon and nitrogen mineralization, soil enzyme activity, and waste breakdown (Becerra-Castro et al., 2015; Leonel & Tonetti, 2021). Furthermore, metal deposition may result in leaching and contamination of deep soils and groundwater, particularly after extended periods of TWW irrigation (Xu et al., 2010). In addition, metals may interact synergistically with other pollutants, such as antibiotics, potentially worsening their effects (Becerra-Castro et al., 2015). Heavy metals' availability and mobility, along with the magnitude of their impacts, depending on the types of plants and their uptake capability, climate (i.e., temperature, humidity, etc.), soil characteristics (i.e., pH, organic matter, and nutrients content, etc.), the composition of treated wastewater, and the properties of the metals (Ofori et al., 2021).

f. Microbiological Content

Pathogenic microorganisms could be present in high concentrations in TWW, especially if disinfection or advanced filtration treatment are not included in the treatment process (Ofori et al., 2021; Pedrero et al., 2010). As a result, irrigation with microbiologically contaminated TWW is associated with the following microbiological risks. First, exogenous microorganisms may directly disrupt the indigenous soil microbiome and jeopardize their activity, thus, harming soil health and long-term fertility. Second, phytopathogens might be introduced, causing yield reduction or lowering the quality of the crops (Lopes et al., 2015). Numerous plant pathogens are waterborne, including bacteria, fungi, viruses, parasitic nematodes, or oomycetes. Common bacterial phytopathogens in TWW are some members of the *Pseudomonas, Xanthomonas, Acidovorax,* and *Herbaspirillum* genera (Becerra-Castro et al., 2015). In the study by Ibekwe et al. (2018), *Pseudomonas* was highly detected in soil irrigated with TWW. Within this genus, *Pseudomonas Syringae* could suppress plants' immune systems, allowing Salmonella to enter the plant through the leaves (Zhang, 2015). However, scarce information is available about phytopathogens in TWW (Becerra-Castro et al., 2015). Lastly, plants might host human and animal pathogens or antimicrobial-resistant microorganisms. These microorganisms contaminate the environment and enter the food chain, impacting environmental and human health (Lopes et al., 2015).

2. ***Public Health Risks***

Several water qualities analyses of treated wastewater irrigation projects have found disease-causing microorganisms and indicators of pathogenic bacteria in the irrigation water, as well as heavy metals, organic pollutants, and other toxic substances (Ofori et al., 2021; Yi et al., 2011). Their transmission to humans through direct contact with irrigation water and food ingestion after entering the food chain is a cause for public health concerns. Indirect transmission pathways include the air through aerosol inhalation and water from runoff or leaching contaminating drinking water (Becerra-Castro et al., 2015). Four groups are at risk: (1) farmers and their families; (2) crop handlers; (3) communities living near the irrigated areas; and (4) crop, meat, and milk consumers (Shakir et al., 2017). The agent's potency, irrigation conditions (i.e., crop restriction, irrigation method, contact with crops, etc.), exposure conditions (i.e., route, duration, frequency, and intensity of exposure), physical environment (e.g.: types of crops, soil properties, climate, etc.), socio-economic and political environment, and the host's susceptibility should be accounted for to assess health risks.

a. Microbiological Pathogens

Human health risks from microbiological agents are determined by the pathogens’ survival in the environment, their potency, conditions of exposure, infective dose, and host immunity. Their survival in the soil is influenced by their resistance and antagonism to indigenous microbiota and soil characteristics (moisture content, organic matter, pH, temperature, and other parameters) (Becerra-Castro et al., 2015). Many pathogens can survive in soil or on crop surfaces for extended time periods to be greatly transmitted to humans or animals (Shakir et al., 2017). Their transmission through food depends on the types of plants irrigated and the irrigation method (surface, drip, or sprinkler irrigation) (Becerra-Castro et al., 2015). Pathogenic contamination of the edible crops will not be evident in case of a lack of direct contact between the edible part of the plants and the irrigation water (Libutti et al., 2018). Unlike fruit trees or vegetables cultivated on vines, vegetables grown on the ground have a higher risk of contamination and transmission of pathogens (Becerra-Castro et al., 2015). As for the irrigation method, surface irrigation of TWW has a higher probability of contracting and contaminating the edible parts of the plants than drip irrigation (Song et al., 2006).

In their study, Libutti et al. (2018) found a significant number of coliforms, *fecal enterococci*, and *Escherichia coli* (E. coli) in the secondary treated wastewater effluent used to irrigate tomatoes and broccoli. Total and fecal coliforms are not pathogenic, but they serve as indicators of the presence of pathogenic microorganisms. Irrigation with TWW might provide suitable conditions for their growth and persistence (Kesari et al., 2021). Moreover, exposure to high levels of coliforms increases the risk of dysentery, typhoid fever, and bacterial gastroenteritis, among other diseases (Oram, 2020). E. coli is a type of fecal coliform. The majority of its strains are harmless, except for a few, such as Shiga toxin-producing E. coli (STEC), which can cause severe illnesses. In terms of public health, the enterohemorrhagic strain E. coli (or *E. coli O157:H7*) is the most important STEC serotype (WHO, 2018). *E. coli O157:H7* from contaminated irrigation water can be internalized into lettuce. They can further proliferate and survive on their plant hosts (Becerra-Castro et al., 2015). Exposure to E. coli might cause diarrhea, abdominal cramps, and extraintestinal diseases. It has also caused mortality globally (Croxen et al., 2013). Furthermore, fecal streptococcus is also considered a pathogenic indicator for agricultural reuse (Al-Saed, 2007). Studies have found *Streptococci* in crops irrigated with TWW. Exposure is associated with gastrointestinal diseases. Symptoms include stomach aches, diarrhea, fever, and sometimes vomiting (Kesari et al., 2021). As for *Pseudomonas*, most members of this genus, particularly *Pseudomonas Aeruginosa*, are opportunistic pathogens frequently associated with infections of the urinary tract, respiratory system, soft tissue, bone and joint, gastrointestinal infections, dermatitis, and a variety of systemic infections, especially in patients with severe burns, cancer, or AIDS (Odjadjare et al., 2012). A major infection route is the exposure of susceptible tissues, such as wounds and mucous membranes (WHO, 2011).

b. Chemical Exposure

i. Heavy Metals

Non-biodegradable and persistent heavy metals may accumulate in the environment (soil, water, and plants) and enter the food chain through treated wastewater irrigation, posing public health risks (Ofori et al., 2021). Some metals, such as cobalt, zinc, and copper, are toxic to plants long before they attain toxic levels in humans (Shakir et al., 2017). However, chronic exposure to Zinc might cause anemia, pancreas damage, and decrease high-density lipoprotein (HDL) cholesterol levels (ATSDR, 2005). Similar to Zinc, copper is necessary for good health. In contrast, higher doses can be harmful. By ingestion, copper toxicity may induce nausea, vomiting, stomach cramps, or diarrhea. Very high copper intake can cause liver and kidney damage and even death (ATSDR, 2004). Chromium has different oxidative states. Depending on the environmental conditions, chromium can transform from one state to another in water and soil (ATSDR, 2012b). Toxic hexavalent chromium (Cr^{+6}) can be quickly reduced to trivalent chromium (Cr^{+3}), a less soluble and less harmful solid phase in water and soil (Shakir et al., 2017). The most common health problems observed in animals after ingestion of chromium (VI) compounds are irritation and inflammation of the stomach and small intestine, anemia, damage to the male reproductive system and sperms, and cancer in humans (e.g.: gastrointestinal tract cancer) (ATSDR, 2012b). Cadmium is one of the heavy metals with the largest risks. Depending on soil concentration, its uptake can increase over time. It is further toxic to humans and animals at much lower doses than it is to plants (Pescod, 1992). Oral exposure to very high cadmium concentrations causes severe stomach irritation, resulting in vomiting, diarrhea, and sometimes death. Long-term oral exposure to lower levels can accumulate cadmium in the kidney, leading to kidney damage. It can also increase bones' fragility. Cadmium is additionally classified as a carcinogen to humans by the International Agency for Research on Cancer (IARC) (ATSDR, 2012a). Furthermore, TWW irrigation might transmit Lead to the environment. Lead targets the nervous system, regardless of the route of exposure. Lead toxicity may also cause weakness in fingers, wrists, or ankles, in addition to a slight increase in blood pressure and anemia. High-level exposure to Lead can severely damage the brain and kidneys, resulting in death. Pregnant women are susceptible to miscarriages, while sperm production can be harmed in men (ATSDR, 2007).

ii. Organic Compounds

TWW may contain organic contaminants, including phenolic compounds, surfactants, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pharmaceutical products, etc. Long-term irrigation may cause these hydrophobic compounds to build up in the environment at high bioaccumulation and biomagnification rates. Some substances are resistant to conventional wastewater treatment entering the food chain in large amounts and may persist in the environment for longer periods (Becerra-Castro et al., 2015). Acute exposure leads to central nervous system depression and irritation of epithelial cells (i.e., respiratory and gastrointestinal lining) (Dhaini, 2021). On the long-term, some are carcinogenic and teratogenic (causing embryo/fetal effects). However, the precise health risk is determined by the type of the compound, its properties, and its concentration (Shakir et al., 2017), along with the other previously mentioned factors. Biological oxygen demand (BOD5) and chemical oxygen demand (COD) can be measured among other indices, such as the organic pollution index (OPI), to identify their presence in water and request for the detection of specific contaminants.

iii. Nitrates and Nitrites

TWW may cause excess nitrate and nitrite to be released into the soil and water bodies. These inorganic nitrogen forms have the potential to contaminate drinking water sources and increase uptake by plants used in the human diet. Leafy vegetables can particularly absorb nitrate and nitrite (i.e., lettuce, spinach, and beetroots). In fact, vegetables account for roughly 80% of the nitrate in the average human diet (ATSDR, 2017). In their study, Muhaidat et al. (2019) detected elevated levels of nitrates in vegetables irrigated with TWW. Leafy vegetables exhibited higher levels than root crops. Spinach had the greatest nitrate accumulation capacity of 4,614.1 mg/kg, while onion had the lowest (1,722 mg/kg). As for nitrites, the highest concentrations were found in parsley (1.19 mg/kg), while cauliflower (0.25 mg/kg) had the lowest (Muhaidat et al., 2019). Oral exposure causes methemoglobinemia (oxidation of hemoglobins, which decreases their ability to transport oxygen to tissues), especially in children. Symptoms include increased heart rate, headaches, decreases in blood pressure, abdominal cramps, vomiting, and even death. The International Agency for Research on Cancer (IARC) classified nitrate and nitrite as probably carcinogenic to humans (Group 2A) (gastrointestinal and bladder cancer) with no sufficient evidence in humans (ATSDR, 2017).

C. Methodology

1. Study Areas

a. Zahle Wastewater Treatment Plant

The Zahle wastewater treatment plant (x = - 299,805.00, y = - 40,143.00) is a tertiary-level treatment facility located in Haouch el Omara with a 10-ha area operational since 2018 (Figure 32) (Oxfam, 2021). Connected to the city of Zahle and the surrounding villages through a network, the plant can serve 274,000 people at a rate of 146 liters of wastewater per capita per day (KREDO, 2015) with a maximum rated capacity of 37,300 m^3/d (Oxfam, 2021). It receives combined sewage (residential and industrial) and stormwater by gravity from seven villages, with the exception of Saadnayel where a lift station is constructed. Its treatment is based on the principle of the activated sludge process with ultra-violet (UV) disinfection. It collects 24,000 m^3/day in the winter and 17,000 m^3/day in the summer (Oxfam, 2021). Currently, the facility treats an average flow of 25,000 m^3 per day (personal communication with the facility operators).

Figure 32: Zahle WWTP Location (Google Earth)

b. Ablah Wastewater Treatment Plant

The Ablah wastewater treatment plant is situated in the village of Ablah in Bekaa (x = 293,616.33, y = -33,637.73) (33.8669°N, 35.9594°E) (Figure 33). The plant uses primary and secondary treatment technologies to treat a maximum capacity of 2,000 m^3 of domestic wastewater per day. This design is expected to serve 14,630 people at a rate of 137 liters per capita per day in 2022. It has a 13.07 km sewer system that serves the town of Ablah (caza of Zahle) and the communities of Niha and Nabi Ayla. The facility was built in 2012 based on a conventional treatment process with trickling filters as biological treatment. The Municipality of Ablah is in charge of its operation and maintenance (KREDO, 2015; Mcheik et al., 2017; Oxfam, 2021). Currently, the plant treats an average flow of 1000 m^3 per day (personal communication with Engineer Mohamad Boudayyah, facility director). Thirty-three grape farmers in Ablah have been using the treated water on their land.

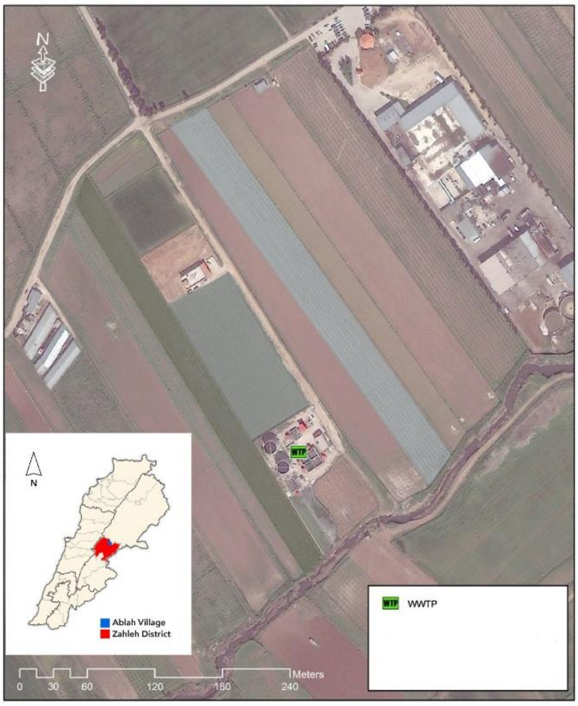

Figure 33: Ablah WWTP Location (Abi Saab et al., 2021)

2. *Effluent Sampling*

Monthly grab samples were collected in the wet season (January, February, and March 2022) and in the dry season (June, July, and August 2022) in the morning from the final water effluent of each wastewater treatment plant. The EPA guidelines for drinking water were followed for sample collection, preservation, and transportation (EPA, 2016).

3. *Effluent Analysis and Guidelines*

The samples were tested for the following parameters:

a. Physical Analysis

Electric conductivity (EC), total suspended solids (TSS), and total dissolved solids (TDS).

b. Chemical Analysis

pH, total hardness (TH), bicarbonate (HCO_3), ammonium nitrogen (NH_3-N), nitrate-nitrogen (NO_3-N), sulfate (SO_4^{2}-), phosphate (PO_4^{3-}), biological oxygen demand (BOD5), chemical oxygen demand (COD), sodium (Na), boron (B), chlorides (Cl), potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), and heavy metals (nickel (Ni), chromium (Cr), lead (Pb), Zinc (Zn), Cadmium (Cd), and Copper (Cu)).

c. Microbiological Analysis

Fecal coliform (FC), total coliform (TC), and E-coli.

The analysis was conducted at the Lebanese Agricultural Research Institute (LARI) using standard methods for the examination of water and wastewater (APHA, 1998). Heavy metals were analyzed at the American University of Beirut (AUB) on a graphite furnace atomic absorption spectroscopy. In the absence of Lebanese standards, this study follows the guidelines for the reuse of treated wastewater for agricultural purposes released by the FAO in 2010 for Lebanon (FAO, 2010; Mcheik et al., 2017), the WHO microbiological quality guidelines for wastewater reuse in irrigation (WHO, 2006), and the FAO guidelines for conventional water irrigation by crop requirements (Ayers & Westcot, 1985; FAO, 2010; Pescod, 1992).

4. Limitations

- The study did not investigate the presence of some biological and chemical contaminants, such as phytopathogens, antibiotic-resistant bacteria, viruses, helminths, pharmaceuticals, and contaminants of emerging concerns (CECs). With the new cases of Cholera in Lebanon, Vibrio Cholerae should also be monitored in TWW since improper disinfection can contaminate food and water with these bacteria upon irrigation, potentially leading to an outbreak.
- Considering the gap in the data in the dry season due to logistical and budgetary limitations, the overall mean might not be a good representative of the six months monitored for some parameters.
- Errors could have occurred during the storage and transportation of the TWW samples due to the long distance between the WWTPs in the Bekaa and LARI lab in Fanara, Beirut.

D. Results

1. Overall Quality Assessment

Figures 34, 35, and 36 and Table 9 report the overall average of the physical, chemical, and microbial parameters of the treated wastewater analyzed during the trial from Ablah and Zahle WWTPs with a moderate and severe restriction compared to their corresponding international guidelines for water reuse and irrigation[3].

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[3] It is crucial to note that the acceptable average levels of TSS and COD in Ablah are representative of the winter season (Jan to March 2022) (appendix VII), considering no data was available in summer. Hence, the levels might increase in the dry season, especially with no dilution. Thus, further monitoring is required.

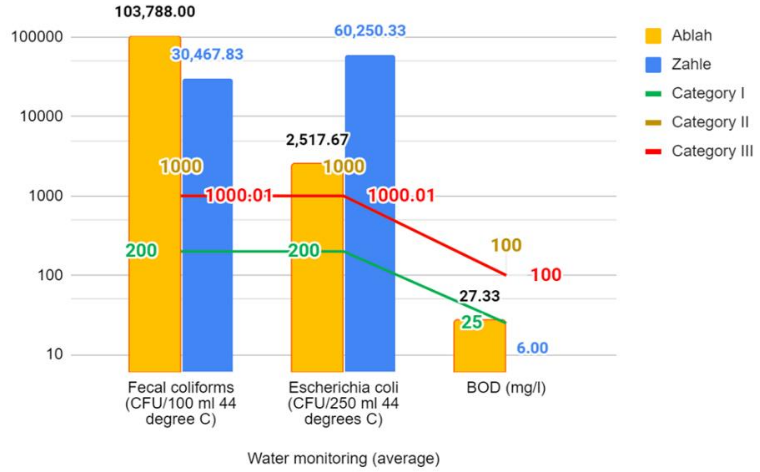


Figure 34: Treated effluent average quality from the Ablah and Zahle WWTPs compared to the FAO (2010) limit values for the reuse of treated wastewater in Lebanon (Complete Data in Appendix IV)

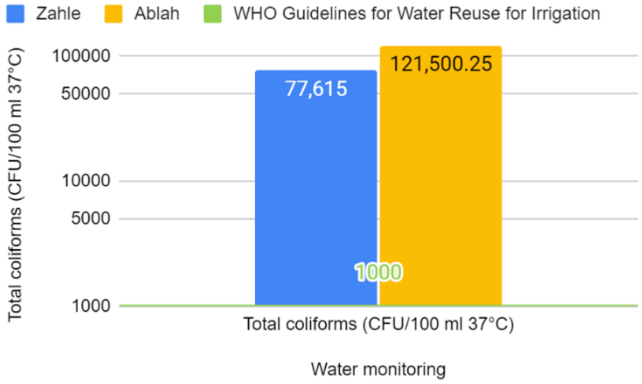


Figure 35: The average quality of Total Coliforms in the outlet of Ablah and Zahle WWTPs compared to the WHO (2006) guideline for water reuse for irrigation.

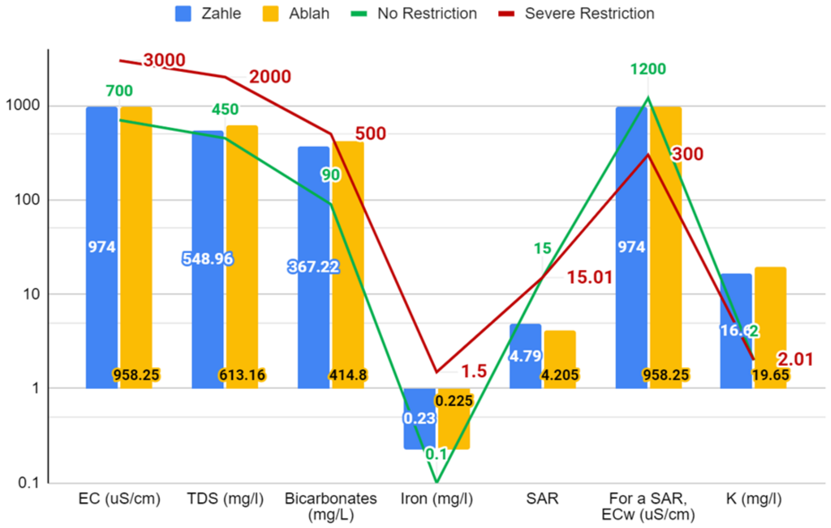


Figure 36: Treated effluent average quality from the Ablah and Zahle WWTPs and FAO limit values for irrigation conventional water (Complete Data in Appendix V and VI)

Table 9: Heavy Metals Monitoring in the TWW of Zahle and Ablah WWTPs in January and February 2022 compared to the FAO guidelines for Conventional Water Quality for Irrigation

Heavy metals analysis (mg/L)	**Zahle**			**Ablah**			FAO Guidelines for Irrigation (FAO, 2010)
	Jan	**Feb**	**Average**	**Jan**	**Feb**	**Average**	
Copper (Cu)	0.0002	0.0002	0.0002	0.000639	0.0004	0.0005	0.2
Zinc (Zn)	0.0007	0.0006	0.0006	0.0008	0.0005	0.0006	2
Nickel (Ni)	0.0306	0.0040	0.0173	0.0065	0.0110	0.0088	0.2
Lead (Pb)	0.003	0.002	0.0025	0.002	0.006	0.0040	5
Mercury (Hg)	0.0025	0.0045	0.0035	0.0067	0.0058	0.0063	
Arsenic (As)	0.002	0.0008	0.0014	0.0005	0.0008	0.0007	0.1
Chromium (Cr)	0	0	0	0	0	0	0.1
Cadmium (Cd)	0	0	0	0	0	0	0.01

a. <u>Ablah Effluent</u>

The average BOD5 in the winter season (no data in summer), with a value of 27.33 mg/L, was higher than the permissible limit of water category I (25 mg/L) for

TWWR proposed by the Lebanese draft guidelines (FAO, 2010). Fecal coliforms (103,788 Colony-forming unit (CFU)/100 mL) and E. coli (2,517.67 CFU/250 mL) were highly present in the overall quality, exceeding the limit value of category II of 1000 CFU per corresponding ml. Accordingly, the treated water from Ablah is of category III as proposed by the Lebanese guidelines FAO project UTF/LEB/019/LEB (Figure 34).

Similarly, total coliforms (121,500.25 CFU/100 mL) exceeded the 1000 CFU/100 mL proposed by the WHO (2006) for the irrigation of all crops with TWW (Figure 35). According to the FAO guidelines for conventional water quality for irrigation (Ayers & Westcot, 1985), salinity (EC = 958.25 micro-Siemen (uS)/cm and TDS = 613.16 mg/L), bicarbonate (414.8 mg/L), and iron for drip irrigation (0.225 mg/L) were moderate. For a SAR of 4.205 (between 3 and 6), ECw (958.25 µS/cm) had a moderate degree of restriction (Figure 36). Lastly, severe levels of potassium (19.65 mg/L) are evident, highly surpassing the FAO acceptable level of 2 mg/L for irrigation water (Figure 36).

b. Zahle Effluent

The average levels of fecal coliforms (30,467.83 CFU/100 mL) and E. coli (60,250.33 CFU/250 mL) were severe, exceeding the limit value of category II of 1000 CFU per corresponding mL. Accordingly, the treated water from Zahle is of category III as proposed by the Lebanese guidelines FAO project UTF/LEB/019/LEB (Figure 34). Similarly, total coliforms (77,615 CFU/100 mL) exceeded the 1000 CFU/100 mL proposed by the WHO (2006) for the irrigation of all crops with TWW (Figure 35). According to the FAO guidelines for conventional water quality for irrigation (Ayers &

Westcot, 1985), salinity (EC = 974 µS/cm and TDS = 548.96 mg/L), bicarbonate (367.22 mg/L), and iron for drip irrigation (0.23 mg/L) were moderate. For a SAR of 4.79 (between 3 and 6), ECw (974 µS/cm) had a moderate degree of restriction (Figure 36). Lastly, high levels of potassium (16.6 mg/L) are evident, highly surpassing the FAO permissible level of 2 mg/L for irrigation water (Figure 36).

2. Trends

After comparing the overall TWW quality with the international guidelines, trends were further assessed for the parameters with a moderate and severe restriction (Appendix VII and VIII).

a. Fecal Coliforms, Escherichia Coli, and Total Coliforms

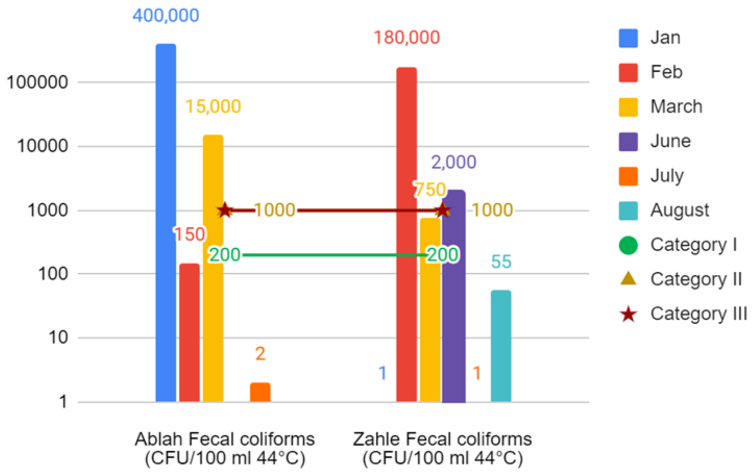


Figure 37: Trend of Fecal Coliforms during the Monitoring Period Compared to the Draft Lebanese Guidelines for the Reuse of Treated Wastewater in Lebanon Developed by FAO (2010) (Category I, II, or III).

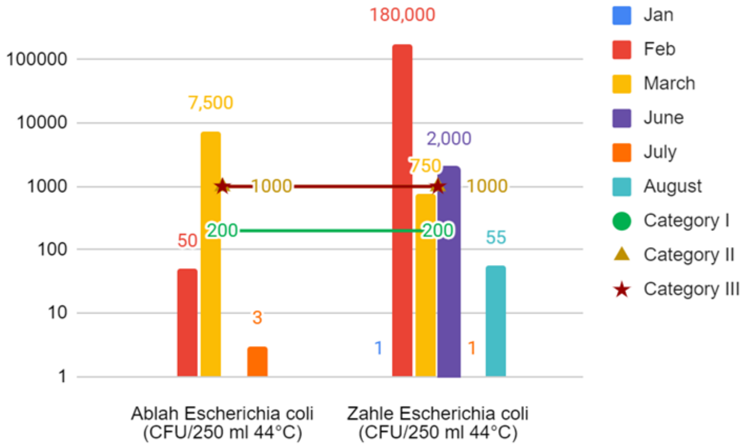


Figure 38: Trend of E. Coli during the Monitoring Period Compared to the Draft Lebanese Guidelines for the Reuse of Treated Wastewater in Lebanon Developed by FAO (2010) (Category I, II, or III).

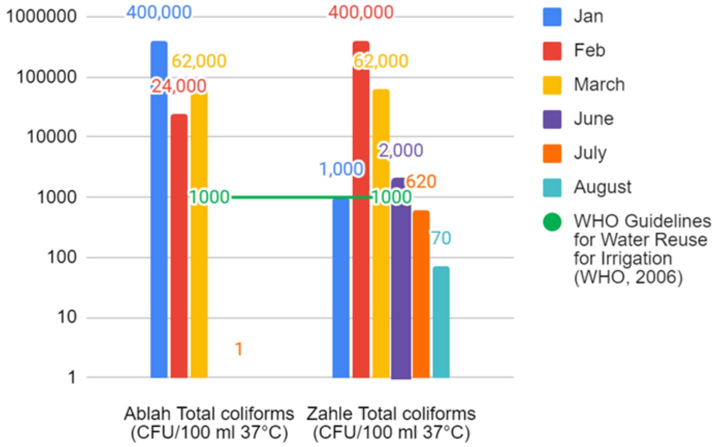


Figure 39: Trend of Total Coliforms during the Monitoring Period Compared to the WHO (2006) Guideline for Water Reuse for Irrigation.

Overall, the microbial water quality is highly inconsistent over the recorded six months. However, a general trend is evident in both Zahle and Ablah effluents, where the microbiological levels are lower in summer compared to winter (Figures 37, 38, and

39). The maximum severe levels were observed in winter, while the minimum acceptable levels were in summer.

b. BOD5

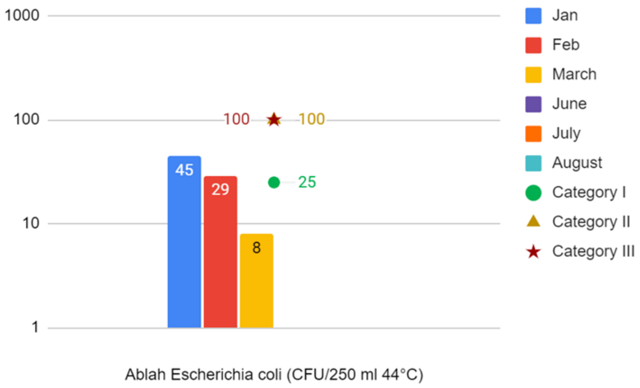


Figure 40: Trend of BOD5 in the Winter Season for the Ablah Effluent Compared to the Draft Lebanese Guidelines for the Reuse of Treated Wastewater in Lebanon Developed by FAO (2010) (Category I, II, or III).

In Figure 40, a decreasing linear trend in BOD5 is observed, from 45 mg/L (category II) to 29 mg/L (Category II) to 8 mg/L (category I), in the effluent of the Ablah WWTP in the wet season.

c. Salinity – EC and TDS

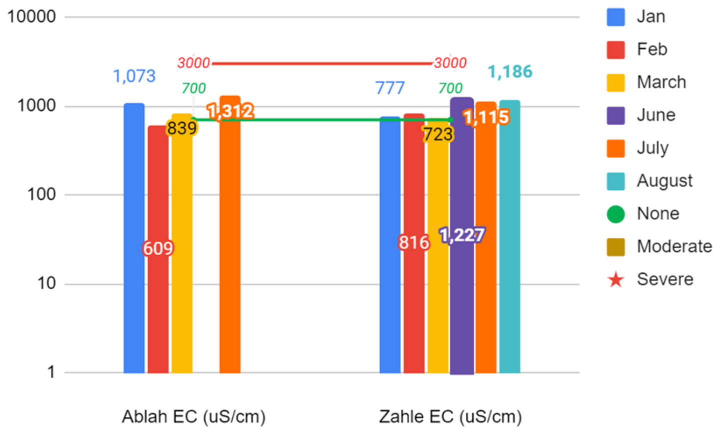


Figure 41: Trend of the Electrical Conductivity during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

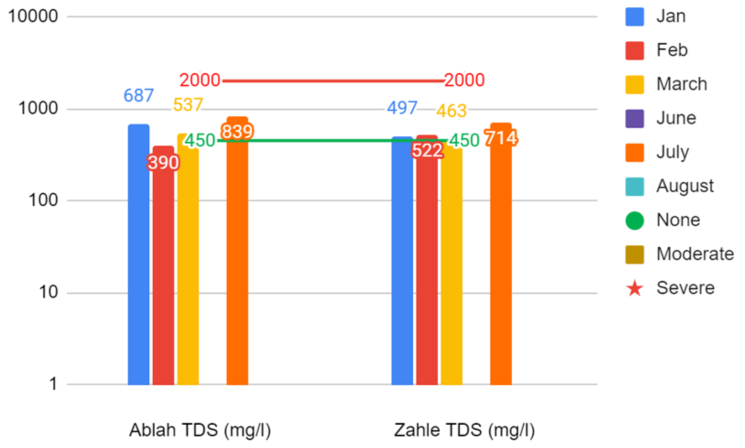


Figure 42: Trend of the Total Dissolved Solids during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

Overall, the salinity levels are inconsistent throughout the monitoring period (Figures 41 and 42). Compared to winter, the ECw and TDS levels increased in summer. The maximum levels are also recorded in summer, but still with moderate restriction. The minimum levels are in winter, with no restriction in February for the outlet of the Ablah plant and moderate restriction in March for the Zahle effluent.

d. ECw for a given SAR

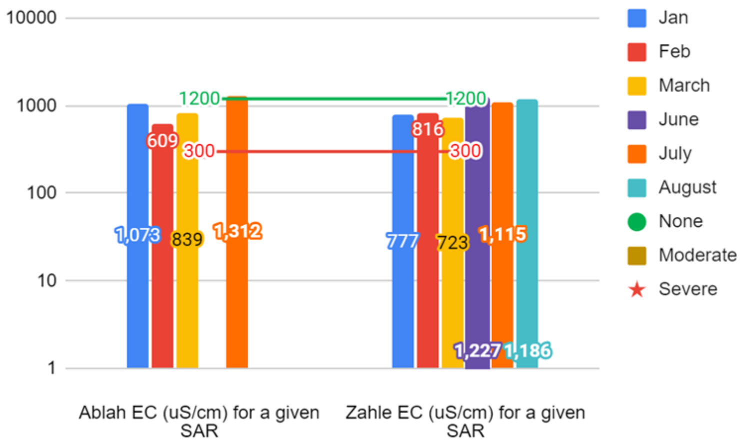


Figure 43: Trend of the Electrical Conductivity for a given Sodium Adsorption Ratio during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

Overall, the water quality is variable over the recorded six months (Figure 43). The levels of EC for a given SAR increased in summer compared to winter. The maximum levels are in summer, in July for the Ablah effluent (1,312 µS/cm) and in June for the outlet of Zahle (1,227 µS/cm), with no degree of restriction. The level with the highest restriction is in March for Zahle (723 µS/cm) and in February for Ablah (609 µS/cm), but still within the moderate range.

e. <u>Bicarbonates</u>

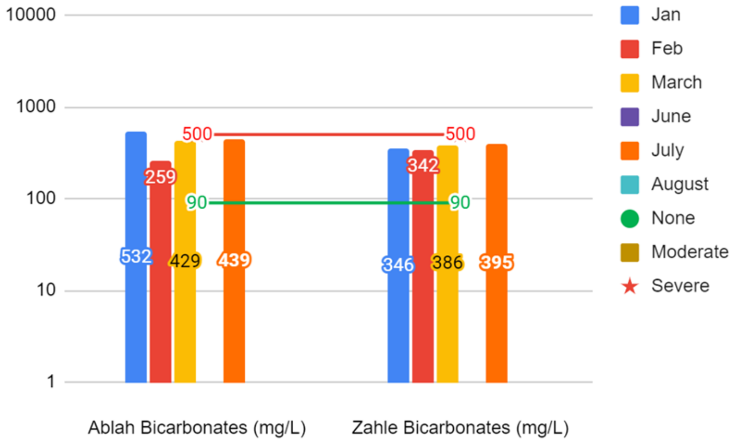


Figure 44: Trend of Bicarbonate during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

In Figure 44, the bicarbonate level is variable throughout the monitored seasons, with an overall increase in summer compared to winter. The maximum level is in summer (July: 395 mg/L) for the Zahle outlet, but still moderate. However, it is the highest in January for the effluent of the Ablah plant and becomes severe (532 mg/L).

f. <u>Iron for Drip Irrigation</u>

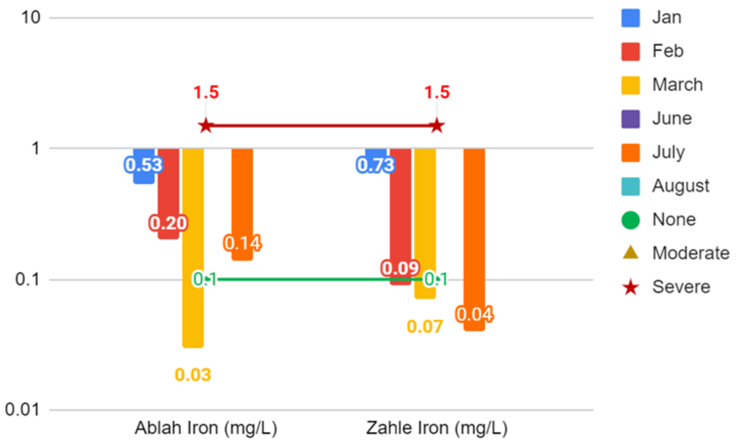


Figure 45: Trend of Iron for Drip Irrigation during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

Overall, the iron levels for drip irrigation (Figure 45) are lower in summer compared to winter. In the Zahle outlet, a decreasing trend is evident from 0.73 mg/L (moderate) in January to 0.04 mg/L (acceptable) in July. As for Ablah, a decreasing trend in winter (from 0.53 mg/L (moderate) in January to 0.03 mg/L (acceptable) in March), then a slight increase in summer (0.14 mg/L - moderate restriction in July) is observed.

g. Potassium

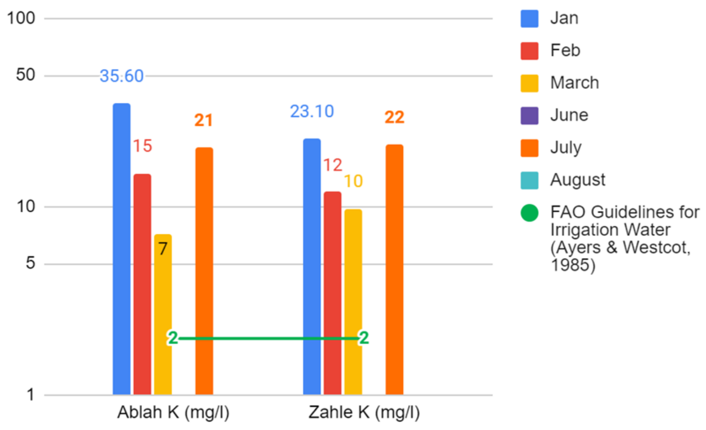


Figure 46: Trend of Potassium during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

A general trend is noticeable in Figure 46, with a decline in the potassium levels in winter from January to March, followed by an increase in summer (July). Note that all levels have severe restrictions for irrigation, with the peak in January and minimum level in March.

h. Nitrate

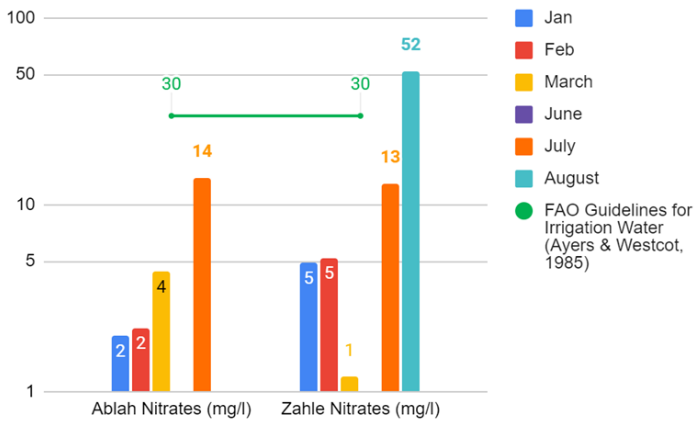


Figure 47: Trend of Nitrate during the Monitoring Period Compared to the FAO Limit Values for Irrigation Conventional Water (none, moderate, or severe restriction).

As shown in Figure 47, the levels of nitrates in the Ablah effluent are linearly increasing, but they remain within the acceptable level proposed by the FAO for irrigation (30 mg/L). In Zahle, the same trend is observed, except for the lowest concentration in March (1 mg/L). Even though the average level of nitrates in the Zahle effluent (12.72 mg/L) is acceptable, the maximum level in August (52 mg/L) exceeds the permissible limit.

E. Discussion

1. Overall Quality Assessment

a. Organic Matter, Nutrients, and ECw for a given SAR

The moderate BOD5 effluent of the Ablah WWTP in the wet season might be caused by the trickling filter open system being affected by the climatic conditions in winter, where low temperatures slow down the microbial activity to decompose the organic matter. However, the fixed film of biomass might also require maintenance because it is difficult to control what grows on the biomass from algae, fungi, worms, and others. Additionally, the overall quality of the effluent of both Ablah and Zahle plants has a severe restriction on potassium, a nutrient essential for plant growth but within a permissible level based on the crop need, and a moderate restriction on the ECw level for a SAR between 3 and 6. However, as previously mentioned, soil tests are needed to determine existing levels of potassium in the soil and the allowed amount of potassium in the TWW irrigation.

Irrigating with this TWW has high environmental risks of a reduction in the water and air infiltration rate into the soil, water pollution, and disrupted crop production. To elaborate, these organic levels may stimulate soil microbial growth and activity, resulting in the formation of biofilms clogging soil pores. The ECw level for a SAR between 3 and 6 might cause soil dispersion and compaction, further reducing the air and water infiltration rate into the soil. Thus, water and nutrient availability will decrease, affecting plant growth and yield. Moreover, nutrients beyond the crop requirements may lead to excessive vegetative crop growth, lodging (i.e., bending of the stem), delayed or uneven maturity, and poor-quality crops (Becerra-Castro et al., 2015; Leonel & Tonetti, 2021). Intensive TWW irrigation may also result in the leaching of organic substances and nutrients into groundwater aquifers and their runoff to surface water bodies, deteriorating the water quality (Ofori et al., 2021). However, further monitoring of the BOD5 and K and testing for specific organic substances are required to better assess the environmental risks. From a health perspective, organic compounds are hydrophobic with high bioaccumulation and biomagnification rates. Hence, they enter the food chain and build up in the environment, resulting in potential health risks upon exposure (Becerra-Castro et al., 2015). Acute exposure leads to central nervous system depression and irritation of epithelial cells (i.e., respiratory and gastrointestinal lining, skin, and eyes) (Dhaini, 2021). In contrast, an investigation is needed considering the health risk is determined by the type of the compound and its properties (Shakir et al., 2017), along with other factors (exposure conditions, physical environment, etc.).

b. Microbial Contamination

The severe levels of total coliforms, fecal coliforms, and E. coli, indicators of human pathogens, are expected in the outlet of the Ablah WWTP due to the absence of a disinfection unit. In contrast, the Zahle plant has an advanced UV disinfection system. Hence, the high microbial levels might be due to technical issues in the UV system. Therefore, applying this TWW for agriculture has a potentially high risk of exogenous microorganisms, phytopathogens, and animal and human pathogens contaminating the soil, crops, and water bodies upon irrigation and eventually harming wildlife and humans. Regardless, continuous monitoring and investigation will help better assess the environmental and health risks.

c. Salinity Impacts

The salinity level of the Ablah and Zahle effluent might moderately increase the total osmotic potential of soil water. As a result, plant water and nutrient uptake will reduce. This salinity rise may also moderately lower microbial diversity, biomass, and metabolic efficiency, thus reducing nutrient availability in the soil. The latter might limit plant growth and productivity.

d. Scale Formation

Bicarbonate and iron in the TWW might lead to a moderate risk of scale deposition on the leaves and fruits, especially with overhead sprinklers. These levels might also n build up in a drip irrigation system and clog the emitters.

e. Heavy Metals

The average trace concentrations for copper, zinc, nickel, lead, mercury, arsenic, chromium, and cadmium in winter (Jan-Feb 2022) were in line with the FAO guidelines for conventional water quality for irrigation (Table 9) (Ayers & Westcot, 1985).

Therefore, the analysis stopped in March. As for the dry season, budgetary issues prevented monitoring. Thus, further monitoring is required, especially in Summer.

2. Trends

a. Unexpected Trends

An unexpected trend was observed for the microbiological parameters and iron when comparing the wet to the dry season. Overall, the decreasing iron levels may be due to the WW origin on the sampling day, with probably less industrial WW discharged in the inlet of the WWTPs in Summer, and possibly a technical issue in the induced aeration in the activated sludge tank of the Zahle plant in winter (Figure 45). The lowest level in March (0.03 mg/L - acceptable) broke this linear trend in the Ablah effluent, which may be associated with the origin of the WW (i.e., less industrial wastewater), inlet dilution, and higher natural aeration in the trickling filter system compared to July (0.14 mg/L - moderate).

Similarly, lower levels were recorded in summer compared to winter, but with more variability, for Fecal Coliforms, E. coli, and Total coliforms opposite to the climatic changes from wet to dry season (i.e., decreasing precipitation and increasing temperature) (Figures 37, 38, and 39). This overall trend is most probably the result of errors during the storage and transportation of the TWW samples from the WWTPs in the Bekaa to LARI lab in Fanara, Beirut, which might have occurred under suboptimal conditions (i.e., melting of the ice preserving the samples inducing microbial growth and the prevailing anaerobic conditions upon oxygen consumption, especially in summer with higher temperatures, killing the coliforms) and/or analytical error at the level of the laboratory. With no disinfection in Ablah, the low-acceptable levels (category I) in February (for fecal coliform 150 CFU/100 mL and E. coli 50 CFU/250 mL) might also be due to a high dilution factor compared to January and March. In Zahle, despite their advanced UV disinfection system, the severe levels might be due to technical issues in the disinfection system between February and June.

b. Expected Trends

Overall, the salinity levels (Figures 41 and 42), ECw for a given SAR (Figure 43), bicarbonate (Figure 44), potassium (Figure 46), and nitrates (Figure 47) increased in summer because of the inlet dilution in the wet season.

The ECw and TDS (Figures 41 and 42) are exceptionally acceptable in February for the outlet of the Ablah plant due high dilution (snow melting and precipitation) on the sampling day. The higher the levels of ECw for a given SAR (Figure 43), the lower is the degree of restriction of TWWR. For a given SAR, salinity rise increases the air and water infiltration rate into the soil, considering the strong affinity between water and salts, thus justifying the peak acceptable levels in summer and the lowest, highly restrictive, but still moderate levels in winter.

Despite the high dilution factor, the bicarbonate level reaches its peak (severe) in January for the Ablah outlet (532 mg/L), which may be caused by errors during the storage and transportation of the samples and/or an analytical error. In contrast, the Zahle outlet reached its maximum, but moderate, bicarbonate concentration in Summer as predicted (July: 395 mg/L) (Figure 44). Similarly, the potassium peak (severe) is in January for possibly the same errors (Figure 46).

As shown in Figure 47, the nitrate trend is linearly increasing, except for the lower concentration in March in the Zahle effluent (1 mg/L). Irrigating with TWW with a high nitrate level in August (52 mg/L > FAO limit of 30 mg/l) will potentially cause high environmental risks, which include water pollution (i.e., eutrophication of surface water and nitrates contamination of groundwater) and disrupted crop production. Health risks upon oral exposure might cause methemoglobinemia, which is the oxidation of hemoglobins, decreasing their ability to transport oxygen to tissues, especially in children.

c. BOD5 in the Ablah Effluent Trend

In Figure 40, the decreasing linear trend in BOD5 is probably associated with climatic conditions. The average temperature rises from January to March. Hence, the decomposition rate of the organic matter in the trickling filter open system increases.

F. Conclusion

- The effluent of both Zahle and Ablah is not suitable for irrigation, except for Category III crops (i.e., cereals and oleaginous seeds, fiber, & seed crops, crops for the canning industry, industrial crops, and fruit trees (except sprinkler-irrigated)). The quality does not fully comply with the international guidelines regarding the direct treated wastewater reuse for irrigation. Severe restrictions are imposed by the high levels of microbiological contaminants and potassium in the TWW.
- Electricity shortages and the economic crisis in Lebanon (i.e., the need for ‘fresh’ US dollars for operation and maintenance and fuel for electricity) are majorly impacting the treatment effectiveness of the two WWTPs.

- Overall, the TWW quality of Ablah and Zahle WWTPs is variable over the monitored six months. Inconsistency in the quality leads to inconsistent supply for the farmers upon reuse. Some parameters (microbiological parameters and iron) have lower levels in summer compared to winter, which is unexpected because of the climatic changes (i.e., decreasing precipitation and increasing temperature). Although the average nitrate concentration of the Zahle effluent (12.72 mg/L) is within safe limits, the maximum concentration in August (52 mg/L) surpasses it (> 30 mg/L). Hence, nitrates should further be monitored and controlled.
- Influencing factors: The suitability of TWW for irrigation and its impact on soil, crops, and water resources goes beyond the effluent water quality. It is influenced by climatic conditions, soil properties, crop characteristics, irrigation regime and method, and agricultural management practices (Ayers & Westcot, 1985; Ofori et al., 2021; Pescod, 1992). As for its impacts on public health, a health risk is affected by the agent, its properties, and potency, irrigation conditions, exposure conditions, physical environment, socio-economic and political environment, and the host's susceptibility.

CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

TWW is a resource that can help increase water availability for agriculture and reduce the pressure on freshwater resources. However, its safe quality is of utmost concern and a prerequisite for water reuse, including farmers' and consumers' acceptability of this practice. This study aimed to determine the willingness of farmers in Zahle and Ablah and consumers from the general Lebanese communities toward safe TWWR in agriculture. Two surveys were conducted targeting (i) the general Lebanese population aged 18 years and above through social media and (ii) randomly selected accessible farmers who can benefit from Zahle and Ablah WWTPs in the Bekaa through face-to-face and telephone interviews. Data collected were statistically analyzed (i.e., descriptive statistics and multivariate logistic regression models of the significant variables at the univariate levels). This thesis further characterized the quality of monthly TWW grab samples from the Ablah and Zahle WWTPs in the 2022 wet and dry seasons for reuse in irrigation and evaluated their environmental and public health risks by comparing the overall average with international guidelines for water reuse and irrigation and analyzing trends.

Results revealed that Zahle and Ablah farmers and consumers from the general Lebanese population have a very high willingness to safely use (if they are farmers) and accept the safe usage (if they are only consumers) of TWW for irrigation. The economic benefits of safe reuse incentivized the acceptance of farmers. In contrast, their WTU was insignificantly associated with the independent variables due to the small sample size of thirty-four farmers due to accessibility issues to 59 farmers-potential beneficiaries of the Zahle and Ablah WWTPs, assumed to be the total population of beneficiaries-farmers of the two plants. Some farmers were also relatives with common land ownership and shared experiences. They reside in the same community with similar norms and practices. The moderate multi-collinearity, often non-severe, between the explanatory variables also affected the insignificance at the multivariate level for farmers' willingness to safely irrigate crops with the lowest (WTU1) and highest health risk (WTU3). Thus, there is a need to conduct further WTU studies with a bigger sample size using a mixed method approach (i.e., both qualitative and quantitative) accompanied by an in-depth WTP study.

As for the consumers, the environmental benefits of safe reuse incentivized their acceptance. Moreover, at the multivariate level, their economic incentive to increase agricultural yield and environmental incentive to reduce the water scarcity problem in Lebanon are significantly increasing their willingness to allow farmers to irrigate crops with the lowest health risk to consumers with safe TWW, provided that field workers are protected. The strongest predictor for this outcome (WTU1) could not be determined because of the insignificant difference between the strength of association of these significant variables with the outcome, indicated by their OR. Consumers' perception of the lack of sustainable access to sufficient freshwater is significantly and strongly increasing their acceptance of safe TWW irrigation for crops with an increased health risk (WTU2), followed by their rural identity, which is significantly hindering this willingness. Lastly, their willingness (WTU3) to accept safe reuse for crops with the highest health risk is only significantly correlated with participants' knowledge that safe TWW conserves fresh potable water. Further studies should target the willingness of consumers from the general Lebanese population to buy, consume, and pay for different crop types.

In contrast to their high WTU, the majority of farmers and consumers do not trust the authorities in Lebanon to adequately-operate, monitor, and maintain the WWTPs and ensure a safe effluent for irrigation. This lack of trust, especially in public authorities, matches the reality due to the very restrictive quality effluent of the Zahle and Ablah WWTPs, which can only be applied to irrigate Category III crops. The overall TWW quality was also variable over the monitored six months. Inconsistency in the quality leads to inconsistent supply for the farmers upon reuse. The restrictions and variability tend to be beyond the WWTPs' control. They are indeed highly influenced by challenges being faced across the country from chronic poor governance, corruption, and devastating economic crisis. These include the worsened electricity blackouts from the continuous rise in fuel cost and the increasing need for fresh US dollars for the operation and maintenance of the WWTPs. However, the MAGO project research team is further monitoring the quality of the TWW of the two studied plants and conducting experimental studies irrigating corn and potato with secondary and tertiary TWW to estimate the environmental (soil and crop) and health impacts more accurately.

Despite the severe restriction identified in the water qualities, some farmers in Zahle and Ablah are directly irrigating their crops with these water outlets. From this study, one Ablah farmer uses drip and sprinkler systems to irrigate grapes, onions, and potatoes, and one Zahle farmer uses surface and sprinkler methods to irrigate onions, potatoes, wheat, and vegetables at his own risk. Additionally, there are no regulations preventing some of these crops from being eaten raw (such as grapes, onions, and vegetables) and cooked (such as potatoes, onions, and vegetables). The Ablah farmer is also using sprinkler irrigation for the grapes, which is not permitted for category III crops because it allows for direct contact between the TWW and the fruits. This long-term application has severe environmental impacts (i.e., reduction in the water and air infiltration rate into the soil, disrupted crop production, and water pollution), especially from the high levels of potassium and nitrates (in the dry season in the Zahle effluent). Public health implications become prevalent, especially from the high levels of human pathogens and nitrates (in the dry season in the Zahle effluent). Environmental impact and epidemiological studies should be conducted to better investigate the environmental and health impacts of this unsafe practice. However, farmers in Bekaa and across Lebanon are indirect users of the 70 to 75% of the nationally generated WW that is discharged into the environment untreated, polluting surface water bodies and groundwater aquifers (IWMI, 2021a). Hence, though some farmers are not fully aware of the actual environmental and public health risks of irrigating with unsafe TWW or WW (whether direct or indirect irrigation), they also might not have another alternative because of the worsened water security issues. Furthermore, a major implementation barrier for safe water reuse in Lebanon identified in this study is the gap between the reality, in terms of the unsafe quality of TWW for reuse, the lack of trust in the authorities in ensuring its safety for irrigation, and weak law enforcement for safe discharge of TWW in surface water bodies, and the goal of an integrated WW treatment and safe reuse practices in agriculture.

On the other hand, TWW remains a sustainable alternative, improved upon abiding by the proposed recommendations:

1. Technical Recommendations

Some technical recommendations are proposed to improve the effluent’ quality of the Zahle and Ablah WWTPs, assuming the availability of funding and the improvement in the electricity provisioning:

a. For Ablah WWTP

   i. Addition of a disinfection unit to lower pathogen concentrations to safe levels before reuse in agriculture.

   ii. Improved maintenance of the trickling filter system to effectively reduce the BOD5 level. Activated carbon, as advanced treatment, might be added to reduce the dissolved total organic load by physical adsorption (for instance, activated carbon powder added to the secondary sedimentation unit). However, continuous monitoring of the effluent for BOD5, especially in the dry season because of the gap in the data in summer, and further testing for specific organic compounds are first required.

b. For Zahle WWTP

Improved maintenance of the UV disinfection system as potential technical issues could have caused the increase in the coliform levels as detected in the Zahle effluent analysis.

c. For Ablah and Zahle WWTPs

Consideration of addition of ion exchange units for bicarbonates since the current average level is closer to the higher range of the moderately acceptable level (i.e., close to 500 mg/L) and for the severe level of potassium. Aeration might also be enhanced to precipitate the iron levels in the biological treatment of both plants. However, further monitoring of these parameters before considering advanced-expensive treatments is essential.

2. *Recommendations at the Irrigation Level*

Technical recommendations should be complemented with recommendations at the irrigation level to mitigate the potential environmental and public health risks upon TWW reuse from the Ablah and Zahle WWTPs. Following technical adjustments and the improved TWW effluent quality, some of the below recommendations might be further considered:

- Irrigatation with TWW could be coupled with freshwater through cyclic and/or blending interventions for dilution purposes, especially because of the inconsistent TWW quality (Leonel & Tonetti, 2021; Muyen et al., 2011; Pedrero et al., 2010).
- To control salinity, leaching might be practiced by applying more irrigation freshwater. The added water, known as the leaching fraction (LF), will percolate through and beneath the root zone carrying a fraction of the excess salts with it (Ayers & Westcot, 1985). However, leaching might contaminate deep soils and groundwater (i.e., groundwater

salinization, especially in shallow aquifers) (Leonel & Tonetti, 2021; Ofori et al., 2021).

- Acid wash treatment to dissolve the scale deposition on the leaves and fruits from iron and bicarbonates to improve the marketability of the crops (Ayers & Westcot, 1985).
- Regulation of the mineral fertilizers' application when using TWW to minimize the potential impacts of the nutrients from the organic load indicated by the BOD, potassium, and nitrates, especially during the late stages of crop growth.

3. Other Recommendations

Recommendations are suggested to promote water reuse and overcome some of the public opposition challenges:

a. Awareness Raising

Awareness-raising should be customized according to the interests and drivers of the different categories of stakeholders:

i. Farmers

Raising awareness among farmers by professionals and trusted organizations through workshops, visits to WWTPs, and media remains essential to increase the knowledge about safe TWWR and its benefits, especially in protecting the environment from pollutants and increasing their income, considering their significant association with WTU1 and WTU3, and WTU3, respectively. Furthermore, farmers should become more informed about wastewater treatment, water quality assessment, and the safe quality of TWW if abiding by international guidelines for water reuse for irrigation despite its dirty origin (i.e., wastewater). The latter might even be cleaner and safer than freshwater, which tends to be polluted and used without proper treatment. Correcting this prejudice that TWW is not clean and safe enough for irrigation compared to freshwater will significantly increase farmers' WTU1 of crops with the lowest risk to consumers, but field worker protection is needed.

ii. Consumers

Awareness campaigns through workshops, media (especially social media), and educational institutions should be designed to increase consumers' knowledge about safe TWWR for irrigation and its benefits, especially in conserving fresh potable water considering its significant association with WTU3. Furthermore, the general population should become more informed about freshwater shortages, wastewater treatment, and the safe quality of TWW if abiding by the respective international guidelines because their perception of risks for safe reuse significantly reduced their general acceptance (WTU).

b. National Policy and Standards

Even though farmers did not report any interest in a clear TWW policy from the Ministry of Agriculture and Water and Energy, designing and enforcing a sound and adequate policy and national standards for TWWR are the basis for its safe practice in Lebanon. The Lebanese Standards Institution (LIBNOR), a semi-autonomous public administration, has resumed developing standards for this practice in coordination with relevant public authorities based on the draft guideline developed by FAO in 2010 for

Lebanon after stopping for a while due to the COVID-19 pandemic. Once the national Lebanese standards and regulations come into effect, they should be efficiently communicated to the farmers, the general public, and the different stakeholders.

c. Quality Control and Communication

In addition to a national policy and standards, a water strategy should effectively target wastewater reuse management and quality control. These aspects are not sufficiently addressed in the Environmental Protection Agency (EPA) strategic plan (2022-2026) and in the updated National Water Sector Strategy (2020) of the Ministry of Energy and Water in Lebanon. Regular monitoring and evaluation through comprehensive monitoring and inspection plans and programs should be conducted by qualified and trusted personnel for the sustainability of the safe effluent and its safe reuse for irrigation. At a decentralized level, the Zahle WWTP has a water monitoring system and regularly analyzes the effluent’s quality in its laboratory. The Bekaa Water Establishment also conducts quality control for several WWTPs in the Bekaa, including the Zahle plant. These initiatives are good starting points for water reuse in the Bekaa.

The effluent quality and its suitability for irrigation in a language appropriate to a non-specialist audience should be easily accessible to the farmers and the general public through a customized and effective communication strategy. For example, an official website of the WWTP and its corresponding municipality might be a tool for quality and risk communication to the public. WWTPs operators and experts should also inform and follow up with their beneficiary farmers through regular meetings and workshops.

b. Adopting an Inclusive and Participatory Approach

A participatory approach is fundamental to effectively involve consumers and farmers with the remaining stakeholders (ministries, municipalities, Bekaa Water Establishment, academicians, media, NGOs, Syndicate of farmers, etc.) in a decentralized TWWR initiative from its earliest stages to create a sense of ownership and build trust. Additionally, decision-makers and institutions in the water and agriculture sector, along with the concerned stakeholders, should develop a detailed and comprehensive strategy addressing the concerns of farmers and consumers, which will likely increase their acceptance of this practice. A steering committee should be created to facilitate this process and ensure transparency and accountability throughout the different phases of wastewater treatment and reuse projects. A National Steering Committee (NSC) was already established with experts from the Ministry of Energy and Water, Ministry of the Environment, Litani River Authority, Bekaa Water Establishment, South-Lebanon Water Establishment, Beirut and Mount-Lebanon Water Establishment, and Council for Development and Reconstruction. However, the committee does not yet have stakeholders from non-public institutions. Other consultation and collaboration activities include holding public events and seminars, providing information online, organizing visits to WWTPs, and others.

As such, wastewater can become a valuable resource that can be reused after effective treatment to a safe level for agriculture, contributing to water availability, food production, and the sustainability of life on Earth.

APPENDIX

APPENDIX I

From a public health perceptive, crops irrigated with TWW are classified into three categories based on the level of health risk to consumers, field workers, and handlers (Jurdi, 2017).

- **Category 1 (for WTU1) -** crops with the lowest health risk to consumers with field workers' protection needed: non-consumable crops (such as cotton); fodder crops and other animal feed crops that are sun-dried and harvested before consumption by animals; crops processed by heat or drying before human consumption (grains, oilseeds, sugar beet); and vegetables and fruits grown exclusively for canning or other processing that effectively destroys pathogens.
- **Category 2 (for WTU2) -** crops with an increased health risk to consumers and handlers: green fodder crops; crops for human consumption that do not come into direct contact with TWW on the condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.); crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroot); crops for human consumption after peeling (melons, citrus fruits, bananas, nuts, groundnuts), and any crop not identified as high-risk if sprinkler irrigation is used.
- **Category 3 (for WTU3)** - crops eaten uncooked and grown in close contact with the TWW effluent (fresh vegetables or spray-irrigated fruit), which have the highest health risk to consumers, field workers, and handlers.

APPENDIX II

Characteristics of the Farmers

Questions		Characteristics	Frequency	Frequency (%)	Merging	Coding
1	**Water source**	Groundwater	31	91.20%	Descriptive Statistics	
		River Water	30	88.20%		
		Tap Water	2	5.90%		
		Treated Wastewater	2	5.90%		
2	**Monthly Irrigation Cost**	30,000 - 40,000 LL	3	8.80%	< 100,000 (7/34, 20.6%)	1
		41,000 - 50,000 LL	1	2.90%		
		51,000 - 60,000 LL	1	2.90%		
		91,000 - 100,000 LL	2	5.90%		
		> 100,000	27	79.40%	> 100,000	0
3	**Total Irrigated Area per Farmer**	0.5 – 1 ha	6	17.60%	Small	0
		2 – 10 ha	9	26.50%	Lower Medium	1
		11 – 30 ha	12	35.30%		
		31 – 60 ha	6	17.60%	Upper Medium	2
		81 – 100 ha	1	5.30%	Large	3
4	**Full Irrigation**	No	10	29.40%	No	0
		Yes	24	70.60%	Yes	1

6	**Irrigation Method**	Surface irrigation	3	8.80%	Surface irrigation	0
		Drip irrigation	3	8.80%	Drip irrigation	1
		Sprinkler irrigation	6	17.60%	Sprinkler irrigation	2
		Surface - Drip irrigation	4	11.80%	Surface - Drip irrigation	3
		Surface - Sprinkler irrigation	8	23.50%	Surface - Sprinkler irrigation	4
		Drip - Sprinkler irrigation	3	8.80%	Drip - Sprinkler irrigation	5
		Surface - Drip - Sprinkler irrigation	5	14.70%	Surface - Drip - Sprinkler irrigation	6
7	**Irrigation Challenges**	Management, operation, and maintenance of irrigation system.	21	61.80%	Yes	1
			13	38.20%	No	0
		Infrastructure in poor condition	18	52.90%	Yes	1
			16	47.10%	No	0
		Reduced river flow/Drought period	28	82.40%	Yes	1
			6	17.60%	No	0
		Increased water salinity.	2	5.90%	Yes	1

			32	94.10%	No	0
		Reduced water quality/water pollution.	6	17.60%	Yes	1
			28	82.40%	No	0
		Lack of dollar funding	26	76.50%	Yes	1
			8	23.50%	No	0
		Lebanese economic crisis causing an increase of the prices USD vs LL.	30	88.20%	Yes	1
			4	11.80%	No	0
		Other: Electricity blackout	1	5.30%	Yes	1
			33	94.70%	No	0
		Other: High electricity bills	1	5.30%	Yes	1
			33	94.70%	No	0
		Other: Lack of employees	1	5.30%	Yes	1
			33	94.70%	No	0
8	**TWW Reuse Awareness**	I have heard and know what it means	20	58.80%	Know	1
		I have heard but do not know what it means	13	38.20%	Do not know	0
		I have not heard about it.	1	2.90%		
9	**1. Perceived risks of TWW Reuse**	There are no risks for the reuse of safe treated wastewater	25	73.50%	No risks for safe reuse	0
		There are risks for the reuse of safe treated wastewater	9	26.50%	Perceived risks	1
	2. Types of perceived risks of TWW Reuse	It increases health concerns (including human exposure to heavy metals and pathogens) and disease outbreaks (such	3	8.80%	Yes (Public health concern)	1

		as cholera, salmonella, diarrhea, typhoid ascariasis, hepatitis, and others).	6	91.20%	No	0
		It attracts disease vectors (mosquitoes, flies, etc.) to the irrigation ponds and irrigated fields.	4	11.80%	Yes (Public health concern)	1
			5	88.20%	No	0
		It is environmentally harmful/risky (e.g., salinity hazard or microbiological hazard).	2	5.90%	Yes (Environmental Concern)	1
			7	94.10%	No	0
		It is not clean and safe enough to be used for irrigation compared to freshwater.	8	23.50%	Yes (Unfit for irrigation)	1
			1	76.50%	No	0
10	**Perceived benefits of TWW Reuse**	Improving soil productivity and boosting agricultural yield.	22	64.70%	Yes	1
			12	35.30%	No	0
		Conserving fresh potable water.	20	58.80%	Yes	1
			14	41.20%	No	0
		Generates more income	20	58.80%	Yes	1
			14	41.20%	No	0
		Reducing synthetic fertilizers' input.	14	41.20%	Yes	1
			20	58.80%	No	0
		Protecting the environment from pollutants.	21	61.80%	Yes	1
			13	38.20%	No	0
		Farmers could have continuous access to treated wastewater for crop irrigation even during drought periods.	25	73.50%	Yes	1
			9	26.50%	No	0

		Promoting sustainability in agriculture and water resource use.	24	70.60%	Yes	1
			10	29.40%	No	0
11	**WTU**	Yes	32	94.10%	Yes	1
		No	2	5.90%	No	0
12	**12.1 Types of crops - WTU1 - Lowest Risk to consumer (Field worker protection needed)**	Fiber and fodder/animal feed crops	26	81.30%	Out of the 32 acceptance, new outcomes	
		Crops for canning or processed by heat or drying (e.g.: grains).	23	71.90%		
	12.2 Types of crops - WTU2 - Increased risk to consumer and handler	Crops eaten only after cooking (e.g.: potatoes).	31	96.90%		
		Crops for human consumption after peeling (e.g.: bananas, melons, nuts, … etc.).	21	65.60%		
	12.3 Types of crops - WTU3 - Highest risk to consumer, field worker and handler	Uncooked crops (e.g.: fresh vegetables).	14	43.80%		
13	**13.1 Why yes - economic reasons (out of 32)**	It increases the agricultural yield.	25	78.10%	Yes	1
			7	21.90%	No	0
		It saves energy.	25	78.10%	Yes	1
			7	21.90%	No	0
		It generates revenues.	22	68.80%	Yes	1
			10	31.20%	No	0

		It is cheaper than other alternatives.	20	62.50%	Yes	1
			12	37.50%	No	0
		It reduces fertilizer costs	11	34.40%	Yes	1
			21	65.60%	No	0
	13.2 Why yes - environmental reasons (out of 32)	It reduces the use of synthetic fertilizers.	8	25.00%	Yes	1
			24	75.00%	No	0
		It reduces the discharge of untreated wastewater in rivers or seas.	19	59.40%	Yes	1
			13	40.60%	No	0
		It helps in reducing the water scarcity problem in Lebanon	22	68.80%	Yes	1
			10	31.20%	No	0
	13.3 Why yes - Trust in authorities (out of 32)	I trust the authorities in ensuring a safe quality of treated wastewater	25	78.10%	No	0
			7	21.90%	Yes	1
	13.4 Why yes - unsustainable freshwater (out of 32)	Lack of sustainable access to sufficient freshwater	14	43.70%	No	0
			18	56.30%	Yes	1
	13.5 Why yes - Safe for health (out of 32)	Treated wastewater is safe for public health (no or minimum health risks).	16	50.00%	No	0
			16	50.00%	Yes	1
14	**WTP**	Same as my current irrigation costs	4	12.50%	Only descriptive statistics	
		More than my current irrigation costs	3	9.40%		
		Less than my current irrigation costs	25	78.10%		
15	**15.1 Why, no - Environmentally risky (out of 2)**	It is environmentally risky	1	50.00%	No	0
			1	50.00%	Yes	1

	15.2 Why, no - Lack of trust in authorities (out of 2)	I do not trust the municipal authorities to adequately operate, monitor, and maintain the wastewater treatment plants (i.e., distrusted water quality)	2	100.00%	Yes	
	15.3 Why, no - Insufficient coordination (out of 2)	Insufficient coordination	1	50.00%	No	0
			1	50.00%	Yes	1
16	**Helpful resources to make an informed decision (among 2 farmers unwilling to reuse TWW)**	16.1 Understanding of the involved treatment processes	1	50.00%	Only descriptive statistics	
		16.2 Studies documenting the safety and benefits of using TWW in agricultural irrigation.	1	50.00%		
		16.3 Professional endorsements and approvals of TWW reuse process.	1	50.00%		
		16.4 Learning about and/or visiting a WWTP facility.	1	50.00%		
		16.5 Being involved (public participation)	1	50.00%		
17	**Region**	Zahle	32	94.10%	Zahle	0
		Ablah	2	5.90%	Ablah	1
18	**Age**	Between 26 and 33	2	5.90%	Between 26 and 49	0
		Between 34 and 41	8	23.50%		
		Between 42 and 49	5	14.70%		
		Between 50 and 57	7	20.60%	Above 50	1

		Between 58 and 65	6	17.60%		
		Above 65	6	17.60%		
19	**Attained Education Level**	No attained level of education	5	14.70%	No education	1
		Elementary School (Grade 1 till 6)	1	2.90%	School	2
		Intermediate School (Grade 7 till 9)	2	5.90%		
		High School	9	26.50%		
		Technical School	3	8.80%		
		University first degree level	9	26.50%	University level	0
		University higher degree (Masters/PhD)	5	14.70%		
20	**Family Size**	1	3	8.80%	4 or less	0
		2	1	2.90%		
		3	3	8.80%		
		4	6	17.60%		
		5	11	32.40%	5 or more	1
		More	10	29.40%		
21	**Income**	676,000 LL to 1,500,000 LL	2	5.90%	Less than 6,000,000 LL	0
		1,501,000 to 2,500,000 LL	4	11.80%		
		2,501,000 to 4,000,000 LL	4	11.80%		
		4,001,000 to 6,000,000 LL	1	2.90%		
		6,001,000 to 10,000,000 LL	4	11.80%	More than 6,001,000 LL	1
		More than 10,500,000 LL	10	29.40%		

		I refuse to answer	9	26.50%	Refuse	

APPENDIX III

Characteristics of the Consumers

	Questions	Characteristics	Frequency	Frequency (%)	Merging	Coding
1	**TWW Reuse Awareness**	I have heard and know what it means	156	60.90%	Heard and know	0
		I have heard but do not know what it means	64	25.00%	Heard, but do not Know	1
		I have not heard about it.	36	14.10%	Not heard	2
2	**1. Perceived risks of TWW Reuse**	There are no risks for the reuse of safe treated wastewater	160	62.50%	No risks for safe reuse	0
		There are risks for the reuse of safe treated wastewater	96	37.50%	Perceived risks for safe reuse	1
	2. Types of perceived risks of TWW Reuse	It increases health concerns (including human exposure to heavy metals and pathogens) and disease outbreaks (such as cholera, salmonella, diarrhea, typhoid ascariasis, hepatitis, and others).	48	18.80%	Yes (Public health concern)	1
			48	81.20%	No	0
		It attracts disease vectors (mosquitoes, flies, etc.) to the irrigation ponds and irrigated fields.	20	7.80%	Yes (Public health concern)	1
			76	92.20%	No	0

		It is environmentally harmful/risky (e.g., salinity hazard or microbiological hazard).	20	7.80%	Yes (Environmental Concern)	1
			76	92.20%	No	0
		It is not clean and safe enough to be used for irrigation compared to freshwater.	47	18.40%	Yes (Unfit for irrigation)	1
			49	81.60%	No	0
3	**Perceived benefits of TWW Reuse**	Improving soil productivity and boosting agricultural yield.	126	49.20%	Yes	1
			130	50.80%	No	0
		Conserving fresh potable water.	162	63.30%	Yes	1
			94	36.70%	No	0
		Cost effective	130	50.80%	Yes	1
			126	49.20%	No	0
		Reducing synthetic fertilizers' input.	97	37.90%	Yes	1
			159	62.10%	No	0
		Protecting the environment from pollutants.	104	40.60%	Yes	1
			152	59.40%	No	0
		Farmers could have continuous access to treated wastewater for crop irrigation even during drought periods.	171	66.80%	Yes	1
			85	33.20%	No	0

		Promoting sustainability in agriculture and water resource use.	163	63.70%	Yes	1
			93	36.30%	No	0
4	**WTU**	Yes	245	95.70%	Yes	1
		No	11	4.30%	No	0
5	**5.1 Types of crops - WTU1 - Lowest Risk to consumer (Field worker protection needed)**	Fiber and fodder/animal feed crops	175	71.40%	Out of 245, new outcomes	
		Crops for canning or processed by heat or drying (e.g.: grains).	144	58.80%		
	5.2 Types of crops - WTU2 - Increased risk to consumer and handler	Crops eaten only after cooking (e.g.: potatoes).	181	73.90%		
		Crops for human consumption after peeling (e.g.: bananas, melons, nuts, … etc.).	96	39.20%		
	5.3 Types of crops - WTU3 - Highest risk to consumer, field worker and handler	Uncooked crops (e.g.: fresh vegetables).	67	27.30%		

6	**6.1 Why yes - economic reasons (out of 245)**	It increases the agricultural yield.	134	54.70%	Yes	1
			111	45.30%	No	0
		It saves energy.	112	45.70%	Yes	1
			133	54.30%	No	0
		It generates revenues.	98	40.00%	Yes	1
			147	60.00%	No	0
		It is cheaper than other alternatives.	109	44.50%	Yes	1
			136	55.50%	No	0
		It reduces fertilizer costs	95	38.80%	Yes	1
			150	61.20%	No	0
	6.2 Why yes - environmental reasons (out of 245)	It reduces the use of synthetic fertilizers.	97	39.60%	Yes	1
			148	60.40%	No	0
		It reduces the discharge of untreated wastewater in rivers or seas.	172	70.20%	Yes	1
			73	29.80%	No	0
		It helps in reducing the water scarcity problem in Lebanon	160	65.30%	Yes	1
			85	34.70%	No	0
	6.3 Why yes - Trust in authorities (out of 245)	I trust the authorities in ensuring a safe quality of treated wastewater	231	94.30%	No	0
			14	5.70%	Yes	1
	6.4 Why yes - unsustainable freshwater (out of 245)	Lack of sustainable access to sufficient freshwater	131	53.50%	No	0
			114	46.50%	Yes	1
			170	69.40%	No	0

	6.5 Why yes - Safe for health (out of 245)	Treated wastewater is safe for public health (no or minimum health risks).	75	30.60%	Yes	1
7	**Rate WTU**	50%	18	7.30%	Only descriptive statistics	
		60%	12	4.90%		
		70%	45	18.40%		
		80%	52	21.20%		
		90%	46	18.80%		
		100%	72	29.40%		
8	**8.1 Why, no - Environmentally risky (out of 11)**	It is environmentally risky	10	90.90%	No	0
			1	9.10%	Yes	1
	8.2 Why, no - Health Problems (out of 11)	It causes public health problems.	8	72.70%	No	0
			3	27.30%	Yes	1
	8.3 Why, no - Public criticism concern (out of 11)	I am concerned of the public criticizing my decision of using treated wastewater for irrigation.	8	72.70%	No	0
			3	27.30%	Yes	1
	8.4 Why, no - Religion (out of 11)	Wastewater reuse is not religiously acceptable.	10	90.90%	No	0
			1	9.10%	Yes	1

	8.5 Why, no - Disgust factor (out of 11)	It is disgusting to reuse water that was once contaminated (perceived as dirty).	6	54.50%	No	0
			5	45.50%	Yes	1
	8.6 Why, no - Technical concern (out of 11)	Treated wastewater might interfere with the sprinkler and drip irrigation systems.	8	72.70%	No	0
			3	27.30%	Yes	1
	8.7 Why, no - Social injustice (out of 11)	The treated wastewater service will be unequally distributed over areas at various topographies	9	81.80%	No	0
			2	18.20%	Yes	1
	8.8 Why, no - Lack of trust in authorities (out of 11)	I do not trust the municipal authorities to adequately operate, monitor, and maintain the wastewater treatment plants (i.e., distrusted water quality)	2	18.20%	No	0
			9	81.80%	Yes	1
	8.3 Why, no - Insufficient knowledge (out of 11)	I do not have sufficient knowledge about treated wastewater reuse.	8	72.70%	No	0
			3	27.30%	Yes	1
9	**Helpful resources to make an informed decision (among 11**	Understanding of the involved treatment processes	5	45.50%	Only descriptive statistics	
		Studies documenting the safety and benefits of using	6	54.50%		

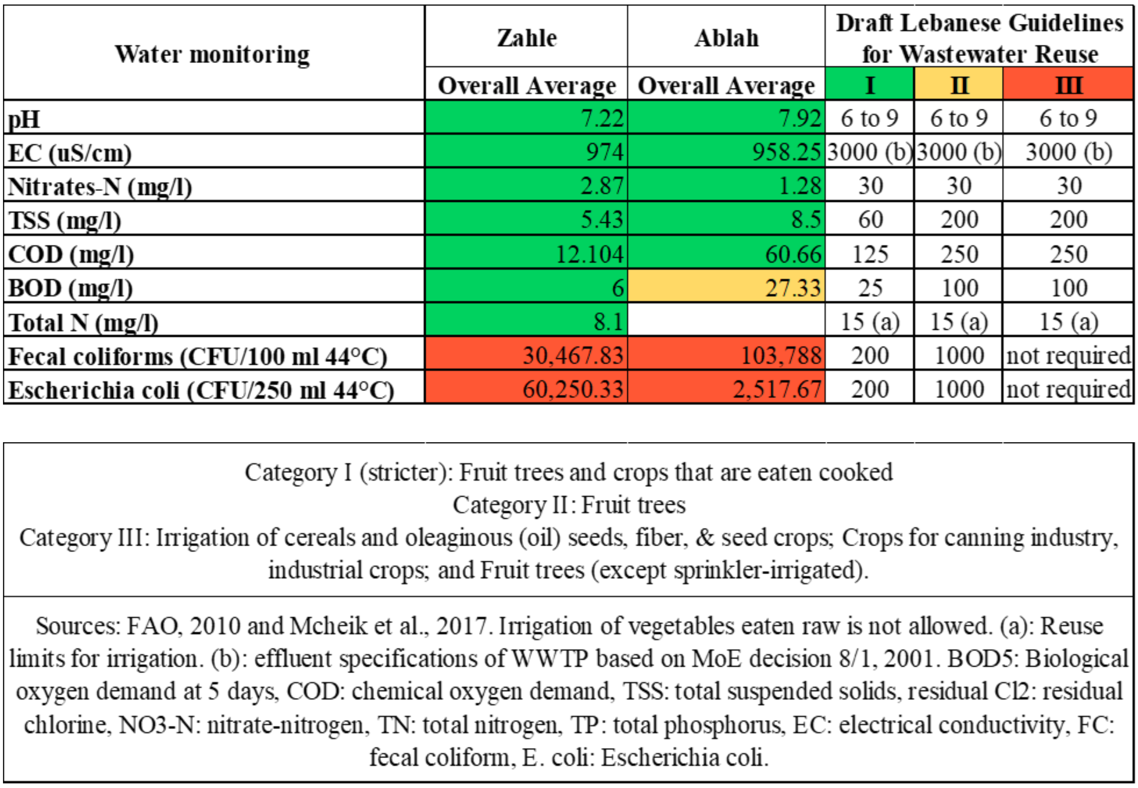
	consumers unwilling to allow the reuse TWW)	TWW in agricultural irrigation.				
		A clear TWW policy from the Ministry of Agriculture and Ministry of Water and Energy.	9	81.80%		
		Professional endorsements and approvals of TWW reuse process.	4	36.40%		
		Learning about and/or visiting a WWTP facility.	4	36.40%		
		Being involved (public participation)	2	18.20%		
10	**Sex**	Male	130	50.80%	Male	0
		Female	126	49.20%	Female	1
11	**Age**	Between 18 and 25	121	47.30%	Between 18 and 41	0
		Between 26 and 33	39	15.20%		
		Between 34 and 41	21	8.20%		
		Between 42 and 49	22	8.60%	Above 42	1
		Between 50 and 57	32	12.50%		
		Between 58 and 65	11	4.30%		
		Above 65	10	3.90%		
12	**Attained Education Level**	No attained level of education	6	2.30%	No education	1
		Elementary School (Grade 1 till 6)	5	2.00%	School	2

		Intermediate School (Grade 7 till 9)	11	4.30%		
		High School	21	8.20%		
		Technical School	9	3.50%		
		University first degree level	107	41.80%	University level	0
		University higher degree (Masters/PhD)	97	37.90%		
13	**Employment Level**	Employed	102	39.80%	Employed	0
		Self-employed	42	16.40%		
		Student	86	33.60%	Student	1
		Unemployed	26	10.20%	Unemployed	2
14	**Income**	≤ 675,000	18	7%	Less than 4,000,000 LL	0
		676,000 LL to 1,500,000 LL	12	4.70%		
		1,501,000 to 2,500,000 LL	23	9.00%		
		2,501,000 to 4,000,000 LL	25	9.80%		
		4,001,000 to 6,000,000 LL	27	10.50%	More than 4,001,000 LL	1
		6,001,000 to 10,000,000 LL	29	11.30%		
		More than 10,500,000 LL	52	20.30%		
		I refuse to answer	70	27.30%	Refuse	
15	**Context**	Urban	197	77.00%	Urban	0
		Rural	59	23.00%	Rural	1
16	**Status**	Farmer/User	38	15.20%	User	0

		Consumer/non-user	217	84.80%	Non-user	1

APPENDIX IV

Treated effluent average quality from the Ablah and Zahle WWTPs compared to the limit values for the reuse of treated wastewater in Lebanon.



Water monitoring	**Zahle**	**Ablah**	**Draft Lebanese Guidelines for Wastewater Reuse**		
	Overall Average	**Overall Average**	**I**	**II**	**III**
pH	7.22	7.92	6 to 9	6 to 9	6 to 9
EC (uS/cm)	974	958.25	3000 (b)	3000 (b)	3000 (b)
Nitrates-N (mg/l)	2.87	1.28	30	30	30
TSS (mg/l)	5.43	8.5	60	200	200
COD (mg/l)	12.104	60.66	125	250	250
BOD (mg/l)	6	27.33	25	100	100
Total N (mg/l)	8.1		15 (a)	15 (a)	15 (a)
Fecal coliforms (CFU/100 ml 44°C)	30,467.83	103,788	200	1000	not required
Escherichia coli (CFU/250 ml 44°C)	60,250.33	2,517.67	200	1000	not required

Category I (stricter): Fruit trees and crops that are eaten cooked
Category II: Fruit trees
Category III: Irrigation of cereals and oleaginous (oil) seeds, fiber, & seed crops; Crops for canning industry, industrial crops; and Fruit trees (except sprinkler-irrigated).

Sources: FAO, 2010 and Mcheik et al., 2017. Irrigation of vegetables eaten raw is not allowed. (a): Reuse limits for irrigation. (b): effluent specifications of WWTP based on MoE decision 8/1, 2001. BOD5: Biological oxygen demand at 5 days, COD: chemical oxygen demand, TSS: total suspended solids, residual Cl2: residual chlorine, NO3-N: nitrate-nitrogen, TN: total nitrogen, TP: total phosphorus, EC: electrical conductivity, FC: fecal coliform, E. coli: Escherichia coli.

APPENDIX V

Treated effluent average quality from the Ablah and Zahle WWTPs compared to the FAO limit values for irrigation of conventional water.

Water monitoring	**Zahle**	**Ablah**	**FAO Guidelines for Conventional Water Quality for Irrigation (Ayers & Westcot, 1985; FAO, 2010)**			
	Overall Average	**Overall Average**		**None**	**Moderate**	**Severe**
Salinity						
EC (uS/cm) (a)	974	958.25		≤700	700–3000	≥3000
TDS (mg/l)	548.96	613.16		≤450	450–2000	≥2000
Specific ion toxicity						
Na (mg/l)	38.025	33.05	Surface	≤69	69–207	≥207
			Sprinkler	≤69	>69	
Chloride (mg/l)	58.06	50.56	Surface	≤142	142–354.5	≥354.5
			Sprinkler	≤106	>106	
Boron (mg/l)	0.0025	0.025		≤0.7	0.7-3	≥3
Permeability						
SAR	4.79	4.205				
For a given SAR, ECw (uS/cm)	974	958.25	SAR = 0–3	$EC_w \geq 700$	EC_w 700–200	$EC_w \leq 200$
			SAR = 3–6	$EC_w \geq 1200$	EC_w 1200–300	$EC_w \leq 300$
			SAR = 6–12	$EC_w \geq 1900$	EC_w 1900–500	$EC_w \leq 500$
			SAR = 12–20	$EC_w \geq 2900$	EC_w 2900–1300	$EC_w \leq 1300$
			SAR = 20–40	$EC_w \geq 5000$	EC_w 5000–2900	$EC_w \leq 2900$
Miscellaneous effects						
pH	7.22	7.92		6.5–8.4		
Bicarbonates (mg/L)	367.22	414.8		≤90	90–500	≥500
Iron (mg/l)	0.23	0.225	Drip Irrigation	≤0.1	0.1–1.5	≥1.5
	0.23	0.225		5		

APPENDIX VI

Treated effluent average quality for the remaining parameters from the Ablah and Zahle WWTPs compared to the FAO limit values for irrigation of conventional water.

Water monitoring	**Zahle**	**Ablah**	**FAO Guidelines for Irrigation Water (Ayers & Westcot, 1985)**		
	Average	**Average**	**None**	**VS**	**Restriction**
Permeability					
Ca mg/l	96.25	92.9	0 - 400		
Mg (mg/l)	29.59	30.6	0 - 60		
SAR	4.79	4.205	0 - 15		
Scale					
Hardness of water (mg/l)	125.845	123.5	0 - 2000		
Sulfate (mg/l)	53.69	55.875	0 - 960		
Nutrients					
Ammonium (mg/l)	0.027	0.19	0 - 5		
Nitrite (mg/l)	0.12		No guideline		
Nitrates (mg/l)	12.72	5.65	0 - 30		
K (mg/l)	16.6	19.65	0 - 2		
Phosphates (mg/l)	0.22	0.6025	0 - 2		

APPENDIX VII

Trends in the Ablah Effluent during the Monitoring Period

Water monitoring Ablah	**Winter**			**Summer**			**Overall Min**	**Overall Max**	**Overall average**
	Jan	**Feb**	**Mar**	**June**	**July**	**August**			
pH	8.1	7.58	8.26		7.73		7.58	8.26	7.92
EC (uS/cm)	1073	609	839		1312		609	1312	958.25
TDS (mg/l)	686.72	389.76	536.96		839.2		389.76	839.2	613.16
Bicarbonates (mg/L)	531.92	258.64	429.44		439.2		258.64	531.92	414.8
Hardness of water (mg/l)	109.71	75.1	175.6		133.6		75.1	175.6	123.5
Ca mg/l	78.67	57.55	120.03		115.35		57.55	120.03	92.9
Mg (mg/l)	31.04	17.55	55.57		18.25		17.55	55.57	30.6
Na (mg/l)	60.4		19.8		33.5		18.5	60.4	33.05
K (mg/l)	35.6	15.1	7.2		20.7		7.2	35.6	19.65
Chloride (mg/l)	71.08	17.02	33.04		81.09		17.02	81.09	50.56
Nitrates (mg/l)	2	2.2	4.4		14		2	14	5.65
Boron (mg/l)	0.1	0	0		0		0	0.1	0.025
Phosphates (mg/l)	1.64	0.11	0.01		0.65		0.01	1.64	0.6
Sulfate (mg/l)	72.5	43.5	56.25		51.25		43.5	72.5	55.875
Ammonium (mg/l)	0.03	0.007	0		0.71		0	0.71	0.19
Iron (mg/l)	0.53	0.2	0.03		0.14		0.03	0.53	0.225
TSS (mg/l)	19	5.1	1.4				1.4	19	8.5
COD (mg/l)	121.25	43.02	17.71				17.71	121.25	60.66
BOD (mg/l)	45	29	8				8	45	27.33
Total N (mg/l)									
Nitrite (mg/l)									
Nitrate-N	0.45	0.50	0.99	0.00	3.16	0.00	0.00	3.16	1.28
SAR	8.16	3.02	2.11		4.10		2.11	8.16	4.21
Total coliforms (CFU/100 ml 37°C)	400,000	24,000	62,000		<1		<1	400,000	121,500.25
Fecal coliforms (CFU/100 ml 44°C)	400,000	150	15,000		<2		<2	400,000	103,788
Escherichia coli (CFU/250 ml 44°C)		50	7,500		<3		<3	7,500	2,517.67

APPENDIX VIII

Trends in the Zahle Effluent during the Monitoring Period

Water monitoring Zahle	Winter			Summer			Overall Min	Overall Max	Overall average
	January	February	March	June	July	August			
pH	7.92	7.35	7.8	6.48	7.58	6.21	6.21	7.92	7.22
EC (uS/cm)	777	816	723	1227	1115	1186	723	1227	974
TDS (mg/l)	497.28	522.24	462.72		713.6		462.72	713.6	548.96
Bicarbonates (mg/L)	346.48	341.6	385.52		395.28		341.6	395.28	367.22
Hardness of water (mg/l)	114.23	133.29	133.92		121.94		114.23	133.92	125.845
Ca mg/l	84.62	107.41	103.52		89.47		84.62	107.41	96.255
Mg (mg/l)	29.61	25.88	30.4		32.47		25.88	32.47	29.59
Na (mg/l)	51.3	31.3	30.1		39.4		30.1	51.3	38.025
K (mg/l)	23.1	12	9.8		21.5		9.8	23.1	16.6
Chloride (mg/l)	67.07	47.05	47.05		71.08		47.05	71.08	58.06
Nitrates (mg/l)	4.9	5.2	1.2	0	13	52.02	0	52.02	12.72
Boron (mg/l)	0.01	0	0		0		0	0.01	0.0025
Phosphates (mg/l)	0.04	0.03	0.01	0.36	0.53	0.35	0.01	0.53	0.22
Sulfate (mg/l)	54	64.5	47.75		48.5		47.75	64.5	53.69
Ammonium (mg/l)	0.003	0	0	0.16	0.001	0	0	0.16	0.027
Iron (mg/l)	0.73	0.09	0.07		0.04		0.04	0.73	0.23
TSS (mg/l)	18.2	0.04	4.9	2		2	0.04	18.2	5.43
COD (mg/l)	15.41	0	13.11	22		10	0	22	12.1
BOD (mg/l)	18	0	6	5		1	0	18	6
Total N (mg/l)	3.1	5	4	5.32		22.92	3.1	22.92	8.07
Nitrite (mg/l)	0.012	0.01	0.01	0.32		0.18	0.01	0.32	0.11
Nitrate-N	1.11	1.18	0.27	0	2.94	11.76	0	11.76	2.87
SAR	6.79	3.83	3.68		5.05		3.68	6.79	4.79
Total coliforms (CFU/100 ml 37°C)	1,000	400,000	62,000	> 2,000	620	70	70	400,000	77,615
Fecal coliforms (CFU/100 ml 44°C)	1	180,000	750	2,000	1	55	1	180,000	30467.83
Escherichia coli (CFU/250 ml 44°C)		180,000	750		1		1	180,000	60250.33

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