Deanship of Graduate Studies
Al-Quds University

Strengthening Water Scarcity Resilience through Transboundary Wastewater Management in Alignment with the National Water and Wastewater Management Strategy: A Case Study of Wadi Al-Sour, Hebron

Rita Abed Abed Samamqa

M.Sc. Thesis

Jerusalem-Palestine

1446/2025

Strengthening Water Scarcity Resilience through Transboundary Wastewater Management in Alignment with the National Water and Wastewater Management Strategy: A Case Study of Wadi Al-Sour, Hebron

Prepared by:

Rita Abed Abed Samamqa

B.Sc. Civil Engineering, Birzeit University, Palestine

Supervisor: Prof. Dr. Jawad Shoqeir

A thesis submitted in partial fulfillment of the requirement for the degree of Master of Water Resource Engineering / Al-Quds university

Jerusalem-Palestine

1446/2025

Deanship of Graduate Studies

Al-Quds University

Water Resource Engineering

Thesis Approval

Strengthening Water Scarcity Resilience through Transboundary Wastewater Management in Alignment with the National Water and Wastewater Management Strategy: A Case Study of Wadi Al-Sour, Hebron

Prepared by: Rita Abed Abed Samamqa

Registration No.: 22212561

Supervisor: Prof. Dr. Jawad Shoqeir

Master thesis submitted and accepted, Date:21/5/2025

The names and signatures of the examining committee members are as follows:

1. Head of Committee: Prof. Dr. Jawad A. Shoqeir Signature 
2. Internal Examiner: Dr. Muath Abu-Sadaa Signature 
3. External Examiner: Dr. Subhi Samhan Signature 

Jerusalem-Palestine

1446/2025

Dedication

"The bodies fall, but the idea lives on." – Ghassan Kanafani

To those who believe that knowledge is a right, not a privilege,

And that justice is not given—it is pursued.

And to everyone who sees learning as a way to understand and transform reality— Not just a paper to hang on a wall.

To my mother your love has been the soft place I always return to, and has carried me through storms I never thought I'd survive. your unwavering belief in me planted the first seeds of this journey long before I knew what I was capable of.

To my father your belief in me gave me the courage to dream bigger than our circumstances.

To my sisters (Dr. Salma, Dr. Maram, Yara and Dana) thank you for standing by me with love that never wavered.

To Yahia, my brother your support has been a steady light through every challenge.

To my beloved husband your love, your faith in me, and your steady hand have been the pillars holding me up through it all. (Khalil)

To my precious daughters, who tolerated my busyness and were always a safe refuge you are the reason I keep moving forward. (Julan, Rahaf)

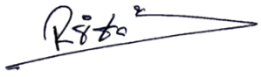
To my mother-in-law your kindness has touched my heart in more ways than I can count.

This effort, though humble, is part of a greater story:

One told by those who believe that the idea never dies

Declaration

I certify that this thesis submitted for the degree of the Master is the result of my own research, except where otherwise acknowledged, and that this study (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed: 

Rita Abed Abed Samamqa

Date: 21/5/2025

Acknowledgments

First and foremost, I would like to express my deepest gratitude to my academic supervisor, Prof. Dr. Jawad Shoqeir, for their invaluable guidance, support, and patience throughout this journey. Your thoughtful feedback and belief in my work have been essential to shaping this thesis and enriching my learning experience.

I would like to extend my sincere thanks to Dr. Muath Abu Sadaa for his generous time, valuable insights, and thoughtful discussions that enriched this thesis. I am especially grateful for his role as the external examiner of this thesis his critical eye added depth and clarity to my research. Thank you for your dedication and for believing in the value of this work.

My gratitude extends to Dr. Subhi Samhan for his thorough examination of this thesis as external examiners. his valuable insights and constructive feedback have significantly enhanced the quality and credibility of this research.

I would like to extend my heartfelt thanks to Eng. Issa Attallah and the management of the Joint Services Council for Water and Wastewater in North Hebron for their unwavering support, flexibility, and belief in me throughout my M.Sc. journey.

I am also sincerely thankful to the Palestinian Water Authority (PWA) staff, particularly Suhad Al-Malki and Eng. Ihab Swaity, for their cooperation and support during my research.

Special thanks also go to the Middle East Desalination Research Center (MEDRC) for granting me the fellowship that made this academic journey possible and for their continuous encouragement of water-related research in the region.

To my family, thank you for being my home. To my mother and father, whose sacrifices built the foundation upon which this entire journey stands. To my sisters and brother Yahia, thank you for every word of encouragement and every moment of care.

To my husband your endless support, love, and belief in me made the impossible possible. You stood beside me through every late night and moment of doubt.

Finally, to everyone who supported me in ways both big and small thank you. This thesis carries the fingerprints of many hearts, and I am deeply grateful to each one.

Abstract

Water scarcity is a pressing global issue and a growing concern in Palestine. This challenge is exuberating by limited natural water resources, the impacts of climate change, and geopolitical constraints. This study explores how transboundary wastewater management (aligned with the Palestinian National Water and Wastewater Management Strategy (2017–2022 and draft 2024–2029)) can contribute to strengthening resilience against water scarcity. Wadi Al-Sour catchment in Hebron Governorate was selected as a representative case study due to its transboundary nature and severe water stress.

A mixed-methods approach was used, combining stakeholder interviews and roundtable discussions with quantitative analyses, including wastewater flow estimation and calculation of the Supply-Demand Balance Index (SDBI).

Results show that the current domestic water supply in Wadi Al-Sour ranges from 63 to 77 liters per capita per day, which falls significantly below the WHO minimum standard of 100 L/c/d which indicate moderate to acute water scarcity. SDBI values between 0.63 and 0.77 further confirm persistent scarcity under current conditions.

The transboundary wastewater issue in the area represents a growing environmental and political concern. Due to the lack of adequate treatment infrastructure and restrictions imposed by Israeli authorities (particularly in Area C) untreated wastewater from Palestinian communities often flows into Israeli-controlled areas. In many instances, this has led to financial deductions from Palestinian tax revenues under the Polluter Pays Principle, without coordination or mutual agreement. Although no deductions have yet been imposed in Wadi Al-Sour, similar measures in other regions based on the wastewater generation, the PA could lose 60 million $ over the next 20 years.

To address these challenges, three transboundary wastewater management scenarios were developed and assessed:

Status Quo: Continued discharge of untreated wastewater across the border, increasing environmental risks and the likelihood of financial penalties.

Decentralized Palestinian Treatment: Development of localized treatment facilities upstream to prevent cross-border discharge and enable reuse within Palestinian areas.

Cooperative Management: Joint treatment and reuse projects between Palestinian and Israeli stakeholders, an approach that requires mutual agreement, legal clarity, and political will, which remain limited.

This research offers a realistic framework for improving wastewater management and safeguarding Palestinian water rights. It demonstrates that enhancing local treatment capacity, reusing treated wastewater, and reducing non-revenue water (NRW) can minimize financial losses, support agriculture, and improve water security. The study also reinforces national strategic goals and contributes to SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action).

Keywords: Transboundary wastewater management, water scarcity resilience, treated wastewater reuse, water resources management, national water strategy, environmental sustainability, political feasibility, wastewater treatment, non-conventional water resources.

Table of Contents

List of Tables:

List of Figures

List of Abbreviations

DWCR	Domestic Water Consumption Rate
GIS	Geographic Information System
JSC	Joint Services Council for Water and Wastewater
l/c/d	Liters per capita per day
MCM	Million Cubic Meters
MOA	Ministry of Agriculture
NRW	Non-Revenue Water
PCBS	Palestinian Central Bureau of Statistics
PPP	Polluter Pays Principle
PWA	Palestinian Water Authority
Q_{dry}	Wastewater flow in dry season (m^3/day)
$Q_{infiltration}$	Additional wastewater flow due to stormwater inflow and infiltration (m^3/day)
Q_{wet}	Wastewater flow in wet season (m^3/day)
SDBI	Supply-Demand Balance Index
SDG	Sustainable Development Goals
TWD	Total Water Demand
TWS	Total Water Supply
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

Chapter One:

Chapter One: Introduction

Water scarcity is a pressing global challenge that affects many regions worldwide, particularly in arid and semi-arid regions where natural water resources are limited and insufficient to meet the demands of population growth and other uses. The persistence of water scarcity in these regions increase the need to explore innovative and sustainable solutions to enhance water scarcity resilience and enhance the well-being of effected communities. The impacts of water scarcity reach far beyond the depletion of water quantities; it impacts a wide range of interconnected challenges including; socio-economic and environmental challenges which could reflect on social development, exacerbate poverty, threaten food security, and endanger ecosystems (UN-Water, 2021).

In Palestine water scarcity is considered as a major priority issue due to limited resources and to geopolitical constrains, with daily water availability of less than 80 liters per capita per day, Palestine is considered a water-scarce country as defined by The World Health Organization (WHO recommended a minimum of 100 liters per capita per day for basic health and hygiene need). In many areas, especially in Gaza strip and in Area C, water consumption is less than 50 liters per capita per day a level to consider serious humanitarian and health concerns (Howard & Bartram, 2003).

The growing demand on limited fresh water resources has put more pressure on already stressed water resources, the use of non-conventional water resources is a necessity to enhance water supplies for different activities and to ensure water budget balance.

In transboundary areas, where water resources are shared between the riparian countries or regions, sufficient water management becomes more complicated, effective governance of transboundary water resources is necessary for sustainable development, equitable allocation and to prevent conflicts (UNECE, 2015). Transboundary wastewater management could be a significant factor in addressing water scarcity challenges in these regions, contributing to resilience and sustainability (Qaddumi, 2008).

The Palestinian-Israeli transboundary wastewater issue is one of the complex political and water resource challenges in the region. Conflict occurs primarily around the Green Line, the border separating Palestine from Israel, at the point where the sewage flows from Upstream (Palestine, West Bank) to Downstream (Area C or Israel).

Palestinians faces significant challenges in wastewater management due to limited financial resources, inadequate infrastructure (poor sanitation system and the limited number of sewage treatment plants) and geopolitical constrains implemented by Israel. Construction wastewater treatment plants in the most cases require approval from different governmental and security parties on the Israeli side, which makes the process extremely difficult and need long time (Assaf, et al., 2010).

The lack of adequate wastewater infrastructure and facilities means that the untreated wastewater is discharged into different natural wadis without treatment leading to health and environmental hazard. In many cases, untreated Palestinian wastewater flows cross border to Israel.

Israeli side treats the transboundary discharge of untreated or partially treated wastewater (approximately 26 MCM/year) on the Palestinians expense, by deducting about 35 M$/year. This is a dynamic process and with no control, these numbers change yearly in a linearly increasing manner. The accumulated amounts are deducted from Palestinian customs and trade taxes before transferring the remaining money to the Palestinian Ministry of Finance following the Polluter Pays Principle (PPP) this process is not clear, how and when Palestinian should pay, how much and even for what (Tomizeh & Shoqeir, 2023).

Furthermore, Palestinians do not share in the environmental or economic benefits of the treated effluent of wastewater from a Palestinian origin. These practices showcase the power imbalance in transboundary wastewater issue, where one party benefits disproportionately while the other bears the environmental and financial burdens (Zeitoun, Talhami, & Eid-Sabbagh, 2019).

The Palestinian Authority recognizes the current water situation in the country and has developed long-term strategies to address water scarcity this research will focus in; The National Water and Wastewater Management Strategy 2017-2022 as well as the draft for the years 2024- 2029. This strategy outlines an integrated framework to manage water resources effectively and efficiently, enhance wastewater treatment and increase the percentage of reusing of treated water in order to enhance the resilience of Palestinian communities to water-related challenges. At its core, the national strategy aims to ensure equitable access to safe and sustainable water resources, promote integrated water management, enhance reuse of treated water, addressing transboundary wastewater and mitigate the adverse impacts of water scarcity on social and economic development. A key component of this strategy involves addressing transboundary wastewater concerns by providing solution that support the Palestinian sovereignty over their resources this include; increasing local wastewater treatment capacity to minimize dependence on Israeli treatment facilities. (PWA, 2016)

The implementation of this strategy is, however, fraught with difficulties, including geopolitical restriction to essential infrastructure and water resource, delays and complex process to get required permissions from Israeli authorities, and inadequate investment in wastewater management projects (Perrier, 2021).

Despite these limitations, local water and wastewater service providers in Palestine (municipalities and Joint Service councils) are trying to align with the national policies by adopting decentralized and small-scale wastewater treatment plant.

While the National Water and Wastewater Management Strategy sets out a comprehensive strategy for water resource management at the national level, successful implementation relies on its coordination and alignment with local water management practice. (PWA, 2014)

The case of Wadi Al-Sour in the north-west of Hebron Governorate unique geographical and political conditions make it a compelling case study to explore the critical need for integrated and sustainable water management approaches that take into account both local constraints and transboundary dynamics.

Wadi Al-Sour catchment, which is considered as a shared surface basin between Palestine and Israel, could be particularly relevant case study for examining the intersection of water scarcity, transboundary wastewater management and national water strategies. The region relies heavily on limited water resources, with population growth and expanding agricultural practices, the balance gap between water supply and demand in Wadi Al-Sour catchment area is increasing.

Current estimates indicate that water supply in Wadi Al-Sour is less than 80 liters per capita per day (WSRC, 2022). Which indicate that the study area suffers from acute to moderate water scarcity, with domestic water consumption rate is lower than the World Health Organization's recommended 100 liters per capita per day for the optimal quantity for domestic use.

As population growth and water needs to meet the current life style is increase, Water scarcity is a growing concern and climate change is exacerbating the problem. According to UN-Water, climate change is primarily a water crisis, and its impacts are felt through worsening floods, rising sea levels, shrinking ice fields, wildfires, and droughts (UN-Water, 2020).

Climate change projections indicate that the Middle East will suffer from increased temperature, reduced in precipitation quantities and increased evapotranspiration rates in the coming years which will increase the strain on the limited water resources. Rising temperature and change in precipitation patterns (amount, intensity and frequency) are expected, this will increase the drought rate and increase water scarcity. (Oroud, 2009). The interconnection between climate change impacts and existing political concerns increase the need to apply strategies that can ensure long-term water security.

To address both immediate water scarcity concerns and long-term sustainability challenges, blueprint projects focusing on innovative wastewater treatment and reuse are emerging as strategic solutions. They aim to develop replicable and scalable models that optimize treated water reuse and enhance environmental sustainability. Several international case studies have demonstrated how blueprint projects can effectively convert wastewater into an important water asset, particularly in arid and semi-arid regions (Angelakis, 2021).

In this context, the implementation of blueprint wastewater projects by the reuse of treated water for agricultural purposes will reduce the demand on freshwater resources, which can help in strengthen climate change resilience and ensure a sustainable future for generations (UNESCO, 2017).

Several studies and reports have illustrated the important of reusing treated water include; save the surrounding eco-system by reducing the pollution of waterways and groundwater contaminant (WWAP, 2019),and its important in providing a reliable and economical water

resource alternative to fresh water resource. This approach has proven to be an effective strategy facing water scarcity (Qadir, 2020).

The reuse of treated water for agricultural irrigation has been successfully implemented in various water-scarce regions worldwide, providing a reliable and cost-effective alternative to freshwater sources, studies shown that treated water reuse can significantly enhance agricultural productivity by providing a consistent water supply, improving soil fertility through nutrient-enriched water, and reducing reliance on chemical fertilizers (Gross, 2007).

Additionally, access to irrigation water helps farmers maintain their livelihoods, reduces the risk of land abandonment, and supports rural economic development (Walraevens, 2018).

In the Palestinian context, where land confiscation and water restrictions present existential threats. providing reliable water resources strengthens the socio-economic stability of farmers and reinforces their ability to remain on their land. Moreover, providing water for irrigation uses aligns with broader state-building efforts by promoting food security, economic independence and sustainable land use.

Strengthening the agricultural sector through promoting the treated water reuse as a water resource is also important in achieving several Sustainable Development Goals (SDGs), including clean water and sanitation (SDG 6), and climate action (SDG 13) (UNESCO, 2017). However, to success in using treated water for irrigation purpose it must fit with country regulatory frameworks, community engagement, and investments in wastewater treatment infrastructure to ensure safe and effective implementation.

1.1 Problem Statement

Water scarcity is a critical issue in Palestine, the ongoing war since October, 2023 with the huge damage to water and wastewater infrastructure has led to environmental and health hazard. The destruction of sewage systems and water facilities has resulted in the discharge of untreated wastewater into the environment, increasing the risk of waterborne diseases and environmental degradation. Overcrowded shelters with inadequate sanitation facilities have worsened these issues, contributing to the spread of infectious diseases and deteriorating living conditions.

The water scarcity has further exacerbated by limited water resources, climate change and geopolitical restrictions. AS Oslo II Accord divided Palestine into a geopolitical area (A, B, C) making it difficult for Palestinians to build wastewater treatment plants due to long and complicated approval processes involving both the Joint Water Committee (JWC) and the Israeli Civil Administration leading to delay or rejections especially in Area C, which is under full Israeli control. Efforts to address these challenges are further complicated by financial constraints. Israel deducts money from Palestinian tax revenues for treating wastewater which led to a financial constraints and political obstacles to infrastructure development leaving the Palestinian communities with inadequate wastewater management systems, resulting in many environmental and public health problems and a huge financial burden.

The absence of adequate wastewater treatment infrastructure has led to the discharge of untreated wastewater into natural valleys, creating a transboundary wastewater issue between Palestine and Israel, as a show case of the challenges faced by Palestinians under Israeli occupation. leading to tax deduction, which considered the main income to cover the basic services for the Palestinian communities. These deductions add to the financial strain, making it even harder to improve wastewater management.

Wadi Al-Sour present a developing case study of transboundary wastewater issue, in which Israel has not yet begun deducting money for treating wastewater from this catchment, such deductions are expected in the near future. Without strategic planning, Palestinian communities will face increased financial losses, worsening environmental pollution and further violations of their right to self-determination and sovereignty over their natural resources.

The linear increase of tax deduction under transboundary wastewater issue not only deepens economic burdens but also could give Israeli chance to increase their control over Palestinian water infrastructure which will lead to increase existing inequalities.

These challenges show the urgent need for applying sustainable wastewater management approach to mitigate environmental and public health risks in the face of ongoing geopolitical constrains.

1.2 Significant of the Research

- **A Blueprint for Addressing Water Scarcity**

This study provides a guide that outline practical steps to strengthen water scarcity resilience in transboundary context.

By focusing in Wadi Al-Sour catchment as a case study, this study provides a detail step by step approach (blueprint) starting from assessing the current water scarcity level reaching practical solution in the light of the political, technical, and socio-economic challenges of wastewater treatment and reuse.

- **Supporting Sustainable Development Goals (SDGs)**

By focusing on wastewater treatment and reuse, this research supports many SDGs (Figure 1);

SDG 6 (Clean Water and Sanitation) by implement Integrated water resource management start from improve sanitation, treatment, reuse the treated water and reduce the eco-system pollution.

And **SDG 13** (Climate Action), promoting sustainable water resource management in a water scarce region by focusing in reuse the treated water which will reduce the pressure in fresh water resource which will enhance water scarcity resilience and mitigate climate change effects.

Figure 1: Sustainable Development Goals (SDG)

- **Eco-Social and Environmental Impact**

Enhancing Wastewater management system will reduce environmental hazard caused by untreated discharge, protects ecosystems and improves public health. Moreover, using the treated effluent for agricultural uses will support farmers resilience and increase their income in the same time this will reduce the pressure on fresh water resource.

- **Early Alarm for Future of Transboundary Wastewater Management Crisis**

Wadi Al-Sour catchment presents a developing case study for transboundary wastewater issue in which untreated flow passes the green line, currently Israel don't deduct money for treating it, but it's expected to do in the near future.

So, this research with its different management scenarios and outcomes could work as an early al-arm and could be scalable to develop solutions for other transboundary catchment which face similar challenge with taken into consideration the specify of each case.

- **Policy Development and National Alignment**

The study aligns with the National Water and Wastewater strategy (2017-2022, 2024-2029) and it provides actionable recommendations for strategy implementation.

1.3 Scientific Question

This research is grounded about the following question;

How can water scarcity resilience be strengthened in the Wadi Al-Sour catchment through integrated and strategic transboundary wastewater management, in alignment with the Palestinian National Water and Wastewater Management Strategy (2024‑2029), while addressing environmental, financial, and geopolitical challenges?

1.4 Aim and Objectives

This research seeks to enhance water scarcity resilience in Wadi Al-Sour catchment by proposing a viable infrastructure, policy and cooperation model that addresses the key environmental, financial and geopolitical barriers. The study particularly focuses on reducing future tax deductions related to transboundary wastewater, improving public health outcomes, and promoting the sustainable reuse of treated wastewater.

The specific objectives are:

1. Assess the current water scarcity situation using water index at Wadi Al-Sour catchment area.

2. Evaluate the existing wastewater management practices in Wadi Al-Sour catchment area to understand the extent and severity of the wastewater problem.

3. Analyze the financial implications of transboundary wastewater flows, with a focus on current and anticipated tax deductions imposed by Israel and their impact on Palestinian budgets and service provision.

4. To develop and assess multiple wastewater management scenarios, including upgrading wastewater treatment infrastructure, enhancing reuse of treated water, and engaging in transboundary cooperation.

5. Develop comprehensive recommendations for policy changes that can effectively support and implement transboundary wastewater management strategy to address water scarcity challenges in the area.

1.5 Thesis structure

This thesis is presented in five chapters:

- **Chapter 1: Introduction**

This chapter provides an overview of water scarcity in Palestine, highlighting it from different aspects include; the limited natural resources, climate change and geopolitical restrictions. It introduces wastewater management as an important factor in addressing water scarcity and explains how the political strains reflected on water sector, particularly Israeli restrictions on infrastructure development, have worsened the situation.
The chapter also presents the research problem, present the current situation in the study area. The aim and objectives of this research are discussed and an outline of the thesis structure.

- **Chapter 2: Literature Review**

This chapter provides a comprehensive review of existing literature relevant to the research topic. It examines previous studies, governmental and international reports and academic papers related to water scarcity in Palestine from natural and political aspects. Additionally, it provides a deep review of the historical context, financial burden and environmental and health concerns related to transboundary wastewater issue.
Moreover, it provides a deep review for the Palestinian National Water and Wastewater Strategy (2017–2022, 2024–2029) and its objectives towards improving wastewater management, reducing transboundary wastewater discharge and optimizing treated water reuse.

- **Chapter 3: Methodology**

This chapter overview of the research design, as well as data collection and analysis procedure.
It outlines how water scarcity in Wadi Al-Sour was assessed through field surveys, water consumption data analysis and using related index.
The chapter also present the different scientific tools that were used in analyzing the collected data, such as the Supply-Demand Balance Index (SDBI), wastewater flow calculation.
The methodology also includes stakeholder involvement, to ensure considering different perspectives and point of view from local authorities, farmers, and water sector professionals.

- **Chapter 4: Results and discussion**

This chapter delves into the detailed analysis and results of the collected data and discussion of the research findings. Also, the chapter provides a deep analysis for stakeholder interviews. It systematically presents and interprets the results obtained from both quantitative and qualitative data, addressing each research question or objective.

- **Chapter 5: Conclusion**

This chapter summarizes the key findings of the study

- **Chapter 6: Recommendations for future research**

This chapter provide recommendations based on the results; challenges faced during the research development for future action.

Chapter Two:

Chapter Two: Literature review

This chapter provides a thorough literature review focusing on water scarcity in Palestine, Transboundary Wastewater Issue between Palestine and Israel and National water and waste water strategy 2017-2022 and draft 2024-2029.

2.1 Water Scarcity in Palestine

Water Scarcity is presenting a national concern in Palestine, many national and international expert analyses it from different perspectives including water scarcity causes in light with negotiations, the occupation, climate change, environmental conditions, the role of international donors and funders and mismanagement (Hussein, 2023).

A key aspect of this crisis is Israel's control over Palestinian water resources. Previous studies highlight how Israeli policies and military orders systematically restrict Palestinian access to both surface and groundwater sources, describing that as a hydro-hegemonic where Palestinians are denied sovereignty over their water resources (Seeberg, 2024); (Isacc, 2017).

Francisco, (2020) Argues that this control is being used both as a strategy for Israeli security and as a form of terrorism against the Palestinian population.

The Palestinian Water Authority (PWA) report in 2008 "The Right to Water" express that Israel’s is using water as a weapon, emphasizing how access restrictions and unequal allocation of water quantities between Palestinian and Israelis are part of a wider strategy to exert control over Palestinians.

(Feitelson, 2002) further emphasizes that the most water quantities of the shared surface and ground water resources is being used by Israel. Despite, the fact that Israel has alternative potential sources of water as large-scale sea water desalination while this option is not available for Palestinian.

Climate change has further exacerbated water scarcity in Palestine, (Yaqob, 2023) identify how the climate change septically precipitation and temperature impact on water re-sources based on analyzing historical data, the recharge of groundwater aquifer is reduced while the demand is increase due to population growth. By 2050, water scarcity is expected to worsen, with 73% of the West Bank governorates expected to severe extreme to acute water scarcity, compared to 64% in 2020 (Judeh & Shahrour, 2021).

Climate change will impact water resources badly, effecting surface and underground water supplies for residential and commercial purposes.

PA depends heavily on external fund through different donors to enhance infrastructure specially water infrastructure projects, many of these projects face delays or cancellations due to Israeli restrictions, particularly in Area C, where most water infrastructure development requires Israeli approval (GWP, 2024) (UNICEF, 2019).

Moreover, Nour & Al-Saidi, 2018 present in their research the internal mismanagement challenges, such as the lack of coordination among water service providers (municipalities), which leads to inefficiencies in water distribution and service delivery. As a result, many Palestinian communities experience irregular water supply and noncontinuous water supply, so people used to purchase expensive water tanks to fulfill their water need.

Despite these constraints, Palestinian institutions responsible for water management have been developing since 1995, aiming to regulate and oversee water resources and services, including wastewater treatment. Many projects have been implemented to improve water infrastructure, such as the construction of wells, water distribution networks, pumping stations, reservoirs and wastewater treatment plants in the West Bank (PWA, 2013).

Additionally, the Palestinian Water Authority (PWA) has led reforms and enacted water laws in coordination with other governmental and international organizations (Perrier, Palestinian water laws: Between centralization, decentralization, and rivalries, 2020). However, the implementation of these plans often faces obstacles, particularly due to Israeli restrictions, as many projects require approval from the Joint Water Committee, which has historically delayed or denied Palestinian water infrastructure projects.

Water scarcity in Palestine is complex issue shaped by multi-factors including the political concerns, climate change and internal management challenges.

2.2 Transboundary Wastewater issue between Palestine- Israel

The Palestinian-Israeli transboundary wastewater issue is one of the complex political and environmental challenges in the region. Conflict occurs primarily around the Green Line (the border separating Palestine from Israel) at the point where the untreated or partially treated water flows from Palestine to Israel. This satiation is further complicated by the wastewater discharges which flow from illegal colonies in the West Bank polluting surrounding Palestinian communities.

2.2.1 Historical Context and Current Situation

Palestine and Israel rely on shared ground water resources, which flows by gravity from the higher parts (located in the West Bank) into lower parts (located in Israel). However, effective cooperation between Palestine and Israel on this resource is limited due to political tensions, current technology constraints, mistrust, lack of enforcement mechanism in which water has, unfortunately, become part of the wider political context (Schneier-Madanes, 2001).

Prior to 1967, Israel had developed the water resources to which it had access and established a national water carrier, operated by Mekorot, that conveyed water from existing sources of supply to the various demand from agricultural, municipal and industrial customers. The National Water Carrier, completed in 1964, is a 130-kilometer-long system designed to

transport water from the Lake Tiberias in the north to the arid southern regions of Naqab desert (CIE, 2021).

Following the 1967 War, Israel took control of water resources, and developed wells, throughout the West Bank, together with a water supply network serving colonies that linked into the Mekorot network. Palestinian water rights in the West Bank were abrogated, including the Jordan river (WorldBank, 2009).

In 1995, **Oslo II** Accord was signed between Palestine and Israel, this accord divided the West Bank into three areas according political control; **Area A**, under full Palestinian civil and security control, **Area B**, with Palestinian civil control but Israeli security oversight and **Area C**, where Israel retained full control over security, land, and natural resources (Figure 2). The accord also established the **Palestinian Authority (PA)**, as a one and only legal representative for Palestinian.

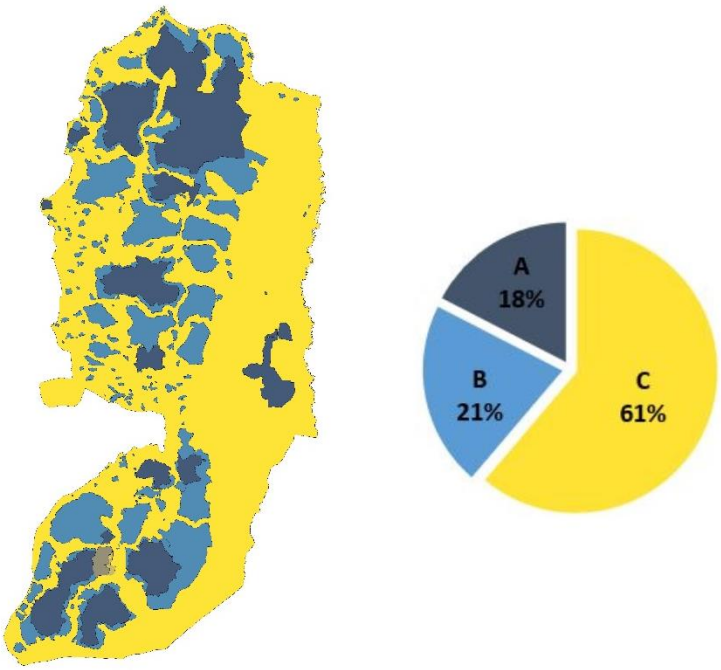


Figure 2: Geopolitical map of West Bank under Oslo II Accord

shapefiles based on Geomolg (By Reeta Abed,2025)

One of the key issues within the accord was the water issue which was illustrated in Article 40; this article recognizing Palestinian water rights and detailed specific water quantities to be allocated to the Palestinian, mostly from the eastern Mountain aquifer in the West Bank and Israel keep the control over the majority of shared water resources, specially the Western and Northeastern Basins, which are the most productive. These allocations made Palestinian received about one quarter to the allocated quantities for Israel and the colonies (Selby, Daoust, & Hoffamnn, 2022).

To oversee water and wastewater projects and infrastructure development, the Joint Water Committee (JWC) was established under the same Accord (Weinthal, 2017).

Despite, the role of the JWC as cooperative facility Messerschmid (2014) and Selby et al. (2022) argue that, the JWC has functioned less as a platform for cooperation and more as a

mechanism of domination, reinforcing Israeli hegemony over water governance by giving Israel side the right to de facto veto over Palestinian water and wastewater projects (even those located in Areas A and B) while giving Israel unstrict freedom to implement its own projects, including those related to illegal colonies in West Bank areas. And this significant power imbalances and political tensions, which have influenced the effectiveness and fairness of the JWC's operations.

Within the Joint Water Committee (JWC), there are different technical committees that aims to review and discuss the details of water and wastewater projects before they are approved. Each technical committee focus on different scope, such as water supply, wastewater treatment, drilling and licensing (Selby , 2013).

According to Selby et al. (2022) and Messerschmid (2014), the Israeli side uses its control to delay or block projects by raising many technical questions or asking for more documents again and again. This creates a slow and complex process for Palestinians. In many cases, Israeli representatives in the technical committees make decisions based on political reasons rather than technical ones. Moreover, technical committees are asking to get permission from the Israeli Civil Administration when the projects are planned in Area C, which adds another layer of complicate.

The Palestinian Authority stopped participating in the JWC to protest imbalance and lack of real cooperation (Messerschmid, 2014) (Selby, Daoust, & Hoffamnn, 2022). This decision came due to the unequal structure of the committee in which Israel used its power to delay or block Palestinian water and wastewater projects, while freely implementing their own projects. Despite this, Israel continued to require permits and approvals for any Palestinian water or wastewater projects in Area C (WorldBank, 2009).

In 2010, responding to continues international request and growing water need the Palestinian side returned to participate in the JWC (Amnesty International, 2009) (Zeitoun, Eid-Sabbagh, Loveless, Weinthal, & Talhami, 2012). But this return did not lead to meaningful change. The structure of the JWC stayed the same, and Israel continued to dominate decision-making. (Weinthal, 2017; Trottier, 2007).

Israeli restrictions on Palestinian wastewater infrastructure are a key obstacle for improving wastewater management. In the West Bank, particularly in Area C, which constitutes about 60% of the West Bank total area which remains under full Israeli control, Palestinians face many challenges in constructing or upgrading wastewater treatment facilities, following complex and bureaucrat process to get permission which leads to delays or rejections, making it nearly impossible to implement wastewater projects (Dai, 2021).
A report by Human Rights Watch (HRW) in 2021 highlighted that while Israel has allowed the construction of wastewater treatment plants in Israeli colonies in the West Bank, Palestinian communities have been forbidden from the same access to wastewater infrastructure (HRW, 2021).

As result, Palestinian wastewater management system is underdeveloped and consist of a combination of small-scale treatment plant and decentralized sewer network, with high percentage of wastewater generated in Palestinian towns and villages is sufficiently untreated and flows directly into open areas (Khatib & Younis, 2020).

Gaza presents an even more acute case: Gaza Strip is currently experiencing a severe water and wastewater crisis, exacerbated by ongoing conflict and infrastructural damage. Recent

military operations have led to destruction the majority of the infrastructure, including water and wastewater treatment facilities, which reduce the access to clean water and sanitation services for Gaza's 2.3 million residents (Al-Mughrabi & Issa, 2025).
Approximately 80% of Gaza's water and sanitation infrastructure has been partially or entirely destroyed. This includes all six major wastewater treatment plants and 85% of sewage pumping stations. The destruction has resulted in the uncontrolled discharge of raw sewage into streets, agricultural lands, and water sources (Elhabil, 2025; Oxfam, 2025).

2.2.2 Financial Constraints:

The financial constraints related to transboundary wastewater management between Israel and Palestine are significantly influenced by the political and economic dynamics of the region, one of the primary financial challenges is the Israeli deduction of Palestinian tax revenues.

Under the Paris Protocol (1994), which governs economic relations between Israel and Palestine, Israel collects Palestinian customs and trade taxes on behalf of the Palestinian Authority (PA) and transfers these funds to the Palestinian Ministry of Finance and Planning. However, Israel has deducted large amount of these tax revenues for different reasons, as unilateral action, including amount under the title of treating transboundary wastewater from Palestinian side (Arnon & Weinblatt, 2014; Hassouneh & Khalidi, 2019).

As the tax revenue forms the primary source of income for the PA these deductions put an additional strain on the already struggling budget, which directly impact the ability to develop and implement wastewater infrastructure projects (Ghanem S. , 2018).

As result PA depend heavily on international aid and donors support to develop basic infrastructure projects and services which is not always sufficient or reliable to ensure long-term solutions to wastewater challenges (Ghanem & Abu-Lebdeh, 2020).

2.2.3 Environmental and Health Impacts:

Wastewater management has become a critical aspect of urban and industrial development worldwide. The increasing global population, coupled with rapid urbanization and industrial expansion, has elevated the demand for effective wastewater treatment (Alazaiza et al., 2025).

The effective treatment and management of wastewater are essential to protecting both the environment and public health, the literature emphasizes that many challenges are faced in treating and managing wastewater, including technological constraints, financial limitations and political challenges which add another layer of complicity to effective wastewater management, particularly in conflict regions (Chrispim, Scholz, & Nolasco, 2019)

In Palestine, these challenges are further exacerbated by a lack of infrastructure, Israeli restrictions on wastewater treatment projects, and limited access to financial and technical resources (Stamatopoulou-Robbins, 2019)

The lack of adequate wastewater infrastructure forced many Palestinian communities to relay on cesspits tanks for wastewater disposal. These cesspits are uninsulated which allow raw wastewater to leak into the surrounding soil and pollute groundwater resources.

Additionally, people used to empty these cesspits using tankers, raw sewage is often discharged directly over land and into wadis (seasonal dry streams). The delay in wastewater project implementation contribute to serious public health and environmental risks, reduce availability of limited water resources, as aquifers are polluted by wastewater.

transboundary wastewater issue is a growing concern, as untreated wastewater significantly impacts both water quality and public health. Studies highlight that untreated or partially treated sewage from Palestinian communities is discharged and flow into natural wadis and in some locations passing to Israel side contributing to groundwater contamination and the degradation of natural ecosystems (Yaqob, Al-Sa'ed, & Suidan, 2014). However, a major cause of this pollution is the restriction on Palestinian wastewater infrastructure development due to Israeli control over Area C, where most wastewater treatment plants need to be built (Isaac & Hilal, 2011). The lack of adequate treatment facilities leads to the direct discharge of wastewater into the environment, exacerbating soil and water contamination (Dotan, et al., 2017).

Conversely, wastewater from illegal Israeli colonies in the West Bank also contributes to pollution as they discharge wastewater to surrounding Palestinian lands. The asymmetry in political power and resource access means that Palestinian often have limited ability to control or mitigate these flows, leading to environmental degradation, public health risks, and diplomatic tension (Shuval & Dweik, 20017;Hilmi, Woldeyohannes , & Muhammed, 2021).

Research shows that colonies untreated wastewater is discharged directly into Palestinian agricultural lands. In 2018, the Palestinian Central Bureau of Statistics reported that 90 per cent of all colonies wastewater (roughly 35 million cubic meters yearly) was untreated and discharged into Palestinian lands destroying large area of agricultural lands and reducing soil fertility and posing directly affecting the local food production. The geological location of the illegal Israeli Colonies in the hilltop of West Bank leads to direct flow of untreated wastewater to downhills Palestinian communities which makes the surrounding Palestinian agricultural land more vulnerable to contamination.

the Current genocide war in Gaza has serious cross-border consequences that affect not only Palestinians but also neighboring countries. These impacts including environmental, health hazard.

As most of the wastewater infrastructure were destroyed thousands of cubic meters of raw or partially treated wastewater is discharge into the Mediterranean Sea, a shared water body, this threatens the costal water and affect the threatens marine ecosystems in neighboring areas (UNDP, 2024). And this also threats Israel's major desalination plants which is located to the North of Gaza strip as water currents carrying pollutants to its intake points this may lead to potentially forcing shutdowns, (Efron, Fischbach, & Giordano, 2018; Fanack-Water, 2024)
Additionally, Gaza's coastal aquifer, which is hydrologically connected across borders, is severely over-extracted and polluted with nitrates, chlorides, and pathogens. These contaminants can migrate across aquifer boundaries, affecting groundwater quality in neighboring Israeli and Egyptian areas (World-Bank, 2016; Fanack Water, 2024).

The environmental impacts of transboundary wastewater pollution are severe, leading to the degradation of agricultural land, loss of biodiversity and contamination of essential water

supplies which will affect water quality badly and increasing the dangerous of waterborne diseases. Polluted water by wastewater increases the appearance of harmful bacteria, viruses and other pathogens, causing health risks to people relying on these water sources for drinking, agriculture and daily use (Hilmi, Woldeyohannes , & Muhammed, 2021). Long-term exposure to polluted water can cause gastrointestinal illnesses, skin infections, and other serious health conditions, disproportionately affecting vulnerable communities with limited access to healthcare (Chrispim, Scholz, & Nolasco, 2019).

The Israeli authorities forced stringent standards on the effluent quality on the Palestinians treatment facilities, as delineated in memorandums of understanding (MoUs) from 2003 and 2008. (Al-Sa`ed & Al-Hindi, 2012)

Phased Implementation of Effluent Standards

The 2003 MoU introduced a two-phase approach for Palestinian WWTPs to achieve specific effluent quality benchmarks:

First Phase: Newly established Palestinian WWTPs are required to attain effluent concentrations of 20 mg/L for Biochemical Oxygen Demand (BOD) and 30 mg/L for Total Suspended Solids (TSS).

Second Phase: Within a five-year timeframe, these facilities must upgrade to meet more stringent standards of 10 mg/L for both BOD and TSS.

2.3 Baseline: National Water and Wastewater Plan 2017-2022 and draft 2024-2029

The Palestinian Council of Ministers was approved a reform action plan to define and implement a comprehensive program of institutional and legislative reform in the water sector. This plan including the reform of the water sector and institutions, capacity building and the development of strategies and policies, based on the decree law Water Law (2014). (PWA, 2014)

The National Water and Wastewater Plan 2017–2022 and the draft 2024–2029 Strategic Plans, which were developed by the Palestinian Water Authority (PWA), is considered as strategic framework that guide Water management in Palestine.

These plans are considered as roadmap to understand the policies, challenges and priorities in managing water resources, including many issues like; water scarcity, wastewater treatment and reuse in light of Integrated Water Resource Management (IWRM) principles. Their primary goal is to ensure the sustainability and resilience of the water sector dealing the political, environmental and institutional challenges.

2.3.1 Overview:

The Palestinian water sector faces several challenges to reach water security; these challenges are interconnected and have hindered the water sector’s development.

Strategic development plans highlighting, identifying and assessing sectoral resources and needs at the national level, taking into account the governorates.

The **2017–2022 strategy** conducted the development Vision of the Water Sector:

"Towards an Organized Water and Wastewater Sector, which contributes in building up the Palestinian Sovereignty and ensures the sustainability of water resources according to robust health, environmental, social and economic structures capable of achieving the essential and developmental requirements of the Palestinian people" (PWA, 2016)

According to this plan the sector faces three main challenges: Political, institutional and financial challenges.

Politically, Israeli control over water resources and restrictions on infrastructure development in Area C have significantly hindered the Palestinian water sector. These restrictions prevent the establishment of necessary wastewater treatment facilities and limit efforts to expand service networks. The plan discusses the institutional reform based on the 2014 Palestinian Water Law (Law No. 14/2014), which restructured the sector by establishing new regulatory bodies like the Water Sector Regulatory Council (WSRC) and the National Water Company. However, institutional overlaps, lack of coordination among municipalities, and inadequate enforcement mechanisms continue to pose obstacles. Financially, the sector remains heavily reliant on external donor funding, which is often unpredictable and subject to political constraints, making long-term planning difficult.

Building on previous reforms, the 2024–2029 Strategic Plan vision is:

"A governed water and Wastewater sector that enhances Palestinian sovereignty, ensures the sustainability of water systems and is responsive to developmental and cross-sectoral issues." (PWA, 2023)

It focuses towards enhancing water sustainability through integrated water resource management (IWRM), highlighting the important of improved governance and focus in increasing the reuse of treated water percentage as a tool to strengthen climate change resilience. Additionally, the strategy addresses transboundary wastewater challenges, by focusing on reducing the quantity of transboundary wastewater by developing existing treatment plants to increase their capacity, establishing new treatment plants and increase the reuse of treated water projects for irrigation purposes**.** to mitigate pollution and maximize the efficient use of available water resources.

2.3.2 Wastewater as tool for strengthen water scarcity resilience:

Wastewater component and the reuse of treated water were key objectives in both strategies; The Strategic development plan (2017-2022) consider improving wastewater services and structure (collection, treatment and reuse) as a core base for developing water sector in Palestine. It focused on improving infrastructure, expanding collection networks, enhancing treatment efficiency, and promoting wastewater reuse to deal with water scarcity.

The National Water and Wastewater Strategy 2024-2029 build on this foundation allocate wastewater management under *'The third strategic objective: improving the infrastructure and services of sanitation and wastewater treatment and increasing its use in various fields.'* Through focusing in increase the household sewer connection and upgrade treatment efficiency, reduce transboundary wastewater flow quantities, maximizing the reuse of treated water for agricultural and industrial purposes, reducing dependence on freshwater sources and mitigating environmental pollution.

Chapter Three:

Chapter Three: Methodology

This chapter provides detailed overview of the methods and procedures that were used to address the research aim and objectives of this study in alignment with scientific research principals. This chapter includes the description of the study area, research design, data collection, and data analysis, providing valid and reliable answers to the research questions.

3.1 Study area

The study was carried out in Wadi Al-Sour catchment in the Northern West part of Hebron governorate in the southern area of West Bank. Over an area of 57.29 Km^2, with an approximate 37,000 inhabitants. The catchment includes; Kharas, Nuba, Beit-Ula, Halhul,

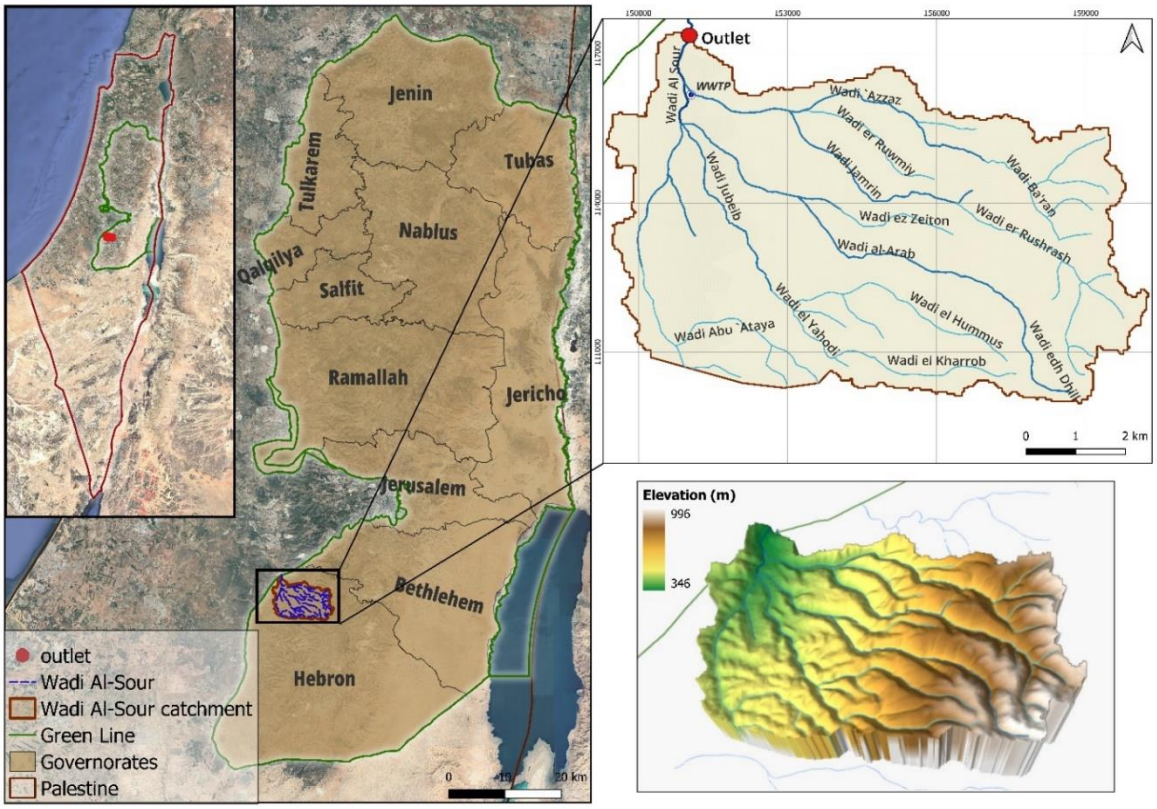


Figure 3:Study area location, waterways name and elevation

Sourif, Beit-Ummar villages. Figure 3 shows the geographical location of the study area and elevation range to the sea level in addition to waterways name.

The study area experiences a Mediterranean climate characterized by hot, dry summers and mild, wet winters. The town receives an average annual rainfall of about 481 mm, with precipitation primarily occurring during the winter months (PMD, 2023)

There is one wastewater treatment plant in Wadi Al-Sour catchment (Kharas wastewater treatment plant) with design capacity of 500 m^3/day and currently it treats 250 m^3/day due to limited household sewer connection. This plant uses the activated sludge technology. Activated sludge technology involves the use of microorganisms, primarily bacteria, to biologically degrade organic matter in wastewater. The process takes place in an aeration tank, where air or oxygen is continuously introduced to maintain aerobic conditions and promote microbial growth (Tchobanoglous et al., 2003).

These microorganisms form clumps or "flocs" that consume organic material as their food source, breaking it down into simpler compounds such as carbon dioxide, water, and biomass. The treated water then flows into a settling tank, or secondary clarifier, where the heavier sludge settles at the bottom, allowing for the separation of clean water from the biological solids (Metcalf & Eddy, 2014).

The sludge collected at the bottom is either returned to the aeration tank to maintain the microbial population or removed for further processing, such as anaerobic digestion or dewatering. This process not only effectively reduces organic pollutants but also helps remove nutrients like nitrogen and phosphorus when integrated with advanced treatment methods (Bitton, 2011).

Wadi Al-Sour catchment was selected due to its transboundary nature and its representation of water-scarce area affected by regional wastewater management challenges. These reasons make it an ideal case for investigating the feasibility of enhancing water scarcity resilience through aligning with the national water and wastewater management strategy.

3.2 Research Design

This Study was designed to explore how transboundary wastewater management can enhance resilience to water scarcity, focusing on Wadi Al-Sour Catchment and can be model to avoid sanctions between parties. The study integrates between qualitative and quantitative methods (Mixed method approach) to provide a deeper understanding of the technical, social, and policy-related aspects of transboundary wastewater management and its impact on water scarcity resilience, aligned with national water and wastewater management strategy of the Palestinian Water Authority.

3.3 Data collection

The data collection process was designed to support the achievement of all research objectives. Using mixed-methods approach that combining qualitative and quantitative data sources.

3.3.1 Qualitative Data:

1. Review documents and data base.

In order to achieve objective 1,2 and 4 a thorough review of relevant documents and databases was conducted to get insight about research. This document includes; National strategies, reports and scientific papers related to water management and wastewater treatment.

- **Relevant Reports and scientific paper:** This includes a set of governmental and local reports, scientific papers and national reports to illustrate the water availability, demand and population growth and information related to transboundary wastewater problem caused by the wastewater flow from Palestine to Israel and from illegal Israeli colonies to Palestinian lands.

- **National Water and Wastewater Strategy (2017-2022):** The review included an analysis of the National Water and Wastewater Strategy (2017-2022), which outlines the strategic direction for water and wastewater management in Palestine. This document provided important background information on government policies, objectives, and planned interventions in the sector.

- **Draft of the National Water and Wastewater Strategy (2024-2029):** Additionally, the draft version of the National Water and Wastewater Strategy (2024-2029) was reviewed. This draft document offered insights into future priorities and policy directions, including potential changes to wastewater treatment and reuse practices.

2. Interview relevant stakeholders

In order to achieve objective 1,2,3 and 4 semi-structured interviews with key stakeholders, the main stakeholders involved included representatives from Palestinian Water Authority, Ministry of Agricultural, West Bank Water Department, local authorities (municipalities) and Joint Service Council for Water and Wastewater/ North Hebron (JSC).

The interviews were conducted face-to-face with stakeholders after describing the subject of the study and clarifying the purpose of the interview, providing a direct approach to understanding the perspectives and experiences of the stakeholders.
A set of questions was developed for each stakeholder, with consideration given to the specific roles and responsibilities of the individuals involved. These questions were designed to collect qualitative and quantitative data about water availability, wastewater management practices and existing challenge related to transboundary wastewater issue.
Eleven face-to-face interviews were carried out with stakeholders. Notes and responses were recorded, with all interviews conducted in Arabic and later translated into English, Table 1 presents the respondent lest and position of each.

Table 1:List of interviewees and their position

Organization	Position
Palestinian Water Authority	Respondent 1
Palestinian Ministry of Agriculture	Respondent 2
West Bank Water Department	Respondent 3
Joint Service Council for Water and Wastewater	Respondent 4
Nuba Municipality	Respondent 5 Respondent 6
Kharas Municipality	Respondent 8 Respondent 9
Beit-Ula Municipality	Respondent 10 Respondent 11

3. Roundtable Discussion

As part of objective 2 a roundtable discussion was organized in Kharas municipality hall with 12 farmers who own land around Kharas Wastewater Treatment Plant (WWTP) with the presence of Kharas Mayor to gather ideas in order to understand their point of view regarding the current wastewater problem and explore their willing to use treated water for irrigation purposes as alternative water source.
The roundtable aimed to:

- **Understand the Perceptions of Farmers**: Farmers were asked about their current experiences with water scarcity and how it affect their agricultural production.

- **Explore Willingness to Use Treated Water**: Discussions focused on the potential benefits and challenges of using treated water for irrigation.

- **Address Concerns**: Farmers expressed concerns related to water quality, potential health risks, and the impact of treated water on soil and crops. These concerns were documented to guide future policy recommendations.

The roundtable discussions were designed to gather qualitative data from farmers and provide a direct understanding of their willingness and concerns regarding reuse treated water for irrigation (The full minutes of meeting (MOM) and Attendance Sheet can be found in Appendix A).

3.3.2 Quantitative Data:

1. Water Supply and Consumption Data:

To support Objective 1 and Objective 2, quantitative data were collected from local service providers, including:

- Purchased Water Quantities (2019–2024) for Kharas, Nuba, and Beit-Ula (Table 2)
- Actual Water Volumes Delivered to Citizens during the same period (Table 3)

Table 2: Purchased water quantities (m3 /year)

	2019	2020	2021	2022	2023	2024
Kharas						
Nuba						
Beit-Ula						

Table 3: Actual volumes delivered to citizens' (m3 /year)

	2019	2020	2021	2022	2023	2024
Kharas						
Nuba						
Beit-Ula						

2. Field Observations

Site visits were made to observe untreated wastewater discharge points, existing WWTPs, and agricultural areas. Observations helped validate stakeholder claims and informed spatial analysis (Objectives 2, 4).

3. Tax Deduction Data

Data related Israel deductions from Palestinian tax revenue were collected for Palestinian Water Authority. This information is relevant to Objective 3, 4.

3.4 Data analysis

Data analysis in this study involved several key steps to derive meaningful insights and conclusions:

1. Assess water scarcity

To fulfill Objective 1, water scarcity was analyzed using two analytical approaches:

First, domestic water availability at the household level was assessed by comparing the current per capita water supply to the World Health Organization (WHO) benchmark of 100

liters per capita per day (l/c/d), which represents the minimum requirement for basic health and hygiene.

Second, a more detailed analysis was carried out using the Supply-Demand Balance Index (SDBI) to evaluate the water scarcity condition under three different water management scenarios, this approach includes two phases. Phase one starts by identifying and quantifying the Total Water Supply (TWS) in million cubic meters per year (MCM/year), the Total Water Demand (TWD) in MCM/year. The second phase employs the SDBI to assess the current domestic water scarcity in the study area.

The assessment of domestic water scarcity starts by identifying and quantifying the sources of water supply (e.g. surface water, groundwater, desalination and etc.). Accordingly, the current TWS data were collected from the service provider in the study area.

The Domestic Water Consumption Rate (DWCR) is specified considering the recommendation of WHO (Howard and Bartram, 2003). Such rates, along with the population statistics, are used to estimate the TWD. (Huang & Yin, 2017).

$$TWD_i = \frac{DWCR * POP_i * 365}{1000}$$

Where,

TWD_i is the TWD for the i^{th} year in (MCM/y)

DWCR: The domestic water consumption rate

POP_i is the population for the i^{th} year in (capita)

TWS and TWD are used to estimate the SDBI. This index is used for the assessment of domestic water scarcity.

$$SDBI_i = \frac{TWS_i}{TWD_i}$$

Where,

$SDBI_i$: supply demand balance index for the i^{th} year

TWS_i: total water supply for the i^{th} year in (MCM/y)

TWD_i: total water demand for the i^{th} year in (MCM/y)

According to (Huang and Yin, 2017), five domestic water scarcity levels are identified (Table 4).

Table 4:Domestic water scarcity values and the associated levels

SDBI level	SDBI value
Extreme water scarcity	0-0.3
Acute water scarcity	0.3-0.6
Moderate water scarcity	0.6-0.9
Slight water scarcity	0.9-1
No water scarcity	>1

2. Calculating current wastewater flow:

To achieve Objective 4, the current and potential volumes of wastewater generated in the study are Wastewater will be analyzed by calculating Q_{dry} and Q_{wet}. Flow changes between the dry season and the wet season due to many reasons, including water usage, external water infiltration into the sewer system and climate condition. In general, domestic wastewater

generation is estimated as a percentage of total water consumption, while the wet season include additional flow due to storm water infiltration and inflow (Metcalf & Eddy, 2014).

Dry Season Wastewater Flow

During the dry season, wastewater flow is primarily composed of domestic sewage, which can be estimated based on per capita water consumption and a return coefficient, the fraction of water discharged as wastewater, as follows:

$$Q_{dry} = P * C * R$$

Where:
Q_{dry} : Wastewater flow in the dry season (m^3/ day)
P: Population (inhabitants)
C: Per capita water consumption (m^3/c/d)
R: Return coefficient (0.7-0.8)

Studies have shown that wastewater return coefficients vary depending on climate, water availability, and household practices (Tchobanoglous, Burton, & Stensel, 2003). In arid and semi-arid regions like Palestine, the return coefficient is usually 0.8 (Abu-Madi, 2011).

Wet Season Wastewater Flow

In the wet season, stormwater infiltration and inflow contribute to increased wastewater flow. This additional water enters the sewage system due to surface runoff, leaking pipes, or improper drainage connections (Butler & Davies, 2010).

The wet season wastewater flow is given by:

$$Q_{wet} = Q_{dry} + Q_{infiltration}$$

Where:
Q_{wet} : Wastewater flow in the wet season (m^3/ day)
Q_{dry} : Wastewater flow in the dry season (m^3/ day)
$Q_{infiltration}$: Additional wastewater flows due to storm water inflow and infiltration (m^3/ day)

The infiltration rate typically ranges between 10-30% of the dry season flow, depending on rainfall intensity, sewer conditions, and soil permeability (Howard & Bartram, 2003). In Palestine, where rainfall is seasonal and infrastructure is aging, infiltration rates closer to 20% are commonly observed (Abu-Madi, 2011).

3. Soft-ware tools

Geographic Information System (GIS) tools through QGIS were used to support spatial analysis related to wastewater infrastructure in the study area. This tool played a key role in mapping, visualizing maps, and analyzing the existing sewer network, areas lacking service coverage.

To ensure accurate and up-to-date spatial analysis, various datasets were collected and integrated from the following sources:

- **Satellite Imagery**:

Sentinel-2 and *Landsat* satellite data were used to analyze land use, vegetation cover, and areas affected by wastewater discharge.

- **Local Government GIS Datasets**:

GIS layers provided by local authorities (such as municipalities and the Joint Service Council) and GeoMolg included information on existing sewer lines, manholes, treatment facility boundaries, and urban planning zones.

4. Analysis stakeholder input

Stakeholder input was carefully analyzed to support the achievement of Objectives 3 and 4. The analysis focused on understanding stakeholder perspectives related to water availability and transboundary challenges, helping to identify feasible and context-specific management options.

Chapter Four: Results and Discussion

This chapter presents the main findings of the study and discusses their significance in relation to the current situation of wastewater management in the study area.

4.1 The current water scarcity situation at Wadi Al-Sour catchment area.

Using the methodology outlined before to achieve **Objective 1** assess the current water scarcity situation at Wadi Al-Sour catchment area, this section presents the results of two analytical approaches. First, water availability at the household level was compared to internationally recognized benchmarks. Then, a more detailed evaluation was conducted using SDBI under three different water management scenarios.

As a first step, the domestic water availability in the study area was assessed against the WHO benchmark of 100 liters per capita per day, which represents the minimum required for basic health and hygiene.

The actual per capita supply within the catchment area villages falls below this benchmark, as shown in Figure 4.

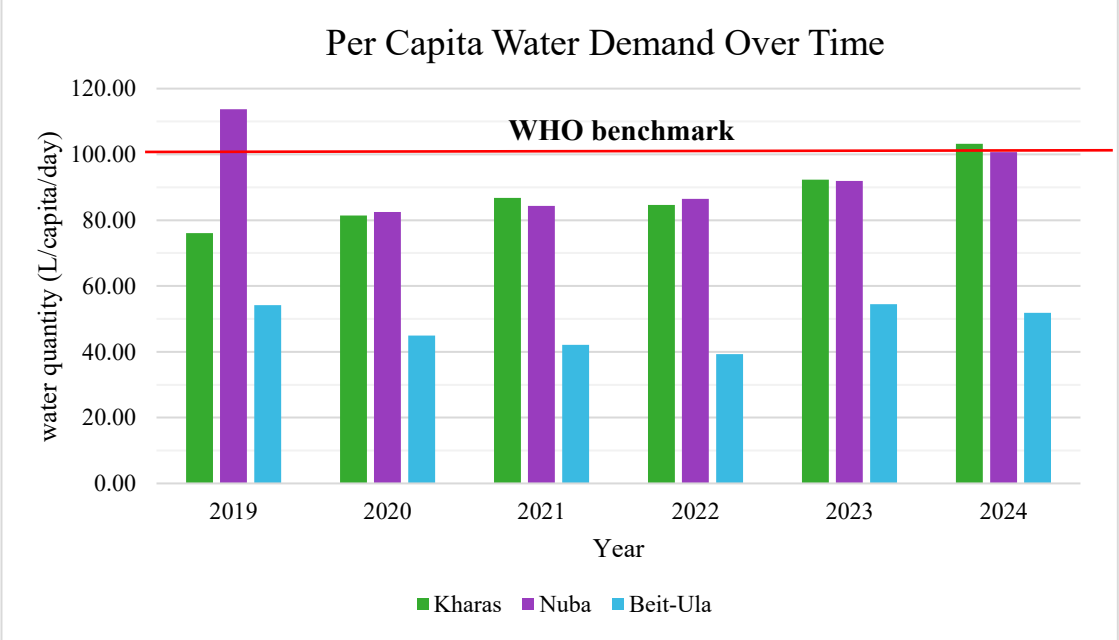


Figure 4: Per capita water demand over time

This comparison clearly highlights the gap between actual water availability and the minimum acceptable level, and reflects the real pressure on the water system even before factoring in agricultural and industrial use.

While comparing current water consumption with the WHO benchmark helps highlight the gap in meeting basic daily needs, it does not fully reflect he water scarcity situation in the area. To better assess this, the SDBI was used as a second step.

The SDBI approach enables a clear comparison between TWS and TWD, helping to quantify the severity of domestic water scarcity over time. This analysis builds on real-world data collected from local institutions including population Figures, water purchase and delivery quantities under three different management scenarios.

The following data supports the analysis and helps clarify the assumptions used in the assessment through the different scenarios:

- The annual supply water quantities for each village within Wadi Al-Sour catchment from 2019 to 2024. These values used in calculating water losses (Non-Revenue Water 'NRW') (Table 5).

  Table 5: Supply water quantities (m3 /year)

Village name	Supply water quantities (m3 /year)					
	2019	2020	2021	2022	2023	2024
Kharas	533134	484506	593269	536848	590380	581973
Nuba	277665	291224	284915	303286	275389	295684
Beit-Ula	480211	422103	547817	503567	537262	600406
Sum	1291010	1197833	1426001	1343701	1403031	1478063

- The actual delivered volumes to citizens (billed water), for each village within Wadi Al-Sour catchment from 2019 to 2024. The summation of these values represents the total volume of water procured by service providers and form the initial input for estimating the TWS (Table 6).

  Table 6:Billed water quantities 'Actual volumes delivered to citizens' (m3 /year)

Village name	Actual volumes delivered to citizens (m3 /year)					
	2019	2020	2021	2022	2023	2024
Kharas	265315	291240	318381	318384	356263	407933
Nuba	244351	181778	190602	200501	218472	245331
Beit-Ula	300183	255807	246078	235459	334213	325996
Sum	809849	728825	755061	754344	908948	979260

- The NRW percentages, calculated through the difference between purchased and billed water, this percentage used within the different management scenarios to reflecting current situation (Table 7).

Table 7: Non-Revenue percentage were calculated based on purchased water quantities and actual volumes delivered to citizens

Village name	Non-Revenue percentage				
	2020	2021	2022	2023	2024
Kharas	40%	46%	41%	40%	30%
Nuba	38%	33%	34%	21%	17%
Beit-Ula	39%	55%	53%	38%	46%

- The population data, essential for estimating TWD using the DWCR recommended by the WHO (100 l/capita/day) (Table 8).

Table 8: Population growth (PCBS)

Village name	Population growth				
	2020	2021	2022	2023	2024
Kharas	9798	10051	10308	10568	10832
Nuba	6037	6193	6351	6512	6674
Beit-Ula	15586	15988	16396	16810	17230
Sum	31421	32232	33055	33890	34736

Scenario 1: Adjusted Domestic Water Quantity by Estimated Agricultural Water with Actual Non-Revenue Water

In this scenario, the estimated agricultural water consumption (based on the assumed crop water requirement and cultivated area) is subtracted from the total available water to isolate the portion allocated for domestic use. The actual NRW rate, as calculated for the study area, is then applied to reflect existing network losses.

This approach provides a more realistic representation of the current situation, where a portion of the water officially categorized as “domestic” is actually being used for agricultural purposes. As a result, the scenario highlights the true extent of domestic water scarcity.

The study area is considered as the food basket for Hebron governorate. Based on Palestinian ministry of Agriculture (MOA) reports in 2024, Farmers plant different crops and trees, with total agricultural land currently covering a total area of about 15,268 dunams within this area 2958 dunams plant with irrigated vegetables like: tomato, cucumber, squash, okra, faba bean and lettuce, 4000 dunams of rainfed plants and 8310 dunams are planted with tress, half of them are olive trees. Large percent of these lands are around Kharas wastewater treatment plant. In addition to 517 dunams of forest land most of them are governmental owned lands. These data were collected through personal communication with the Ministry of Agriculture (MOA, personal communication, 2025).

For analyses purpose it was assumed that the water need for each dunams of the irrigated vegetables lands is 700 m3/year. As there is no water for agricultural use in the study area farmers tend to use the domestic water to provide the water needs for their farms.

Based on the data collected from the MOA, the total water needed for crops irrigation in the study area is about 4,870,600 m^3 per year. This is more than twice the total amount of water currently supplied to the entire area each year for all uses, including both domestic and agricultural needs.

To better visualize this imbalance, Figure 5 presents a comparison between the estimated agricultural water demand and the current water supply in the study area.

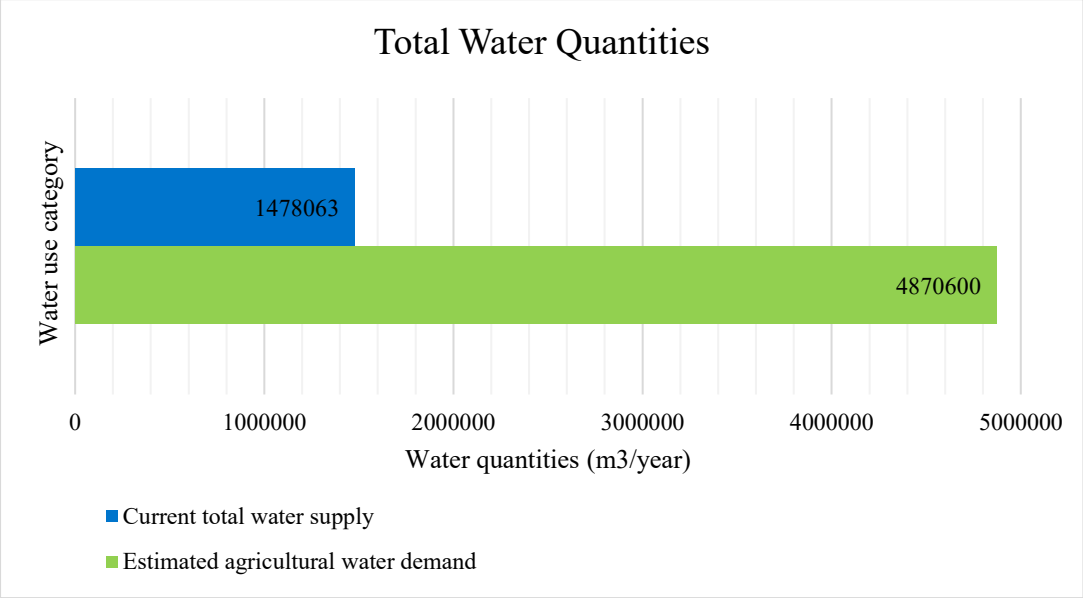


Figure 5: Water quantities comparison

This figure raises concerns about the accuracy and reliability of the agricultural data, particularly since there is no dedicated water source for irrigation in the study area.

The reported irrigated land areas, and consequently the calculated water needs, is overestimated and not aligned with the current available water quantities. This overestimation introduces a critical error into the analysis. Since Scenario 1 relies on an accurate understanding of the existing domestic water quantities — through subtract water used for irrigation from total purchased water quantities —the presence of such questionable data undermines the scenario's validity. So, Scenario 1 could not be implemented as planned.

Scenario 2: All Water Considered Domestic with actual Non-Revenue Water

This scenario assumes that the entire water supply is allocated exclusively for domestic use, with no water consumption attributed to agriculture. The actual NRW rate, as calculated is applied. By excluding agricultural consumption, the scenario reflects a condition in which agriculture is fully supported by non-conventional water resources, such as treated water. This allows for assessing how domestic water availability could improve if alternative water sources were effectively utilized for irrigation.

Under scenario 2 condition (Table 9) present the calculated annual values of TWS and TWD in million cubic meters (MCM/year), along with the calculated SDBI. These values are derived from the data calculations detailed in the Appendix B.

Table 9: The Values of TWS, TWD and SDBI under scenario 2 condition

Year	2019	2020	2021	2022	2023	2024
TWS	0.81	0.73	0.76	0.75	0.91	0.98
TWD	1.12	1.15	1.18	1.21	1.24	1.27
SDBI	0.72	0.64	0.64	0.63	0.73	0.77

The results of the scenario show increase in domestic water availability between 2019 and 2024, with total domestic supply increasing from approximately 0.81 million m^3 in 2019 to 0.98 million m^3 in 2024. This was reflected in increasing per capita water availability, rising from 72.4 liters per person per day to 77.2 liters per person per day during the same period.

However, despite this improvement, the SDBI was below 0.9 for all years, ranging between 0.63 for 2022 and 0.77 for 2024, which indicate that the area is suffering from moderate water scarcity.

The results of scenario 2 show that using all available water for domestic purposes slightly improves water availability. Per capita supply increased over the years, and the total domestic supply reached its highest level in 2024. However, the SDBI values stayed below 0.8, which means the area still suffers from moderate water scarcity. This confirms that removing agriculture from the equation alone is not enough. The main problem remains the high losses in the water network. Even when agriculture shifts to non-conventional sources like treated wastewater.

To conclude, this scenario highlights two important points. First, shifting agricultural use to non-conventional water source can help improve domestic water availability. Second, solving the water scarcity issue depends significantly on reducing water losses through better management practices and improved infrastructure, making them essential components of any sustainable water management strategy.

Scenario 3: All Water Considered Domestic with Reduced Non-Revenue Water to the World Bank Standard (<25%)

This scenario presents the case at which all available water is dedicated to domestic use, similar to Scenario 2, but under improved management conditions where NRW is reduced to 20%, in line with the World Bank's recommendation of maintaining NRW below 25%. This scenario reflects a realistic and achievable goal for service improvement and allows for assessing how much better water availability could be if water losses were effectively minimized.

Under these improved conditions, the total volume of water delivered to citizens increases significantly (Table 10). These values were estimated by adjusting the actual supply using the assumed reduction in NRW.

Table 10: Water quantities through years under scenario 3 conditions (L/capita/day)

Village name	Water quantities through years (L/capita/day)					
	2019	2020	2021	2022	2023	2024
Kharas	122.37	108.38	129.37	114.15	122.44	117.76
Nuba	103.43	105.73	100.84	104.67	92.69	97.10
Beit-Ula	69.29	59.36	75.10	67.32	70.05	76.38

Figure 6 shows a comparison between average supplied water quantity in Scenario 3 to Scenario 2 which marks substantial improvement.

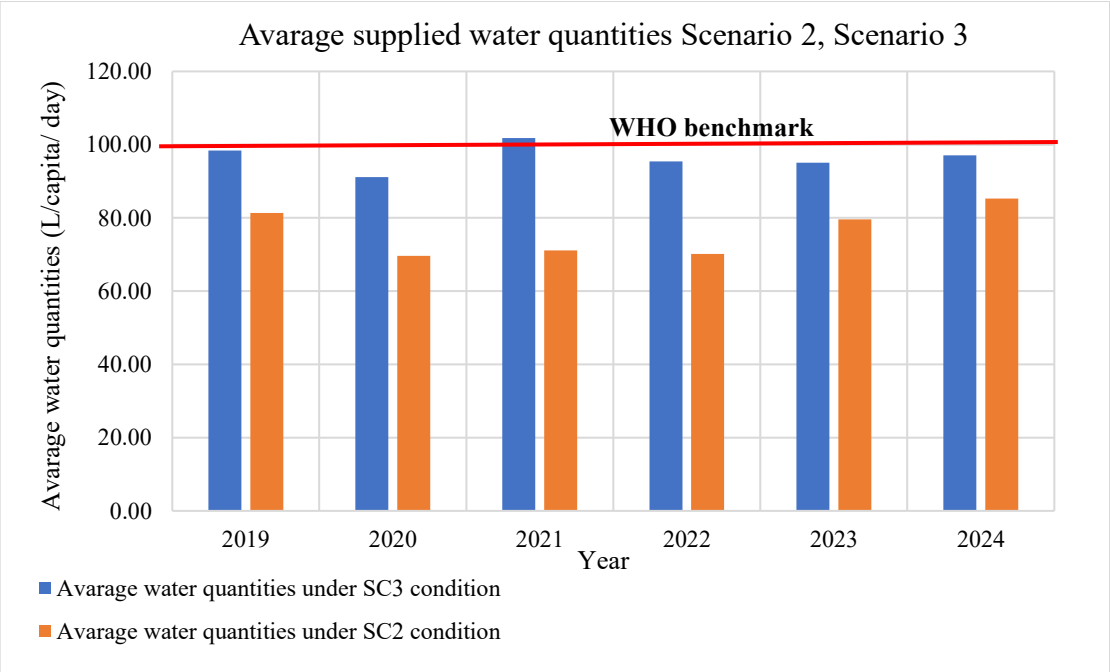


Figure 6: Average supplied water quantities under Scenario 2, Scenario 3

The calculated annual TWS, TWD and the corresponding SDBI from 2019 to 2024 (Table 11).

Table 11: The Values of TWS, TWD and SDBI under scenario 3 condition

Year	2019	2020	2021	2022	2023	2024
TWS	1.03	0.96	1.14	1.07	1.12	1.18
TWD	1.15	1.15	1.18	1.21	1.24	1.27
SDBI	0.9	0.84	0.97	0.98	0.91	0.93

The results show clear improvement in water availability for domestic use. For example, in 2021, the SDBI reached 0.97, suggesting a nearly balanced supply and demand condition. Even in the other years, the index remained above 0.84, reflecting a shift from moderate to slight water scarcity. Compared to the previous scenarios, especially scenario 1 and scenario 2, these values represent the best outcome for domestic water security.

The results from both the benchmark comparison and the SDBI analysis confirm that Wadi Al-Sour catchment area faces a clear water scarcity problem, even when only domestic needs are considered. Per capita supply remains below the WHO minimum, and the SDBI values across all scenarios point to moderate to slight water scarcity. This reflects the challenges of managing water resources effectively, especially since the available water quantities data is classified as domestic water, but actually its used for all uses (domestic, agricultural, industrial ..), which means that the situation on the ground is worse. As a result, the real pressure on the system is greater than what the numbers suggest, and the actual level of water scarcity is likely more severe than the index reflects.

Although the SDBI provides a simple way of assessing the domestic water scarcity by estimating the ratio of the water supply to the water demand and has single value that characterizes the water scarcity level on a scale ranging from "extreme" to "no" water shortage. Its accuracy depends heavily on the quality and clarity of the input data. In contexts like the study area (where data overlaps between sectors and inaccurate) SDBI should be applied carefully and supported by more detailed, disaggregated assessments to better reflect the real conditions on the ground.

To improve water scarcity in the area, efforts should focus on reducing NRW by upgrading water infrastructure and improving management practices in addition to support the using of non-conventional water resource to reduce the pressure on fresh water resource in order to achieve more sustainable water balance.

4.2 The existing wastewater management practices in Wadi Al-Sour catchment area

As a result of objective **2** to evaluate the existing wastewater practices in Wadi Al-Sour catchment in order to understand the extent and severity of the wastewater problem a comprehensive assessment was carried out for the current system capacity. This included reviewing technical surveys of sewer networks and wastewater treatment plants, evaluation of plant capacity and performance and data collection on untreated wastewater discharge.

The study area suffers from lack in wastewater infrastructure; Kharas have partially sewer network (30% coverage percentage) with a wastewater treatment plant, Nuba have a partially collection system (40% coverage percentage) without any treatment. Other areas depend on cesspit tanks which are a multi-pollution source; wastewater either emptied with vacuum tankers and discharged raw sewage over land and into wadis (seasonal dry streams), generally the cesspits are unlined, allowing sewage to leak and pollute the groundwater.

There is one treatment plant in Wadi AL-Sour catchment (Kharas Wastewater Treatment Plant) which treats the wastewater collected by Kharas sewer network.

The designed capacity for the WWTP is 500 m^3/day, while the current inflow is about 250 m^3/day during peak period, it uses Activated sludge technology.

Effluent quality from the wastewater treatment plants was evaluated by measuring key parameters, including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and pathogen levels (e.g., coliform bacteria). According to data provided by the treatment plant management, the results align positively

with the Palestinian Standards Institution (PSI) specifications for treated wastewater intended for agricultural use.

In addition, poor sludge management practices were noted, with sludge either accumulating on-site without proper disposal or being discharged into the environment, further reducing the overall efficiency of the system.

The treated water is currently not used. Farmers around the Wastewater treatment plant are in the process of obtaining the necessary permissions for using the treated water for irrigation uses, in parallel they are working on establishing treated water user association to regulate the reuse process.

However, they are facing several challenges, one major issue is the seasonal variations of treated water quality, the plant's performance, with reduced treatment efficiency during peak inflows or extreme weather conditions.

Additionally, the high cost of treated water; currently, the cost of treating 1 m^3 of wastewater is more than 7 NIS, while the price of fresh water is about 5 NIS/m^3 this is economically insufficient. This high cost is largely due to the absence of an optimized operational plan for the treatment plant, which could help reduce treatment expenses. (JSC, 2024)

It's important to improve operational and maintenance program to reduce the cost of treating wastewater and to ensure achieve the targeted quality level in order to reuse the treated water for irrigation purpose.

Moreover, the problem of the effluent of Nuba Sewer network which flow through the natural valley reaching the outlet of Kharas wastewater treatment plant and hence mixes with the treated water (Figure 7), this not only re-pollutes the treated water but also continues downstream, harming the environment and damaging the surround agricultural lands.

The discharge of untreated wastewater causes several problems:

- **Polluting the ecosystem**: The continuous discharge of untreated or partially treated wastewater harming the whole ecosystem including; water, soil and also affects the biodiversity within the area. Natural vegetation and animals are exposed to harmful pollutants, such as, nitrogen and phosphorus, which can lead to issues like algae blooms. It reduces the environmental quality and makes it harder to restore. The pollution also leaks into surrounding agricultural lands, affecting the soil health, crop productivity, and potentially contaminating the food chain.

- **Public Health**: At Wadi Al-Sour the wastewater flow freely in the open valleys near agricultural lands which will cause a health hazard when people especially children and farmers contact with polluted water which increase the risk of waterborne diseases such as diarrhea, hepatitis A, cholera, and skin infections. Moreover, if the wastewater reaches groundwater sources or mixed with irrigation water this will affect the drinking water

quality and food safety.

- **Transboundary issue**: Wadi Al-Sour is a transboundary catchment between Palestine and Israel, which makes the issue not just local, but political and regional. When untreated wastewater flows downstream across the Green Line, it becomes a cross-

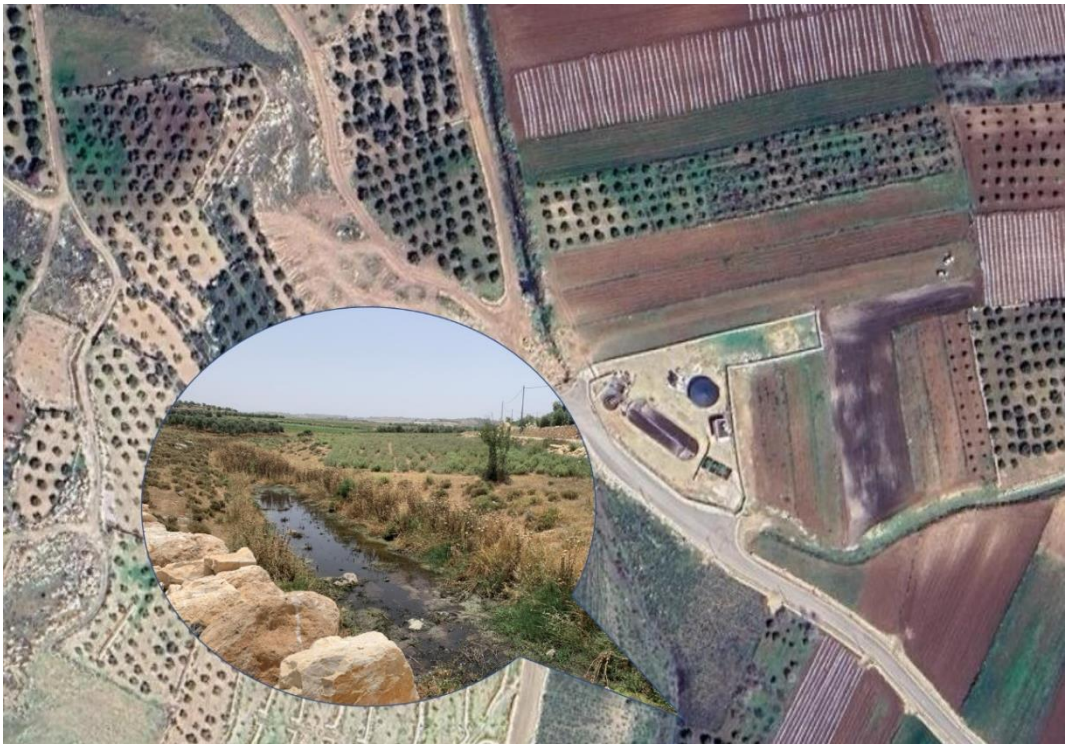


Figure 7: Wastewater from Nuba reaching Kharas WWTP effluent

border pollution source. This can lead to tension, especially since water rights and responsibilities are already sensitive topics.

Despite these limitations, reusing the treated water is a significant opportunity to strengthen water scarcity resilience in the catchment. Through the reuse treated water for irrigation the demand on freshwater resources can be reduced, this can help mitigate the impact of climate change on environment and ensure sustainable for future generations.

4.2.1 Willing to use non-conventional water resources:

Building on the insights mentioned above, a roundtable discussion was conducted with key stakeholders (primarily farmers) to assess their acceptance and willingness to use treated wastewater for irrigation purposes, as outlined below:

Farmers willing to use the treated water:

As part of this study, a roundtable discussion was conducted with farmers in Wadi Al-Sour study area to better understand their needs, views and wiling to use treated water for irrigation. The aim was to gather direct input from those most affected by water scarcity and to explore local acceptance of treated water reuse as a potential solution.

The roundtable discussion was carried out in two main steps. As shown in Figure 8a, the first step involved large group discussion, bringing together 11 farmers who have lands

around Kharas wastewater treatment plant introduces them to the study objectives, current water scarcity and the expected transboundary issue in the area. This session served as the base for understanding the community's overall interest in using treated water for irrigation. When the farmers were asked about the possibility of using treated water for irrigation they showed a strong interest in the idea, which was supported by the majority of participants. The respondents explain that ‘*’agriculture is the main source of income, but farmers suffer from water shortage in light of the fact that there is no agricultural water supply in the study area*’’ As a result, many farmers are using part of their domestic water for irrigation, and some of them have land they wish to farm but cannot due to the lack of water.

Figure 7.a: Main roundtable session with farmers discussing water reuse opportunities and challenges.

Following the roundtable, more focused individual and small group discussions were held (Figure 8.b) to deepen the conversation and collect specific insights. These meetings helped clarify initial responses, address questions in more detail, and create a comfortable space for participants to express concerns that might not have come out in the larger group.

Figure 8.b: Follow-up discussions to explore individual farmer views and specific barriers.

During the roundtable discussion, the farmers were asked about their expectations if treated water became available in larger quantities. In response, they clearly requested an increase in the supply of treated water, believing that this would enable them to irrigate their land more effectively and expand their agricultural activities. Several farmers explained that ‘’*with a reliable and consistent source of treated water, they could return to farming lands that have been abandoned due to water scarcity’’.* Some of them even mentioned specific crops they would like to grow if irrigation became possible again.

The farmers also discussed the possibility of purchasing treated water, and most of them agreed that this would be acceptable, as long as the cost remained reasonable and aligned with their financial capabilities. This shows that the community is not only open to alternative water sources, but also willing to contribute financially if it helps improve their livelihoods. This kind of attitude reflects a strong local commitment to finding solutions to water shortages and reducing dependence on uncertain water sources.

In the other hand, the farmers shared concerns about the political and legal challenges they face, especially because most of the agricultural land in the study area falls within Area "C." This area is under Israeli administrative control, which makes it very difficult to obtain permits for new infrastructure, including pipes, tanks, or irrigation systems for treated water. And they discuss the future restriction that they may face if the transboundary wastewater situation developed. These restrictions will limit the farmers’ ability to benefit from treated water and might prevent them from reach their lands which will directly affect them in interconnected perspective.

To address potential challenges in managing access to treated water fairly among farmers, the idea of establishing a Water Users Association (WUA) was proposed and welcomed by many participants. They saw this as a way to organize water distribution, monitor usage, and avoid conflicts, especially in times of shortage. A local WUA could also represent farmers in discussions with service providers and authorities, giving them a stronger voice in decision-making related to water.

In addition, farmers expressed interest in learning more about how to use treated wastewater safely and effectively. They said they are ready to participate in training

programs that cover proper irrigation methods, crop selection, soil management, and potential health and environmental risks. This reflects a clear interest in building their knowledge and ensuring that the reuse of treated water is done in a way that is safe and sustainable.

Overall, this discussion provided important insights into the views and readiness of farmers to adopt treated wastewater for agriculture. Their strong interest, combined with their willingness to contribute and cooperate, confirms that reuse is not only acceptable but necessary in the context of ongoing water scarcity. However, the transboundary nature of water control in the area remains a key challenge, and addressing it will be essential to turning local interest into real, long-term impact.

4.3 Transboundary wastewater issue

To address **Objective 3** analyzing the financial implications of transboundary wastewater flows, this section focuses on the current deductions Israel imposes on Palestinian tax revenues for wastewater treatment.

Oslo II Stressed the need for wastewater treatment to protect shared water resources, both parties are required to develop proper wastewater treatment facilities to prevent pollution of shared water resources, but does not mention any regulation or details on the mechanism of dealing with transboundary wastewater issues (Palestinian and Israeli fall to develop the WW protocols up to date of writing this manuscript, PWA personal communication, 2025)

In 2011 Israel deduct 51.1 million Shekel from the Palestinian tax revenue, which is collected by Israel, before transferring to the Palestinian Ministry of Finance under the principle of polluter pay principle (PPP).

This amount was deducted under the title of covering the costs of treating wastewater, this figure has been steadily increasing each year until it reaches 139 million Shekel in 2024. (PWA,2025)

Until 2018 Israeli side does not provide the Palestinian side with any invoice for this deduction, in response to international actors pressure and Palestinian request Israel start to send sheets that contains the transboundary wastewater location, wastewater quantitates and the cost.

Figure 9 illustrates the transboundary wastewater location for which Israel deducts money from Palestinian tax revenues as treatment costs. The map also shows the names of the Israeli wastewater treatment plants (WWTPs) that receive and treat this wastewater. Each treatment plant is operated by a different company, as wastewater treatment in Israel is typically managed by various private or semi-private operators. The Israeli government keeps track

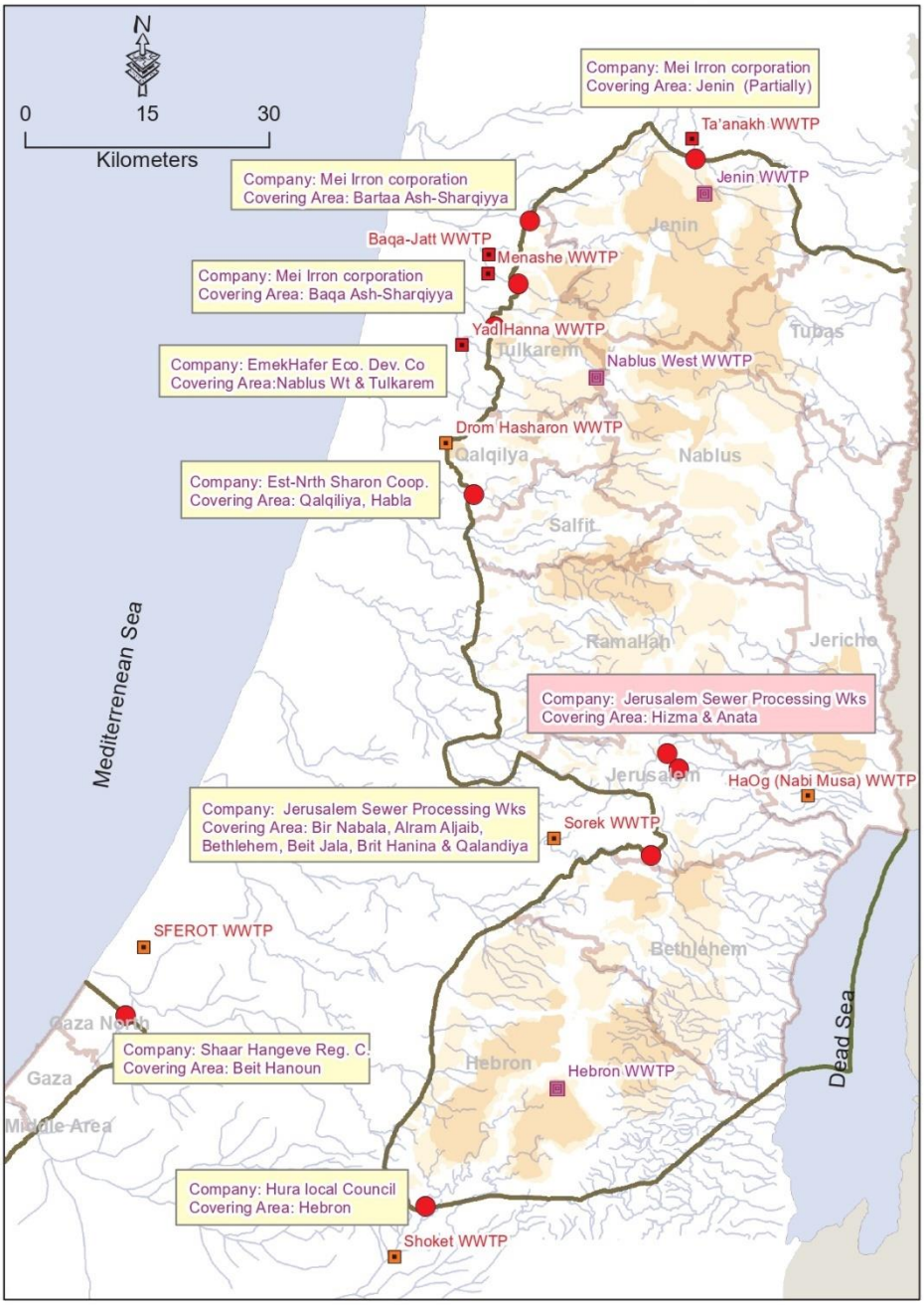


Figure 8: Current transboundary wastewater points for which Israel deduct money from Palestinian tax revenue

of the treatment costs reported by each company and uses this information to calculate the amount deducted from Palestinian tax.

Though the Palestinian Authority accept the PPP, the mechanism is contested for many reasons. First, after Palestinian request and international actors pressure Israel start sending sheets (called invoices) in irregular manner to the Palestinian Authority presenting the deducted amounts of money, without breakdown analysis, some invoices specify the quantities of discharged wastewater without showing the calculation methodology, while others outline costs without correlating them with treated wastewater volumes.

Secondly, no agreement or accord between the two sides address the transboundary wastewater issue or clearly defines a mechanism for dealing with it.

Key missed elements in the provided invoices which is written in Hebrew language only:

- The amount of treated wastewater listed on some invoices in some cases exceeding the total water consumption for drinking purposes, this indicate that these quantities might be estimated rather than actual measured, Palestinian side dose not participate in estimating the wastewater flow quantity.

- There is a strong possibility that wastewater from Israeli colonies is included in the calculated volumes, as seen in areas like Ramallah, Bethlehem, and Hebron.

- The treatment fees are very high, and with no clarification about how its calculated (level of treatment, maintenance and operation, facility development, others).

- Treatment fees have been raised year after year without justification or a clear basis.

- Large amounts are deducted for development purposes. In time that they are detecting high treatment costs, this results in double deductions

The following chart (Figure10) shows the deductions amount in Million NIS in yearly base, which shows a yearly increasing in the deduction amount. (Personal communication, 2025)

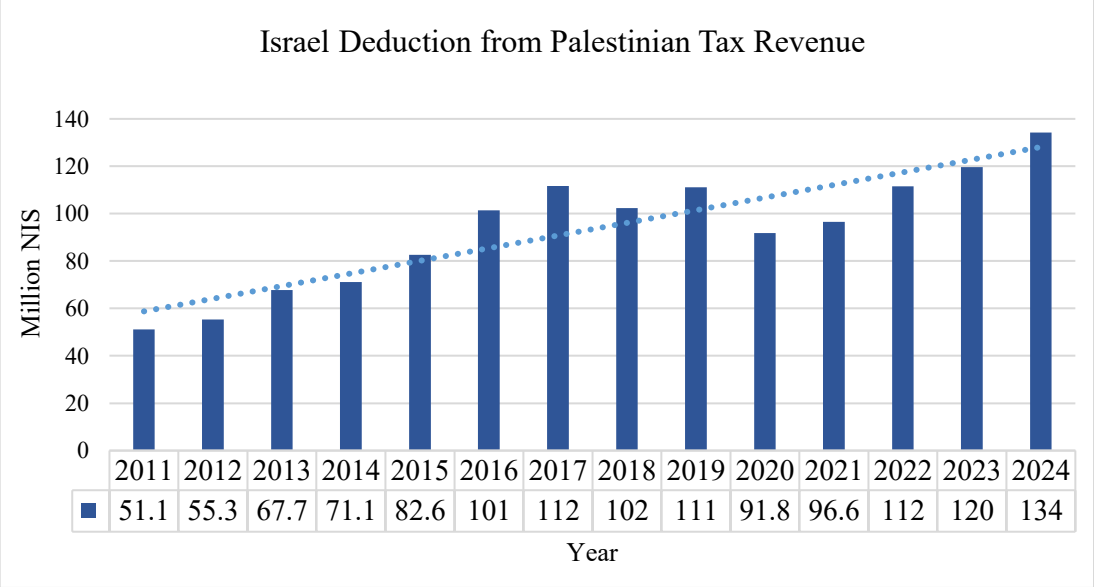


Figure 9:Amount of money Israel deduct related to transboundary wastewater issue

Thirdly, Palestinian pay for the cost of treatment but don't share in the benefits; The treated water is reused for agricultural in Israel, but Palestinians do not receive any quantities of the treated water or benefit from it.

The financial implications of transboundary wastewater flows remain a major concern for the Palestinian side. Without an official framework and clear regulations and precise information about quantities and qualities it becomes difficult to ensure actual costs for wastewater treatment.

4.4 Estimating Current and Future Wastewater Contributions to Wadi Al-Sour Catchment

This section presents an analysis of generated wastewater quantities that contributede to Wadi al-Sour, in order to support the development of appropriate management scenarios under Objective 4. The calculations focus on the current and future wastewater flow toward Wadi al-Sour. As wastewater from Kharas, Nuba and additional future villages will flow, reaching this transboundary catchment. **Q_{dry}** and **Q_{wet}** have been calculated to estimate typical wastewater flow; extreme conditions such as heavy rainfall or other extreme weather events were not included.

4.4.1 Current Contribution to Wadi al-Sour:

Currently, the wastewater flow in Wadi Al-Sour is primary from Kharas wastewater treatment plant, effluent of Nuba sewer network, and wastewater from Beit-Ula mainly through tankers. Figure 11 illustrates the flow paths and contributed villages.

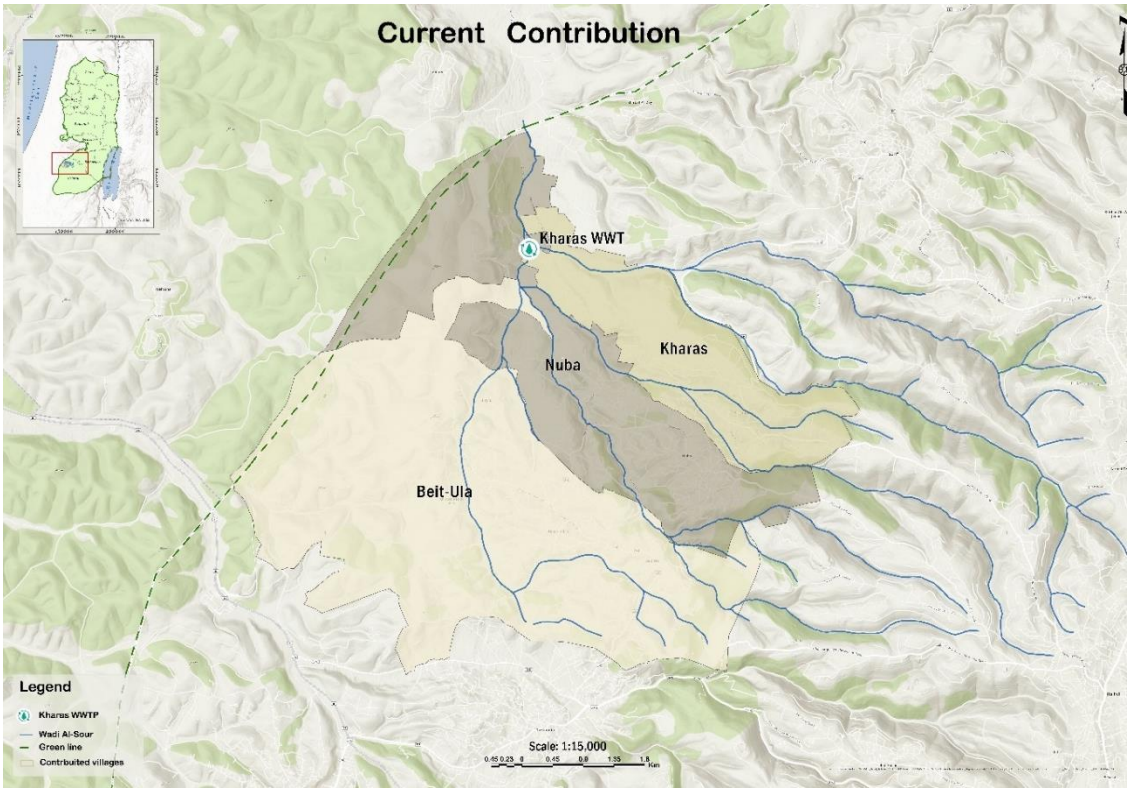


Figure 10:Current wastewater flow in Wadi Al-Sour

The estimated annual generated wastewater currently in Wadi Al-Sour catchment (Table 12):

Table 12: Estimated annual generated wastewater currently in Wadi Al-Sour catchment:

Village name	Population 2025	contribution ratio	Generated wastewater (Q_{dry}) (m^3/day)
Kharas	11100	100%	266
Nuba	8242	100%	264
Beit-Ula	17656	20%	282
Total			**812**

The wastewater calculations are based on an average generation rate of approximately 100 liters per capita per day (0.1 m³/day), adjusted by the contribution ratio reflecting actual network coverage and discharge behaviors.

It's important to note that all wastewater generated in the catchment area currently converges toward the Kharas Wastewater Treatment Plant (WWTP). However, the WWTP's treatment capacity is only 500 m³/day (approximately 182,500 m³/year) under full operation. Which will lead to critical imbalance between flow and capacity.

By comparison, the total wastewater generated in 2025 (~296,380 m³/year) already exceeds the plant's capacity by about 62%. This imbalance results in (Figure 12):

- Only Kharas wastewater (~97,090 m³/year) being fully or partially treated at the WWTP.
- Wastewater from Nuba and Beit Ula (~172,290 m³/year) largely bypassing treatment, mixing with the treated effluent, and ultimately flowing untreated into Wadi Al-Sour.

This situation causes recontamination of the treated effluent, undermining the environmental benefit of the WWTP. Moreover, untreated or partially treated wastewater continues to flow across the Green Line into Israeli territory, escalating the transboundary wastewater conflict and posing legal, environmental, and financial risks for Palestinian authorities.

If no action is taken, the wastewater problem will not only worsen locally but will also increase Israeli financial deductions from Palestinian tax revenues.

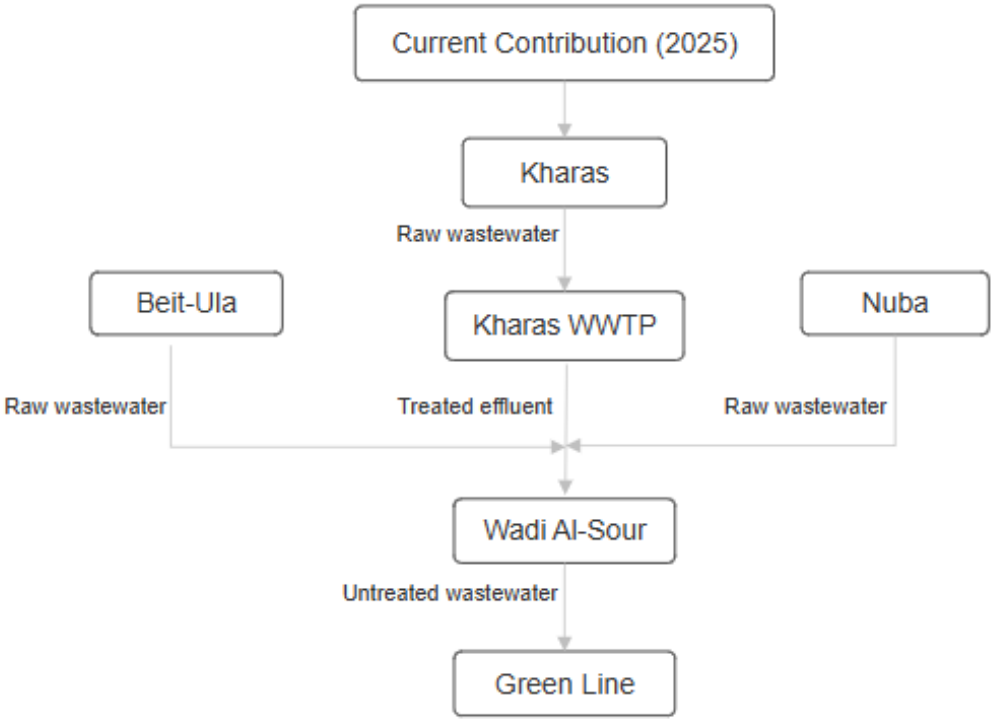


Figure 11:Current Wastewater contribution in Wadi Al-Sour

4.4.2 Future Contribution to Wadi al-Sour (2045 projection):

Future wastewater flows are estimated according to the **Palestinian Water Authority (PWA) Strategy** goals:

By 2045, about 75% of the catchment is expected to be connected to the sewer network. If the wastewater treatment plant isn't upgraded and expanded, most of the wastewater will end up crossing the Green Line untreated. The future contribution of wastewater in this catchment originates from six villages, using Digital Elevation Model (DEM) analysis in QGIS, the projected contributing localities include:

- **Full contribution**: Kharas, Nuba, Beit Ula
- **Partial contribution**: Halhul (20%), Beit Ummar (20%), Sourif (3%)

Figure 13 shows the projected wastewater flow distribution by 2045.

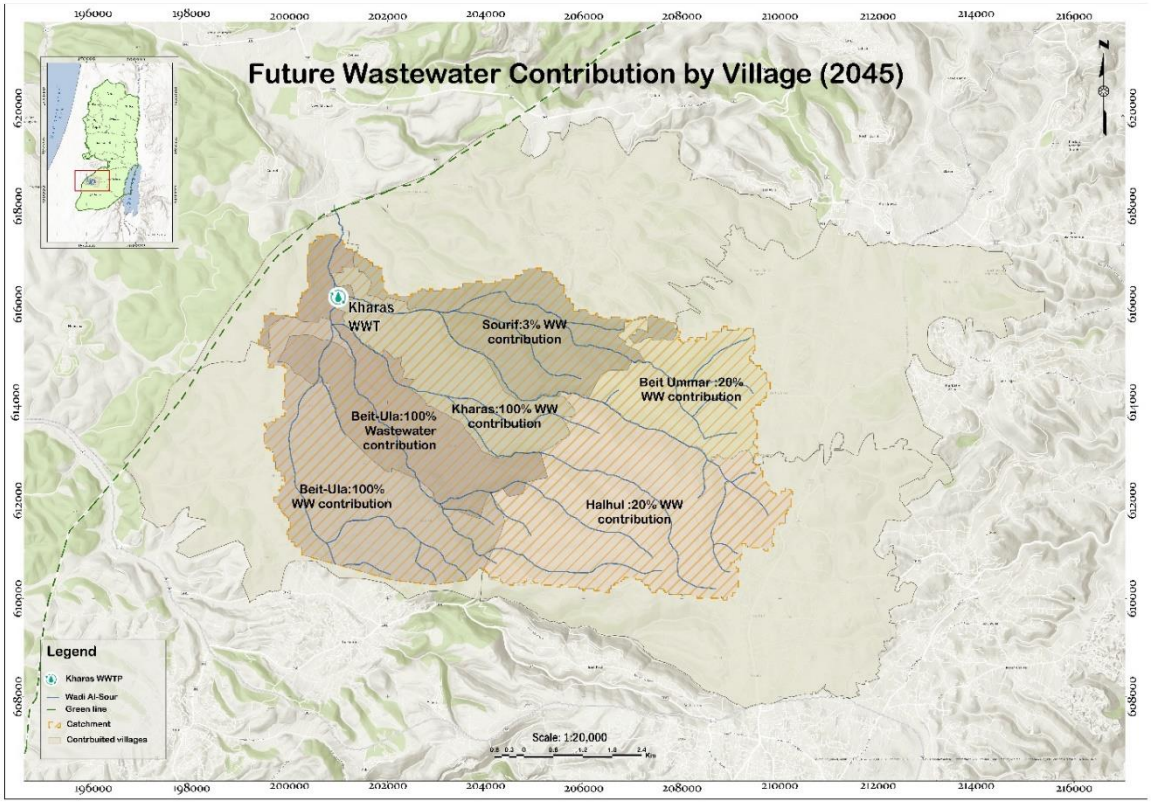


Figure 12: Future wastewater contribution in Wadi Al-Sour

The expected wastewater generation quantities in 2045 using population growth projections and standard generation rates (Table 13):

Table 13:expected wastewater generation quantities in 2045 using population growth projections and standard generation rates

Village name	Population 2045	Coverage ratio	contribution ratio	Generated wastewater (Q_{dry}) (m^3/day)
Kharas	17269	75%	100%	1036
Nuba	12822	75%	100%	769
Beit-Ula	27468	75%	100%	1648
Beit-Ummar	32781	75%	20%	524
Halhul	51075	75%	20%	817
Sourif	32663	75%	3%	78
Total				**4872**

The following chart (Figure 14) shows the steady increase in generated wastewater volumes each year, reaching approximately 1.78 million cubic meters per year during dry weather by 2045.

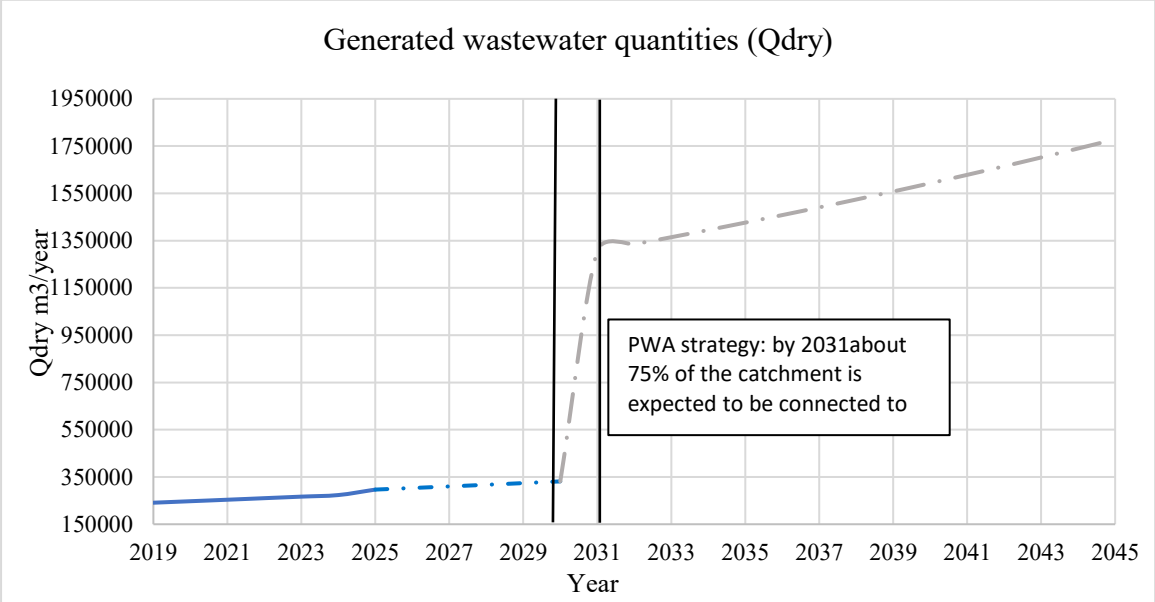


Figure 13:The steady increase in generated wastewater volumes each year

In wet condition, the flow in Wadi Al-Sour is expected to increase, reaching 2.13 MCM/year (Q_{Wet}) by 20245 This increase is mainly due to rainwater that mixed with the generated wastewater that flow in the open valley. This will put extra pressure in the urgency of solving the problem.

The results in this section indicate that wastewater volumes in Wadi Al-Sour are expected to increase significantly by 2045, with much of the flow potentially crossing the Green Line untreated if no intervention is made. These findings highlight the urgent need to assess and compare practical wastewater management strategies to prevent environmental degradation and reduce financial burdens from potential Israeli deductions. The following section presents and evaluates multiple transboundary wastewater management scenarios.

4.5 Explore different wastewater management scenarios

Wadi Al-Sour presents a developing transboundary wastewater challenge, where Israel has not yet initiated financial deductions for wastewater flows; however, such deductions are expected in the near future, posing significant financial and political implications for Palestinian communities. This issue must be addressed proactively to prevent unfair financial deductions, protect Palestinian water sovereignty and ensure environmental sustainability.

Wadi Al-Sour case study presents a critical challenge and could be used as a measurement tool for other cases in Palestine. However, it's important to note that each transboundary catchment has its own condition (environmental, technical, social ...) that must be taken into consideration to address fit solutions. There is no single best solution that fits all cases. Instead, solutions will need to be chosen in light of the specific conditions of each case.

All proposed solutions fall under the umbrella of the following three management scenarios, which emphasize Palestinian priorities, rights, and challenges, while taking into account environmental sustainability, as well as political and social considerations.

Scenario 0: Status Quo – No Palestinian Action

This Scenarios present the case in which Palestine does not take immediate action, and untreated wastewater continues to flow into Israel through Wadi Al-Sour and the amount increases year by year. And Israel starts deducting money and implement its own wastewater strategy, ignoring Palestinian needs.

- **Environmental Impact:** The continuous discharge of untreated wastewater into natural valleys causes serious environmental problems. This wastewater contains pollutants like nitrates, ammonia, pathogens, and heavy metals, which can seep into the soil and reach groundwater, threatening its quality. The ecosystem of the wadis is also affected, as the high levels of organic matter, suspended solids, and harmful bacteria lead to environmental degradation.
  Over time, this situation may result in reduced agricultural productivity and deterioration of soil quality.

As observed during field site visits as shown in Figure 15, the untreated wastewater has flooded over the agricultural lands behind Kharas WWTP destroying old olive trees and destroying large area of agricultural lands.

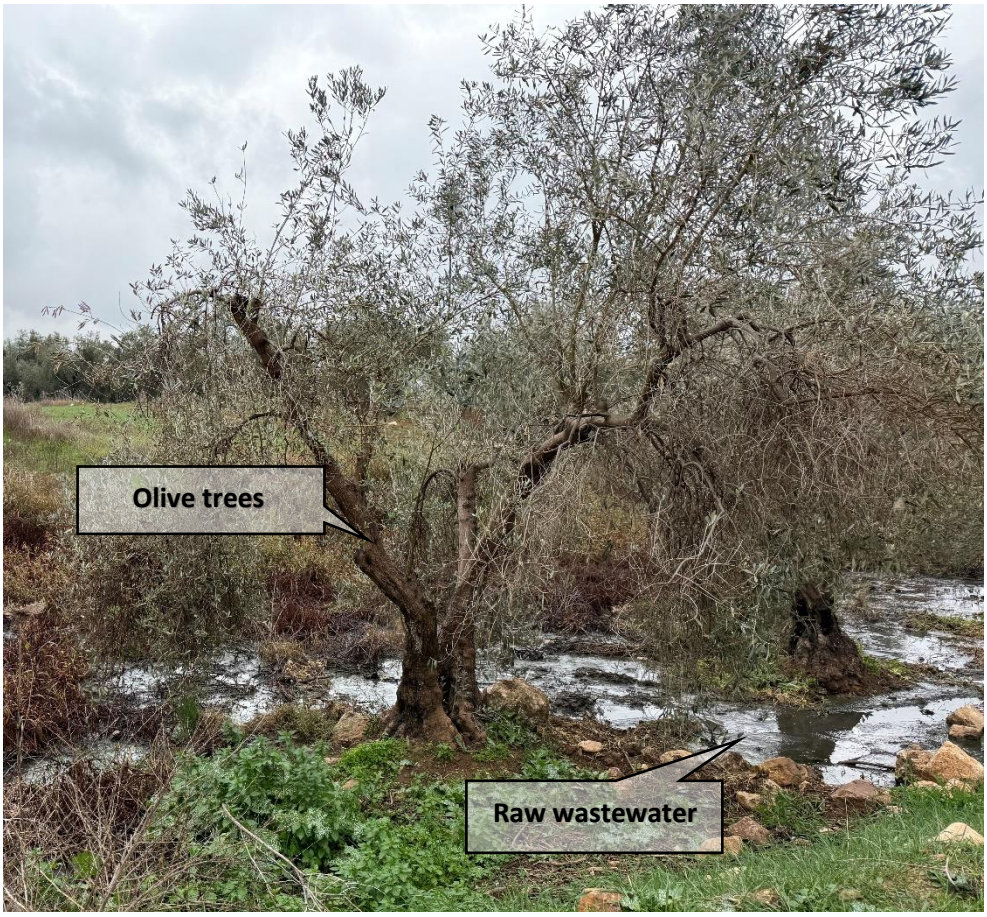


Figure 14:Environmental Hazard caused by wastewater flow behind Kharas WWTP

Israel may treat the wastewater once it passes the green line, by implementing unilateral actions, excluding Palestinians beyond the reuse gains or its benefits.

- **Political:** This scenario increases pressure on the Palestinian Authority. As seen in other transboundary wastewater cases, Israel is expected to start deducting money from Palestinian tax revenues. This will directly affect the PA's ability to provide basic services, since tax revenue is a main source of income. At the same time, it gives Israel more control over shared water resources.
  In this scenario, Palestinians also lose the chance to reuse treated water, which is a key element in long-term water management. The situation forces Palestinian institutions to deal with a growing issue under limited resources and complex restrictions, especially the complex and long process to get permission when trying to implement wastewater infrastructure projects in or near Area C. These challenges weaken Palestinian control over their own water sector and delay sustainable solutions.

- **Financial:** This situation forces Palestinians to compliance under Israeli control, potentially leading to costly, unclear, and unilateral deductions. If Israeli side started deducting money in 2026, based on the wastewater generation, the PA could **lose 206.2 million NIS** over the next 20 years (Figure 16).

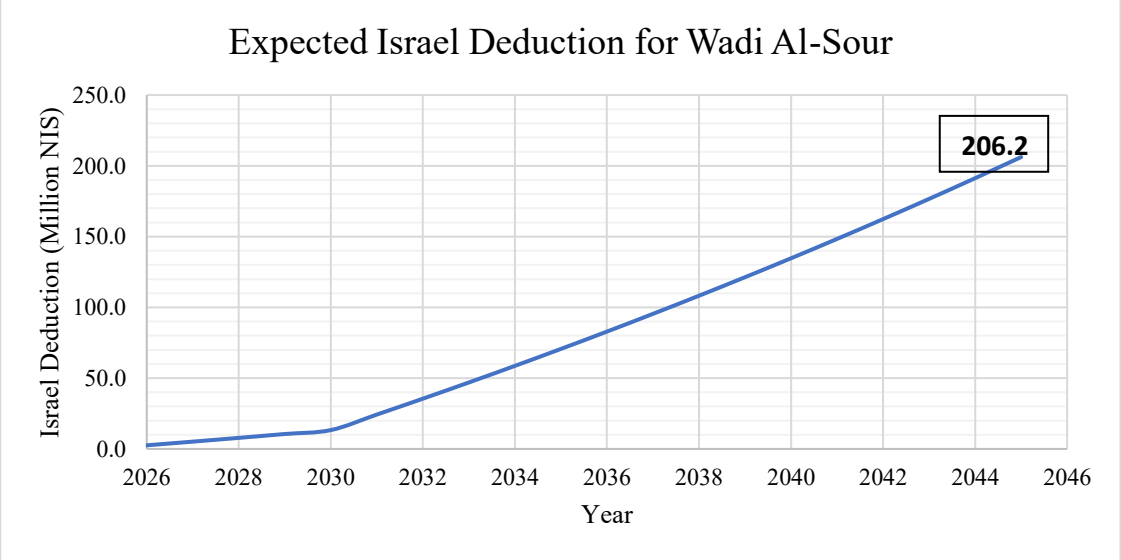


Figure 15: Expected Israel Deduction for Wadi Al-Sour over Next 20 years

- **Socio- economical:** This scenario has serious and long-lasting effects on both the people and the economy in the area. Socially, communities around Wadi Al-Sour continue to live with the daily risks of untreated wastewater. It passes through their land and fields, affecting health and creating an unsafe living environment. People are exposed to bad smells, insects, and disease risks. In many areas, public health services are already limited, and this situation only makes things worse.
  Economically, it impacts the livelihoods of local farmers who rely on these lands and their families, as productive lands are being lost. Additionally, restoring damaged land takes time, money, and in many cases, is not even possible.
  On the other hand, Israel deducts money from Palestinian tax revenues, increase the financial strain on PA, which led to governmental employees receiving less than 70% of

their monthly salaries on irregular basis for the last three years, directly reflecting on the overall economic situation in Palestine.

Scenario 1: Palestinian enhance Wastewater management

By 2045, the wastewater generation in Wadi Al-Sour's catchment will reach approximately 1.78 million cubic meters (MCM) per year in dry weather. This Scenario focus on Palestine taking proactive steps through increasing the coverage of household sewer connection and expanding the capacity of Kharas WWTP and its' quality. To prevent the untreated wastewater from flowing passing the Green Line and to start reusing the treated water for agricultural purposes.

- **Environmental Impact:** This scenario reduces pollution, prevents groundwater contamination. Moreover, increasing the level of treated water will provide a valuable non-conventional resource, using it will reduce the pressure on fresh water resources, protect and increase the area of productive land, and help maintain crop yields, especially during dry seasons.
  In the study area, there are more than 4,109 dunums of land that can be irrigated with treated water, with an estimated annual water requirement of 2.8 MCM. The following figure presents the reuse area (Figure 17). While Figure 17 a. and Figure 17 b. from the site visit show agricultural lands where treated water can be used to support ongoing farming activities, demonstrating the practical environmental advantages of this approach.

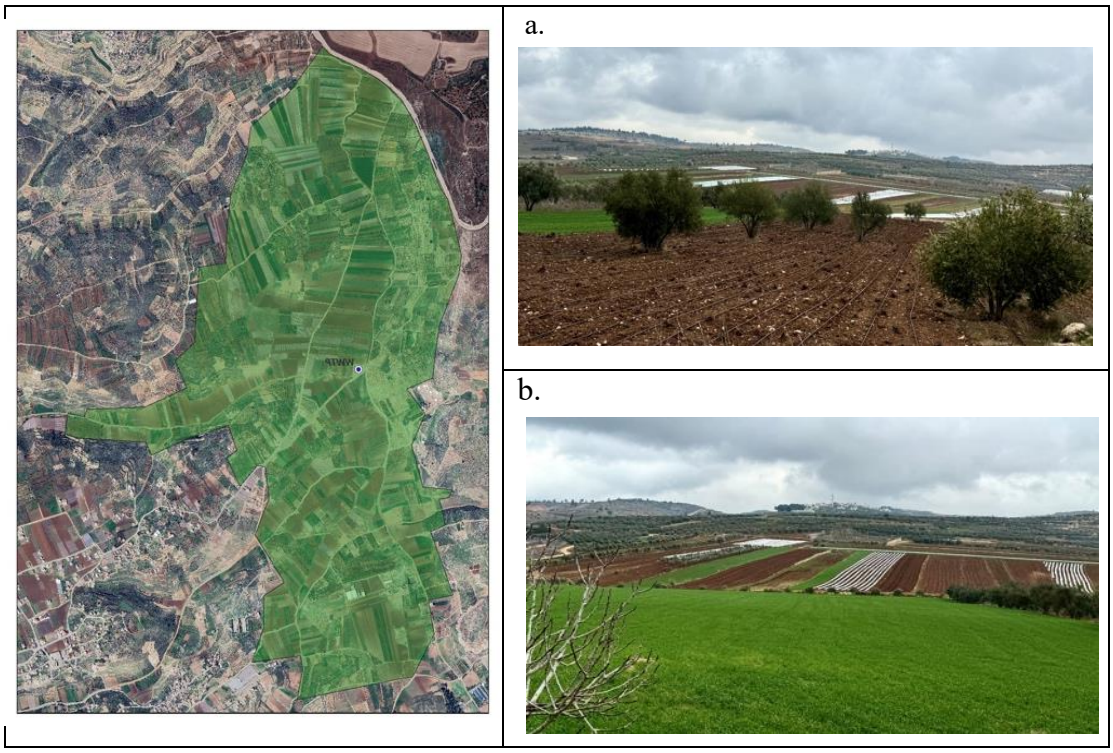


Figure 16:Potential area for reuse treated water. a. present olive yards, b. cash crops

- **Political:** This scenario is aligned with Palestine National Water and Wastewater Strategy and shows a clear step toward self-reliance in wastewater management. However, implementing this might face Israeli restrictions since the current WWTP location is very close to area 'C' any enhancement or expansion requires Israeli permits, which are hard to obtain and often delayed.

- **Finical:** implementing this scenario requires a high capital investment to improve wastewater facilities which can reach 33-40 million NIS. Still, if the scenario is implemented, it prevents Israeli tax deductions when untreated wastewater crosses the Green Line and strengthens Palestinian control over water resources and gets wastewater reuse benefits, but by treating wastewater locally and preventing it from flowing across the Green Line. In the long term, the PA avoids costly Israeli tax deductions that could reach over 206.2 million NIS within twenty years. Also, treated water could become a reliable source for irrigation, reducing the dependence on purchased water and directly supporting agriculture. So, while the upfront cost is high, this scenario builds financial independence. It turns ongoing losses into long-term savings, boosts water security.

- **Socio-economical:** This scenario supports farmers by giving them a reliable water source. It means they can keep farming during dry seasons, which helps protect their income and increase food production. Treated water reduces their reliance on expensive or limited water sources. This will increase farmers resilience on their lands. At the same time, managing wastewater properly means fewer health and environmental risks for nearby communities. It also reduces financial losses from Israeli deductions, keeping more money in the local economy.

Overall, this scenario improves stability for both people and land.

Scenario 2: Palestinian-Israeli arrangement (with Water Swapping or Treatment Service Option)

This scenario focuses on developing a clear mechanism to address transboundary wastewater issues between the two parties, The arrangement could go in one of two directions. One option is a water-swapping model, where Israel treats the wastewater and, in return, provides a certain amount of fresh water (through Mekorot) to Palestinian communities. This is especially relevant since many Palestinian communities already depend on purchasing water from Mekorot due to limited Palestinian water access.

The second option is a service-based model, where Palestine pays Israel a fair price to treat the wastewater (estimated at around 2 NIS per cubic meter). In this case, Palestine could either choose to receive the treated water back for agricultural or industrial use, or if the treated water stays on the Israeli side, Palestinians receive a financial discount or compensation in return.

- **Environmental Impact:** This scenario provides an immediate and technically effective way to reduce environmental damage caused by untreated wastewater flowing in Wadi Al-Sour. With proper treatment, the direct discharge into natural valleys and agricultural lands on both sides of the Green Line would stop. This would significantly reduce the risk of groundwater contamination, bad odors, insect breeding and pollution of surface water streams (especially during dry seasons when flow concentration is high).
  From the Palestinian side, this arrangement helps protect vulnerable lands around Kharas WWTP, where agricultural lands are currently being damaged by wastewater overflow.
  But, this option limits local environmental damage; it does not directly contribute to local reuse or circular water economy. If treated water stays on the Israeli side, then environmental benefits are achieved at the expense of losing a potential resource for Palestine.
  Overall, this scenario provides fast relief from pollution risks but may delay the development of local Palestinian reuse systems unless paired with long-term planning and clear rights to treated water.

- **Political:** This scenario could help in dealing with the tax deduction issue by establishing a transparent and agreed mechanism for wastewater treatment costs. By setting a fair treatment price and documenting responsibilities, it helps shift the conversation from unilateral deductions to a more structured and accountable approach.
  At the same time, this approach carries political risks. Relying on Israeli infrastructure for such a vital service could increase long-term dependency and weaken Palestinian control over their own water and sanitation management. And highlight the concern about using this service as a weapon in the future to put pressure on PA.
  Additionally, this scenario could face internal resistance, as it may not align with the position of certain political factions or stakeholders who see such an arrangement as normalization under unequal conditions. Therefore, any agreement under this model needs to be in clear political guarantees, time-bound conditions and steps toward building Palestinian capacity, not just solving a technical issue.

- **Finical:** This scenario can provide immediate action by addressing the issue of Israeli tax deductions by paying a fair treatment fee, the Palestinian Authority could have a clearer, more reliable cost, which helps with financial planning.
  However, relying on Israeli infrastructure for wastewater treatment long-term could create financial risks. If prices rise or access becomes restricted, Palestine could face additional costs and financial strain. This scenario also highlights the risks of delaying investments in local wastewater infrastructure. The PA might prioritize paying for Israeli services rather than investing in its systems, which could be more expensive in the long run.

- **Socio-economical:** This scenario offers some potential short-term financial stability, but for socio-economical point of view, if treated wastewater remains on the Israeli side without any return or fair compensation, Palestinian farmers lose access to a critical water source that could support irrigation across thousands of dunums. That loss directly affects agricultural productivity, reduces income, and weakens farmers resilience on their lands.
  Even if there's a mechanism allowing Palestinians to receive treated water or get compensation, it still doesn't fully replace the value of local reuse. Transporting water back or depending on financial returns cannot fully match the socio-economic benefits of having reliable, local water for agriculture. Farmers need direct access to water to plan crops, maintain trees, and reduce costs from water trucking or buying fresh water.
  If farmers continue to lack water, many might leave their land, leading to both social and economic loss that no financial agreement can compensate for. The following table (Table 14) summarize the forementioned management scenarios (scenario 0, scenario 1, scenario 2) based on environmental, political, financial and socio-economic impacts.

Table 14: Transboundary management scenarios

Scenario	Description	Environmental Impact	Political Impact	Financial Impact	Socio-Economic Impact
Scenario 0 Status Quo – No Palestinian Action	No Palestinian action. Untreated wastewater flows to Israel; Israel treats and deducts costs from PA tax revenues.	- Pollution of wadis and groundwater - Ecosystem and farmland damage	- Financial deductions from PA - Reduced Palestinian water control - Permitting challenges	- Loss of 206.2 million NIS over 20 years - No local reuse or financial benefits	- Health and environmental risks - Loss of income for farmers - Difficulty restoring land
Scenario 1 Palestinian Wastewater Management	Palestine expands Kharas WWTP and sewer coverage for local wastewater treatment and reuse.	- Reduced pollution - Potential reuse of 2.8 MCM/year - Protects soil and ecosystems	- Aligned with national strategy - Permit challenges in Area C	- 33-40 million NIS investment - Avoids Israeli deductions - Strengthens financial independence	- Reliable irrigation water for farmers - Increased resilience and food security - Better livelihoods and health outcomes
Scenario 2 Palestinian-Israeli Arrangement	Bilateral arrangement for wastewater treatment. Options include water-swapping or service-based model.	- Immediate reduction in environmental damage - Protects land near Kharas WWTP - Limits local reuse	- Transparent cost-sharing reduces deductions - Risk of dependency on Israeli services - Internal political resistance	- Lower initial investment - Potential long-term costs if prices rise - Delays local infrastructure investment	- Loss of treated water access for farmers - Reduced land productivity and income - Risk of farmers abandoning land

4.6 Future Implications for Palestinian Resource Management

This section presents analysis for an interview with a key stakeholder, with a representative from the West Bank Water Department, hereafter referred to as "Respondent 3." whose perspectives, while not directly addressing specific issues, provide insight into prospective future challenges for Palestinian resource management.

Interview Context

In January 2025, during a visit to the Joint Service Council for Water and Wastewater/North Hebron and Kharas Municipality, Respondent 3 shared that ‘’*the Israeli side is conducting a national study to assess the impact of wastewater flow and cesspits tank on groundwater quality, particularly in the western basin, which is considered a strategic basin for Israel*”. According to Respondent 3, this assessment is being carried out as part of the preparation for establishing joint wastewater treatment plants for both Palestinians and Israelis to mitigate wastewater pollution impacts on the shared ecosystem.

Subsequently, as part of this research, a direct interview was conducted with Respondent 3 to verify and expand upon this information. The discussion confirmed that the study is ongoing and highlighted the need to anticipate the political, environmental, and social consequences that could arise once the study is completed.

Recognizing the uncertainties associated with this development, different management scenarios were analyzed to explore potential future outcomes effect in light of wastewater challenges, including the environmental, political, and social sides.

Scenario 0: Assessment only

This Scenario (SC) assumes that the Israeli side is creating a study as an assessment tool to the current situation without any immediate action or implementation of wastewater treatment solutions. Taken into consideration that the outcome of this study may inform or guide future discussions, but do not lead to direct actions at this stage.

- Environmental: the environmental impact is limited in the short term, as no action is on the ground; however, it may contribute to a better understanding of the current situation especially the groundwater aquifer pollution level.

- Political: Highly feasible, as assessment studies are generally more acceptable to be presented at the Palestinian and international levels than implementing physical infrastructure. However, concerns may arise over data accessibility and transparency for Palestinian stakeholders.

Moreover, if the Palestinian role in this study is limited to providing data for West Bank Water Department employees through Palestinian service providers separately and the PA will not be involved in the study, this will neglect the influence over how the data will be analyzed and how results are interpreted and applied. This will directly affect future wastewater management decisions.

Scenario1: One-Sided Study Leading to direct Action on ground

This SC argue that the Israeli side is leading a study for wastewater management and the cesspit tanks effect on ground water quality, without any contribution from Palestinian side and this study could be followed by direct action including; the establishment of new wastewater treatment infrastructure which will be fully controlled by Israel, policy affecting Palestinian communities or imposed regulations on wastewater disposal this may include PA financially responsible for ground water pollution due to wastewater infiltration from cesspits, by deducting money from Palestinian tax revenues similar to its current practice regarding transboundary wastewater flows.

- Environmental: This SC will prioritize addressing wastewater issues that impact Israel directly, particularly in areas where polluted water from the West Bank crosses into Israeli territory. As a result, efforts to manage wastewater will focus on mitigating risks to Israeli side while delaying or neglecting solutions for Palestinian areas facing several pollution and public health risks. This mean that the wastewater management planning and implementation will be fully from an Israeli point of view.

- Political: This approach violates Palestinian right to self-determination and sovereignty over their natural resources, as mentioned in international law and PA will bear the financial and infrastructural burden imposed on them by Israel.

Scenario 2: Palestinian- Israeli arrangement

Since pollution knows no borders, this SC presents the case of collaboration and cooperation between both sides to address the management of wastewater to find an integrated solution and ensure equity including future planning and implementation.

- Environmental Impact: The impact of future planning and implementation will positively influence the environmental and social sustainability.

- Political: This approach requires high-level negotiations and understanding of the environmental sense.

Scenario 3: Israel-led Study with a Deadline for Palestinian Action

Israel leads its study on wastewater impact and provides PA with its outcome. Based on these results, Israel gives a fixed deadline for the PA to enhance its wastewater management strategy. If improvements are not made within the given timeframe, Israel will implement its wastewater management measures, which could include infrastructure projects, policies affecting Palestinian communities, or imposed regulations on wastewater disposal.

- Environmental Impact: If the results of the study are transparent, scientifically accurate, and applicable, and Palestinians enhance their wastewater infrastructure within the given period, this will lead to preventing the negative effects of wastewater to the ecosystem. On the other hand, if Palestinian can't meet the deadline, Israelis will apply their actions, which will give priority to their own interests and neglect Palestinian needs or make solutions that are not fair to Palestinian communities.

- Political: This scenario put high pressure on Palestinian institutions and municipalities, as they are mainly depending in donors and NGOs for funds, and the establishing of wastewater facilities need a long and complex process to get permits, in addition to that many

municipalities service provider suffer from lack of qualified human resource which can lead this process to meet the deadline and if Israel enforces wastewater management local communities will face restrictions or increased costs.

In addition, giving a deadline is politically incorrect, as it constitutes an intervention with Palestinian control over their own resources.

4.7 Investigate potential strategies for transboundary wastewater management

The Palestinian water Authority illustrate key objectives to enhance and improve water sector in Palestine through the National Water and Wastewater Management Strategies (2017–2022 and 2024–2029). These strategies provide the planning and management framework necessary for the protection, conservation, sustainable management and development of water resources and for the improvement and sustainable management and provision of water supply and wastewater services and related standards.

They focus in expanding wastewater treatment, increasing reuse in agriculture, reducing non-revenue water (NRW), and addressing transboundary wastewater management challenges as tools for development.

This research aligns with the National Strategies on many key objectives related to transboundary wastewater management with the focus in Wadi Al-Sour catchment. This includes:

- Wastewater Treatment & Reuse Expansion: Both strategies set targets to increase wastewater treatment capacity and promote the reuse of treated water for irrigation. This study explores different management scenario based on treatment and reuse, which directly support these national goals.

- Reduction of Transboundary Wastewater Discharge: The national plans emphasize decrease the flow of untreated Palestinian wastewater to Israeli, which aligns with the study's objective of exploring different scenarios for addressing sustainable solutions for transboundary wastewater issue.

- Financial Sustainability: one of the national strategy goals is to improve cost recovery, reduce unjustified deductions, and ensure financial transparency in wastewater management. that is directly addresses in Objective 3 of this research which analyze the tax deductions Israel imposes under the PPP principle and their impact on Palestinian budgets.
- Infrastructure Development & NRW Reduction: National policies aim to improve wastewater collection and treatment infrastructure while reducing NRW from over 30% to below 25%, supporting the study's SDBI analysis and efficiency scenarios.

Chapter Five

Chapter Five: Conclusion

This research examined how integrated transboundary wastewater management can strengthen water scarcity resilience in the Wadi Al-Sour catchment. The study was guided by the Palestinian National Water and Wastewater Management Strategy (2017–2022 and draft 2024–2029), which promotes treated wastewater reuse and improved sanitation infrastructure as critical tools for enhancing water security under severe political, financial, and environmental constraints.

The results clearly show that Wadi Al-Sour suffers from moderate to acute water scarcity, with per capita domestic water supply ranging from only 63 to 77 liters per day, far below the WHO-recommended minimum of 100 L/c/d. This scarcity was quantified using the Supply-Demand Balance Index (SDBI), which ranged from 0.63 to 0.77 between 2019 and 2024, confirming a persistent moderate scarcity under the current conditions.

To address these challenges, the study assessed **three transboundary wastewater management scenarios**:

- **Scenario 0: Status Quo**

This scenario represents the current situation, where wastewater continues to flow untreated across the Green Line. No strategic intervention is applied. While no deductions are currently made for Wadi Al-Sour, such deduction is predicted in the near future, in which PA could lose 206.2 million NIS over the coming 20 years.

- **Scenario 1: Palestinian Enhanced Wastewater Management**

This scenario assume that Palestinian improve local wastewater treatment infrastructure and promote the reuse of treated effluent for agriculture. Although it shows potential to reduce untreated discharges and strengthen water reuse practices, as many lands are classified as C area any improvement or farming in these lands may face Israel restriction and required permissions.

- **Scenario 2: Transboundary Arrangement**

This scenario involves a formal arrangement between Palestinian and Israeli sides, with clear responsibilities, shared benefits, and environmental monitoring. It includes expanding treatment capacity, full reuse of treated water for irrigation, and official recognition to stop deductions.

The study also found that current estimated water demand for irrigation is 4.87 million m^3/year, which exceeds twice the total water supplied for all uses, including domestic, to the entire catchment. This reflects a critical imbalance and the urgent need to regulate water use and improve monitoring of agricultural practices.

Furthermore, it was confirmed that Wadi Al-Sour currently discharges untreated wastewater across borders, but no financial deductions have been imposed yet by the Israeli side. However, based on the pattern observed in other catchments, future deductions are highly likely.

Chapter Six

Chapter Six: Recommendations

This research highlights critical challenges in managing water scarcity and transboundary wastewater in Wadi Al-Sour. The following recommendations aim to address existing gaps, unresolved issues, and future priorities:

- One of the major issues identified was the inaccuracy and inconsistency of key data, particularly regarding NRW. These inaccuracies directly affected the ability to properly assess the water balance, wastewater flows, and future planning needs. So, it is strongly recommended that future work must prioritize improving and analyzing NRW data.

- To avoid future implications and ensure consistency in reporting, it is necessary to organize the relationship between local service providers and the Palestinian Water Authority (PWA). Specifically, all technical data related to water supply, NRW, and wastewater must be approved and authorized by the PWA before being shared with any external or nongovernmental side. This will help create a single, credible source of information and prevent confusion or misuse of unofficial data, especially when dealing with transboundary issues that may have financial and political consequences.

- It's recommended to move forward with the implementation of a clear and structured transboundary wastewater management strategy. Such a strategy must aim to reduce the untreated wastewater flowing across borders, enhance water scarcity resilience through treated water reuse, and reduce the risk of future financial deductions. When developing this strategy, all associated benefits, challenges, and feasibility aspects must be carefully considered, especially under the existing political restrictions and limited financial resources.

- It's recommended that the MOA develop and maintain a centralized, up-to-date agricultural database. Throughout the development of this study, it was found that agricultural information had to be collected from scattered reports, many of which lacked clear references, maps, or reliable estimates for crop types and irrigation practices which limits the ability to plan, monitor, and manage water resources effectively. A detailed and accurate agricultural land-use map, supported by satellite imagery or ground surveys, should be prepared and made accessible to stakeholders working in water and agricultural planning. This would ensure better decision-making and improve future water balance assessments in the region.

References

- Abu-Madi, M. (2011). Wastewater Treatment and Reuse in the Mediterranean Region. Springer. Retrieved from https://www.pseau.org/outils/ouvrages/springer_waste_water_treatment_and_reuse_in_the_mediterranean_region_2011.pdf
- Al-Mughrabi, N., & Issa, M. (2025, April 3). Hundreds of thousands flee as Israel seizes Rafah in new Gaza 'security zone'. Retrieved from Reuters: https://www.reuters.com/world/middle-east/hundreds-thousands-flee-israel-seizes-rafah-new-gaza-security-zone-2025-04-03/
- Amnesty International. (2009). Troubled waters: Palestinians denied fair access to water. Amnesty International Publications. Retrieved from https://www.amnesty.org/en/documents/mde15/027/2009/en/
- Angelakis, A. N. (2021). The impact of climate change on water resources availability in the Middle East: A case study of Jordan. Water, 2(13), 1-18.
- Arnon, A., & Weinblatt, J. (2014). The Economics of the Israeli-Palestinian Conflict. London, UK: Palgrave Macmillan.
- Assaf, K., Al-Sa'ed, R., Samhan, S., Friese, K., von Afferden, M., Müller, R., . . . Zimmo, O. (2010). Wastewater Management Overview in the Occupied Palestinian Territory. In W. W. Region, Waste Water Treatment and Reuse in the Mediterranean Region (pp. 229–248). Berlin: Springer. Retrieved from https://doi.org/10.1007/698_2010_64
- Bitton, G. (2011). Wastewater Microbiology (4th ed.). Wiley-Blackwell.
- Butler, D., & Davies, J. (2010). Urban drainage (2nd ed.). CRC Press.
- Chrispim, M. C., Scholz, M., & Nolasco, M. A. (2019). Phosphorus recovery from municipal wastewater treatment: Critical review of challenges and opportunities for developing countries. Journal of Environmental Management, 248, 109-268. doi:https://doi.org/10.1016/j.jenvman.2019.109268
- Dai, L. (2021). Implementation Constraints on Israel–Palestine Water Cooperation: An Analysis Using the Water Governance Assessment Framework. Water, 13(5), 620. doi:https://doi.org/10.3390/w13050620
- Dotan, P., Yeshayahu, M., Odeh, W., Gordon-Kirsch, N., Groisman, L., Al-Khateeb, N., . . . Arnon, S. (2017). Endocrine disrupting compounds in streams in Israel and the Palestinian West Bank: Implications for transboundary basin management. Journal of environmental management.
- Efron, S., Fischbach, J., & Giordano, G. (2018). Gaza's water and sanitation crisis: The implications for public health. In The crisis of the Gaza Strip: A way out. Institute for National Security Studies, 85-101. Retrieved from https://www.rand.org/pubs/external_publications/EP67494.html
- Elhabil, I. (2025, February 27). Gaza wastewater crisis threatens Palestinian survival. Retrieved from The Electronic Intifada. : https://electronicintifada.net/content/gaza-wastewater-crisis-threatens-palestinian-survival/50440?utm_source=chatgpt.com

- Fanack-Water. (2024, October 10). Why Gaza is Running Out of Fresh Water. Retrieved from Fanack water: https://water.fanack.com/why-gaza-is-running-out-of-fresh-water/
- Feitelson, E. (2002). Implications of Shifts in the Israeli Water Discourse for Israeli-Palestinian Water Negotiations. Water International, 27(3), 293-310. doi:https://doi.org/10.1080/02508060208687010
- Ghanem, M., & Abu-Lebdeh, T. (2020). Financial challenges in Palestinian water and wastewater sectors: The role of external aid. Water Internationa, 179-194.
- Ghanem, S. (2018). Water, Conflict and Politics in the Middle East: A Reflection on the Palestinian-Israeli Water Dispute. Switzerland: Springer.
- Gross, A. S. (2007). Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households. Chemosphere, 66(5), 916-923. doi:10.1016/j.chemosphere.2006.06.006
- GWP. (2024). Palestine Policy Brief: Towards comprehensive integrated water resources, sanitation, and hygiene management in Palestine for developing responsive strategic plans to manage impacts of climate change. Global Water Partnership (GWP). Retrieved from https://www.gwp.org/globalassets/global/gwp-med-files/list-of-programmes/gwl/palestine-policy-brief.pdf
- Hassouneh, M., & Khalidi, A. (2019). Fiscal policy and public finance in the Palestinian territories: The role of tax revenues and international aid. The Journal of Development Studies, 55(3), 397-412. doi:https://doi.org/10.1080/00220388.2018.1491142
- Hilmi, S., Woldeyohannes , Y., & Muhammed, H. (2021). The Status of Freshwater and Reused Treated Wastewater for Agricultural Irrigation in the Occupied Palestinian Territories. Journal of Water and Health.
- Howard, G., & Bartram, J. (2003). Domestic Water Quantity, Service Level and Health. Geneva, Switzerland: World Health Organization. Retrieved from https://www.who.int/publications/i/item/WHO-SDE-WSH-03.02
- HRW. (2021). A threshold crossed: Israeli authorities and the crimes of apartheid and persecution. Human Rights Watch (HRW). Retrieved from https://www.hrw.org/report/2021/04/27/threshold-crossed/israeli-authorities-and-crimes-apartheid-and-persecution
- Huang, L., & Yin, L. (2017). Supply and Demand Analysis of Water Resources Based on System Dynamics Model. Journal of Engineering and Technological Sciences (J. Eng. Technol. Sci.), 705-720.
- Hussein, H. &.-A. (2023). Exploring the framings of water scarcity in Palestinian textbooks. Contemporary Levant, 8(1), 3-15. doi: https://doi.org/10.1080/20581831.2023.2178090
- Isaac, J., & Hilal, J. (2011). Palestinian landscape and the Israeli–Palestinian conflict. International Journal of Environmental Studies, 68(4), 413-429. Retrieved from https://doi.org/10.1080/00207233.2011.582700
- Isaac, R. (2017). Transformational host communities: justice tourism and the water regime in Palestine. Tourism Culture & Communication, 17, 139-158. doi: https://doi.org/10.3727/109830417X14966810027580

- Judeh, T., & Shahrour, I. (2021). Rainwater Harvesting to Address Current and Forecasted Domestic Water Scarcity: Application to Arid and Semi-Arid Areas. Water, article number: 3583.
- Khatib, I., & Younis, B. (2020). Wastewater Reuse in Palestine: Challenges and Opportunities for Agriculture. Water, 12(7).
- Mekonnen, M., & Hoekstra, A. (2016). Four billion people facing severe water scarcity. Science Advances, 2(2). doi:https://doi.org/10.1126/sciadv.1500323
- Messerschmid, C. (2014). Hydro-Apartheid and Water Access in Israel-Palestine: Challenging the Myths of Cooperation and Scarcity. In Water, Cultural Diversity, and Global Environmental Change: Emerging Trends, Sustainable Futures? (pp. 53-76). doi:https://doi.org/10.1057/9781137448750_4
- Metcalf, & Eddy. (2014). Wastewater Engineering: Treatment and Resource Recovery. McGraw-Hill Education.
- Motasem Y.D. Alazaiza, T. M. (2025). Global perspectives on industrial wastewater management: A bibliometric analysis of research output. Journal of Hazardous Materials Advances, 17. Retrieved from https://www.sciencedirect.com/science/article/pii/S2772416624001670
- National Water Carrier Begins pumping. (2021). National Water Carrier Begins Pumping. Center for Israel Education.
- Nour, R., & Al-Saidi, M. (2018). Regulation reform process and perception in the Palestinian water sector. Water International, 908-925. doi:https://doi.org/10.1080/02508060.2018.1490863
- Oroud, I. M. (2009). The Impacts of Climate Change on Water Resources in Jordan. In Climatic Changes and Water Resources in the Middle East and North Africa (Vol. 13, pp. 109-123). Berlin, Germany: Springer. doi:10.1007/978-3-540-85047-2_10
- Oxfam. (2025, February 18). Less than seven percent of pre-conflict water levels available to Rafah and North Gaza, worsening a health catastrophe. Retrieved from Oxfam America: https://www.oxfamamerica.org/press/less-than-seven-percent-of-pre-conflict-water-levels-available-to-rafah-and-north-gaza-worsening-a-health-catastrophe/
- Perrier, J. (2020). Palestinian water laws: Between centralization, decentralization, and rivalries. Agence française de développement. Retrieved from https://www.pseau.org/outils/ouvrages/afd_palestinian_water_laws_between_centralization_decentralization_and_rivalries_2020.pdf
- Perrier, J. (2021). Land defenders, infrastructural violence, and environmental coloniality: Resisting a wastewater treatment plant in East Nablus. In S. C. Stamatopoulou-Robbins (Ed.), Environmental Defenders: Deadly Struggles for Life and Territory (pp. 198-217). Routledge.
- PMD. (n.d.). Palestinian climate. Ramallah, PAlestine: Palestinian Meteorological Departmen. Retrieved from Retrieved April 7, 2025, from https://www.pmd.ps/pal-climate

- PWA. (2013). The Right to Water. Ramallah, Palestine: Palestinian Water Authority. Retrieved from https://www.pwa.ps/userfiles/file/marselya.pdf
- PWA. (2014). Water Sector Reform Plan 2014–2016. Ramallah, Palestine: Palestinian Water Authority (PWA). Retrieved from https://faolex.fao.org/docs/pdf/pal227466E.pdf
- PWA. (2016). National Water and Wastewater Strategy 2017-2022. Ramallah, Palestine: Palestinian Water Authority .
- PWA. (2023). Draft: The National Water and Wastewater Strategy 2024-2029. Ramallah, Palestine: Palestininan Water Authority .
- Qaddumi, H. (2008). Practical approaches to transboundary water benefit sharing. London, United Kingdom: Overseas Development Institute (ODI).
- Qadir, M. D. (2020). Non-conventional water resources and opportunities for water augmentation to achieve food security in water-scarce countries. Agricultural Water Management, 231, Article number 105958.
- Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? Agricultural Water Management, 80(1-3), 5-22.
- Schneier-Madanes, G. (2001). The Israeli-Palestinian Mountain Aquifer: A case study in groundwater conflict resolution. Journal of Natural Resources and Life Sciences Education, 30(1), 50-55.
- Seeberg, P. (2024). Israeli Hydro-Hegemony and the Gaza War. Middle East Policy. doi: https://doi.org/10.1111/mepo.12740
- Selby, J. (2013). Cooperation, domination and colonisation: The Israeli-Palestinian Joint Water Committee. Water Alternatives, 6(1), 1-24. Retrieved from http://www.water-alternatives.org/index.php/volume6/v6issue1/198-a6-1-1/file
- Selby, J., Daoust, G., & Hoffamnn, C. (2022). Divided environments: An international political ecology of climate change, water and security. In Divided Environments: An International Political Ecology of Climate Change, Water and Security. Cambridge University Press.
- Shuval, H., & Dweik, H. (20017). Water Resources in the Middle East: Israel-Palestinian Water Issues – From Conflict to Cooperation. Springer.
- Stamatopoulou-Robbins, S. (2019). Waste siege: The life of infrastructure in Palestine. Stanford University Press.
- Tchobanoglous, G., Burton, F., & Stensel, H. (2003). Wastewater Engineering: Treatment and Reuse. McGraw-Hill Education.
- Tomizeh, I., & Shoqeir, J. (2023). Classification model for selecting appropriate sanitation technology compatible with the community capacity. 11th International Congress on Environmental Modelling and Software. Brussels, Belgium: International Environmental Modelling & Software Society (iEMSs).
- Trottier, J. (2007). A wall, water and power: The Israeli ‘separation fence’. Review of International Political Economy, 14(4), 633-655.

- UN. (2019). The 17 goals. United Nations Department of Economic and Social Affairs. United Nations. Retrieved from https://sdgs.un.org/goals
- UNDP. (2024). Environmental impact of the conflict in Gaza: Preliminary assessment of environmental impacts. United Nations Environment Programme. Retrieved from https://www.unep.org/resources/report/environmental-impact-conflict-gaza-preliminary-assessment-en
- UNECE. (2015). Policy guidance note on the benefits of transboundary water cooperation: Identification, assessment and communication. Geneva, Switzerland: United Nations Economic Commission for Europe.
- UNESCO & UN-Water. (2020). United Nations World Water Development Report 2020: Water and Climate Change. United Nations Educational, Scientific and Cultural Organization (UNESCO). Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000372985
- UNESCO. (2017). The United Nations World Water Development Report 2017: Wastewater – The Untapped Resource. Paris, France: UNESCO (United Nations Educational, Scientific and Cultural Organization). Retrieved from https://www.unesco.org
- UNESCO. (2017). Wastewater – The Untapped Resource. Paris, France: UNESCO (United Nations Educational, Scientific and Cultural Organization). Retrieved from https://www.unesco.org
- UNICEF. (2019). State of Palestine Country Report 2018. New York, USA: United Nations Children's Fund (UNICEF).
- UN-Water. (2020). UN World Water Development Report 2020: Water and Climate Change. Paris, France: United Nations Educational, Scientific and Cultural Organization (UNESCO).
- UN-Water. (2021). Summary Progress Update 2021: SDG 6—Water and Sanitation for All. Geneva, Switzerland: United Nations. Retrieved from https://www.unwater.org/publications
- Walraevens, N. A. (2018). Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions. Water, 10(11), Article Number: 1608. doi: https://doi.org/10.3390/w10111608
- Weinthal, E. (October 10, 2017). Water as a basic human right within the Israeli-Palestinian conflict. American Diplomacy.
- WorldBank. (2009). Assessment of Restrictions on Palestinian Water Sector Development. World Bank. Retrieved from https://documents.worldbank.org/en/publication/documents-reports/documentdetail/369451468139564049/assessment-of-restrictions-on-palestinian-water-sector-developme
- World-Bank. (2016, Novemeber 11). Water Situation Alarming in Gaza. Retrieved from World Bank Group: https://www.worldbank.org/en/news/feature/2016/11/22/water-situation-alarming-in-gaza

- WSRC. (2022). Performance Monitoring Report for Water and Wastewater Service Providers in Palestine. Ramallah, Palestine: Water Sector Regulatory Council (WSRC). Retrieved from https://www.wsrc.ps/public/uploads/Publication/1703588627781695.pdf
- WWAP. (2019). The United Nations World Water Development Report 2019: Leaving No One Behind. UNESCO (United Nations Educational, Scientific and Cultural Organization). Retrieved from https://www.unesco.org/en/digital-library/world-water-development-report-2019
- Yaqob, E. (2023). Climate Change Implication on Palestine: A Case Study Jenin Governorate. American Journal of Multidisciplinary Research and Innovation, 2(3). doi:https://doi.org/10.54536/ajmri.v2i3.1441
- Yaqob, E., Al-Sa'ed, R., & Suidan, M. (2014). Situation analysis and perspectives of transboundary wastewater management along Israel/Palestine borders. Asian Journal of Applied Sciences and Engineering, 3(2), 82-95.
- Zeitoun, M., Eid-Sabbagh, K., Loveless, J., Weinthal, E., & Talhami, M. (2012). Hydro-hegemony in the Upper Jordan waterscape: Control and use of the flows. Water Alternatives, 5(2), 86-107. Retrieved from https://www.water-alternatives.org/index.php/alldoc/articles/vol5/v5issue2/163-a5-2-5
- Zeitoun, M., Talhami, M., & Eid-Sabbagh, K. (2019). Power asymmetry and water security in transboundary settings. Water International, 44(3), 278-297.

العنوان: تعزيز القدرة على مواجهة ندرة المياه من خلال إدارة مياه الصرف الصحي عبر الحدود بما يتماشى مع الاستراتيجية الوطنية لإدارة المياه ومياه الصرف الصحي: دراسة حالة وادي السور، الخليل

إعداد: ريتا عابد عابد سمامقه. **المشرف: الأستاذ الدكتور جواد شقير.**

الملخص

يتطرق هذا البحث لمشكلة شح المياه في فلسطين من خلال دراسة حالة حوض وادي السور الواقع شمال غرب الخليل، وتعاني هذه المنطقة شئنها شئن باقي مناطق فلسطين من نقص حاد في المياه وزياد الضغوط على الموارد المتوفرة. في ظل التحديات الطبيعية والسياسية والاقتصادية، أصبحت إدارة المياه ومياه الصرف الصحي عنصرًا أساسيًا في تعزيز صمود المجتمعات الفلسطينية.

ركزت الدراسة على فهم الواقع المائي في الحوض، وتقييم الممارسات الحالية لإدارة مياه الصرف، وتحليل الأثر المالي والسياسي المترتب على مشكلة المياه العابرة للحدود مع الجانب الإسرائيلي، خاصة مع تزايد المخاوف من اقتطاعات مالية مستقبلية من أموال الضرائب الفلسطينية بسبب هذه القضية. اعتمد البحث على منهجية تجمع بين التحليل الكمي والنوعي، شملت حساب مؤشر موازنة العرض والطلب (SDBI)، وتحليل بيانات المياه والصرف الصحي، إلى جانب مقابلات ميدانية مع أصحاب العلاقة من الجهات الوطنية والمحلية. كما تم تقييم ثلاثة سيناريوهات لإدارة مياه الصرف العابر للحدود:

SC0: الوضع القائم – استمرار الجريان العابر غير المعالج وخطر الاقتطاعات.

SC1: تحسين الإدارة الفلسطينية – تطوير محطات المعالجة دون تنسيق رسمي.

SC2: اتفاقيات – إعادة الاستخدام الكامل للمياه المعالجة بتنسيق مؤسسي.

أظهرت النتائج أن حوض وادي السور يعاني من شح مائي معتدل إلى حاد، حيث بلغ نصيب الفرد من المياه بين 63 و77 لتراً يومياً. كما كشفت الدراسة عن وجود فجوات حرجة في البيانات الزراعية ومعدلات الفاقد(NRW) ، وضعف في التنسيق بين المؤسسات ذات العلاقة، ما يعيق التخطيط المتكامل. بناءً على ذلك، توصي الدراسة بضرورة تحسين دقة البيانات واعتماد مصادر رسمية وموحدة، وتوسيع شبكات الصرف الصحي، وزيادة القدرة الاستيعابية لمحطات المعالجة، وتفعيل مشاريع إعادة استخدام المياه المعالجة للزراعة، بما يدعم الأمن المائي والغذائي.

كما تؤكد على أهمية التنسيق بين المجالس المحلية والجهات الوطنية، خصوصًا سلطة المياه الفلسطينية، وعلى ضرورة أن يكون هناك تخطيط مبكر وواضح لمواجهة أية اقتطاعات مالية محتملة.

هذه الرسالة لا تطرح حلولاً مثالية، لكنها تقدم خطوات عملية ومبنية على واقعنا الصعب، إيمانًا بأن حماية حقوقنا المائية والبيئية تبدأ من الداخل، ومن قدرتنا على إدارة مواردنا بشكل أفضل رغم كل التحديات.

الكلمات المفتاحية: إدارة المياه العادمة العابرة للحدود، إعادة استخدام المياه المعالجة، إدارة الموارد المائية، الإستراتيجية الوطنية للمياه، الاستدامة البيئية، الجدوى السياسية، العدالة الاجتماعية، معالجة المياه العادمة، الموارد المائية غير التقليدية.