



An-Najah National University
Faculty of Graduate Studies

**TOWARDS SUSTAINABLE SEWAGE
SLUDGE MANAGEMENT IN PALESTINE**

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**This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree
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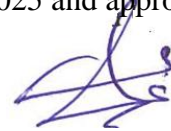
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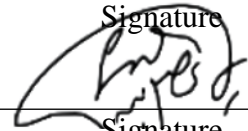
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Dedication

I would like to dedicate this thesis to my loving family, the source of my strength and inspiration throughout my life.

To my dear parents, who have always guided me with their endless sacrifices, profound wisdom, and unconditional love, all of my achievements are a testament to your guidance.

To my beloved wife, Isra', for her unwavering patience, enduring love, and gentle understanding of me in every challenge and every success, which have lifted me.

&

To my beautiful daughter, Jeelan: Her innocent eyes inspire me to pursue a kind, hopeful, and sustainable world every day. You are my joy, my motivation, and the reason I try to make the world a better place for you.

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Last but not least, I have the most significant appreciation for my family, love, who helped me with their understanding, encouragement, and support that enabled me to finish this work successfully.

Thank you all.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

TOWARDS SUSTAINABLE SEWAGE SLUDGE MANAGEMENT IN PALESTINE

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Date: 27/02/2025

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TOWARDS SUSTAINABLE SEWAGE SLUDGE MANAGEMENT IN PALESTINE

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Abstract

Sewage sludge management in Palestine faces considerable environmental, economic, and public health challenges due to fragmented governance, technological limitations, and social barriers. The research aims to understand the current state of practice in sludge management in Palestine, assess the sludge's potential for agricultural and energy uses, and determine the possibilities of value-added processing. It also aims to assess the environmental and public health risks associated with the current management practices. By analyzing these factors, the study aims to enhance sludge management and promote resource utilization.

The research employed the Governance Assessment Tool (GAT) to evaluate governance structures' effectiveness, coherence, and responsiveness. Data collection included a comprehensive review of the available literature, such as policies, standards, and related literature. Also, stakeholder interviews were conducted, and case studies of wastewater treatment plants in Nablus, Jericho, and Al-Bireh were conducted, along with an overview of the countries in the region.

The study also included the best global practices and innovative technologies such as biogas recovery, composting, and hydrothermal carbonization to identify suitable solutions for the local context.

The findings reveal some challenges in governance, technology, and public perception. Current governance frameworks are fragmented, with inadequate coordination and enforcement of regulations. Technical issues, including high sludge moisture content and the absence of efficient disposal pathways, also raise operational costs and environmental risks. Sociocultural and behavioral barriers to sludge reuse, including the perception of farmers as opposed to it, also restrict progress. However, the study shows potential for resource recovery, including biogas production and composting, that can decrease reliance on landfills and be compatible with circular economic approaches.

To address these challenges, a multifaceted, comprehensive approach is needed. Recommendations include proposing unified governance systems, selecting and implementing advanced treatment technologies, and enhancing stakeholder engagement. Increasing biogas recovery and composting activities is a way of enhancing resource utilization, decreasing costs, and decreasing adverse environmental effects. Public education campaigns and targeted stakeholder engagement are essential to removing socio-cultural barriers and encouraging acceptance of new solutions.

Keywords: Sustainable sludge management, governance, wastewater treatment, resource recovery, circular economy, Palestine.

Chapter One

Introduction and Theoretical Background

1.1 General Background

The need for wastewater treatment has increased with the rising generation of waste products as human activities increase rapidly in a world that is changing rapidly. In 2020, billions of people (around 1 in 4 people) worldwide are facing the central problem of lacking access to securely managed household drinking water, sanitation, and hygiene services (WHO & UNICEF, 2021).

Reports from authoritative bodies such as the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) suggest that a substantial portion of the global population will continue to lack access to these essential services unless the rate of progress quadruples (WHO & UNICEF, 2021). This pressing issue aligns with the global commitment encapsulated in Sustainable Development Goal (SDG) number six, a cornerstone of the 2030 Agenda that outlines our collective pursuit of a more sustainable and equitable future. As humanity confronts the complex challenges posed by its expanding footprint, the quest for effective wastewater treatment shines as a beacon of our shared responsibility to protect the fundamental resources that sustain life on our planet (Dramé et al., 2023).

Against this backdrop, one of the pivotal outputs of wastewater treatment, sewage sludge (SS), emerges as a focal point. Sewage sludge, a byproduct designed to mitigate risks to both health and the environment, also holds the potential to serve as a source of agricultural nutrients (fertilizers) and energy through processes such as anaerobic digestion and combustion. Balancing these dual objectives to ensure sustainable sewage sludge management becomes complicated and controversial (Bagheri et al., 2023).

Moreover, handling fecal sludge in low- to middle-income countries, from containment to disposal or beneficial use, poses a critical challenge, hindering effective treatment for sustainable resource recovery (Eliyan et al., 2023). The management of sewage sludge is increasingly recognized as a significant concern. It presents a complex societal and environmental issue that challenges legislators, researchers, and engineers alike (Tyagi, 2017). Within this context, sludge management emerges as one of the most intricate

tasks for wastewater treatment plants. It is characterized by high water content, poor dewaterability, and stringent regulations governing sludge reuse or disposal (Nazari et al., 2018).

Exploring sewage sludge management requires an understanding of wastewater treatment in urban areas. Habitats produce noteworthy amounts of wastewater, typically treated in wastewater treatment plants (WWTPs). These plants use biological reactors to generate waste sewage sludge (SS), primarily from sedimentation basins and clarifiers. Additional sludge can result from chemical precipitation, screening, grinding, and filtration (Sugurbekova et al., 2023). The increasing volume of sewage sludge has become a global environmental issue. Unfortunately, many countries dispose of sewage sludge on land without proper control, leading to adverse environmental impacts. Landfills, another standard disposal method, often face capacity issues and fail to meet engineering standards. Waste management is governed by international conventions, national laws and codes of practice, and each country has its sewage sludge management system. Some conventions, including the Basel Convention, regulate waste transport across international borders. However, no direct conventions specifically address sewage sludge management, such as the Stockholm Convention on controlling persistent organic pollutants (Sugurbekova et al., 2023). This lack of guidance emphasizes the need to create efficient plans and international cooperation to solve several issues related to sewage sludge.

The generation of municipal sewage sludge (MSS) worldwide in 2017 amounted to 45 million tons, and hence, reasonable management solutions are needed even now in 2017 (Giwa et al., 2023). This volume underlines the need to address environmental and health problems and the relevance of the sustainability idea in treating sewage sludge. To negotiate this complexity, however, calls for sophisticated approaches consistent with the step-by-step improvement of ecological sustainability and human well-being that solve the mounting issues of climate change (Chang et al., 2023; Zhang et al., 2017).

Thus, it is imperative to treat municipal sludge to benefit the environment and human health. Improving energy recovery, lowering environmental impact, and guaranteeing the sustainability of the methods constitute the challenges. Global best practices in the management, treatment, disposal, and governance of sludge concentrate on sustainable

sludge management and environmental standards adherence. New technologies and management strategies to these challenges have been investigated in recent studies spanning many geographical areas informed by the most recent technical knowledge.

In areas that have special problems e.g. Palestine, the proper management of sludge is of significant interest within the context of environmental stewardship (PWA, 2016). Sludge management in Palestine is not only a question of environmental concerns but also of political and geographical complexities, which only call for proper and considerate solutions.

This research reveals the urgent need for sustainable management of municipal sludge in Palestine. The increasing production challenges, the stricter environmental requirements and the sustainability dimensions require urgent action. It suggests a decision support framework that is relevant to the context of wastewater sector in Palestine to fill the existing gaps and enhance the sludge management decisions. The framework recommends a change in the strategy towards more sustainable and efficient wastewater management through the integration of government initiatives and investments in advanced treatment facilities. This approach is intended to advance technological and environmental goals, improve the health of inhabitants, and contribute to the overall stewardship of the environment. As such, this study is important as it presents solutions which are relevant to the increasing sludge management issues that the region faces. Sludge management is an important part of the wastewater treatment process and poses a significant environmental and health risk in Palestine.

This research reviews the current national governance structure for sludge management in detail. The study aimed at assessing the legal framework, technical guidelines, funding, and major actors to reveal problems and potential for enhancement. This approach ensures that significant public health and environmental sustainability improvements are possible through effective governance and collaboration with other stakeholders. This research is practical in that it offers specific recommendations that can be used to address sewage management in Palestine and other places.

1.2 Problem Statement

Due to the increasing production of sewage sludge and the need to meet ever stricter environmental quality standards, as well as the lack of treatment and disposal facilities, conventional management of sludge has to be reexamined. However, the need to find sustainable approaches provides an excellent opportunity to shift the paradigm in sludge management from the current approaches that are mainly oriented towards the disposal of sludge to new approaches that can enhance the recycling and recovery values. This shift is in conformity with sustainability and circular economy frameworks and is a hopeful vision of the future of sludge management in Palestine.

Sewage sludge treatment and disposal have environmental impacts that are a big problem. Sewage sludge is high in organic load and low in dewaterability, a significant contributor to climate change, and leads to high operating costs. However, some disadvantages of the current sludge management technologies have been identified. Therefore, there is a clear need to research and devise new sludge management strategies. Discussion of the current literature in this area is gradually shifting to the perspectives of the recovery of valuable compounds from sludge.

1.3 Research Objectives

This research thoroughly examines the barriers hampering the advancement of sewage sludge management in Palestine, specifically focusing on the West Bank, a region that has shown a certain level of political and technical openness over the past decade. This openness signals an inclination to enhance the utilization of sewage sludge management—an option starkly contrasting Israel's punitive blockade on the Gaza Strip, a region that is currently restricted in its access by land, air, and sea.

The main goal of this study is to contribute significantly to developing sustainable practices for sewage sludge management in the West Bank. This will be accomplished by evaluating the governance context surrounding sludge management and clarifying the fundamental elements of sewage sludge management in Palestine.

1.4 Research Questions

Given the questions mentioned above, the primary research objectives are as follows:

- How supportive is the governance of sludge management in Palestine?
- Do the characteristics of the produced sludge comply with Palestinian and international guidelines and sludge legislation?

1.5 Study hypothesis

The current state of sludge management in Palestine is perceived as burdensome; nevertheless, it is hypothesized that if strategically addressed and optimized, this condition can generate both environmental and economic benefits.

1.6 Literature Review

The literature review in this chapter adopts a semi-systematic approach, aiming to contribute to a comprehensive understanding of sludge management research. This review sheds light on biosolids/sludge management and sludge research contributions and navigates the challenges inherent in conducting systematic reviews within the management research domain (Snyder, 2019).

The review thoroughly examines various sources, including scientific articles, theses, books, governmental and non-governmental reports, and other relevant professional publications. This diverse array of sources illuminates issues related to sludge management, with a specific regional focus on Israel and Jordan, considering the cross-border issues. The review primarily scrutinizes reports published within the last ten years, supplemented by pertinent scientific articles spanning the past 15 years. With a keen emphasis on the social dimension, the review aims to present a holistic view of governmental and stakeholder practices, contributing to the region's broader understanding of sustainable water development.

1.6.1 Definitions of Key Concepts

1.6.1.1 The Concept of Governance

Governance defines a structured framework consisting of systems, processes, methods, and strategies for managing resources and relationships within a societal environment (Acharya, 2024). It includes offering leadership and direction to enterprises, addressing societal issues, and creating regulatory frameworks and accountability systems (Sullivan, 2023). Moreover, governance extends beyond governmental acts to include interactions with civil society, thus promoting participation and participatory methods (Acharya, 2024).

International entities like the United Nations (UN) and the Organization for Economic Cooperation and Development (OECD) promote governance, the European Commission and the World Bank from a normative standpoint.

- UNDP defines governance as exercising political, economic, and administrative authority to manage a nation's affairs at all levels. Governance comprises the mechanisms, processes, and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations, and mediate their differences (UNDP, 1997).
- The European Commission views governance in how public institutions conduct public affairs and manage resources—emphasizing openness, participation, accountability, effectiveness, and coherence. Good governance ensures that decisions are taken and implemented transparently and inclusively, grounded in the rule of law (EUC, 2001).
- The World Bank views governance as “how power is exercised in managing a country's economic and social resources for development.” It emphasizes accountability, transparency, and effective institutions as central pillars of good governance (Adams et al., 1996).
- From a public governance perspective, the OECD highlights governance as the formal and informal arrangements that determine how public decisions are made and how public actions are carried out. It focuses on openness, integrity, accountability, and stakeholder participation in government processes (OECD, 2017).

Governance involves guiding organizations to address societal challenges, extending beyond politics to include diverse institutions (Sullivan, 2023). It adapts state functions to structural interdependencies (Chevallier, 2003). And reflects social expectations, connecting leadership to citizenship and individual rights (Fasenfest, 2010).

Governance is an adaptable concept that can be applied to various contexts, from local to global, enabling collaboration among various entities, including NGOs, businesses, and civil society (Bevir, 2012). Local governance prioritizes community engagement and customized solutions yet may encounter difficulties in inter-jurisdictional coordination (Pahl-Wostl, 2015; Ansell & Gash, 2008). Corporate governance emphasizes transparency and accountability in corporate management (Aguilera et al., 2006). Global governance addresses transnational challenges like climate change by coordinating actions across borders and recognizing that climate impacts are interconnected. It is facilitated by international collaboration (Dzebo, 2023).

Effective governance is critical for tackling complex issues like sustainable water management. To mitigate resource depletion and promote sustainable growth, as seen in Nordic countries, decision-making must be transparent, accountable, and inclusive and integrate economic and environmental strategies (Lisenko, 2024). The "integrated approach to water management" focuses on community-based and participatory solutions to make things more sustainable (Bilalova, 2024). In particular, the Water-Energy-Food-Ecosystems (WEFE) Nexus also shows how water and other resources are connected and calls for multidisciplinary and inclusive governance to address these problems (Monico-Gonzalez et al., 2024).

Governance adaptability is essential for addressing intricate societal issues. Frameworks integrate diverse perspectives, promote inclusive decision-making, and adapt to evolving sociopolitical and economic conditions (Bevir, 2012). Adaptive governance prioritizes learning and collaboration to address environmental challenges (Folke et al., 2005). Whereas digital governance utilizes technology to improve transparency and citizen engagement (Bryson et al., 2014).

Sustainable governance enhances environmental quality, health standards, and economic well-being (Sodhi & Gök, 2024). It involves managing society's resources and interactions through systematic processes and accountability measures (Acharya

,2024). Moreover, effective governance directs organizations, addresses societal challenges, and encourages collaboration with civil society to facilitate active participation (Acharya, 2024; Sullivan, 2023).

However, sustainable governance, which harmonizes economic, social, and environmental goals, is essential, particularly in water management, where long-term security depends on sustainable practices (Jeffrey, 2015).

1.6.1.2 Wastewater Governance Concept

Water and wastewater governance is vital for sustainable resource management, addressing allocation, pollution, climate change, water scarcity, and rapid urbanization and industrialization challenges. As a key component of broader water governance, wastewater governance operates within the same political, social, economic, and administrative systems, focusing on managing, treating, and recovering reusable wastewater while ensuring equitable access and sustainability (Wawi, 2017).

This multifaceted domain requires tailored policies that reflect regional socio-political contexts, institutional capacities, and environmental conditions. Adaptive and context-sensitive approaches ensure that governance frameworks effectively tackle local challenges.

Organizations like the World Bank emphasize strengthening institutions, promoting private-sector participation, and implementing policies for cost recovery, sustainability, and inclusiveness in wastewater governance. Similarly, UNESCO advocates for a circular approach, viewing wastewater as a resource. It highlights science-based policymaking, capacity-building, stakeholder engagement, and robust monitoring to harness its potential for agricultural, industrial, and environmental benefits (UNESCO, 2017). UNEP calls for an integrated approach, combining treatment, resource recovery, ecosystem protection, and multi-stakeholder involvement, supported by clear policies and institutional (UNEP, 2016).

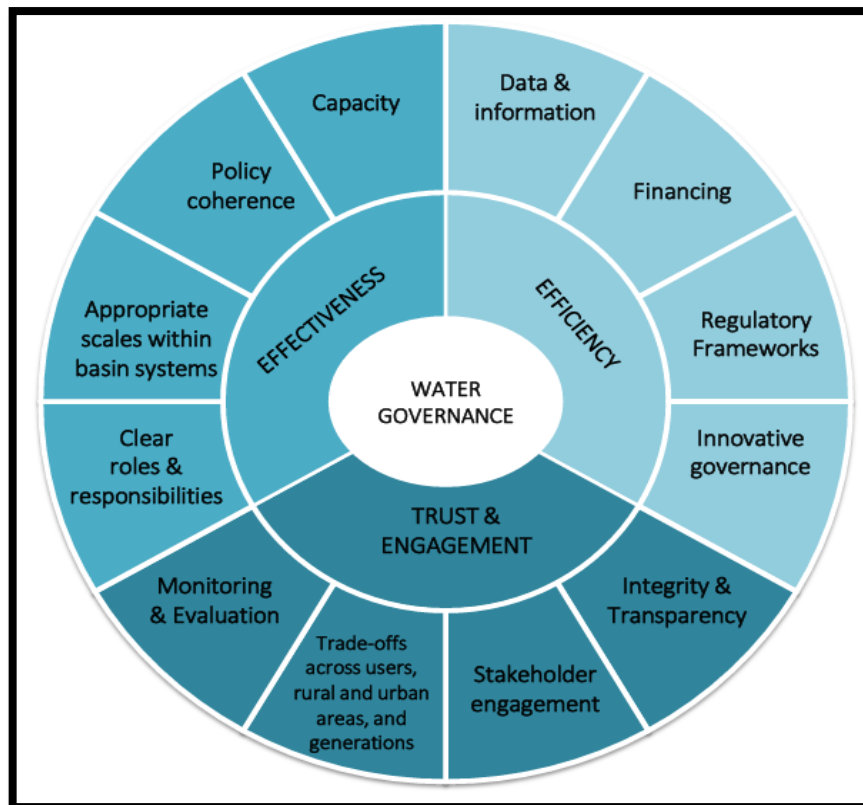
According to the OECD Principles on Water Governance (2015), Below is a concise overview of the three mutually reinforcing and complementary dimensions of water governance. These principles guide policymakers in crafting and implementing effective, efficient, and inclusive water policies as presented in figure (1).

Effectiveness: Setting and achieving clear, sustainable water policy goals and targets at all levels of government.

- Efficiency: Maximizing societal benefits and welfare from water management at the least cost.
- Trust & Engagement: Building public confidence and ensuring inclusive stakeholder participation through transparent, fair, and accountable decision-making.

Figure 1

Overview of OECD Principles on Water Governance



Note: OECD (2015).

1.6.2 Water, Wastewater, and Sludge Management in Palestine

The water, wastewater, and sludge management sector in Palestine is built on a complex set of historical agreements, governance, structures, and legal and regulatory systems. The governance structure within Palestinian territories is fragmented due to decentralized service delivery and limited coordination. In contrast, Israel has heavily controlled water resources, a situation rooted in historical arrangements, most notably in the Oslo Accords. The Water Law of 2014, for instance, is one of the few legal frameworks that have been put in place to enhance water and wastewater management

by defining institutional responsibilities, monitoring standards, and implementing changes to consolidate service providers. Regulatory gaps, weak enforcement, and outdated laws remain significant challenges in ensuring water quality and sustainable management, especially for industrial pollutants and untreated wastewater.

1.6.2.1 Historical Context and Political Disputes

Water and sanitation governance in the arid and politically divided Palestinian territories is a complicated mix of history, law, and ongoing negotiations. In the mid-1990s, as hopes for long-term peace grew, the Declaration of Principles (Oslo Accords I) briefly addressed water issues, referencing the “water rights of each party” and “equitable use of joint water resources.” It also called for cooperation on water infrastructure and desalination studies.

The 1995 Interim Agreement (Oslo II) expanded on these provisions. Article 40 of Annex III and related schedules detailed water allocation between Israel and the Palestinian Authority (PA), focusing on the Mountain Aquifer, wastewater treatment, and reuse. It also established the Joint Water Committee (JWC) to oversee water-related projects in the West Bank.

Under this agreement, Palestinians could withdraw 118 mcm annually from the Mountain Aquifer, with 28.6 mcm transferred from Israel. Future water needs of 70-80 mcm for the West Bank remain disputed, with Israel controlling 75% of the aquifer and barring Palestinian access to the Jordan River.

For over seven years, the JWC was largely inactive due to political disputes, particularly the PA’s refusal to approve Israeli water projects in settlements. This deadlock left a backlog of nearly 100 Palestinian projects awaiting approval. In 2017, the JWC was renewed on a modified basis, exempting Palestinian projects in Areas A and B from JWC approval, though natural water allocations remained unchanged as shows in Appendix (A).

For projects located in or passing through Area C, which covers over 60% of the West Bank and is under complete Israeli control, an additional construction permit must be obtained from the Israeli Civil Administration. In this area, approximately 300,000 Palestinians live in 532 residential communities (World Bank Group, 2018).

These multiple approvals make developing and maintaining critical water and sanitation infrastructure difficult, especially in Area C, where Palestinian access and development are severely restricted. Restrictions and delays in Area C exacerbate reliance on inadequate sewage management practices, such as cesspits and untreated sewage discharge, while limiting broader socio-economic progress (Rammal & Alkhazzan, 2022).

The interim agreement does not define Palestinian water rights or address all shared water sources. It mentions only the West Bank side of the Mountain Aquifer, allowing Israel to control extraction rates and access, abstracting 75% of its annual supply. Israel also controls the West Bank stretch of the Jordan River as a closed military zone, denying Palestinian farmers access.

The agreement lacks clarity regarding "future needs." Israel understands this to mean the provision of 28.6 million cubic meters per year during the interim period and 70 to 80 million cubic meters per year for final status requirements. Palestinians, however, perceive 70-80 mcm/year as provisional requirements from the Mountain Aquifer, with a conclusive agreement encompassing all shared resources, including the Jordan River (Al Haq, 2013, p. 10; World Bank, 2018).

1.6.2.2 Governance Framework

Underneath the political arrangements, a formal Palestinian official structure developed to define the distinct responsibilities for water and sanitation. Palestinian Water Authority (PWA) was established in 1995 by Presidential Resolution No. 90 to govern the water and sanitation sections. Operating with legal independence, the PWA is responsible for policymaking, strategic planning, and implementing large-scale investment projects. Under legal independence, the PWA oversees strategic planning, policy development, and execution of significant investment projects.

Water Law No. 3 of 2002 and Water Law No. 2014 strengthened and defined institutional roles and supervision. Though it plays a role, the PWA lacks official administrative control over local entities providing water and wastewater services, generating a continuous governance gap that hinders coordination and capacity-building in water management, fragmenting the system (World Bank Group, 2018).

This decentralized service delivery model results in regional governance practices and variations in service quality. The National Water and Wastewater Policy and Strategy for Palestine (2013) promotes integrating water resource management and consolidating service providers to enhance efficiency and sustainability (PWA, 2013). Nonetheless, the autonomy of local entities, coupled with restricted accountability and coordination, undermines these initiatives. Research Asmar & Arda (2023) Suggests that while principles like accountability, efficiency, and sustainability influence municipal performance, transparency and participation remain secondary concerns in governance practices.

Given the importance of improving governance arrangements and creating efficiencies in the Palestinian water sector, a comprehensive reform has been introduced to strengthen institutional structures and ensure long-term sustainability, as highlighted in the National Water Strategy under Chapter 21 – Institutional Reform, specifically Section 21.4 – Institutional Structure and Function Development (PWA, 2013).

The reforming process began in 2009, and the Palestinian Authority (PA) launched a program to reform the water sector. The program focused on separating executive and regulatory functions and establishing a transparent institutional framework to improve the performance and efficiency of water services (PWA, 2016). These efforts culminated in Decree No. 14 in 2014, which introduced Water Law No. 14 of 2014. The law sets out to develop and manage Palestine's water resources, enhance their capacity and quality, protect them from pollution and depletion, and improve water services through the principles of integrated and sustainable water resource management (PWA, 2014).

The 2014 Water Law established a new institutional framework for the water sector by separating regulatory, planning, and operational functions, as well as identifying the roles and relationships of key stakeholders:

- The Palestinian Water Authority (PWA) manages and regulates water resources, sets policies, determines allocations, protects water quality, and develops projects.
- The law authorized the creation of a National Water Company by restructuring the West Bank Water Department (WBWD) (Later to be called the National Water Company; NWC) to commercialize the water supply.

- It also established an independent Water Sector Regulatory Council to monitor the performance of water service providers, with legal and financial independence from the PWA.
- Furthermore, the law mandates the creation of Regional Water Utilities (RWUs) as legally and financially independent entities to provide water and wastewater services, requiring the consolidation of existing service providers into regional entities.

These reforms aim to enhance governance, improve efficiency, and ensure the long-term sustainability of water service provision. Chapter 8 of the legislation further reinforces these changes by detailing the framework for RWUs, which operate independently of municipalities to supply water and wastewater services (PWA, 2014). As shown in Appendix (H), a Roadmap was developed to establish RWUs, reducing more than 300 service providers (SPs) in 2018 to just three SPs by 2030.

Also, Efforts to update the administrative and legal framework for wastewater reuse focus on revising standards and bylaws to better align with Palestine's unique conditions. Current standards demand costly treatments, rendering reuse unsustainable. The revisions aim to establish more practical, affordable guidelines tailored to local needs (EQA, 2021, p. 9).

Moreover, The Palestinian national adaptation plan for climate change recognizes treated wastewater as a crucial agricultural water resource and deems it a national priority (EQA, 2016). The implementation plans outlined in the Nationally Determined Contributions (NDC) for the water sector focus on wastewater reuse from large-scale treatment plants. One key activity within this strategy is sludge management, which outlines steps to achieve wastewater reuse objectives (EQA, 2021).

As part of these broader reforms:

1. Instructions No. 3/2012 regulate the reuse of treated wastewater in agriculture. They set conditions for its use in crop irrigation, prohibit its use for watering livestock and poultry, and outline requirements for its transfer and farm-level preventive measures. The Minister of Agriculture is responsible for forming committees to establish, approve, and monitor compliance. Violations are subject to penalties under the Palestinian Agriculture Law.

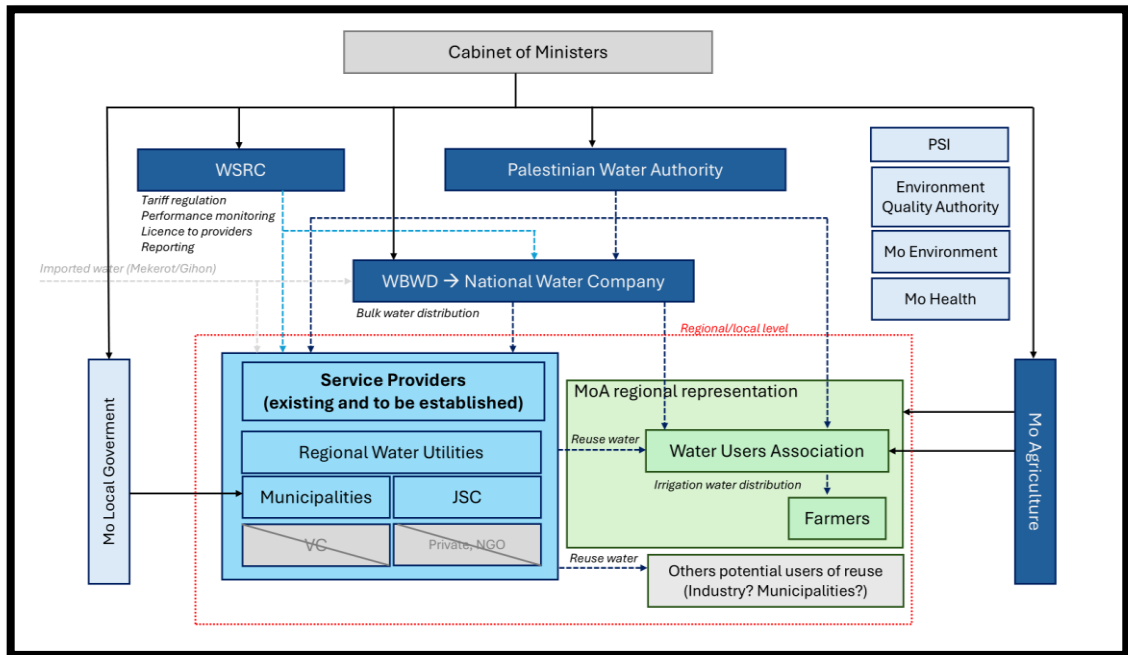
2. Decree-Law No. 18 of 2019 amends Decree-Law No. 14 of 2014 on water. It modifies the Water Sector Regulatory Council's responsibilities, requiring its decisions, such as water pricing and utility licensing, to be approved by the Council of Ministers. The Council's revenues must now be deposited in the public treasury instead of its account.
3. Instructions No. 1 of 2020 regulate well drilling, rehabilitation, groundwater extraction, and related contracting. They outline licensing procedures, well-processing, changes in use (including for drinking, with approval), license cancellation, safe closure, and record-keeping requirements.
4. Decision No. 1/2023 introduced instructions for establishing and licensing regional water facilities. These instructions outline a clear legal and procedural framework for creating and licensing regional water facilities, reinforcing efforts to enhance water sector governance, ensure regulatory compliance, and promote the efficient and sustainable delivery of water services.

Specific for Wastewater Reuse and Sludge Management:

1. Cabinet Resolution No. 16/2013 revised the Bylaw-House and Facilities' Connection System to the Public Sewage Network. This revision seeks to standardize and improve the connection of households and facilities to the public sewage network, aligning with modern infrastructure requirements and reducing environmental contamination risks.
2. The Palestine Standards Institution (PSI) updated the Sludge-usage of Treated Sludge and Sludge Disposal (PS 898:2010) to strengthen rules for its usage and disposal. This initiative aims to connect standards with environmental, agricultural, and public health concerns, local conditions, and sustainable practices.
3. The PSI revised the Technical Regulation-Treated Sludge for Agricultural Re-use (TS 59/2015) to ensure safer and more effective use of treated sludge in agriculture, aligning with updated environmental and health standards.

Figure 2

Overview of the Institutional Structure of the Water, sanitation, and Reuse Sector, 2024



1.6.2.3 Key Stakeholders and Sector Structure

Water quality control in Palestine is regulated by the Environmental Law (1999), Public Health Law (2004), and the Water Law (2014), which address water and wastewater management, environmental protection, and public health. The Water Law (2014) designates the Palestinian Water Authority (PWA) to manage water resources and monitor wastewater quality, supported by Resolution 16 of 2013 for wastewater discharge monitoring. The Palestinian Standards Institute (PSI) sets standards for water and wastewater but lacks specific regulations for industrial pollutants like slurries from quarries and stone-cutting industries, a major source of heavy metal pollution. Outdated laws and weak enforcement further limit effectiveness. Addressing these gaps is essential for improving water quality and sustainable resource management in Palestine As Presented in figure (2).

In the context of the Palestinian water and wastewater sector, several key stakeholders play significant roles. These stakeholders are involved in water management, policymaking, and service delivery. Government Ministries and Agencies, Water Utilities and Municipalities, Non-Governmental Organizations (NGOs), Private Sector, Civil Society and Local Stakeholders

- The Cabinet of Ministers oversees the Palestinian Water Authority (PWA) and the Water Sector Regulatory Council (WSRC), ensuring alignment with national policy.
- The PWA is responsible for regulatory oversight, policy formulation, and resource management.
- The WSRC monitors the performance of service providers to ensure quality, efficiency, and consumer protection.
- Regional water utilities (RWUs), municipalities, and joint service councils (JSCs) manage bulk water distribution and local service delivery.
- The Ministry of Agriculture (MoA) works with Water Users Associations (WUAs) and farmers to support irrigation and wastewater reuse for agricultural purposes.
- Environmental Quality Authority (EQA): Monitors environmental regulations to ensure compliance in water and wastewater management practices.
- Ministry of Health (MoH): Ensures compliance with public health regulations, focusing on safe drinking water and sanitation.

1.6.2.4 Legal and Regulatory Framework

Palestinian water governance is underpinned by a series of laws and decrees that address water quality, wastewater reuse, and sludge management:

I. Related Palestinian Water Law

A. The Palestinian Water Law No. 3 (2002) sought to develop and manage water resources in Palestine, improve their quality, and protect them from pollution and depletion. The law designated the Palestinian Water Authority (PWA) as the managing body for water and wastewater sectors and required that all related projects be permitted and managed by the PWA. It also declared all water resources in Palestine as public property and recognized access to water as a basic human right.

In 2014, Water Law No. 4 was introduced to enhance water service levels and establish a new institutional framework for the water sector. The law clearly defined the roles of key institutions and separated regulatory, planning, and operational functions:

- The PWA manages and regulates water resources, sets policies, allocates water, protects water quality, and oversees project development.
- The law established a National Water Company to commercialize water supply by restructuring the West Bank Water Department (WBWD).

- An independent Water Sector Regulatory Council (WSRC) was tasked with monitoring the performance of water service providers, ensuring water and wastewater quality, and overseeing efficiency.
- The law required the creation of four regional water utilities to provide water and wastewater services as financially and legally independent entities. This consolidation aimed to streamline and strengthen service provision.

Additionally, the law mandated the PWA to establish policies for monitoring water and wastewater projects, including quality control and technical standards. Article 4 highlighted the WSRC's role in overseeing service providers' performance, ensuring compliance with water and wastewater quality standards, and monitoring efficiency.

The 2014 Water Law laid the foundation for regulating, monitoring, and evaluating water and wastewater services, introducing performance indicators for service providers.

B. Palestinian Environmental Law: The Palestinian Environmental Law (1999) has not been updated since its enactment. It is the primary legal framework for environmental protection, pollution control and law enforcement. Its objectives include:

- Protecting the environment from pollution.
- Safeguarding public health and welfare.
- Promoting sustainable development and integrating environmental considerations into social and economic planning.
- Conserving biodiversity and rehabilitating damaged ecosystems.

Key articles include:

- Article 29: Mandates the Environment Quality Authority (EQA) to set standards for waste collection, treatment, reuse, and disposal in coordination with specialized agencies.
- Article 30: Prohibits discharging solid, liquid, or other substances unless the process complies with conditions set by relevant authorities.

- Article 45: Requires environmental impact assessment (EIA) studies for certain projects, with rules and procedures established by the Ministry in coordination with other agencies.
- C. The Palestinian Environmental Assessment Policy (PEAP, 2000), developed by the EQA, formalized the approval process for environmental assessment studies. Its key goals are:
- Ensuring quality of life and preserving cultural and historical values during development activities.
 - Promoting the sustainable use of natural resources and biodiversity conservation.
 - Avoiding irreversible environmental damage and minimizing reversible impacts.
- D. Palestinian Public Health Law: The Palestinian Public Health Law No. 20 (MoH, 2004), developed by the Ministry of Health (MoH), defines the government's responsibility to control diseases and remove public health risks. Relevant articles include:
- Article 42: Addresses sanitation treatment and reuse.
 - Article 45: Focuses on safeguarding water sources (wells, springs, and valleys) from pollution and misuse, in cooperation with relevant authorities.
- E. The Local Government Law: The Local Government Law No. 1 (MoLG, 1997) assigned Local Government Units (LGUs) with 27 functions and responsibilities within their jurisdictions. These include managing sewage systems under Article 15, which states that LGUs are responsible for setting up, operating, and monitoring sewage networks and public sanitation facilities.
- F. Agriculture Law: The Agriculture Law No. 2 (MoA, 2003) prohibits the irrigation of crops with untreated wastewater. Article 55 specifically requires wastewater to be treated in accordance with national standards approved by technical authorities. The Ministry of Agriculture (MoAg) supplements this with guidelines for reusing treated water in agriculture.

II. Related Resolutions

- A. Resolution 16 (2013), agreed upon by the PWA, MoLG, and MoNE, regulates the *Connection of Premises to Public Sewers*. It applies to all individuals or entities benefiting from water and wastewater services or involved in wastewater production, transport, or disposal.

The resolution covers:

- Establishment of sewage systems and treatment plants.
- Mandatory connection to public sewage networks and related procedures.
- Management of septic tanks (setup, emptying procedures, fees).
- Permits and conditions for connecting industrial, commercial, and agricultural facilities to public sewage systems.
- Standards for treated wastewater and effluent discharge.
- Maintenance, operation, and inspection fees.
- Oversight and penalties for non-compliance with sewage connection regulations.

It sets effluent limits for industrial wastewater discharged into public sewage networks, including heavy metals and other pollutants. This ensures compliance with quality standards to protect public sewage and treatment systems.

B. Resolution 25 (2010) governs environmental conditions for masonry, marble, tile, and concrete factories. It establishes requirements for granting approvals to these industries under the Environmental Assessment Policy.

Key provisions include:

- Plans and Drawings (Article 6): Factories must submit layouts showing sewage connections and wastewater treatment units.
- Wastewater Treatment (Article 11): Facilities must install systems for catchment, recycling, and treatment of industrial wastewater, including sedimentation and filtering basins separate from domestic waste.
- Additional Treatment (Article 12): Industrial wastewater must undergo further treatment if it does not meet Palestinian specifications, with testing at the owner's expense.
- Waste Transport (Article 16): Factories must safely transport waste (e.g., wastewater, residues, solid and stone waste) to designated disposal sites.

This resolution ensures industries responsibly manage wastewater and reduce environmental harm through recycling, treatment, and safe disposal practices.

III. Relevant Palestinian Standards and Technical Guidelines

Palestine has established a series of standards and technical guidelines to ensure the proper management of water, wastewater, and sludge. These standards govern water quality for various uses, wastewater reuse, and sludge disposal, prioritizing human and environmental health.

A. Drinking Water Standard (PS 41-2005)

PS 41-2005 defines the quality standards for water used for drinking, domestic purposes, and food production. It classifies water quality into three categories:

- Biological characteristics (e.g., bacterial contamination).
- Physical characteristics (e.g., color, odor, and turbidity).
- Chemical characteristics (e.g., pH, heavy metals, and other contaminants).

This standard ensures the safety of water for human consumption and its compatibility with food production processes.

B. Treated Wastewater Effluent for Agricultural Purposes (Restricted) (PS 742-2015)

The PS 742-2015 specifies the requirements for treated wastewater (TWW) and effluents from wastewater treatment plants for agricultural use. The guidelines include:

- General standards for TWW reuse in agriculture.
- Assessment of water quality parameters to determine its grade.
- Guidelines for adopting cropping patterns based on water quality, as well as mitigation measures like leaching fractions (water percolating into the soil to reduce salinity).

These standard forms the basis for agricultural wastewater reuse, ensuring safe application while minimizing environmental and health risks.

C. Obligatory Technical Instructions 34-2012: Treated Wastewater for Agricultural Irrigation

The Obligatory Technical Instructions 34-2012 regulate the reuse of treated wastewater for agricultural irrigation. Key points include:

- Treated effluents must not harm human health, animals, or plants.

- The reuse of TWW is restricted to non-vegetable crops and excludes direct groundwater recharge.
- Maximum chemical and biological limits for effluents are defined.
- Approval for irrigation reuse must be obtained from the Ministry of Agriculture (MoAg), and permits are issued in accordance with PS 742-2015.

This regulation ensures that TWW reuse in agriculture aligns with health and environmental safety standards.

D. Industrial Treated Wastewater (PS 227-2010)

The PS 227-2010 outlines the requirements and restrictions for industrial wastewater discharges and their treatment. Key provisions include:

- Industrial wastewater (treated or untreated) must comply with the effluent characteristics.
- Discharges into rivers, valleys, or water bodies, as well as reuse for irrigation, are regulated under this standard.
- Unrestricted reuse of industrial wastewater is prohibited, as per Obligatory Technical Instructions 34-2012.

This standard minimizes the environmental impact of industrial wastewater and ensures its safe reuse where applicable.

E. Palestinian Standard PS 609-2014 for Organic Fertilizers and Soil Conditioners

The PS 609-2014 defines organic materials as carbon-based materials of animal or vegetable origin or their mixtures. It also sets standards for organic soil additives, ensuring they meet quality and safety requirements for soil enhancement in agricultural applications.

F. Use of Treated Sludge and Sludge Disposal (PS 898-2014)

The PS 898-2014 provides guidelines for the use and disposal of sludge from domestic sewage treatment plants. Key provisions include:

- Treated sludge can be reused to improve soil properties or as an organic fertilizer for agriculture.

- Disposal of sludge in landfills must meet the requirements outlined in the standard.
- Standards for treated sludge align with Obligatory Technical Requirements 59-2015.

This standard ensures the safe use and disposal of treated sludge, balancing agricultural benefits with environmental safety.

1.6.2.5 Service Providers and Infrastructure

A. Service Providers

Currently, the water and wastewater services are provided through 311 service providers (SPs), which are part of local government units and village councils. This SPs Network includes 286 SPs in the West Bank. 42 SPs manage water and wastewater services, while the rest focus exclusively on water. While 25 SPs are in the Gaza Strip, 20 offer water and wastewater services, and the other five supply water (WSRC, 2023). This network serves more than 5.5 million residents, 3.2 million Palestinians in the West Bank, and 2.3 million in Gaza (PCBS, 2024).

WSRC reported that only 8% of workers in the water and sanitation services sector are women. This low percentage calls for additional efforts to empower women and expand their participation in this essential sector (WSRC, 2023).

B. Domestic water

Palestinians face significant water insecurity regarding quantity, quality, and reliability. In 2022, total water availability for domestic use in Palestine was 250.8 million cubic meters (m³), sourced from 140.4 million m³ of water pumped from Palestinian wells (51.0 million m³ in the West Bank and 89.4 million m³ in Gaza), 45.4 million m³ from springs discharge in the West Bank, and 9.6 million m³ from desalinated water in Gaza, where desalination is primarily managed by the private sector for bottled drinking water. Additionally, 94.6 million m³ was Purchased from Israeli Water Company Mekorot, with 76.3 million m³ supplied to the West Bank and 18.3 million m³ to Gaza. However, over 90 million m³ of the total water was lost due to leakage or other losses, exacerbating the already critical water scarcity (PCBS, 2024).

Palestinian per capita water consumption in the West Bank was 86.4 Liters per day (l/c/d), while in Gaza, it is 84.6 (l/c/d) (PCBS, 2024). These figures fall below the international standard of 100 liters set by the WHO (ANERA, 2023). Israeli supplies

dropped by 95% after October 2023. The UN estimates that the average Gazan survives on just 3 liters of water daily, far below the emergency standard of 15 liters. Additionally, 70% of the water is salty and contaminated, coming directly from wells (Hall et al., 2024).

Israeli restrictions on Palestinian access to water resources have long been a point of contention, significantly impacting daily life and economic stability in Palestinian communities. These restrictions include limiting the construction, maintenance, and expansion of water infrastructure in the occupied West Bank, often compelling Palestinians to purchase water from *Mekorot*, the Israeli national water company (B'Tselem, 2017). The situation is further compounded by the fact that Israeli authorities deduct the cost of this water directly from Palestinian tax revenues. According to several reports, these deductions are made without rigorous verification by the Palestinian side or oversight by an independent third party, intensifying the financial and political pressures on Palestinians (Al Haq, 2013; *AMAN*, 2024, p. 11). The Appendix (E) presents the Trends in water and sewerage deductions from Israel 2008–2016 (USD)(World Bank, 2018, p. xxii).

C. Wastewater

Regarding wastewater infrastructure, 58.5% of Palestinian households were connected to a sewage network. Although substantial investments have been made to expand sewerage networks, while over 40% of the Palestinian households are not connected, 28% depend on cesspits, 11.8% on sealed cesspools, and 1.7% on other sanitation methods, increasing the risk of groundwater contamination (PCBS, 2022).

Accurate data regarding the volume of wastewater produced in the West Bank and Gaza is lacking. According to the estimation, the total amount of sewage produced annually in the West Bank is over 62 (MCM) collected through the sewage network. Only 12.4 MCM of wastewater was through the 19-operated WWTP, and only a fifth (2.3 MCM) of the treated water was reused. As a result of inadequate planning and restrictions on developing the infrastructure needed to transport treated water to farming areas, the rest was discharged to the wadi. The most significant issue is the discharge of 25 MCM of untreated sewage into wadis each year from 350 locations. PWA estimated that (17-19) MCM of treated or mixed wastewater crossed the border in 2022, as presented in

Appendix (I), where it is treated and reused for agriculture (PCBS, 2024; PWA, 2022; World Bank, 2018).

By the mid-2000s, Israel directed sewage crossing the Green Line to treatment plants and built new facilities to address cross-border pollution. It deducted treatment costs from PA tax revenues, hoping to pressure the PA to manage wastewater (Giordano, 2018). Adding to the technical and political tensions, Israel reportedly deducts nearly 120 million shekels annually from Palestinian tax receipts for treating this sewage, even though it is mixed with wastewater from Israeli settlements in the West Bank (AMAN, 2024, p. 29). Appendix (E) presents the Trends in water and sewerage deductions from Israel 2008–2016 (USD) (World Bank, 2018, p. xxii).

In 2021, 16 Israeli wastewater treatment operators invoiced the PWA for 35 million ILS, citing "one-time costs" for WWTP operation, maintenance, and infrastructure investments (e.g., transmission lines, pumping stations, expansion). The PWA cannot contest these invoices because they are directly deducted from PA tax revenues, and the link between them and transboundary wastewater flows is often unclear (PWA Interview, 2024).

In 2022, the Palestinian Water Authority (PWA) in West Bank, with funding from the Dutch government and the United Nations Development Programme (UNDP), launched an initiative aimed at easing the Palestinian Authority's (PA) financial burden from net lending deductions. Meters were installed near the Separation Wall to record the quantity and quality of water crossing the Green Line, intending to enable a more transparent discussion about unilateral deductions for wastewater treatment costs. However, this measure only led to disputes over the reading accuracy of the collected data—particularly from the Israeli side in the Joint Water Committee (JWC)—and ultimately failed to resolve the broader clearance issue (Interview, 2023).

D. Wastewater treatment Plants

The status of wastewater treatment plants (WWTPs) in the West Bank reflects a mixed landscape of operational, under-construction, planned, and inactive facilities, highlighting the region's varied progress in wastewater management. Out of the 28 listed facilities, 19 are fully operational, accounting for approximately 70%, with a total daily capacity of around 60,000 cubic meters. Meanwhile, four facilities (14%) are in

the planning phase, with funding allocated, and three facilities (10%) are under construction. One facility is inactive despite being established, representing 3%, while another remains in the design phase, comprising 3%. (Interview PWA, 2024)

In terms of commissioning dates, a significant wave of operationalization occurred in 2014, with nearly 21% of operational facilities inaugurated that year. Technologies employed across facilities vary widely, with activated sludge systems being the most prevalent, utilized in approximately 39% of operational plants. Other advanced systems, such as membrane bioreactors (MBR) and constructed wetlands, account for a notable proportion, focusing on modern wastewater treatment methods.

Sludge management relies on treatment and disposal methods suited to local conditions and sludge characteristics from wastewater plants. Standard techniques include dewatering, thickening, and anaerobic digestion to reduce volume and stabilize organic matter. Disposal typically involves land application or sanitary landfills, with attention to environmental limits and public health.

In West Bank, the nineteen operated wastewater treatment plants (WWTPs), applying different techniques. The primary methods can be outlined as follows:

- Anaerobic Digestion: Large facilities like Nablus West use anaerobic digestion to stabilize sludge and produce biogas, then dewatering to reduce moisture content.
- Aerobic Digestion: Jericho and Tayaseer utilize aerobic processes for sludge stabilization, often combined with drying beds or centrifugation for dewatering.
- Constructed Wetlands: Smaller facilities, including Misilyya and Sarra, use low-energy, eco-friendly constructed wetlands for sludge treatment.
- Drying Beds: Drying beds to remove water from sludge naturally through evaporation in Jericho the process was effective due to the weather conditions.
- Mechanical Dewatering: Advanced facilities like Al Bireh and Al-Tireh rely on centrifuges and filter presses for efficient sludge dewatering.
- Future Innovations: Facilities like Sa'ir Arrub plan to implement composting to convert treated sludge into agricultural fertilizer, promoting resource recovery.
- Advanced Technologies: Some plants, such as Rawabi, employ modern systems like Integrated Fixed Film Activated Sludge (IFAS) for efficient treatment.

In Gaza, about 52.6 MCM. of wastewater is collected annually, 90% of which is partially treated at five operational wastewater treatment plants (WWTPs). Annual treated quantities amount to about 50.6 MCM. Around 17.3 MCM is utilized for artificial recharge and 7.1 for irrigation.

However, this wastewater is discharged into the environment instead of being reused. The treatment plants are overburdened and inefficient due to chronic underfunding and Israeli restrictions on the entry of energy and materials. As a result, untreated and partially treated wastewater is released into wadis and the sea, fueling waterborne diseases that harm the local population and neighboring regions (Irfan et al., 2024; World Bank, 2018).

After October 2023, all wastewater treatment plants (WWTPs) in Gaza, including key facilities, remain non-operational, contributing to a worsening environmental and public health crisis (CMWU Interview, 2024). The environmental and social vulnerabilities caused by inadequate sanitation infrastructure disproportionately affect poorer communities, reflecting an apparent ecological injustice (Rammal & Alkhazzan, 2022). Furthermore, insufficient data accuracy hinders wastewater management in the West Bank and Gaza Strip. Numerous service providers do not delineate wastewater costs from water services, complicating expense calculations. Operating expenses fluctuate based on subscriber count, network extent, energy consumption, and personnel costs, complicating planning and management (WSRC, 2022, p. 79).

The appendix (C) presented the status of WWTP plants in West bank, and the appendix (F) presented the status of WW managing in Gaza before October 2023.

1.6.3 Sludge Management

Before the Industrial Revolution, organic and human waste was frequently repurposed as fertilizer due to its nutrient content, such as nitrogen and phosphorus, thereby mitigating waste and water pollution (Kandiah, 1991). However, much wastewater and sludge were still dumped untreated into rivers, lakes, or oceans, causing environmental harm.

By the early 20th century, urbanization led to sewage plants separating sludge from liquid waste, but untreated sludge was still frequently dumped, damaging ecosystems.

Ocean dumping became a cost-effective method for managing growing sludge volumes, polluting coastal waters and harming marine life. The London Convention IN 1972 marked a turning point by banning sewage sludge dumping to protect marine environments (IMO, 2022).

The landfills became the primary disposal method. Sludge was dewatered or incinerated to reduce its volume before disposal. This transition also led to innovations like sanitary landfills with leachate controls.

Conventional practices such as landfilling and incineration encountered regulatory and community obstacles while substantially contributing to greenhouse gas emissions, with landfilling exerting a considerably more significant environmental impact than composting or anaerobic digestio (Zaman & Lehmann, 2013). Traditional methods like landfilling and incineration faced legislative and community challenges while contributing significantly to greenhouse gas emissions. Landfilling has a far greater environmental impact than composting or anaerobic digestion (Kiliç Taşeli, 2020).

Environmental challenges posed by conventional sludge management practices, such as landfilling and incineration, led to the development of innovative technologies and processes, supported by national and international legislation to ensure sustainable handling.

Key policies included the European Sewage Sludge Directive of 1986 (86/278/EEC), which encouraged land application of sewage sludge as a recovery strategy, and the US EPA Part 503 Biosolids Rule, which similarly promoted land application while regulating disposal practices. Additionally, the European Landfill Directive of 1999 (99/31/EC) restricted the landfilling of organic waste, including sewage sludge, to minimize environmental harm and further incentivize sustainable management methods (Bagheri et al., 2023).

1.6.3.1 Reuse Options of the Sludge

Reuse options are essential for sustainable waste management and align with the circular economy concept. Several factors need to be considered before reuse, such as health, environmental, socioeconomic, and regulatory factors, which can affect the effectiveness of sludge reuse programs. Several applications have been implemented for

sludge reuse, including agriculture, energy recovery, construction and material production, water treatment and pollution control, and others. The appendix (G) summarizes the sludge reuse options.

A. Land Application

Land applications represent one of the most prevalent methods for sludge treatment globally. Approximately 40% of sludge is utilized on agricultural land in European nations, while roughly 55% of municipal wastewater sludge in the United States is applied to land. (Shareef & Salman, 2023). The Jordanian Ministry of Agriculture regulated the land application of biosolids in late 2021 following a ban (MOWI, 2020).

Adding sludge to the soil increases soil fertility, improves soil properties, and motivates microbial activity, which enhances plant growth. It positively impacts food security, specifically in land and soil depletion communities (Rydgård et al., 2024; Xu & Wu, 2022; Yang et al., 2023).

Sludge frequently contains heavy metals such as cadmium, copper, and zinc, which can present ecological hazards if inadequately managed (Yang et al., 2023). A further challenge is the possibility of greenhouse gas emissions, as sludge application may result in elevated N₂O and CO₂ emissions. However, these emissions are usually lower than those of chemical fertilizers (Yang et al., 2023). Sludge contains pathogens and organic pollutants like pharmaceuticals that harm humans and the environment (Gianico et al., 2021; Seleiman et al., 2020).

Several countries have implemented strict regulatory frameworks to mitigate health and environmental hazards. Pyrolysis type advanced treatments can decrease hazardous contaminants, enhance phosphorus recycling and decrease GHG emissions to make sludge safer for land application (Rydgård et al., 2024). The necessity of sustainable practices is evident to reconcile the benefits of nutrient recycling with the risks of contamination. Sludge quality needs monitoring while following regulations to ensure the long-term sustainability of both the environment and agriculture (Mabrouk et al., 2023).

B. Sludge as Product

Composting: A low-cost, eco-friendly approach for treating and managing wastewater biosolids. It also helps in reducing greenhouse gas emissions which is more effective than other approaches like incineration or landfilling, thus reducing the sludge management effects (Manea & Bumbac, 2024). The process converts organic matter into humic acids, thus enriching the compost with nutrients such as nitrogen and phosphorus that enhance soil fertility and, in turn, enhance farming (Gogina et al., 2024)

Compost is a relatively cheap and environmentally safe product which can be used instead of mineral fertilizers. However, there are norms regarding the quality of composted sludge as a product (Muscarella et al., 2023). are rather loose. Nevertheless, the difficulties of implementing these standards should not be higher, especially for developing countries. The use of sludge as fertilizer has not been fully taken up by farmers and the situation is rather variable, with some expressing concerns with health risks and cultural factors (Rashid et al., 2017).

Sludge Carbonization: Carbonization, which heats dewatered sludge in low-oxygen conditions, produces carbon-rich products like biochar and charcoal. Hydrothermal carbonization (HTC) is an effective sludge energy recovery method. Sludge is converted into hydrochar, a carbon-dense, high-calorific substance that can be used as a renewable energy source (Rathika et al., 2024). In addition to hydrochar, HTC produces process water with volatile fatty acids and nutrients for anaerobic digestion to produce energy (Rathika et al., 2024). Sludge carbonization has advantages and drawbacks. The process's economic viability depends on its operational scale and by-product demand. Monitoring emissions and energy consumption is essential for ensuring sustainability. Sludge composition influences carbonized products' quality and consistency; therefore, optimizing and regulating process parameters is essential (Jellali et al., 2022). In summary, sludge carbonization, especially through hydrothermal carbonization (HTC), constitutes an efficient approach for resource recovery and energy production. Nevertheless, before extensive implementation and enduring viability, operational, financial, and environmental challenges must be resolved.

Other practices with fewer pieces of literature, such as Construction and Material Production such as Brick and Filler Material and Landfill Liners, Enzyme and Protein Extraction, and Biopolymers and Bioplastics

C. Energy Recovery

Incineration: Wastewater management relies on sludge incineration to reduce volume and recover energy. Beyond this, it also offers opportunities for sustainable resource use, making it a key element in modern waste management. The process turns waste into ash by burning the organic materials in the sludge. The ash usually makes up less than 4% of the original volume of the dewatered sludge. This method destroys pathogens and toxic compounds, making waste management safer (Shareef & Salman, 2023). However, incineration has problems, like high start-up and running costs, the need for skilled workers, and worries about the environment because it releases pollutants.

Several Countries have implemented various regulations for sludge incineration tailored to their environmental priorities and capacities (Sanin et al., 2014). In the United States, the Environmental Protection Agency (EPA) enforces strict pollution limits, necessitating advanced technologies for compliance. Similarly, European regulations prioritize uniformity, with the CEN Technical Committee 308 advocating standardized methods and practices. Despite these frameworks, challenges such as high costs, emissions, and public concerns continue to pose significant obstacles (Grobelak & Spinosa, 2023). Despite progress, challenges remain. Issues include ash disposal, public perception, and sludge incineration's economic viability. Particulate matter, nitrogen oxides, sulfur dioxide, and heavy metals from sewage sludge incinerators pose environmental risks. Improved combustion processes and air filtration systems are needed to reduce these effects. Legislation continues to balance environmental protection with sludge disposal (Golovin & Saparov, 2022).

Extracting energy from wastewater sludge has become crucial to environmentally sustainable waste management. This alteration signifies a worldwide initiative to utilize resources more effectively and mitigate environmental impact. The main methods used to get energy from sludge are:

- Anaerobic Digestion to Produce Biogas
- Thermal Processes (like Incineration, Pyrolysis, and Gasification)
- Co-Digestion and Co-Combustion

Several researchers have found that these methods have many benefits, such as using fossil fuels and lowering greenhouse gas (GHG) emissions. However, many problems need to be solved, such as the fact that technology is very complicated, costs a lot, and has to be done in a way that meets government rules.

1.6.3.2 Examples of Sludge Management Practices Jordan

In Jordan, sludge generation has markedly risen owing to the proliferation of wastewater treatment plants. In 2010, Thirty-one treatment facilities generated approximately 300,000 m³ of liquid sludge and 15,000 m³ of dewatered biosolids each year. The Al-Samra treatment facility, responsible for processing 65% of the nation's wastewater, has amassed 500,000 m³ of biosolids (Qdais, 2019).

A. Regulatory Framework

National Regulations and Standards Jordan's main regulations for sludge management come from the Environment Protection Law (No. 52 of 2006) and specific by-laws related to wastewater and sludge reuse. These rules set limits for harmful substances like heavy metals (e.g., lead and cadmium) and pathogens in treated sludge. The purpose is to ensure that sludge used in agriculture or disposed of in landfills does not harm the environment or public health. Jordan's standards are influenced by the European Union's Sewage Sludge Directive (86/278/EEC), which provides safety guidelines for land application of biosolids (Qdais, 2019; Shareef & Salman, 2023). Jordan has also introduced quality requirements for biosolids, including regular testing for harmful materials. These efforts aim to improve public trust in using treated sludge, especially in agriculture, while reducing potential risks to soil and water quality (UNHABITAT, 2009, p. 404). Alongside the above and the below- primary related laws and standards for sludge management, related Guidelines for Environmental Impact Assessments of Wastewater Treatment Plants, Occupational Health Regulations, and Climate Resilience and Geohazard Considerations were considered the sludge management in the practices.

1. Water Authority Law No. 18 of 1988 (and its amendments) (GOVJ, 1988).

This law created the Water Authority of Jordan (WAJ) as the central body responsible for overseeing water and wastewater services in the country. It grants WAJ the authority to:

- Regulate the collection, treatment, and disposal of wastewater, including sludge management.
- Develop and enforce guidelines for handling and reusing sludge.

2. Environmental Protection Law No. 6 of 2017, (MOENV, 2017).

This law replaced earlier environmental regulations, including Law No. 52 of 2006, and introduced updated provisions for protecting natural resources and preventing pollution. Its main objectives include:

- Ensuring sustainable use of resources and addressing pollution risks.
- Establishing a legal framework for regulating sludge disposal and reuse to avert soil, water, and air damage.

3. Soil Protection Regulation (MOENV, 2005):

Issued Pursuant to Subparagraph (10) of Paragraph (A) of Article (23) of Environmental Protection Law No. 1 of 2003. Official Gazette. This regulation safeguards soil against pollution and overuse, including contamination from sludge disposal, thereby maintaining soil quality for sustainable use.

4. By-law for Regulating the Discharge of Wastewater to the Public Sewerage Network (WAJ, 1994).

Issued by: Water Authority of Jordan.

This bylaw regulates industrial and commercial sewer discharges, indirectly affecting sludge management:

- Standards for controlling pollutants entering wastewater treatment plants.
- Protocols to guarantee the quality of processed sludge for secure disposal or repurposing.

5. Solid Waste Management By-Laws (MOENV, 2020).

Issued by: Ministry of Environment / Municipalities.

These by-laws address solid waste management, including provisions relevant to sludge classified as non-hazardous or hazardous waste. Key aspects include:

- Guidelines for the landfill disposal of sludge that does not meet the criteria for reuse.
- Broader measures for managing sludges alongside other types of solid waste.

6. Jordanian Standard for Reclaimed Water JS 893:2006.

Scope: Sets limits for treated wastewater quality for irrigation and other purposes.

It is often referenced in tandem with sludge management instructions because the treatment process and influent wastewater directly influence sludge quality.

(Industrial Reclaimed Water JS 1145:2006) and Related Amendments (JSMO, 2016).

Scope: Focuses on industrial effluents and water reuse criteria.

Helps to regulate pollutants that, if not properly controlled, end up in treatment plants and accumulate in sludge.

B. Oversight and Enforcement Bodies

Governance Structures and Institutional Roles Sludge management in Jordan involves multiple organizations working together:

- Ministry of Water and Irrigation (MWI): Responsible for creating policies and overseeing wastewater and sludge management across the country.
- Water Authority of Jordan (WAJ): Carries out these policies, manages wastewater treatment facilities, and monitors compliance with standards.
- Municipal Governments: Play a local role in ensuring proper sludge transport and disposal.
- Ministry of Environment.
- Jordan Standards and Metrology Organization (JSMO): Issues and maintains national standards (JS) applicable to water, wastewater, and sludge, serving as the official Jordanian standards referenced by other agencies.

- **Private Sector Operators:** Some wastewater treatment plants, such as Al-Samra, are managed under public-private partnerships, bringing in external expertise and investment.

While the private sector has contributed to improving operations at major plants, there are still issues such as weak coordination among stakeholders and a lack of resources in smaller municipalities (Qdais, 2019; Shareef & Salman, 2023). Monitoring and Enforcement the Ministry of Environment (MoEnv) works with WAJ to monitor sludge management practices. Inspections of wastewater treatment facilities and regular testing of biosolids ensure that regulations are followed. However, limited funding and staff make enforcement challenging. Violators of sludge regulations may face penalties, though stricter enforcement mechanisms could improve compliance (Shareef & Salman, 2023).

C. Technical Aspects of Sludge Treatment and Handling in Jordan

Jordan employs a variety of methods to manage sludge from wastewater treatment plants. Solar drying beds are a common method for removing water from sludge. This is a cost-effective and efficient solution for Jordan's dry climate. Plants in cities like Irbid and Zarqa rely on this method, which requires a lot of space and is less effective during rainy seasons (Qdais, 2019, p. 97).

Anaerobic digestion is another method used at the Al-Samra plant. In this process, organic material is broken down without oxygen. This stabilizes sludge and generates biogas, which is used for electricity production. This method emphasizes the possibility of energy recovery from sludge treatment (Qdais, 2019, p. 98).

Composting has been investigated in some places as a potential agricultural sludge reuse method. For example, the salt treatment plant has experimented with combining sludge and organic waste to make fertilizer. However, its adoption has been slowed by issues like farmer concerns and land scarcity (Shareef & Salman, 2023, p. 10).

Sludge-drying reed beds have been implemented in locations such as Wadi Hassan. These beds utilize reeds to improve drying and stabilization. Although promising, they necessitate regular maintenance and are most suitable for smaller-scale applications

(UNHABITAT, 2009, p. 403). These techniques show Jordan's attempts to manage sludge in a sustainable manner while investigating resource recovery.

1.6.4 Factors That Influence Sludge Management

1.6.4.1 Socio-Economic Factor Barriers

Socio-economic factors have a strong impact on how sludge is managed in many regions. High disposal and treatment expenses often stand out as a main concern, sometimes making up about 30% of capital costs and nearly half of operating costs in mid-sized wastewater plants (Qdais, 2019). Because of these high costs, decision-makers may opt for lower-cost approaches, such as simple drying beds or co-composting, instead of more advanced technologies (Koné & Strauss, 2004). However, this can come with trade-offs in terms of treatment efficiency and public safety.

Public attitudes and cultural values are also major considerations. Farmers in the West Bank may avoid using treated sludge due to health fears, a general feeling that sludge is unclean, and religious rules that focus on purity (Rashid et al., 2017). In other places, similar social barriers have been reported, including worries about odor and soil contamination (Cofie & Jackson, 2013). To overcome such fears, public awareness programs and institutional support can provide correct information about the benefits and risks of sludge reuse, boosting community acceptance (Taweesan et al., 2017).

Several nations consider skills deficit in the water sector. In the absence of competent technicians and managers, even well-financed projects may fail to operate efficiently. This deficiency underscores the necessity for vocational training and additional capacity-building initiatives (KFW). This training enables operators to acquire appropriate safety protocols, effective treatment methodologies, and cost-reduction strategies, thereby enhancing the long-term efficacy of sludge management systems.

In conclusion, sustainable sludge management requires balancing environmental concerns, cost, and social acceptance. Through education, affordable technology, and better workforce training, communities can protect public health, respect local values, and reduce costs (Shareef & Salman, 2023).

1.6.4.2 Regulatory and Policy Frameworks

Regulations and quality management programs play a very important role in controlling how biosolids (treated sewage sludge) are used on land. These rules usually set limits for harmful substances like heavy metals and pathogens, and they also guide how nutrients should be applied in a safe way (European Commission, 1986; U.S. Environmental Protection Agency [EPA], 1994). These kinds of rules help keep the land, water, and people's health safe. Strict rules are needed in many places to make sure that sludge disposal meets high safety standards (UN).

Simultaneously, policies concerning climate change and renewable energy are impacting sludge management practices. These policies promote “green” practices like anaerobic digestion, which can generate biogas and reduce greenhouse gas emissions. Such methods also allow for the recovery of resources, like phosphorus, which helps support a circular economy (IPCC, 2019; Shareef & Salman, 2023).

Moreover, stringent environmental regulations necessitate appropriate sludge treatment to mitigate risks to ecosystems and human health. Consequently, managers must select appropriate treatment and disposal methods that comply with local or national regulations, which can differ significantly. Safe and sustainable sludge management requires balancing practical costs, environmental benefits, and regulatory compliance.

1.6.4.3 Technology Barriers

Local conditions can greatly influence how sludge is treated, especially in places like the Middle East and North Africa, where climate and resources vary widely (Shareef & Salman, 2023). In Jordan, many plants rely on solar drying beds to dewater sludge, which can lead to large amounts of biosolids that must be managed properly (Qdais, 2019).

More advanced approaches, such as pyrolysis or pelleting, are underutilized due to a lack of expertise and funding (KFW). Even traditional methods necessitate precise control over variables such as temperature and mixing, which can be difficult without skilled operators (Rao et al., 2022).

Another issue is the presence of emerging pollutants, including pharmaceuticals, which can stay in sludge and pose extra risks if the sludge is reused in farming (Mabrouk et al.,

2023). Removing these pollutants—as well as harmful metals and pathogens—often calls for specialized processes that are not yet common in many MENA countries (Mabrouk et al., 2023). Overall, adapting technologies to local conditions and building technical know-how remain major challenges for sustainable sludge management in this region.

1.6.4.4 Climate Change Considerations in Sludge Management

Sludge can both aggravate and help slow global warming. Under oxygen-starved conditions—that is, landfills—breaking down this material releases methane (CH₄), a greenhouse gas with 28 times the global warming potential of carbon dioxide over 100 years (IPCC, 2019). Sludge management has to reduce methane emissions since even small quantities can significantly affect the temperature.

In Palestine, inadequate sludge management can slow down environmental damage and goals of sustainability, health, and resource security. The National Adaptation Plan (EQA, 2016), and the NDC Partnership Plan (EQA, 2021). Underline the pressing need of bettering sludge handling under national policy initiatives. By moving from disposal to advanced techniques like anaerobic digestion, which converts methane into biogas, or composting, which recycles organic matter into nutrient-rich fertilizer, Palestine can cut methane emissions and improve soil fertility. (Zhang et al., 2017)

Chang et al. (2023) claim that resource-recovery initiatives can lower greenhouse gas emissions in sludge management by 50% compared to landfilling. If the piles are well-aerated to limit nitrous oxide release, composting alone can cut emissions by 25–40%. These techniques generate renewable energy and soil amendments that enable farmers to produce more food and use less fertilizer, lowering greenhouse emissions. These initiatives help Palestine's climate action targets and strengthen nearby businesses and communities.

Chapter Two

Research Methodology

The research design, methodologies, and tools used to evaluate sludge management in Palestine are presented in this chapter. The focus is on governance, technology, and stakeholder perspectives to ensure comprehensive analysis.

2.1 Research Design

A structured and purposeful approach to addressing the identified challenges and opportunities was ensured by the meticulous establishment of the goals, requirements, and driving factors to support the attainment of the core purpose of this research study.

The research design consisted of the following key components:

2.1.1 Development of Research Objectives

The research objectives were presented schematically. As mentioned in 1.3, this approach involves a systematic approach to the research objectives:

- The study goal is to assess the sludge management and its governance framework, gaps, challenges that influence it, and explore options for sustainable resource recovery.
- Objectives were schematically presented to guide the systematic evaluation and ensure that the research addressed practical and policy-relevant issues.

2.1.2 Research Framework

The research framework identified the activities, methods and tools used, including managerial, technical, economic and environmental aspects to support effective sludge management.

Key elements of the design included setting clear objectives for evaluating sludge management in Palestine, using the Governance Assessment Tool (GAT), and combining primary and secondary data collection methods. The evaluation criteria focused on governance, technical efficiency, economic feasibility, stakeholders, as well as actors' perspectives.

2.1.3 Methodical Research Methodology

The methodology is designed to be iterative and adaptable, allowing adjustments to be made as new insights emerge. Integrating diverse perspectives and examining the interplay between policy, technology, and social and cultural factors ensured a comprehensive assessment.

2.1.4 Resources Identifications

To effectively study the key concepts of Sludge Management, Actor's interactions, Sludge/Wastewater governance, the Influence of governance on reusing sludge, and the Potential of increasing utilization of treated sludge reusing. The research integrated a targeted and multi-dimensional approach.

The research was developed by studying the related documents and collecting the available data through the following:

1. Deep Literature review: Related Laws, Regulations, Policies, Standards, and Practices (Local and International)
2. Literature review: Scientific articles, Books, Thesis, Reports, and others
3. Stakeholder Identification:
 - The national stakeholders were identified following the two steps conducted above. Through a comprehensive mapping process, several groups emerged as crucial to the discussion. These included ministries and institutions within the Palestinian Authority, landfill sites, WWTP, the private sector, research centers, and local and international organizations, which were also recognized for their significant roles. Agricultural cooperatives also surfaced as important stakeholders. As presented in the table (1).
 - A facilitation letter was prepared, signed by the dean of the college, and submitted to all identified stakeholders.
 - Following approval from stakeholder administrations, semi-structured interviews and the GAT application were conducted.
4. 17 Semi-structured interviews (in person or virtually) with the identified stakeholders and actors on the national and regional level. This aimed to Examine the roles and relationships of key stakeholders, including government authorities, WWTP operators, private sector entities, and community members.

5. The Governance Assessment Tool (GAT) application uses contextual interaction theory. Assess the existing governance framework, including the GAT quality criteria and the identified four dimensions, as explained in section 2.2, in figures (3, 4).

This study applied the GAT to assess how governance frameworks influence sludge treatment, disposal, and reuse. It evaluated the adequacy of existing policies, coordination among actors, and responsiveness to challenges like landfill rejection and public resistance to sludge reuse.

As presented in the table (1), 47 E-applications were considered and filled, either with researcher assistance or through self-filling. The application presented in appendix (B)

6. Filed observations and investigations for Documentation on Sludge Management Practices and other related documents:
 - East Nablus, Jericho, and AL Berih WWTPs. This will be followed by filling out the Wastewater Treatment Plants application, including operations, staffing, sludge management, treated water reuse, and plans. It aims to identify challenges, explore innovations, and support sludge and wastewater management improvements.
 - Zahret Al Finjan Landfill.
 - South Hebron/Meitar Crossing the nearby slurry catchment facility and the Shoket wastewater treatment plant.

Table 1*Stakeholder Identifications and Data Collection Documentations*

Tool	Stakeholder	Total Number
GAT 47 Application	Palestinian National Authority – PA	12
	Waste Water Treatment Plants (WWTPs)	9
	Landfills (Al Minya and Zahret Al Finjan)	2
	Related Experts and Researchers	10
	International and Local Non-Governmental Organizations	7
	Private Sector	4
17 Semi- structured interviews	Farmers	2
	Palestinian National Authority - PA	5
	Private Sector	3
	Farmer	1
	WWTP	3
	Related Experts and Researchers (Local and International)	3
Field Observation	International and Local Non-Governmental Organizations	2
	WWTP and Slurry Catchment area	5
	Landfill	1

2.1.5 Data Analysis

The main objective of data analysis is to obtain information that is both significant and useful. The following is a description of the qualitative analysis that was performed in this study:

Inception Phase: During this phase, desk study methodology was followed. The available related documents stated in the previous section were reviewed to analyze the current status of sludge management in Palestine, mainly in the targeted three WWTPs for the technical aspects, and the governance structures were observed in terms of the identified dimensions. This phase enriches the first research question and almost entirely responds to the second research question.

According to previous studies and current status, the result of this phase was that it did not include the "levels and scales" dimension in the assessment process due to insufficient data and lack of significance in interviews. We used the term "actors" instead of "networks" to refer to the political system in Palestine, where stakeholders often act individually rather than as networks (Wawi, 2017).

Second Phase: The second phase illustrates the interactions, field observations, and the filling of the E-Applications for GAT, which aims at assessing the Governance context with the identified four qualities criteria and their relations with the dimensions. And the WWTP application filled by the WWTP focal points.

Interviews with the main stakeholders followed the GAT Application, and the filed observations for the WWTPs, landfills, and slurry catchments area were carried out.

During this phase, a guideline from Wawi (2017) it was customized to evaluate the responses to the questions in the GAT matrix, explicitly tailored to the research case. This manual aligns with the GAT questions and provides a framework for assessing the degree of supportiveness based on all dimensions. The degree of supportiveness for each quality criterion was measured as follows:

- The context is classified as “supportive” when at least two dimensions support implementation and no dimensions are restrictive.
- The context is classified as “moderate” when at least three dimensions moderately support implementation, and there is at most one restrictive dimension.
- The context is classified as “restrictive” when at least two dimensions restrict implementation.

Data analysis and consolidation phase: The analysis results gathered from the two previous steps provided a solid foundation for structuring the data and formulating actionable recommendations for the responsible public authorities. This consolidation phase not only produced well-organized outputs but also addressed the main research question, offering clear insights and guidance.

2.2 Governance Assessment Tool

Multiple tiers are involved in water governance, which is impacted by administrative and sociopolitical structures. The complexity stems from the necessity of managing water resources in a sustainable manner, which is currently a major challenge in global water governance (Arya C S & Sole, 2024). These perspectives helped create context-sensitive frameworks. This research develops and uses the Governance Assessment Tool (GAT).

The Governance Assessment Tool (GAT) is designed to help practitioners in midsize cities assess their governance context in relation to climate adaptation and resilience. It focuses on understanding how governance factors affect the implementation of strategies and projects aimed at making cities more resilient to climate extremes. (Özerol & Bressers, 2023). Since its development in 2011, the GAT has been applied extensively in over 20 countries, primarily in the field of water policy and governance, but also in other areas such as energy efficiency (Bressers et al., 2016).

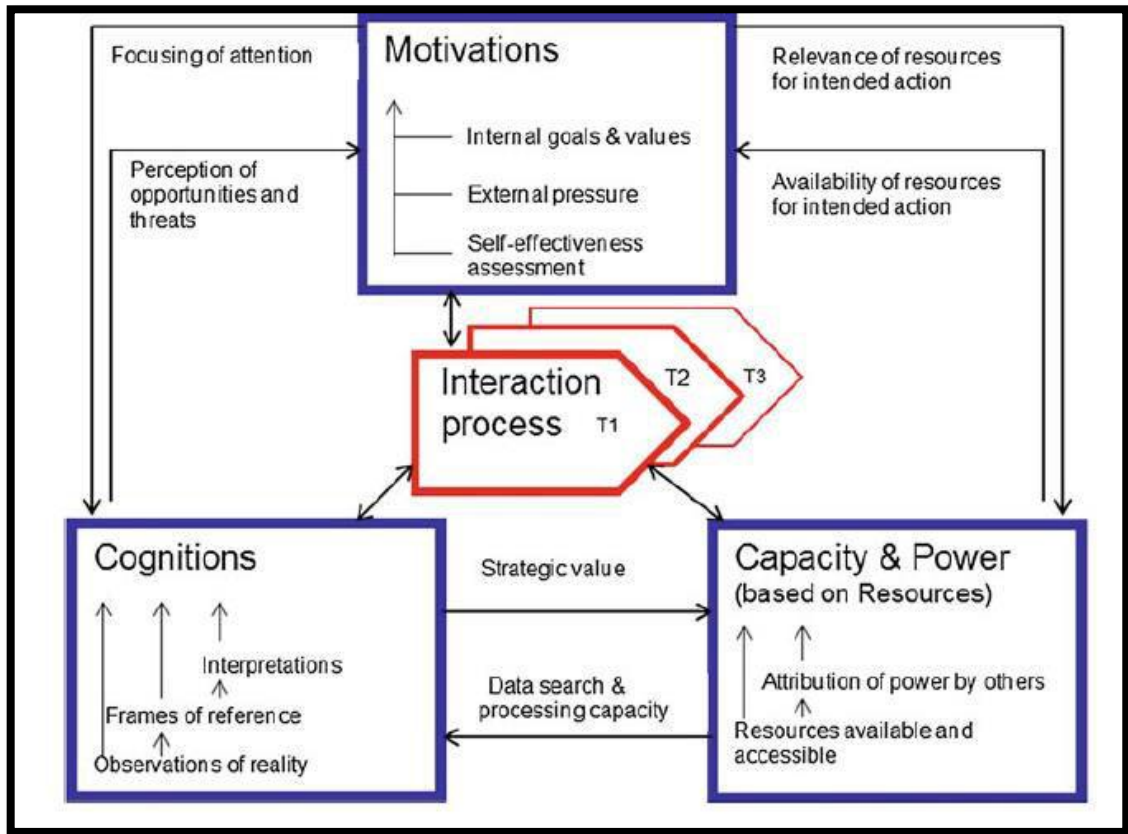
The GAT is designed by social and political scientists, incorporating inputs from practitioners and stakeholders (Casiano et al., 2017).

The GAT is included in a list of 25 assessment tools compiled by the OECD, highlighting its significance in evaluating governance frameworks (Casiano et al., 2017). It aims to provide a systematic analysis of governance contexts to support effective policy implementation (Özerol & Bressers, 2023).

The Contextual Interaction Theory serves as the foundation for the GAT. According to the theory, the actors drive a multi-actor interaction during the policy implementation process. The three traits of the actors are fundamental to the policy-making process: resource (power), cognition (information), and motivation (targeted goal). These fundamental elements drive the policy-making process by influencing one another. A process can be successful when actors have a strong combination of resources, motivations, and cognitive abilities. (Bressers et al., 2016; Wawi, 2017).

Figure 3

Actor-related factors of the policy implementation interaction process



Note: Bressers et al. (2016).

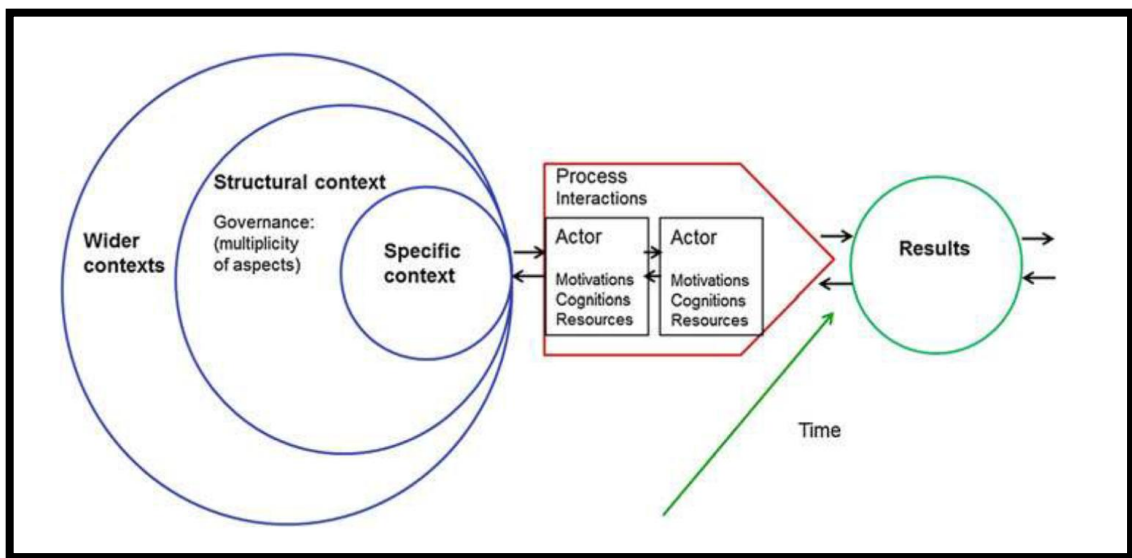
As Presented in figure (3) and according to research, Contextual Interaction Theory has simple assumptions. Main theory assumptions (Bressers et al., 2016, p. 3):

1. Policy interactions involve multiple actors. Individuals, often representing organizations or groups, or organizations themselves, can be actors when participating.
2. Many factors may affect actors only if they change relevant characteristics.
3. Motivation, cognitions, and resources give them capacity and power (Knoepfel et al., 2011: 68).
4. These three characteristics influence each other but cannot be reduced to two or one without losing insight (Mohlakoana, Nthabiseng, 2014).
5. Actor characteristics shape the process, but they can change during the process due to course and experience. A dynamic interaction between key actor characteristics drives social interaction processes and is reshaped by them. Actors can deliberately promote such changes in other actors and their own group or organization. It will be discussed further in this section.

6. Conditions and changes in the case context, such as geographical characteristics and previous decisions, can set the stage for some actors and exclude others.
7. Governance regime structure is next. Our Governance Assessment Tool targets this context.
8. Another broader circle of political system, socio-cultural, economic, technological, and problem contexts influences actor characteristics directly and indirectly through the governance regime.

Figure 4

Processes of interaction that are affected at the same time by different layers of context



Note: Bressers et al. (2016).

This research will focus on the second level, the structural or governance context. The governance context comprises five dimensions (Bressers et al., 2016; Wawi, 2017):

1. Levels and Scales Governance embodies a fundamentally multi-level nature of policy implementation. This means that policies include local, regional and national governments. This multi-level approach ensures comprehensive policies that take into account the impacts and requirements of each level.
2. Actors and networks: Governance involves government, private, and civil society actors. This dimension emphasizes the need to consider policy implementation's diverse stakeholder network and their interactions.
3. Problem and Goal Ambitions: Governance approaches problem conceptualization and goal formulation from multiple perspectives. This dimension emphasizes the

diverse perspectives and aspirations that influence policy objectives, acknowledging that stakeholders may have different views on relevant issues.

4. **Strategies and Instruments:** Governance is defined by the application of various strategies and instruments to execute policies. This aspect emphasizes the necessity of employing a variety of tools and methodologies to effectively tackle policy challenges.
5. **Responsibilities and Resources for Implementation:** Governance requires complex, multi-resource policy implementation. The distribution of responsibilities and resources between actors is crucial to policy implementation.

The GAT evaluates the five dimensions using four governance qualities: extent, coherence, flexibility, and intensity (Bressers, Bressers, et al., 2013; Bressers, Özerol, et al., 2013). The following questions define the four quality criteria:

- **Extent:** Are all relevant aspects taken into account?
- **Coherence:** Are all aspects reinforcing rather than contradicting each other?
- **Flexibility:** Are multiple roads to the goals, depending on opportunities and threats as they arise, allowed and supported?
- **Intensity:** the degree to which the regime elements urge changes in the status quo or in current developments

The GAT has been utilized in the evaluation of various water project implementations in Palestine, the Netherlands, Canada, Turkey, Romania, north-west Europe (Germany, United Kingdom, France, Belgium, and the Netherlands), and Mexico. (Wawi, 2017)

2.3 Study Area

Sludge management in Palestine, notably the West Bank, presents distinct environmental, social, economic, and geopolitical concerns. The investigation focused on three wastewater treatment plants. Anaerobic digestion, mechanical dewatering, and drying beds are used at these facilities, offering a diversified setting for monitoring sludge generation, treatment, and disposal.

Key elements impacting study area selection include:

1. The rising volume of wastewater treatment plant sludge in Palestine and the difficulties of safe disposal and utilization.

2. Geopolitical constraints affect infrastructure development, particularly in Area C, where Israeli restrictions limit access to land and resources.

The study area demonstrates the issues experienced by emerging regions with similar limits, highlighting the need for sustainable sludge management techniques.

2.3.1 East Nablus WWTP

In 1998, the financial agreement for the implementation of Sewage Project Nablus-West was signed between the German Government through KfW and Nablus Municipality. The allocated fund reached to 32million Euros. The Project consisted of construction trunk and interceptor of 12 km and wastewater treatment plant (WWTP) of 150,000 PE.

The WWTP was designed to treat 14,000 m³/day and 8.0 tons of BOD per day. The plant is located near Beit Leed village intersection. The wastewater is collected from Nablus West and five villages; namely Zawata, Beit Eba, Beit Wazan, Deir Sharaf and Qusin in the future by gravity.

The construction works of the project have been completed in July 2013; however it was put into operation in November 2013. Operation assistance for two years at the cost of 1.10 million Euros has been allocated through KfW to provide operational assistance to operate, guide and train Nablus Municipality WWTP staff.

The plant is composed of the following processes:

- Screens and grit/grease removal; as primary treatment. The screening unit consists of two types of screens. The first is coarse screen (bar space of 5 cm), and the second is fine screen (bar space of 5 mm). The screened solid material is then disposed off. Grit/grease removal unit was designed to remove sand and grits/grease from wastewater. The grease is sent to the anaerobic digester. However, grits/sands are washed out by treated wastewater in the grit classifier for sanitary disposal;
- Primary sedimentation tanks. Around 80% of organic suspended solids are settled down in two rectangular tanks, forming primary sludge. The primary sludge is thickened in a gravity primary thickener to increase its concentration from 1% to 4% to be digested in the anaerobic digester;
- Aeration Tanks. The biological wastewater treatment in the aeration tanks is the core of the WWTP. High concentration of special aerobic bacteria and other

microorganisms are activated in the aeration tanks at existence of high concentration of oxygen, called activated sludge. The soluble and other suspended organic material is digested by bacteria. Almost 90% of the power consumption of the WWTP is required to operate these tanks;

- Final sedimentation tanks. The activated sludge is settled down in two circular final sedimentation tanks. The settled bacteria is withdrawn from the bottom of the tanks and returned back to the aeration tanks as returned sludge. However, the excess sludge is pumped to the mechanical thickeners for further treatment in the anaerobic digester.

2.3.2 Al Berih WWTP

Al-Bireh Wastewater Treatment Plant is located 2 km Southeast of Al-Bireh City, which is 16 km north of Jerusalem. It is located in Wadi Al-Ein Street at 31.8903117N and 35.2304292E.

Al-Bireh WWTP was constructed in 1998 and operation started in the year 2002 with a total area of 22,000 m². It was designed to serve 50,000 people in the first phase with the possibility to serve 100,000 people in the second phase with an extended aeration treatment technology. At present, Al-Bireh WWTP serves more than 40,000 people and treats an average flow rate of 5,500 m³/d. The plant produces high quality effluent in compliance with World Health Organization (WHO) guidelines for wastewater reuse in agriculture. A refurbishment project (2015) was conducted to improve the quality of the treated effluent. The main improvement was to change the surface aeration into bubble aeration and to enhance the nitrification/denitrification process.

The plant is composed of the following processes:

- Screens and grit removal as primary treatment; composed of coarse screen, two fine screens (15 mm) and two vortex-type aerated grit chambers. The grit is cleaned in a classifier and then discharges into a container;
- The degrittied effluent passes after through a Parshall flume for flow measurement and is then collected in the distribution chamber;
- The concept of biological wastewater treatment is based on simultaneous nitrification/denitrification, using carousel-type activated sludge tanks. This biological step is carried out in two activated sludge tanks with a volume of 6,922

m² and a depth of 6.5 m. The two tanks are equipped with fine bubble aeration systems and three (2 +1) air blowers;

- The pre-treated sewage (after the primary treatment) is mixed with the return sludge and distributed to the two aeration tanks by overflow weirs. The effluent from the aeration tanks is also collected in the distribution chamber and is then allocated to the final sedimentation tanks;
- The activated sludge is separated from treated wastewater into two circular final sedimentation tanks with a diameter of 24 m and a depth of 3.85 m. Both are equipped with scrapers. Floating material and scum are collected in skimmers and are pumped from there to the scum chamber that is located close to the distribution chamber;
- UV disinfection with an open channel is installed as tertiary treatment but by-passed;
- The biological sludge is pumped from the distribution chamber into a thickener. The volume of this thickener is 350m³. The thickener concentrates the excess biological sludge before sending it to the sludge dewatering stage;
- The sludge dewatering stage is composed of two press band filters. Polymer solution is added at the entrance of the press band filters to increase the dry solids contents of the sludge. The dewatered sludge is transported to a container via two belt conveyors;
- Part of the treated effluent is reused for cleaning the wastewater network, irrigating trees in the streets, and moistening the base course layers in roads construction. Nevertheless, the largest portion of the treated effluent is discharged into Wadi Al-Ein towards the Jordan Valley.

2.3.3 Jericho WWTP

Jericho WWTP is brand new and was built as part of a cooperation program with Japan (JICA). It is based on two 4,500 m³/d capacity files, each of which treats Phosphorus and Nitrogen. Before irrigation, water is chlorinated as tertiary treatment. Counting devices monitor the inflow and outflow of WWTPs.

According to municipality data, the average inflow in 2015 was 235 m³/d. Due to the increase in connection programs, the capacity reached 500 m³/d by the end of 2016.

Drinking water sales in the Municipality are 6,860 m³/d. Thus, only 8.3% of the drinking water supply delivered to subscribers reaches WWTP as wastewater. Comparing the 8.3% ratio with the 7.8% ratio of sanitation/drinking water supply subscribers, we can assume current sanitation subscribers are among the significant water users. It is essential to track the water consumption of subscribers who are not yet connected to sanitation services.

Chapter Three

Results and Discussion

3.1 Assessment of the Governance Framework for Sludge Management

This section presents the assessment of collected data, outlined in the previous chapter, and details the results obtained by applying the GAT. The assessment is contrasted by reviewed literature to examine the effectiveness of the sludge management governance system in Palestine. As mentioned in the methodology section 2.2, the GAT is based on four critical quality criteria:

- completeness,
- coherence,
- flexibility,
- and responsiveness to change.

The evaluation involved an in-depth analysis of policies, standards, and interview responses, employing the GAT matrix and targeted questions to assess how the governance system impacts the reuse of treated sludge. These criteria are analyzed within the context of four identified governance dimensions:

- actors and networks,
- problem perspective and goal ambition,
- policy instruments,
- and responsibilities and resources.

This approach enhances the validity and reliability of the findings.

3.1.1 Assessment Summary

Table (2) presents the overall compiled responses of sludge management in Palestine, based on the GAT assessment of sixteen areas evaluated by relevant respondents. Findings indicate that the relationship between the four governance dimensions and the four quality criteria is strongly supported in three places. In contrast, ten areas are assessed as having moderate governance support, and three fall within the restrictive category. According to the methodology outlined in Section 2.2, the overall rating for the four quality criteria is moderate.

The results indicate that the existing sludge governance in Palestine is fragmented and necessitates immediate intervention. However, this also presents a considerable opportunity for enhancement via a reassessment of management techniques and regulatory structures. This potential for improvement should instill a sense of hope and optimism in the audience. Enhancing governance in this area is crucial for sustainable and efficient sludge management, and the need for immediate intervention underscores the potential for improvement.

Sludge management laws vary significantly between nations, which affects treatment and disposal methods. While some countries have particular rules for sludge combustion, others include sludge inside more general waste management systems (Sanin et al., 2014). In Europe, regulations promote the agricultural reuse of sludge, provided it meets established safety standards to protect human health and the environment (Rizzardini & Goi, 2009).

Private sector involvement and farmer participation are increasingly recognized as essential for ensuring sludge management's economic viability and sustainability. However, these stakeholders often face barriers such as limited access to policymaking, insufficient financial incentives, and the absence of supportive regulatory frameworks. In many developing or transitional governance contexts—such as parts of the MENA region, persistent institutional, financial, and capacity-related challenges exacerbate these issues, limiting the active participation of private sector actors and local communities (Mizyed, 2013).

Good governance is critical for overcoming these barriers, ensuring that sludge management strategies are environmentally sustainable and socially inclusive. Stronger institutional frameworks, equitable access to decision-making processes, and tailored financial incentives are needed to support collaboration and drive effective, long-term solutions.

Table 2*GAT Results for Sludge Management in West Bank*

Governance Dimensions	Quality Criteria			
	Completeness	Coherence	Flexibility	Intensity
Actors and Network	Supportive	Restrictive	Moderate	Moderate
Problem perspective and goal ambition	Restrictive	Supportive	Moderate	Moderate
Policy Instruments	Moderate	Moderate	Moderate	Supportive
Responsibilities and resources	Moderate	Moderate	Moderate	Restrictive
Overall assessment of the qualities	Moderate	Moderate	Moderate	Moderate

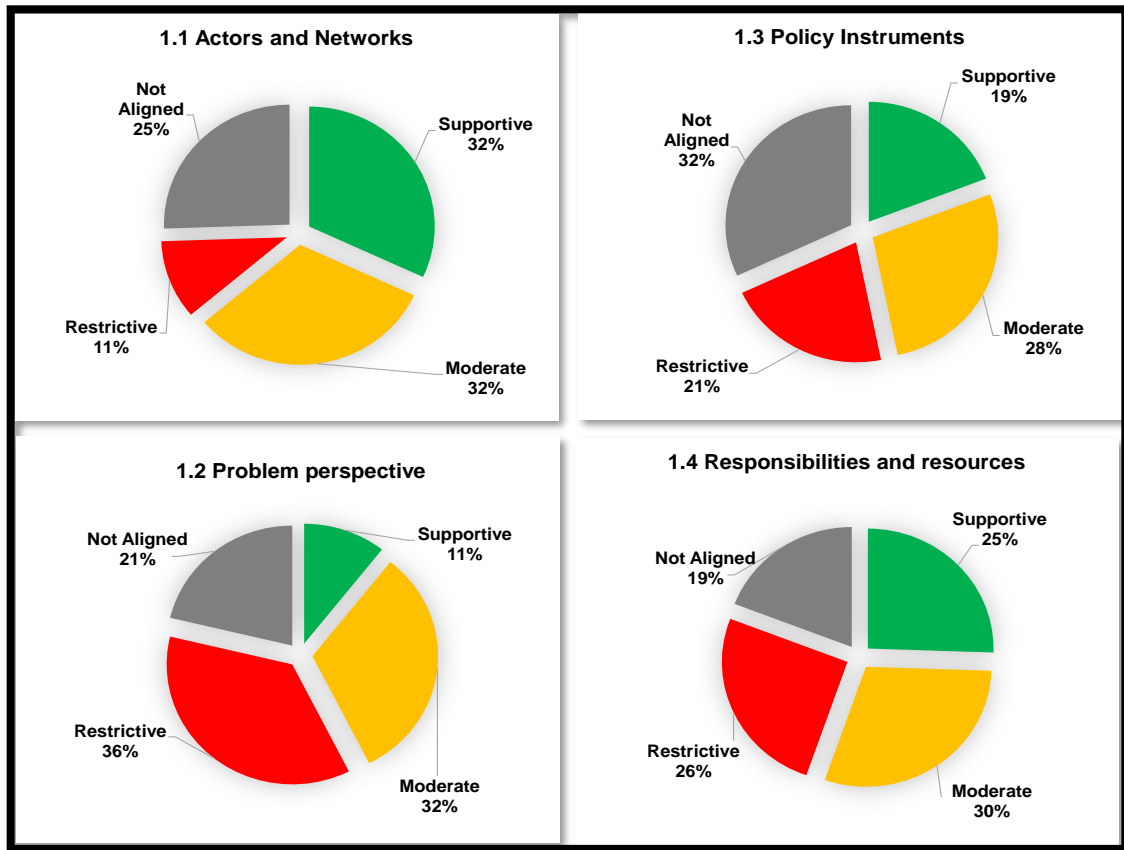
3.1.2 Completeness

Completeness in sludge management governance refers to the extent to which all vital elements, such as regulations, institutions, financing mechanisms, and stakeholder engagement, are in place and function synergistically. In Palestine's sludge governance framework, the completeness criterion has been assessed as Moderate, highlighting a partially comprehensive but still evolving system.

The evaluation of completeness in Palestine's sludge management indicates a governance framework that includes essential components yet lacks the robustness and consolidation necessary for comprehensive implementation. Coordinated action, resource allocation, and stakeholder engagement are central considerations. The importance of stakeholder engagement cannot be overstated, as it makes each participant feel valued and integral to the process. Addressing these areas, specifically the role of the private sector, funding, and technical capacity, can facilitate the transition of the sludge governance system from a moderate level of completeness to a more comprehensive and practical approach.

Figure 5

Completeness Analysis



A. Actors and Network

As presented in figure (5) this dimension, which aligns with the Completeness Criteria, was Supportive.

Approximately one-third (32%) of respondents confirm that stakeholders from all sectors are actively involved in the decision-making process. This highlights a robust foundation within Palestine’s sludge management framework, where cross-sector collaboration is prioritized and functioning effectively.

The Palestinian Authority (PA) has considered Public-Private Partnerships (PPPs) to enhance Solid Waste Management (SWM), including sludge management. In these partnerships, private companies manage and operate waste facilities, enabling sustainable waste management. Legal support and incentives from the Ministry of Local Government (MOLG) are crucial for these partnerships. MOLG is key in regulating and overseeing waste management activities (Saadeh et al., 2019).

While it is encouraging that 32% of the responses reported most stakeholders to be involved in the decision-making process, it is essential to note that this falls into the Moderate category. This suggests that while some stakeholders from essential sectors are engaged, their involvement may not be comprehensive or consistent. This inconsistency underscores the urgent need for more comprehensive stakeholder engagement.

Despite positive responses regarding stakeholder participation, 11% of respondents indicated that not all relevant stakeholders participated in the process, placing this issue in the restrictive category. This category signifies a significant governance barrier, as it indicates that specific stakeholders, particularly those from the private sector and farming community, are often excluded from the decision-making processes. These conditions highlight governance barriers that limit the involvement of stakeholders, thereby undermining the development of inclusive and adaptive governance outcomes.

A significant segment of respondents, 25%, falls into the *Not Aligned* category. Stakeholders in this category either do not fully understand the relevance of sludge management responsibilities to their work or do not regard them as important to their organizations. This lack of alignment can pose a significant challenge to achieving comprehensive stakeholder engagement and can hinder the development of effective waste management strategies.

This indicates a considerable gap in the inclusiveness of the decision-making process or a lack of interest in answering. Lessons from water governance frameworks in other regions, such as the European Union's Water Framework Directive, highlight the value of sustained efforts to enhance transparency, foster clear communication, and create inclusive stakeholder platforms. Such measures have been shown to improve engagement and reduce misalignment (Voulvoulis et al., 2017).

B. Problem perspective and goal ambition

As presented in figure (5) this Dimension was assessed as Restrictive with alignment with completeness criteria.

The most significant proportion of respondents (30%) view the standards as Restrictive. This group indicated whether technical instructions and standards enhance cooperation

and synergy between stakeholders across sectors: *"No, many of the main problems we face remain unresolved."*

Another 28% of respondents fall into the Moderate category. This group acknowledges that while the standards address many essential areas, specific gaps persist, limiting their effectiveness. The respondents answered: No, the instructions and standards address most problems and provide most solutions, but not all of them.

On the other hand, 25% of respondents regard the technical instructions and standards as sufficiently Comprehensive. This group believes the standards support broad, cross-sectoral involvement, enabling greater alignment and collaboration.

As reported in the interviews conducted with WWTPs and Landfills, the central challenge is the lack of viable sludge disposal or reuse options: With landfills rejecting sludge, Wastewater Treatment Plants (WWTPs) encounter significant hurdles in meeting standards for sludge humidity and quality. This logistical constraint can impair cooperation between WWTPs, landfills, regulatory bodies, and end-users like farmers or industry. When technical standards neither address disposal pathways nor facilitate alternative uses (e.g., composting or land application under controlled conditions), sectoral cooperation becomes piecemeal. The lack of clear technical standards can lead to fragmented stakeholder cooperation, as stakeholders may not have a unified approach to waste management. This fragmentation can hinder the development of effective waste valorization strategies, such as composting and waste-to-energy conversion (Muneswara Rao et al., 2024).

While those viewing the instructions and standards as Restrictive perceive significant policy gaps that complicate intersectoral collaboration, others find the existing framework moderately or sufficiently inclusive, demonstrating that the groundwork for alignment does exist, albeit with room for improvement.

C. Policy Instruments

Perceptions of policy instruments in Palestine's sludge management governance show considerable variation. This dimension received a moderate rating, which is consistent with completeness requirements as presented in figure (5).

The most significant percentage of the respondents, 28%, highlight that the provided tools to ensure the effectiveness of the sludge management and governance process in Palestine, according to existing strategies and laws, are insufficient.

Meanwhile, 21% view policies as Restrictive, reflecting concerns that critical mechanisms for effective sludge control are missing or hard to implement. A smaller group (19%) considers them supportive.

Nonetheless, the two groups demonstrate significant challenges. Initially, 21% perceive instruments as excessively strict, suggesting that policies may be overly rigid and insufficiently adaptable to real-world conditions, particularly in contexts of limited financial and technical resources.

The largest group, comprising 32%, demonstrates a disconnect attributed to limited awareness or the belief that sludge management tools are irrelevant to their operations. This finding indicates a communication gap or sectoral silo wherein specific stakeholders fail to acknowledge the intersection of sludge governance with their domain.

According to the interviews, the current policy framework fails to address several critical issues and lacks essential tools for effective sludge management. Although specific laboratory tests are recommended to meet Palestinian specifications, local laboratories cannot conduct or apply these tests. Though the plant has basic infrastructure for sludge treatment, it lacks advanced dewatering technologies and sufficient funding for regular maintenance, which are critical for optimal sludge management (according to insights from the PWA interview and WWTP).

Absent reliable local testing, municipal and industrial operators struggle to meet established standards, potentially causing environmental and public health risks. Overly stringent or under-resourced policies can inadvertently drive noncompliance, undermining the intended governance objectives (UNEP, 2016, p. 22).

D. Responsibilities and resources

As presented in figure (5) this dimension is assessed as Moderate. A more significant segment, 30%, indicates that while some responsibilities are assigned and resourced, others remain incomplete. For instance, WWTP has operational roles that are assigned,

but it lacks consistent funding for advanced equipment and maintenance. This partial allocation of resources impacts the facility's ability to implement its responsibilities fully, demonstrating that while some aspects of sludge management governance are supported, crucial areas still need attention. This reality exemplifies a situation where an institution's formal responsibilities are specified, yet its capacity to execute them fully is compromised by funding or technical limitations (OECD, 2015, p. 24).

Moreover, 26% of respondents reported it as restrictive. This reflects that the responsibilities are neither assigned nor provided with the necessary resources. Constraints on allocated tasks or available resources could hinder sludge management development. In governance structures with unclear budgets and mandates, organizations can find it challenging to perform their designated tasks or collaborate effectively with other sectors, leading to delays in addressing sludge management issues (UNWATER, 2017, p. 33). On the other hand, 25% reported feeling adequately supported, with roles clearly defined and resourced.

Interviews expressed that while the responsibilities of authority stakeholders are not clearly defined and allocated, the role of the private sector is still ambiguous and poorly integrated into the overall framework.

Comparing the Palestinian experience with international examples reveals both similarities and differences. In developed regions, structured governance frameworks and robust legal mandates often promote regular and meaningful stakeholder participation, leading to more cohesive and inclusive decision-making (Breulmann et al., 2022a; Van Rijswick et al., 2014)

Without such clarity, private actors may remain underutilized, missing opportunities to enhance sludge management processes.

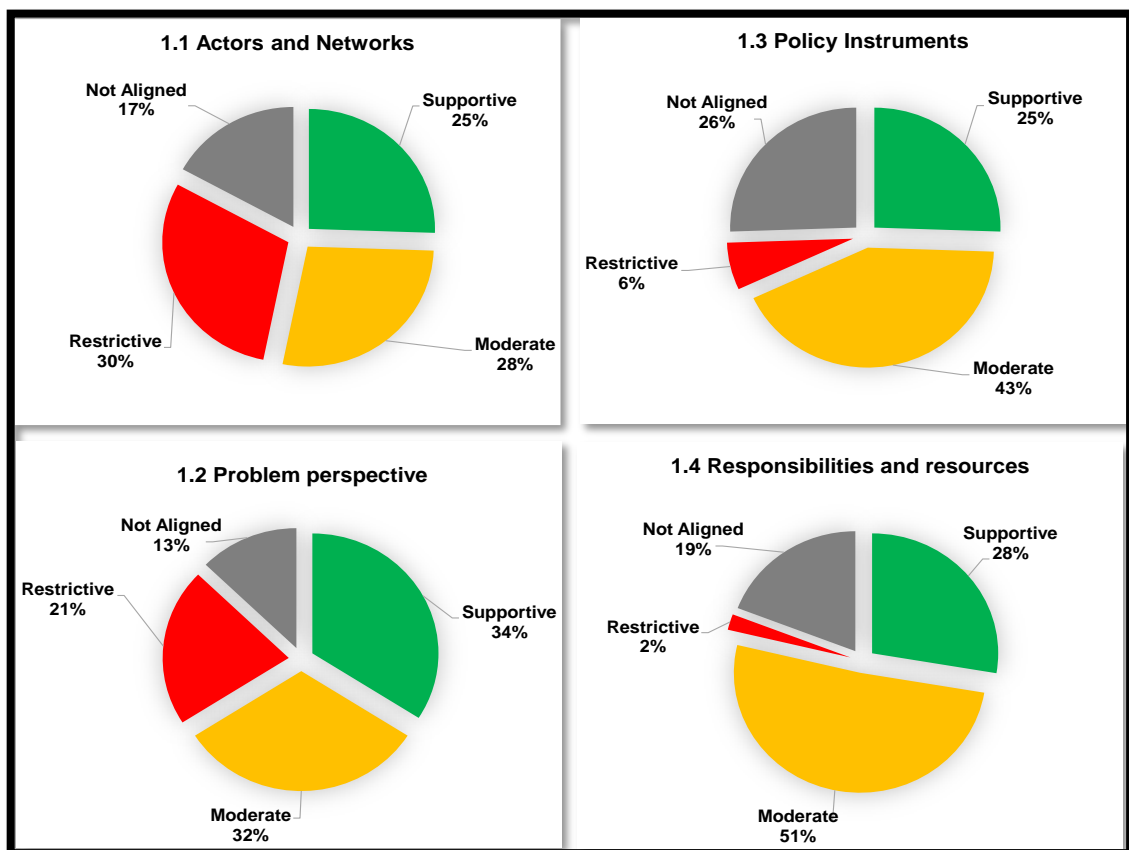
3.1.3 Coherence

Coherence in the governance framework for sludge management in Palestine reflects a mixed landscape of progress and challenges across the four key dimensions mentioned. While some areas exhibit moderate to supportive alignment, significant gaps and fragmentation persist, affecting overall efficiency and effectiveness of governance efforts.

Palestine's sludge management governance framework is moderately coherent, with notable supportive aspects but persistent gaps. Addressing these gaps requires strengthening institutional alignment, fostering stakeholder collaboration, and ensuring integrated policy development. Drawing from global best practices can provide actionable insights to improve coherence and governance outcomes in the sludge management sector.

Figure 6

Coherence criteria analysis



A. Actors and Networks:

As presented in figure (6) the relationship between coherence and Actors was assessed as Restrictive, with 30% of respondents reporting many conflicts among the relevant stakeholders. While 28% falls into the "Moderate" category, this indicates that, although most stakeholders generally uphold teamwork, certain inconsistencies remain. 25% of respondents believe collaboration among stakeholders is effectively sustained, indicating significant coherence in specific aspects of sludge management. Meanwhile, 17% of respondents responded that they were not aligned.

In the restrictive category, conflicts or misalignment between stakeholders create obstacles, limiting the cohesion necessary for a unified approach to sludge management. This restrictiveness could stem from conflicting priorities, differing mandates, or regulatory constraints that prevent smooth collaboration. Such conflicts hinder the governance framework's ability to implement sludge management policies effectively. Similar findings are observed in the broader literature, where governance frameworks with fragmented institutional mandates frequently encounter challenges in achieving stakeholder coherence (Emerson et al., 2012). For example, Emerson et al. emphasize that stakeholder collaboration is undermined when agencies lack shared objectives or clear communication channels.

Governance frameworks often face challenges in achieving coherence due to divergent problem perceptions among stakeholders. This leads to a lack of an everyday basis for agreements, particularly when different policy sectors, such as spatial planning and energy transition, have contradictions.

B. Problem perspective and goal ambition

As presented in figure (6) the GAT results of Palestine's sludge management framework from the perspective of problem-solving and goal ambition reveal varied levels of adaptability. Stakeholders' perceptions of the framework's flexibility in setting priorities and goals show promise, suggesting that challenges can be overcome and progress made with continued effort.

As Presented in Figure (6), a sizable proportion of stakeholders 34%—find the sludge management governance framework adaptable and Supportive, indicating flexibility in adjusting priorities and ambitions when necessary. This supportive response underscores the urgent need for stakeholders to align their objectives, as it is critical in governance systems dealing with complex environmental challenges like sludge management. It ensures that evolving socio-political and environmental conditions do not hinder achieving long-term goals.

For instance, similar flexibility was observed in governance studies (Dietz et al., 2003), which emphasized the importance of adaptive governance in managing environmental commons. In this context, the willingness to adjust sludge management strategies

highlights the framework's resilience and capacity for innovation, underscoring the need for flexibility in governance.

Another considerable group, representing 32% of responses, views the framework as Moderate. This moderate level of coherence presents that, despite limited adaptability, sludge management objectives align with broader sectoral interests, thereby minimizing the risk of direct conflicts.

Furthermore, 21% of respondents view the governance framework as restrictive, highlighting its inflexibility in adjusting sludge management priorities and its propensity to conflict with the goals of other sectors and stakeholders. While 13% of respondents are not aligned, they either lack sufficient knowledge or believe the issue is unimportant for the organization they represent.

Emerson et al. highlight that stakeholder collaboration is undermined when agencies do not have shared objectives. Without a common goal, it becomes difficult for stakeholders to work together effectively, leading to disjointed efforts and reduced impact (Emerson et al., 2012).

Despite these opinions, stakeholders agree with the main goals of sludge management. Reusing treated wastewater is recommended as a short-term aim to achieve long-term objectives in the Palestinian Water Authority (PWA) plans presented in 2013, 2014, and 2016 (PWA, 2013, 2014). Unresolved concerns mentioned in earlier sections may impact these reuse initiatives, hindering attempts to lessen land degradation.

C. Policy Instruments

The dimension of policy instruments within Palestine's sludge management governance framework reveals a Moderate level of coherence, as evidenced by the analysis of collaborative efforts and policy implementation strategies.

With 43% of respondents indicating a moderate relationship to coherence, it is evident that while some level of collaboration exists, full integration among stakeholders has not been achieved, as presented in Figure (6). Efforts to eliminate conflicting elements from the standards have facilitated smoother policy implementation, but these efforts have not been comprehensive enough to ensure consistent collaboration across all

stakeholders. Partial collaboration in sustainability policy frameworks often leads to fragmented implementation outcomes.

However, the moderate alignment observed in Palestine's sludge management indicates that stakeholders likely function independently, contributing to a shared goal such as reducing environmental pollution but lacking the synergy needed for deeply integrated processes. This independence can reduce friction but may also limit the transformative potential of policy implementation, such as implementing innovative sludge treatment technologies.

25% as Supportive responses indicate collaborative efforts among stakeholders, promoting coherence via shared input and joint decision-making.

Implementing a structured decision-making process that is science-based, transparent, and inclusive ensures that solutions are objective-oriented and scalable (Ko et al., 2024).

Conversely, 26% of respondents reported misalignment among policy instruments. This reflects inconsistencies in implementation strategies, with some policies promoting agricultural reuse of sludge while others impose restrictions. Such inconsistencies create barriers to coherence and weaken the overall policy framework. Expert interviews reinforced this issue, pointing to gaps in coordination and conflicting priorities that undermine the governance framework (Expert Interview, 2024).

Globally, governance frameworks with well-coordinated policy instruments often benefit from clear incentives and strong stakeholder collaboration. For example, Denmark's sludge management policies emphasize agricultural reuse and achieve high coherence through collective stakeholder engagement and economic incentives (Mabrouk et al., 2023).

D. Responsibilities and resources

As presented in figure (6) this dimension was assessed as a Moderate coherence landscape. Notable coordination and resource allocation challenges underscore the need for improved synergy and efficiency.

A significant portion of respondents, 51%, assessed the coherence of responsibilities and resources as moderate, reflecting some alignment among stakeholders. However,

overlapping responsibilities and sporadic conflicts hinder full synergy. Stakeholders often face conflicting obligations, which reduce governance efficiency. This case drove fragmented responsibilities, often leading to inefficiencies in water resource governance, particularly in contexts with multiple overlapping institutions.

In contrast, 28% of respondents view that resources and tasks are well-coordinated, fostering synergy and teamwork. Supportive responses suggest progress in areas where roles and resources are clearly defined, allowing for smoother collaboration and instilling a sense of optimism for the future.

According to the data, 19% of respondents reported being not aligned.

Before the implementation of the Water Law in 2014, a lack of coherence was prevalent, primarily due to ambiguous responsibilities and redundant roles among stakeholders (Saadeh et al., 2019). While the Water Law aimed to clarify these roles, challenges persist, particularly in coordinating the management of wastewater treatment plants (WWTPs) and environmental regulators.

WWTPs must work closely with environmental regulators to ensure adherence to sludge management standards and manage sludge effectively. However, fragmentation and inefficiencies are frequently the result of inadequate coordination between these entities. Expert interviews with the Environmental Quality Authority (EQA) reaffirmed this problem, emphasizing that a lack of synchronization compromises the overall coherence of the framework.

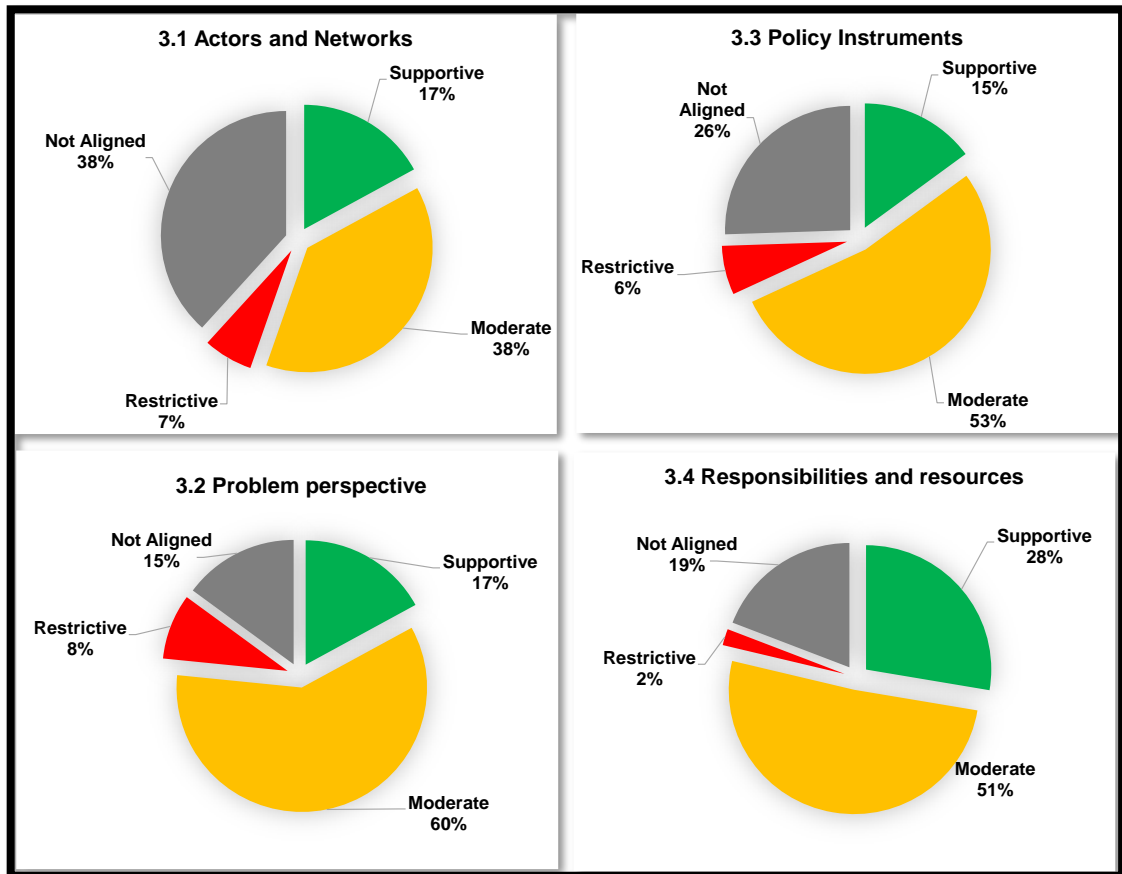
In contrast, governance systems in Sub-Saharan Africa, like those in Uganda, face similar fragmentation and resource mismanagement issues, limiting their effectiveness (Kanyesigye et al., 2019).

3.1.4 Flexibility

The rigidity of environmental laws and regulations can lead to delayed administrative processes, causing delays and inefficiencies. This inertia can prevent timely responses to environmental issues and stifle innovation by creating barriers to implementing new ideas (Souza et al., 2019).

Figure 7

Flexibility Criteria Analysis



A. Actors and Networks

As presented in figure (7) the Actors and Network dimensions have moderate flexibility. While this enables some adaptability, rapid adjustments may present potential challenges. Enhancing flexibility across governance dimensions would allow the framework to better respond to emerging challenges, integrate relevant expertise, and maintain a responsive network of engaged actors.

The largest group of respondents (38%) reported moderate flexibility, where changes are possible but require prior consultation and approval. This view suggests that while some adaptability is enabled, it may come at the cost of slower decision-making and response times. The consultative processes that enhance legitimacy may also hinder responsiveness in urgent situations (Emerson et al., 2012).

On the other hand, 17% of the respondents viewed the regulation as highly flexible in modifying the stakeholder team, which refers to the group of individuals or

organizations involved in sludge management. A smaller percentage, 7%, indicated no chance for modifications.

In another notable segment, which equals the highest portion, 38% of respondents are not aligned. This suggests that some stakeholders may be disengaged and do not prioritize team flexibility. This disconnect could hinder the system's adaptive capacity, as constraints remain on modifying roles or strategies when needed.

In Palestine's political context, import restrictions on essential equipment for sludge management and transportation can lead to significant delays. Despite these challenges, organizations like the Palestinian Water Authority (PWA), local municipalities, and NGOs have demonstrated resilience by working together to create temporary solutions or alternative strategies to sustain their operations. This ability to adapt in the face of external obstacles reflects a strong responsiveness among stakeholders.

Effective stakeholder engagement can also serve as a bridge for coordination in fragmented systems. In Switzerland, reputational power and accountability were key factors facilitating coordination among water sector actors (Lieberherr & Ingold, 2019).

B. Problem perspective and goal ambitions

The Problem Perspective and Goal Ambition dimensions demonstrate a moderate alignment with flexibility quality criteria, as 60% of respondents acknowledged the system's adaptability in adjusting priorities and ambitions for sludge management, provided consensus among all relevant stakeholders is achieved as showed in figure (7).

Consensus-driven governance will lead to slow decision-making, especially in resource-intensive environments, while increasing legitimacy by involving various stakeholders (Emerson et al., 2012). Consensus-based rigid adherence may reduce the system's adaptive capacity since reaching consensus may postpone necessary innovations or quick reactions.

On the other hand, governance structures, including predefined action thresholds or delegated decision-making authority, are more suited to handle dynamic problems (Gupta et al., 2010).

A minority of respondents (17%) regarded this dimension as supportive, highlighting the system's ability to revise instructions and standards for sludge management when needed or in response to emerging issues. Also, 8% assessed this dimension as restrictive, while 15% deemed it irrelevant to their organization or admitted a lack of knowledge to assess it.

These conflicting opinions reflect different results in other governance environments; the dormancy of formal procedures in practice is usually the outcome of fragmented authority, low stakeholder involvement, and intricate sociopolitical dynamics (Armitage, 2007).

Addressing the issues in Palestine's sludge management governance requires urgent and innovative approaches. These approaches must be inclusive and adaptive to the needs and contexts of all stakeholders involved. The urgency of this matter cannot be overstated, and innovative solutions are crucial for the future of sludge management in the region.

While Palestine's sludge management governance framework shows partial flexibility—particularly in its capacity to adapt ambitions through consensus—critical barriers remain, such as limited resources, procedural inertia, and occasional stakeholder fatigue. A balanced approach, pairing inclusive consensus-building with clear mandates for rapid action when needed, appears key to bolstering adaptive capacity in this vital environmental sector.

C. Policy Instruments

This dimension was assessed as Moderate in alignment with the flexibility quality criteria. As presented in figure (7) indicating that while specific adaptive mechanisms exist, the overall capacity to adjust to emerging needs remains limited (OECD, 2015).

Most respondents (53%) indicate flexibility in revising the guidelines and standards for sludge management when necessary or when a new issue requires attention, but only if all relevant stakeholders agree—indicating limited flexibility in reallocating tasks and responsibilities.

Approximately 15% of respondents viewed the policies as "Supportive," meaning they facilitate effective task reallocation and stakeholder collaboration. As the East Nablus

Biogas Project exemplifies, this adaptability fosters innovation and cooperation in some areas. The East Nablus Biogas Project is a significant initiative that demonstrates how existing policies can inspire creative solutions while addressing environmental challenges by converting sludge into biogas.

Of the respondents, 6% believe it is impossible to make any modifications, categorized as restrictive. This reflects inflexible institutional systems that stifle innovation and restrict the possibility of applying original ideas.

However, the fact that 26% of respondents categorized the policy instruments as 'Not Aligned' is a cause for concern. This indicates either disengagement or insufficient awareness of flexible mechanisms, which are significant barriers to promoting collaboration and effectively addressing the complexities of sludge management. It underscores the urgent need for all stakeholders to be on the same page when it comes to policy alignment.

While this level of flexibility allows for some adjustments, it does not adequately address the growing complexities of sludge management.

The East Nablus Biogas Project shows how current policies might inspire creativity and draw attention to ineffective ways of adjusting to new technologies. Current policies lack the strategic depth to guide toward sustainable practices across other WWTPs, such as energy recovery from sludge. A better government strategy could encourage more extensive application of such projects, harmonizing world efforts on sustainable wastewater management.

D. Responsibilities and Resources

Following the assessment of the Responsibilities and Resources, moderate flexibility was observed in figure (7). Although there is a certain degree of adaptability in task reallocation, complete coherence and responsiveness are impeded by persistent disengagement and slow decision-making.

Most respondents (51%) noted partial flexibility in reallocating tasks and responsibilities among stakeholders to address shared challenges, though caution remains about overlapping with others' roles.

Though it usually slows down decision-making, this sensible approach encourages stability and helps avoid mismanagement. Usually, stakeholders ask for official clearance before assigning work and postpone handling growing problems.

Effective water governance requires strong political leadership to navigate institutional arrangements' complexities and drive policy coherence. However, weak leadership can result in fragmented decision-making and hinder the implementation of comprehensive water policies (Hassenforder & Barone, 2019).

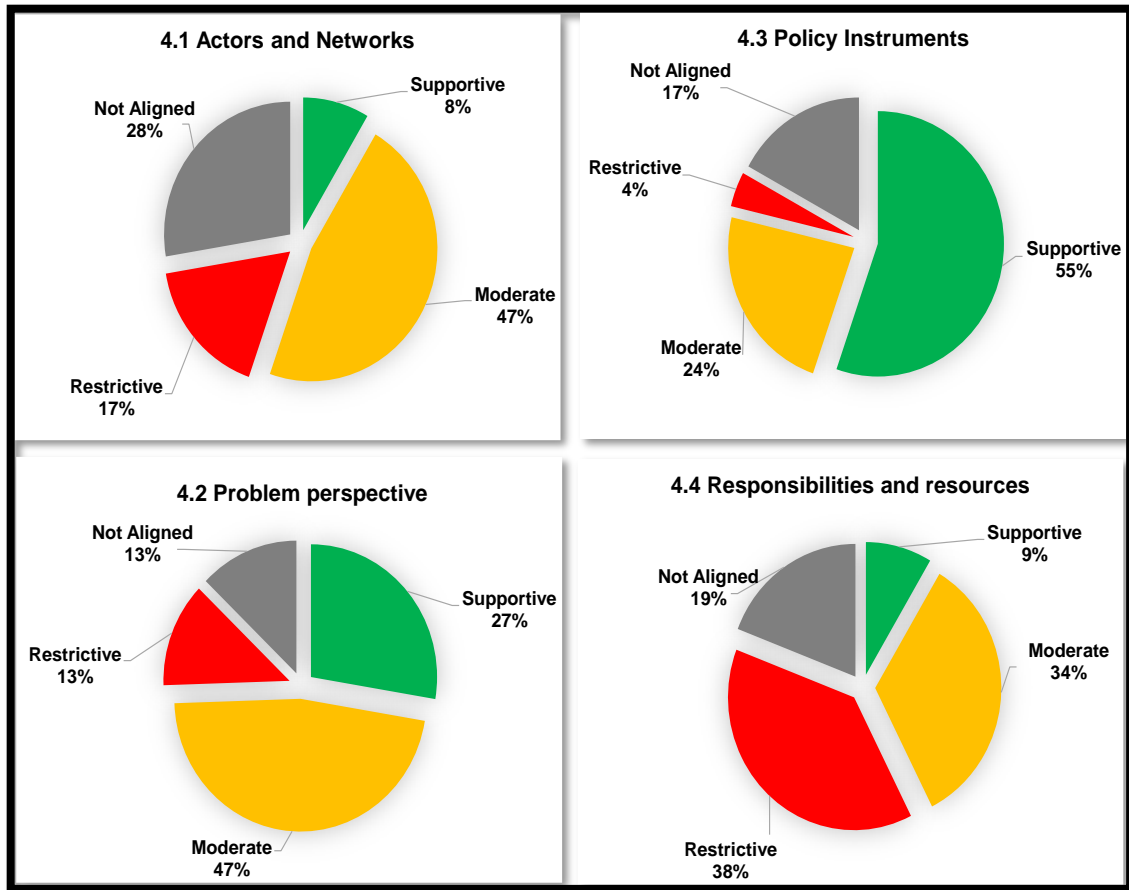
On the contrary, 26% of respondents said they were not in line because of apathy or ignorance about adaptable task-sharing policies. When certain players act independently, compromising group objectives, this part leaves holes in the governance structure. Inadequate participation systems can stop stakeholders from helping governance be efficient. Stakeholder engagement depends on meaningful and inclusive involvement (Miller et al., 2020).

Challenges in the Context of Palestine: In Palestine, external factors such as political restrictions exacerbate the challenges of flexible governance. Import bans, restricted access to materials, and jurisdictional overlaps complicate task reallocation and cooperation. Despite these constraints, some wastewater treatment facilities have demonstrated resilience by reallocating resources for critical initiatives, such as the East Nablus Biogas Project, which utilizes anaerobic digestion to convert sludge into energy. This project highlights the potential for innovation within the existing governance framework, even under restrictive conditions.

3.1.5 Pressure for change

Figure 8

Pressure for change criteria analysis



A. Actors and Network

As presented in figure (8) the Actors and Networks dimension was moderately assessed in alignment with the pressure of change. The recognized need for coherent roles and resource allocation is urgent and crucial. However, persistent barriers—such as role ambiguity, inadequate infrastructure, and occasional stakeholder disengagement—continue to undermine the network’s adaptability to the complex challenges of sludge management.

The largest portion of the respondents, 47%, reported that without the required extent, the legislative and relevant stakeholders work with continuous motivation and incentive for change and improvement and for successfully implementing the technical instructions for sludge management. In contrast, 17% of respondents believe no one cares, even if the plan fails. Only 8% of respondents fully agreed that legislative bodies

and relevant actors demonstrate continuous motivation and incentives for change, improvement, and successful implementation of sludge management instructions.

Approximately 28% of respondents reported the dimension as not aligned. Stakeholders in this category demonstrate limited knowledge or engagement for their designated entities. This will increase fragmentation increases prevailing institutional difficulties, hindering the execution of cohesive solutions (Breulmann et al., 2022b).

Disengaged actors are less likely to participate in collective initiatives for sludge management. Similar patterns have been observed in Vietnam, where stakeholder networks are often fragmented due to hierarchical governance and a lack of horizontal cooperation, leading to ineffective management strategies (Le et al., 2018).

resulting in *rigid governance structures*. Collaboration and adaptability are minimal, mirroring the context in Gaza, where political instability, infrastructural fragility, and external blockades exacerbate already weak institutional networks (UNESCO - 2018).

In Palestine, contested jurisdictions and budgetary shortfalls further exacerbate these challenges, impeding the adoption of far-reaching reforms.

B. Problem perspective and goal ambitions

This dimension was assessed as moderate according to figure (8).

This assessment indicates a combination of partial cooperation and ongoing competition, reflecting broader issues identified in Palestinian water governance. Role ambiguity, overlapping mandates, and competition for limited resources frequently result in fragmented policies, which impede the effective implementation of comprehensive sludge management strategies (World Bank Group, 2018).

In the first segment, 47% of respondents consider the current guidelines and standards as an initial step toward meaningful improvements in sludge management, though not yet transformative.

In the second segment, 27% of the respondents believe these guidelines already contribute to improvements, while 13% stated that the guidelines would not aid sludge

management. In the third segment, 13% of respondents reported being unaware of their relevance or believed unimportant to their organization.

However, some countries in the region have aligned the problem and goals and implemented them in practice. Jordan's National Green Growth Plan 2021-2025 establishes transparent sustainability and resource efficiency objectives for the waste sector, including wastewater management (Shalamai, 2023).

However, these measures risk remaining transactional (short-term and immediate) rather than transformational (long-term and strategic) without a more ambitious and cohesive shared vision. As UNESCO (2020) highlights, while incremental steps can temporarily alleviate pressures, systemic challenges persist if governance reforms lack long-term strategic objectives (UN Water, 2020).

However, progress remains incremental rather than transformative, as partial agreements and modest goals primarily aim to maintain current service levels rather than significantly improve sludge treatment or resource reuse strategies. This underscores the complexity of governance, where integrating diverse stakeholder perspectives is essential to addressing these multifaceted issues (Jones, 2005).

These limitations reduce pressure for change to a minimal level, as participants remain locked in silos with little incentive to resolve disputes or revise roles. Global analyses of water-sector governance similarly emphasize that institutional fragmentation and siloed decision-making hinder adaptive responses to evolving challenges (UNWATER, 2017).

C. Policy Instruments

Policy instruments are essential in directing sludge management practices, affecting stakeholder collaboration and adaptation to emerging sectoral challenges. The absence of regulations and the incapacity to enact legislation owing to the dysfunctional Legislative Council in Palestine pose substantial obstacles to the extensive implementation of wastewater reuse practices (Wawi, 2017).

The figure (8) indicates that a majority (55%) of respondents believe that the existing sludge management guidelines require substantially modifying operational practices relative to the current situation. Simultaneously, 24% of respondents report only

moderate flexibility, suggesting slight deviations between current practices and the guidelines.

A minor yet significant minority 4% perceives adaptation as entirely unfeasible, highlighting enduring obstacles such as political instability, insufficient funding, and inadequate regulatory enforcement mechanisms. Furthermore, 17% either lacked the guidelines or deemed them irrelevant, underscoring stakeholder engagement and awareness difficulties.

This limits collaboration reduces policy instrument effectiveness and weakens governance adaptability. Disengagement compromises the system's resilience, making it harder to address the multifaceted challenges of sludge management (OECD, 2015, P20).

In Palestine, initiatives to facilitate collaboration among stakeholders exemplify these global trends. Stakeholder endorsement for task reallocation illustrates how adaptive policies can foster cooperation and augment system sustainability.

Essential governance elements, including standardized characterization techniques and institutional dynamics, are crucial for enhancing sustainable sludge management strategies. These frameworks must conform to sustainability principles to guarantee enduring efficacy. Stakeholder support for task reallocation demonstrates how adaptive policies can improve cooperation and enhance system sustainability.

In developed nations, regulations regarding sewage sludge management have progressed to include environmental safeguarding, public health considerations, and socio-economic advantages. Expedited policy implementation has enabled this thorough approach, facilitating the swift incorporation of innovative technologies and practices (Christodoulou & Stamatelatou, 2015).

The introduction of innovative technologies, such as anaerobic digestion for sludge-to-energy conversion, has been identified as a sustainable scenario for sludge management in Egypt, further demonstrating the impact of these reforms.

Governance aspects, including the availability of standardized characterization methods and institutional dynamics, play a crucial role in developing sustainable sludge

management strategies. These frameworks must comply with basic principles of sustainability and circular economy concepts ("Sustainable/integrated/sewage sludge management," 2023).

D. Responsibilities and Resources

The assessment findings show that Palestine's sludge management resources are mostly seen as insufficient or temporarily sufficient, underscoring the excellent demand for reform in this government area.

In particular, the figure (8) shows that 38% of respondents believe that present resources are insufficient for maintaining long-term operations; another 34% believe that the resources that are now in use are only temporary fixes likely to cause problems over time. These figures show significant structural flaws in the Palestinian water system, where limited technical knowledge, outdated infrastructure, and uneven financing prevent the application of efficient sludge treatment and reuse policies (World Bank, 2018, p. 84).

Only 9% of respondents say the present resource base is sufficient, suggesting possible "pockets of sufficiency" whereby local capacity-building and outside help (such as donor projects) may have somewhat reduced general constraints.

Still, 19% of respondents say they either lack knowledge or believe resource limitations have no bearing on their activities, so indicating a different distribution of awareness and influence among different stakeholder groups—often a reflection of the disjointed governance systems found in conflict-torn countries.

The severe resource limitations facing Palestinian municipalities and water authorities reflect a broader challenge of aligning responsibilities and resources in conflict-affected regions. High Pressure for Change emerges as these constraints directly inhibit operational efficiency, risk service interruptions, and weaken resilience. In Palestine, the Palestinian Water Authority (PWA) has formal water and sludge governance mandates, but insufficient funding, outdated infrastructure, and staff capacity shortfalls impede robust implementation (Shareef et al., 2022). Similarly, the World Bank notes the combination of fragmented administrative frameworks, geopolitical constraints, and

infrastructure challenges creates significant barriers to implementing cohesive sludge treatment strategies (World Bank, 2018).

While some Palestinian stakeholders report partial adequacy of resources for the near term, they also acknowledge the vulnerability of current systems if structural changes fail to materialize. This situation reflects *Constrictive Pressure for Change*, where immediate functionality does not guarantee long-term viability. Such short-sighted sufficiency often leads to mounting system stress over time. Research on international best practices suggests that reliable funding mechanisms and robust oversight structures are critical to avoid these cyclical shortfalls (OECD, 2015).

3.2 Stakeholder Analysis

Achieving an efficient and equitable water sector in Palestine requires understanding the distinct roles and responsibilities of stakeholders and actors. While stakeholders typically include any individuals or organizations that have an interest in, or are affected by, water-related decisions, actors are those institutions legally mandated to regulate and manage water resources (OECD, 2015). This distinction is especially relevant in Palestine, where political constraints, limited resources, and fragmented infrastructure make water governance difficult (World Bank, 2018).

Table 3*Comparison of Stakeholders and Actors in the Palestinian Water Sector*

Criteria	Stakeholders	Actors
Definition	Individuals, groups, or organizations influenced by or influencing water policies.	Institutions with legal mandates for governance, regulation, and water service operations.
Role	Provide advocacy, funding, and broader policy influence.	Oversee implementation, regulate the sector, and manage water resources and services.
Responsibilities	Seek equitable distribution, community representation, and resource mobilization.	Maintain infrastructure, set and enforce regulations, and ensure service quality.
Examples	International donors, NGOs, local communities, and global organizations.	Palestinian Water Authority (PWA), Water Sector Regulatory Council (WSRC), Coastal Municipalities Water Utility (CMWU).
Challenges	Possess limited authority over direct implementation and rely on formal institutions for action.	Cope with restricted budgets, fragmented governance structures, political barriers, and enforcement issues.
Key Focus	Focus on ensuring marginalized groups are heard and resources are allocated fairly.	Emphasize efficiency, operational capacity, legal compliance, and infrastructure development.
Coordination	Collaborate with legally mandated bodies to align policies and funding with national strategies.	Engage with stakeholders for effective policymaking, resource allocation, and sector monitoring.
Examples in Context	WASH Cluster, donor agencies, community representatives.	PWA (regulatory authority), WSRC (tariff setting, licensing), CMWU (service provision in Gaza).

A. Key Differences

As Presented in Table (3) stakeholders encompass a broad range of parties that influence or are influenced by water sector decisions, including local communities, non-governmental organizations (NGOs), and international donors (Freeman, 1984). They can influence policy through advocacy, research, and funding, but formal institutions usually implement their recommendations (OECD, 2015). These groups focus on

providing water to vulnerable populations and promoting sustainability (UNICEF, 2020).

Conversely, actors are the legal entities that are authorized to implement policies, supervise operations, and enforce regulations. Entities such as the Palestinian Water Authority (PWA), the Water Sector Regulatory Council (WSRC), and regional utilities like the Coastal Municipalities Water Utility (CMWU) are responsible for the primary regulation, infrastructure development, and day-to-day service provision under the Palestinian Water Law (Law No. 14 of 2014) (PWA, 2018). This position necessitates the ability to negotiate budget constraints, political constraints, and infrastructure maintenance obstacles (World Bank, 2018).

Examples of Actors

- Palestinian Water Authority (PWA).
- Water Sector Regulatory Council (WSRC).
- Coastal Municipalities Water Utility (CMWU).
- Ministry of Agriculture (MoA).

Examples of Stakeholders

- WASH Cluster: This cluster brings together humanitarian agencies, NGOs, and donors to address emergencies and chronic needs in water, sanitation, and hygiene (UNICEF, 2020). Its main function is coordination rather than direct service provision.
- International Donors (e.g., World Bank, USAID, European Union): Donor agencies supply funding, technical expertise, and training for local institutions. They rely on formal actors like the PWA and WSRC to ensure that investments align with national strategies (World Bank, 2018).
- Local Communities: Residents and community leaders are essential stakeholders, advocating for equitable access and voicing local priorities. Their engagement can improve transparency, accountability, and overall project relevance (Freeman, 1984).

B. Importance of Coordination

Collaboration among stakeholders and actors is essential for tackling the intricate challenges confronting Palestine's water sector (OECD, 2015). Fragmented governance frameworks, constrained financial resources, and political discord can impede progress if roles and responsibilities are not explicitly delineated and administered (World Bank, 2018). Collaborative efforts among actors can guarantee that their regulatory and service delivery responsibilities align with the overarching advocacy, funding, and community engagement initiatives stakeholders promote (PWA, 2016). This collaboration enhances accountability, optimizes resource distribution, and promotes more sustainable and equitable water services.

This fragmented governance landscape causes regional variations in governance practices and service delivery due to local entity autonomy (Signoles, 2010). Governance principles like accountability, efficiency, and sustainability affect municipal performance more than transparency and participation (Asmar & Arda, 2023).

3.3 Current Sludge Management Practices and Status

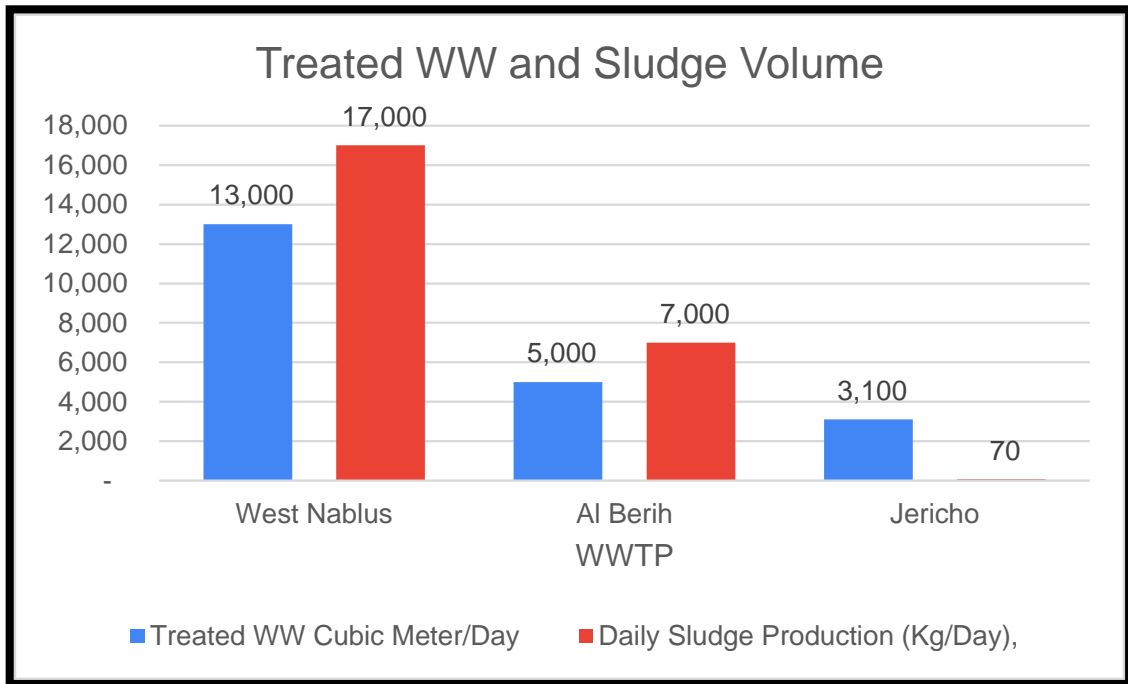
3.3.1 Overview of Sludge Production

Depending on the treatment method, different amounts of sludge are made. Activated sludge technology produces much larger amounts than other methods. The methods for sludge disposal in these technologies are predominantly determined by the water content in the sludge, which considerably amplifies its volume and the ratio of dry solids present (Shareef & Salman, 2023).

The difference in sludge generation among the assessed three wastewater treatment plants (WWTPs) – Nablus, Al-Bireh, and Jericho – is examined below regarding treatment technologies, climatic conditions, and local wastewater characteristics. As presented in Figure 9.

Figure 9

Treated WW and Sludge Volume

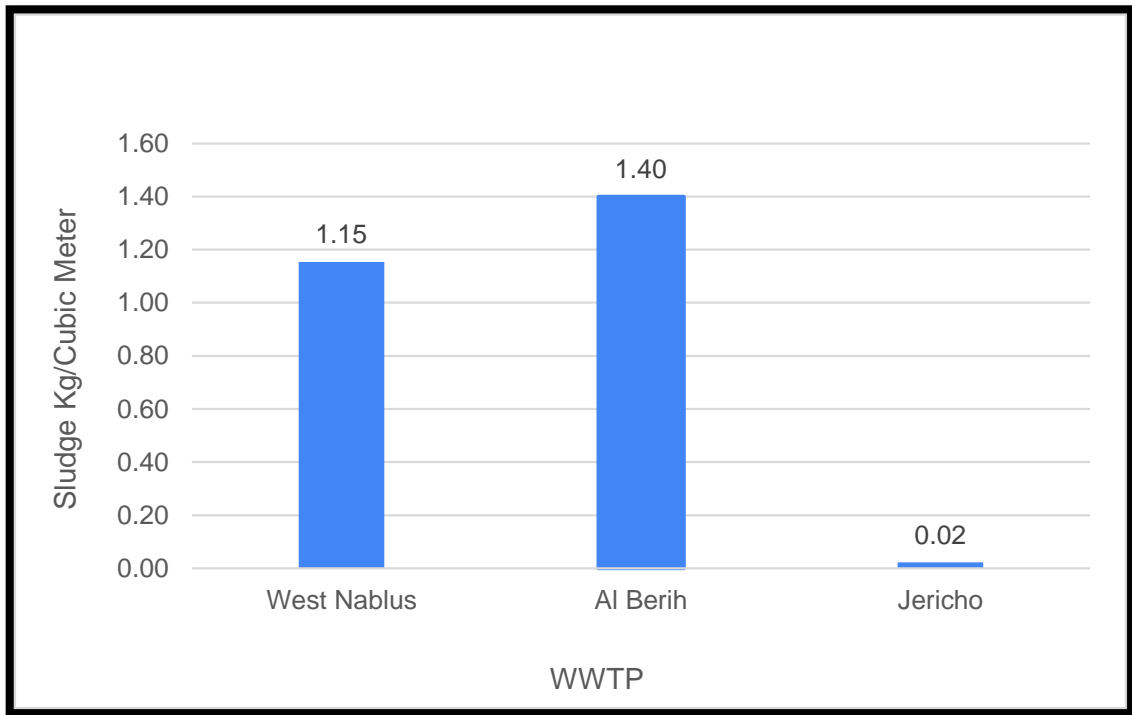


- Nablus WWTP: The treatment of 13,000 M³ wastewater daily produced approximately 17 tons of sludge, which equates to approximately 1.3 Kg/M³ and a total humidity of 75%.
- Al-Bireh WWTP: treated 5,000 cubic meters of wastewater daily, which produced about 7 tons of sludge. That is 1.4 Kg/M³ with a total moisture content of around 85%.
- Jericho WWTP: Treating 3,100 cubic meters of wastewater daily resulted in about 70 kilograms of sludge. This equals 0.0226 Kg/M³, with a total water volume of around 10%.

On the other hand, according to data from the PWA in 2014, the average sludge production was estimated at around 37 grams of dry sludge per person per day, corresponding to roughly 1.92 liters of wet sludge per person daily.

Figure 10

Extracted Sludge KG per Cubic Meter of treated Wastewater



3.3.2 Treatment Technologies and Their Impact

A. Nablus WWTP: Primary Settling and Anaerobic Digestion

Primary settlement and anaerobic digestion. The Nablus WWTP reduces the amount of sludge by dewatering, primary settling, and anaerobic digestion. Not only does anaerobic digestion lower the amount of volatile solids, it also makes biogas, which can be used to get energy back. But primary settling makes the sludge bigger, even though it is needed to get rid of suspended solids and organic matter. This step makes the next steps in the treatment process more effective by separating the solids from the liquids and making a concentrated sludge that needs more work (Koné & Strauss, 2004).

B. Al-Bireh WWTP: Extended Aeration

Al-Bireh Wastewater Treatment Plant (WWTP): Prolonged Aeration The extended aeration process produces substantial amounts of biomass owing to its extended aeration durations. The activated sludge method is recognized for generating a greater volume than alternative treatment technologies, as indicated by PWA (2014) and Shareef and Salman (2023). This method stabilizes organic matter but simultaneously elevates sludge production, complicating disposal due to elevated water content.

C. Jericho WWTP

Oxidation Ditch and Drying Beds at the Jericho Wastewater Treatment Plant (WWTP) An oxidation ditch, aerobic digestion, and drying beds at the Jericho WWTP work together to keep sludge production to a minimum. The hot and dry weather in the area is used by the drying beds to effectively remove water from the sludge. This method effectively stabilizes organic material but also elevates sludge production, complicating disposal due to elevated water content.

3.3.3 Climatic Conditions

One of the primary factors influencing sludge dewatering efficiency is climatic conditions. Among the three studied locations, Jericho is one of the best locations for cost-effective sludge dewatering. This is attributed to its hot and arid climate, which provides natural advantages for sludge drying. High temperatures and low humidity in Jericho enhance evaporation rates, significantly reducing the moisture content of sludge without the need for energy-intensive mechanical dewatering systems.

A. Nablus WWTP: Dewatering Challenges in a Mediterranean Climate

Located near Deir Sharaf village at an elevation of 400 meters above sea level, the Nablus WWTP faces distinct challenges due to its Mediterranean climate:

- **Cooler Temperatures:** The annual average temperature in Nablus is 16°C, with cold winters and mild summers. Cooler conditions slow the natural evaporation of water from sludge, reducing the efficiency of drying beds.
- **Higher Rainfall:** Receiving approximately 600 mm of rainfall annually, Nablus experiences significant operational disruptions during the rainy season, necessitating mechanical dewatering systems such as centrifuges or filter presses to maintain year-round sludge management.
- **Impact on Oxidation:** Higher elevations and cooler temperatures facilitate oxygen availability, which can enhance aerobic digestion processes. However, the slower microbial activity at lower temperatures extends digestion periods, as documented in other Mediterranean climates.

B. Al-Bireh WWTP: Semi-Arid Conditions with Urban Challenges

Al-Bireh, located near Ramallah at an elevation around 700 meters above sea level, experiences a semi-arid climate with conditions similar to Nablus but slightly more extreme:

- **Moderate Temperatures:** Al-Bireh's average temperature is approximately 18°C, which, while warmer than Nablus, still limits the efficiency of natural drying processes compared to Jericho.
- **Seasonal Rainfall:** With around 690 mm of annual rainfall, seasonal wet conditions disrupt sludge drying operations, making mechanical dewatering a necessity.
- **Urban Influence:** The high organic load from Al-Bireh's urban wastewater requires advanced treatment technologies such as extended aeration. This process generates more sludge and necessitates efficient dewatering systems, adding to operational costs.

C. Jericho's WWTP

Its location at an elevation of more than 260 meters below sea level, makes it the lowest and warmest inhabited regions globally. These unique climatic and geographical characteristics provide optimal conditions for low-cost sludge dewatering:

- **High Temperatures:** With an annual average temperature of 23°C and summer peaks above 40°C, Jericho benefits from enhanced evaporation rates, significantly reducing sludge moisture content. Studies have shown that high ambient temperatures can accelerate the drying process in open sludge drying beds, achieving moisture reductions of up to 85–90% (Rao et al., 2022).
- **Low Humidity:** The arid climate, with an annual rainfall of only 150 mm, further aids rapid evaporation, making Jericho an excellent location for natural dewatering processes.
- **Geographical Factors:** Being below sea level contributes to high atmospheric pressure and oxygen availability the best condition for bacteria activities, though this is less impactful for sludge dewatering than temperature and humidity. The reduced costs associated with natural drying in Jericho highlight its potential as a model for similar arid regions

3.3.4 Sludge Transportation Cost

Regarding the cost of sludge transportation for three asset wastewater plants, the results were as follows:

Nablus WWTP: It was highlighted that the significant expenses of untreated sludge management are due to transportation and disposal costs. Nablus WWTP incurs high costs due to the large volume of sludge (17 tons/day) requiring transport and disposal. The annual dumping cost is around 450,000 ILS.

While for Al-Bireh and Jericho, zero transportation was recorded.

3.3.5 Sludge Characteristics

The sludge quality data collected from the Jericho and Nablus wastewater treatment plants (WWTPs) suggests consistently low heavy-metal concentrations, indicating high compliance with Palestinian regulatory frameworks (PSI, 2014; TI□59–2015). Metals of particular concern, such as cadmium (Cd), mercury (Hg), and lead (Pb), are all well below recognized thresholds. These findings are consistent with studies indicating that municipal WWTP sludges, especially those subject to strict industrial controls, can maintain low contaminant levels (European Commission, 2001).

From an agronomic point of view, Jericho’s sludge stands out for its remarkably high solids content, roughly 90□percent on a dry-weight basis. When sludge is dewatered to below 20□percent moisture—an important benchmark in PS□609—it typically becomes more economical and practical to store, transport, and apply to agricultural land (United States Environmental Protection Agency *US□EPA*US□EPA, 1994). By contrast, the Nablus sludge has a moisture content of approximately 38□percent, which surpasses the 15□percent limit specified for fertilizer use under PS□609 (PSI, 2014). Consequently, additional dewatering or alternative handling methods may be necessary if Nablus sludge is to be managed as fertilizer. Nevertheless, research shows that even higher moisture sludges can be utilized successfully in agriculture under the right conditions (WHO, 2006).

Another key asset of Jericho’s sludge is its relatively high nitrogen content (2.86–4.00□percent) and the absence of fecal coliforms, suggesting robust pathogen reduction practices that align with international standards (WHO, 2006). This contrasts with

regions lacking effective pretreatment, where heavy metals and pathogens in sludge can exceed regulatory limits (Saleh & Abu Madi, 2018). Consequently, the Jericho and Nablus WWTPs appear well positioned to expand their sludge management strategies, particularly for agricultural reuse, provided they continue to meet the requirements set by PS 609–2014 and TI 59–2015. Future research, including long-term field trials, would help verify the impact of recurring applications on soil quality, crop safety, and public health, in line with WHO guidelines (WHO, 2006).

Chapter Four

Conclusions and Recommendations

4.1 Conclusions

4.1.1 Summary of Key Findings

This research aims to investigate the challenges and possibilities of sludge management in Palestine, identifying the gaps and promising areas. Nonetheless, implementing wastewater treatment facilities has been accompanied by deficiencies in sludge management due to political, economic, and technical barriers.

Key findings include:

1. **Fragmented Governance:** Current governance is marked by the absence of effective coordination, which hampers the sludge management process. Lack of coordination among the organizations involved, low compliance with the regulations, and the absence of the private sector and farmers are some of the factors noted as posing a challenge to progress.
2. **Gaps in and Technology Opportunity:** New technologies for sludge management, such as anaerobic digestion in Nablus and mechanical dewatering in Al-Bireh, are available. Nevertheless, the lack of funds, inadequate infrastructure, absence of skilled personnel, and other related constraints, including the high moisture content of the sludge, have inhibited their uptake.
3. **The Economic Cost of Waste Management:** This type of waste includes sludge, which is nonbiodegradable and expensive to manage; for example, Nablus spends \$116,000 every year to transport its sludge waste to the landfill. In addition, landfills do not accept sludge of low quality, which shows that there is a need for better pretreatment and quality control of sludge.
4. **Resource Recovery—Untapped Sources:** There are still many unexploited Biogas recovery, composting, and other reuse opportunities, which can help reduce the burden of disposal, produce energy, and enhance the production of agriculture as a sustainable effort. Continue reading.
5. **Cultural Presentations:** Farmers are generally reluctant to use the treated sludge because of health hazards, cultural reasons, and naive attitudes.

4.1.2 Implications for Sludge Management in Palestine

The results of the study reveal that in order to address the challenges in sludge management, an integrated approach is necessary. The following are the key considerations are identified below:

A. Strengthen Governance and Policy Frameworks:

- Governance reform is necessary to integrate the disjointed efforts and develop a unified plan. Roles and responsibilities must be defined, regulatory enforcement enhanced, and private sector participation encouraged.
- Public-private partnerships (PPPs) could be very beneficial in enhancing the effectiveness and the new ideas in funding and managing infrastructure projects.

B. Expand Technological Adoption:

- The use of technologies suitable for the region such as drying beds in the arid zones of Jericho should be enhanced. These systems use natural evaporation, thus making it a cheap method of reducing the sludge volume.
- The Mechanical dewatering technology which is used in Al-Bireh should be improved in order to decrease the moisture content of the sludge and make it easier to handle and dispose of it safely and at a lower cost.

C. Promote Resource Recovery:

- Anaerobic digestion of biogas is a way of producing energy from renewable sources while solving the sludge management problem. The system in Nablus can be copied and developed from the existing one.
- Composting sludge for use in agriculture may be a better option than using chemical fertilizers since it reduces the reliance on landfills.

D. Address Economic and Operational Challenges:

- Innovative funding mechanisms, such as performance-based grants, subsidies, and cost-sharing models, can improve financial sustainability.
- Regionalizing sludge management could reduce costs by consolidating resources and infrastructure, improving economies of scale.

E. Engage Stakeholders and Build Awareness:

- Community education and awareness campaigns are required to change the community's perceptions about the treated sludge. If we can convince farmers and

other consumers of the product's safety and advantages, they may have no problem using it.

- Decision-making processes that include the participation of farmers, NGOs, and private sectors will result in the implementation of appropriate and acceptable solutions.

F. Prioritize Environmental and Health Protections:

- It is crucial to continue to surveillance of the sludge treatment and reuse practices in order to prevent the risks to the groundwater and the population. Future strategies have to be based on international and local standards.
- sensitive Areas, in this case, the ones that still use untreated cesspits, require special focus in order to avoid environmental effects.

4.1.3 Concluding Remarks

Palestine's current position regarding sludge management is critical. Challenges include political, financial, and social barriers, and there are signs of a possible change. While pursuing sustainable development and resource management, Palestine can develop a model sludge management system that can help in effective waste management with minimum costs and maximum benefits.

The findings of this study underscore the need to move away from the conventional approaches to management to new and innovative approaches that are consistent with sustainable development. Biogas recovery, composting, and regional management systems offer economic advantages and benefit the environment and health. These goals will be met through the cooperation of policymakers, engineers, and local communities.

Governance, technology investment, and public participation will be key to building resilience and sustainability. Despite the geopolitical and economic barriers, Palestine can lead the way and show other countries how a resource-directed strategy can transform difficulties into strengths. This study is a call to action for all the stakeholders to re-conceive sludge management as a key to sustainable development and creating a better and more equal future.

4.2 Recommendations

This research aims to contribute more deeply to the topic of sludge management; however, due to limited resources and available data in Palestine, its scope remains focused. Still, this study is intended to serve as a gateway for future research and a starting point for greater attention to this important sector. The following recommendations provide a foundation for improving sludge management and guiding sustainable development in this field.

4.2.1 Policy Recommendations

To achieve sustainable sludge management in Palestine, there is a need for a strong and organized policy system. This system should be able to address the gaps in governance, involve all the key stakeholders, and align with the global sustainability goals. The following policy actions are recommended:

A. Develop a Unified and Comprehensive Governance Framework:

- Create a central regulatory body that will oversee sludge policies and coordinate the efforts of local governments, NGOs, and private companies.
- Strengthening the current policies by removing ambiguities in roles and responsibilities and providing a strict enforcement structure.

B. Enhance Legal and Regulatory Standards:

- Revision of the sludge treatment and disposal regulations to high standards and considering the local factors.
- Implement penalties for violations and incentives for sustainable practices to enhance compliance.

C. Promote Public-Private Partnerships (PPPs):

- Provide tax incentives, grants, and technical assistance to private companies developing new, environmentally friendly sludge treatment technologies and resource recovery solutions.
- Partner with private entities to enhance efficiency, reduce costs, and implement advanced solutions in resource-poor areas.

D. Prioritize Community Awareness and Stakeholder Engagement:

- Run public awareness campaigns to inform people about the advantages of using treated sludge, such as generating energy, improving soil, and saving money.

- Involve local communities, particularly those of farmers—in decision-making to meet their needs and foster trust.

E. Leverage International Support and Collaboration:

- Work with international organizations to obtain funding and advanced sludge management technologies, leveraging international support and cooperation.
- Work with nearby nations to share knowledge, begin cooperative projects, and handle shared environmental issues.

4.2.2 Technical Recommendations

Sludge management modernization for Palestine calls for technical improvements catered to its particular environmental and financial situation. The following suggestions seek to bring fresh ideas and enhance present systems:

A. Optimize Existing Infrastructure:

- Maximize using natural drying beds in places like Jericho, where the temperature supports low-cost evaporation techniques.
- Update mechanical dewatering systems—like those in Al-Bireh—using more energy-efficient technologies to cut expenses and improve performance.

B. Expand the Use of Advanced Treatment Technologies:

- Using Nablus as a successful example, invest in anaerobic digestion systems to generate biogas, lower sludge volume, and create renewable energy.
- Encourage composting to convert treated sludge into organic fertilizers, so lowering the demand for chemical fertilizers and so improving the quality of the soil.

C. Adopt Circular Economy Practices:

- Use treated sludge in agriculture to guarantee it satisfies safety criteria and so increase soil fertility and reduce waste.
- Investigate creative technologies such as pyrolyzed carbonization and hydrothermal carbonization to transform sludge into biochar, which might either be used as renewable energy or an enriching agent for soil.

D. Regionalize Sludge Management Systems:

- Establish centralized treatment facilities to serve several municipalities, thus saving expenses and enhancing the resource economy through Sludge Management Systems.

- Improve means of transportation to carry sludge from local treatment and resource recovery facilities from smaller plants.

E. Strengthen Monitoring and Data Management:

- Introduce digital tools to track sludge production, treatment efficacy, and environmental impact in real time, so strengthening monitoring and data management.
- Use this information to direct policy decisions and enhance procedures so they guarantee sustainability and economy.

4.2.3 Opportunities for Future Research and Collaboration

Future Research and Cooperative Prospectives, improving sludge management, filling knowledge gaps, and using creative ideas depend on research and collaborations. The following suggested research and cooperative projects:

A. Investigating Emerging Treatment Technologies:

- Researching new treatment technologies, including gasification, pyrolysis, and enzyme-based treatments, to see how well they fit Palestine's circumstances
- Research co-digestion of sludge with other organic waste to increase biogas generation and anaerobic digestion system efficiency.

B. Address Socio-Cultural and Economic Barriers:

- Examine how social and cultural elements shape public opinions of sludge reuse, particularly in relation to farmers worried about health and safety.
- Analyze the financial effects of several sludge treatment choices to find sensible and reasonably priced answers.

C. Promote Regional Collaboration:

- Encourage regional cooperation through knowledge sharing, adoption of best practices, and tackling common sludge management issues between adjacent nations.
- To conduct trade research and workable solutions and provide forums for international nations with comparable sociopolitical settings.

D. Develop Financing Models for Sludge Management:

- Research creative financing tools, including green bonds and climate adaptation funds, to help create advanced treatment facilities. Sludge management also calls for these models.

- Look at public-private cooperation models to combine resources and reduce financial risk for interested parties.

E. Conduct Long-Term Environmental and Health Studies:

- Examine long-term environmental consequences of sludge disposal and reuse, including effects on greenhouse gas emissions, soil, and groundwater.
- Research the public health effects of applying treated sludge to guarantee safety and match practices with worldwide norms.

Concluding Thoughts: The following suggestions call for addressing technical, social, and governance issues in sludge management. Palestine can move to a circular economy for sludge management by matching policies with sustainability goals, embracing creative technologies, and encouraging cooperation. This change will lower environmental hazards and open chances for agricultural expansion, energy generation, and economic growth.

Through these initiatives, Palestine can establish itself as a regional leader in sustainable sludge management, offering a model for other countries confronting similar issues.

List of Abbreviations

Abbreviation	Meaning
AFD	Agence Française de Développement (French Development Agency)
ANERA	American Near East Refugee Aid
CBO	Community Based Organization
CMWU	Coastal Municipalities Water Utility
EIA	Environmental Impact Assessment
EQA	Environmental Quality Authority
EU	European Union
FAO	Food and Agriculture Organization
GAT	Governance Assessment Tool
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOVJ	Government of Jordan
HTC	Hydrothermal Carbonization
IFAS	Integrated Fixed Film Activated Sludge
IPCC	Intergovernmental Panel on Climate Change
JSC	Joint Service Council
JSC	Joint Service Council
JSMO	Jordan Standards and Metrology Organization
JWC	Joint Water Committee
LGU	Local Governmental Units
MBR	Membrane Bioreactor
MCM	Million Cubic Meters
MoA	Ministry of Agriculture
MOA	Ministry of Agriculture

MoEnv	Ministry of Environment
MoH	Ministry of Health
MoLG	Ministry of Local Government
MSS	Municipal Sewage Sludge
MWI	Ministry of Water and Irrigation
NGO	Non-Governmental Organization
NWC	National Water Company
OECD	Organization for Economic Co-operation and Development
PA	Palestinian Authority
PCBS	Palestinian Central Bureau of Statistics
PEAP	Palestinian Environmental Assessment Policy
PPPs	Public-Private Partnerships
PS	Palestinian Standards
PSI	Palestinian Standards Institution
PSI	Palestinian Standard Institution
PWA	Palestinian Water Authority
RWU	Regional Water Utility
SDG	Sustainable development Goal
SP	Service Provider
SS	Swage Sludge
SWM	Solid Waste Management
TWW	Treated Wastewater
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNICEF	United Nations Children's Fund
WAJ	Water Authority of Jordan

WB	World Bank
WBWD	West Bank Water Department
WEFE	Water-Energy-Food-Ecosystems Nexus
WHO	World Health Organization
WSRC	Water Sector Regulatory Council
WUA	Water Users Association
WWTP	Wastewater Treatment Plant

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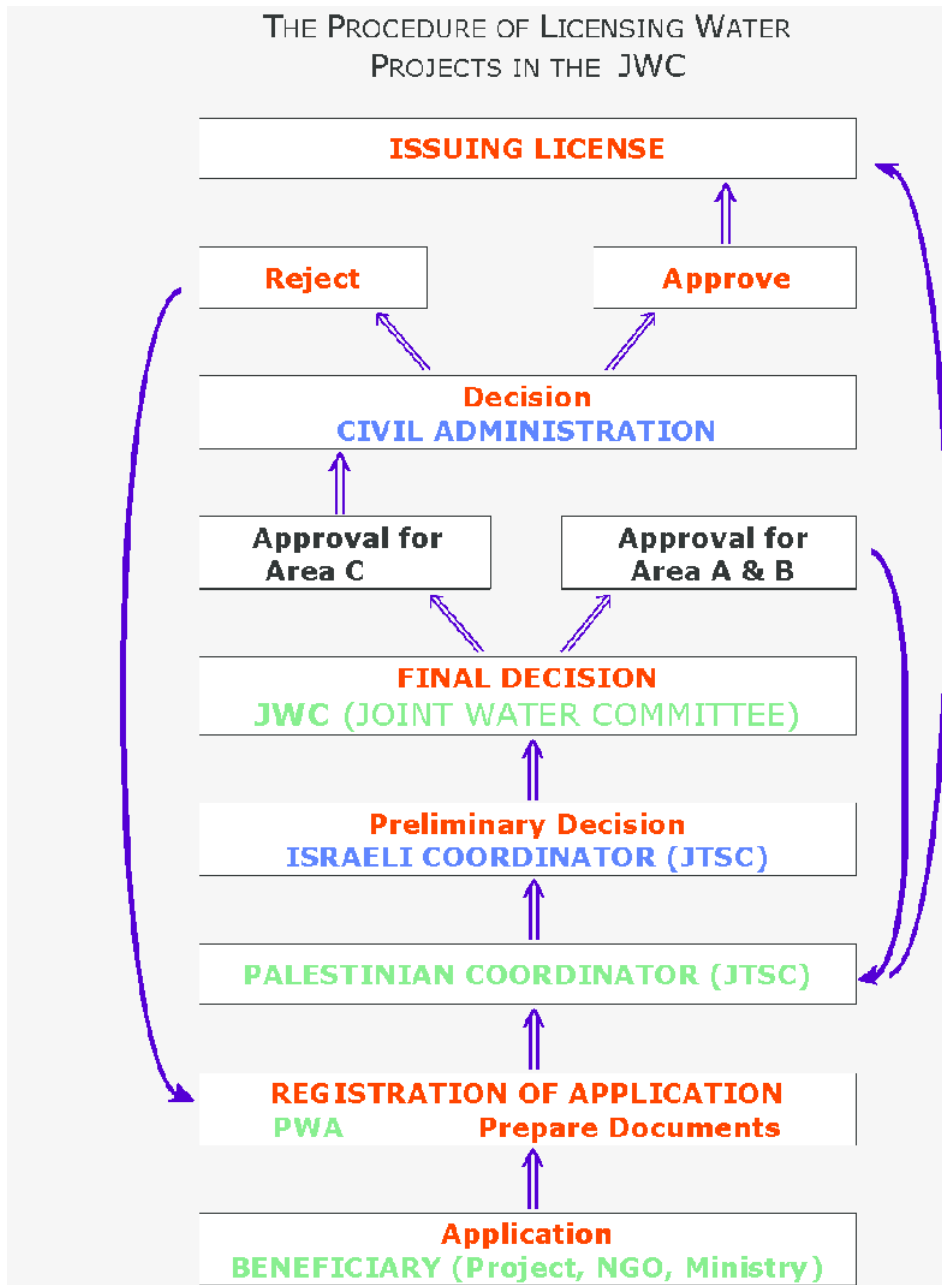
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Appendices

Appendix A

Overview of the Joint Water Committee's Licensing Procedures and Structure (emphasizing Civil Administration approval for Area C)



Appendix B

Governance Assessment Tool - Questions and Manual

Governance Dimension	Qualities Criteria Question							
	Completeness	Value	Coherence	Value	Flexibility	Value	Pressure for Change	Value
Actors and Network	1.1 Are the relevant stakeholders from all sectors involved in the decision-making process, which can potentially contribute to developing and improving sludge management?		1.2 Do the relevant stakeholders maintain teamwork in all matters related to sludge management?		1.3 Is it easy to add or remove a new member to the direct stakeholders' team involved in sludge management if needed?		1.4 Do the legislative and relevant stakeholders work with continuous motivation and incentive for change and improvement and for successfully implementing the technical instructions for sludge management?	
	Yes	Supportive	Yes	Supportive	Yes	Supportive	Yes	Supportive
	No, but most of the relevant stakeholders have been involved or consulted.	Moderate	No, most of the relevant stakeholders maintain teamwork, but not all of them.	Moderate	Yes, but the other members must be consulted, and their approval must be obtained first.	Moderate	Yes, but not to the required extent.	Moderate
	No, but most of the relevant stakeholders have not been involved or consulted.	Restrictive	No, there are many conflicts among the relevant stakeholders.	Restrictive	No, it is not possible.	Restrictive	No, no one cares, even if the plan fails.	Restrictive

	I don't know	Not Aligned	I don't know	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned
	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned
Problem perspectives and goal ambitions	2.1 From your perspective, were all the obstacles and problems faced by sludge management considered in the formulation, and do they provide constructive solutions to address them?		2.2 From your perspective, do technical guidelines and standards enhance collaboration and synergy among relevant stakeholders and across various sectors? Do they help address prevailing and shared issues and contribute directly or indirectly to achieving the ambitions of other sectors?		2.3 Is there flexibility in redefining the priorities and ambitions for sludge management when an opportunity worth investing in arises or when a new issue emerges that requires attention?		2.4 In your opinion, do the current guidelines and standards serve as a means to improve sludge management in Palestine?	
	Yes	Supportive	Yes	Supportive	Yes	Supportive	Yes	Supportive
	No, the instructions and standards address most of the problems and provide most of the solutions, but not all of them.	Moderate	No, they do not conflict with the ambitions of other sectors or relevant stakeholders.	Moderate	Yes, but only if all relevant stakeholders agree, which takes a long time.	Moderate	No, but it is a first step towards achieving that significant shift	Moderate
	No, many of the main problems we face have not been solved.	Restrictive	No, they contain options and solutions that explicitly conflict with the ambitions and goals of other sectors or some of the relevant stakeholders.	Restrictive	No, it is not possible.	Restrictive	Not at all.	Restrictive

	I don't know.	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned
	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned
Strategies and instruments	3.1 Are you provided with all the necessary tools to ensure the effectiveness of the sludge management and governance process in Palestine according to the existing strategies and laws?		3.2 Were the technical instructions and standards formulated based on collective work among the relevant stakeholders, considering the aspect of incentives?		3.3 Is there flexibility in revising the guidelines and standards for sludge management when necessary or when a new issue emerges that requires attention?		3.4 Do the instructions require more adaptation in practices by workers in the sludge management sector compared to the current situation?	
	Yes	Supportive	Yes	Supportive	Yes	Supportive	Yes	Supportive
	No, but many tools were considered.	Moderate	No, but it was possible to remove some aspects that might conflict with each other.	Moderate	Yes, but only if all relevant stakeholders agree.	Moderate	No, the current practices do not differ much from what the instructions require.	Moderate
	No, as many necessary and essential tools were excluded.	Restrictive	No, some points are interrelated and cannot be separated.	Restrictive	No, it is not possible.	Restrictive	No, it is not possible.	Restrictive
	I don't know.	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned
	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned

Responsibilities and resources	4.1 Have all responsibilities been clearly defined and facilitated with the appropriate resources to execute those responsibilities?		4.2 Do the responsibilities and resources assigned to the relevant stakeholders support each other, enhancing synergy and reducing conflicts and issues?		4.3 Is there flexibility in reallocating tasks and defining responsibilities among the relevant stakeholders to achieve tasks that cannot be accomplished by a single entity alone?		4.4 Is the current state of resources and responsibilities of all types sufficient to sustain work in the long term without interruption?	
	Yes	Supportive	Yes	Supportive	Yes	Supportive	Yes	Supportive
	No, but some are assigned and provided with the necessary resources.	Moderate	No, some responsibilities compete and conflict with other duties.	Moderate	Yes, but there is caution about working on the tasks and responsibilities of other entities.	Moderate	No, it is sufficient only in the short term, and then it will become a problem.	Moderate
	No, they are neither assigned nor provided with the necessary resources.	Restrictive	No, it is not possible.	Restrictive	No, it is not possible.	Restrictive	No, it is not sufficient, and this is a problem	Restrictive
	I don't know.	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned	I don't know.	Not Aligned
	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned	This is not important for the organization I represent.	Not Aligned

Appendix C

Operating WWTP in Westbank Informations

Id	Name, Governarate	Perimeter (localities)	Service Provider	Status, Capacity	Commissioning	Technology	treated WW Cubic Meter	Reused TWW Cubic Meter
1	Nablus West WWTP	Nablus West, Zawata, Beit Eba, Deir Sharaf, and Qusin. Sabastya and Assira Ashmaliyya for 2040.	Nablus Municipality	Operating	2013	Primary settling Activated sludge process, Tertiary treatment: Filtration (sand filter) and disinfection (UV) Sludge treatment: Anaerobic digestion followed by sludge dewatering	5,110,000.00	182,500
2	Jenin WWTP	Jenin, Jenin Camp	Jenin Municipality	Operating and to be upgrdaed	2014	Preliminary treatment (screen and grit chambers) and secondary treatment in two trains followed. Each train has two aeration ponds and one stabilization pond.	1,460,000.00	1,095,000
3	Jericho WWTP	Jericho, Doyok, Nuwe'emeh, Sultan camp, Oqbat Jabr Camp	Jericho Municipality	Operating	2014	Activated Sludge with Extended Aeration (Oxidation Ditch), UV Disinfection, and Sludge Treatment with aerobic digestion and Drying Beds.	657,000.00	547,500
4	Al Bireh WWTP	93% Al Bireh City, Am'ari Camp, Qaddura Camp, and Al Awdeh Camp	Al Bireh Municipality	Operating	2000	Extended Aeration Activated Sludge Sludge treatment: Filter press and Centrifuge	2,555,000.00	0
5	Tayaseer WWTP	Tubas, Tayasir, Aqqaba, Al-Al-Aqaba	Tubas Water Utility	Operating	2016	Activated Sludge Process (EAS), followed by Tertiary Treatment with Sand Filtration and UV Disinfection. Sludge Treatment: Aerobic Sludge Digestion and Dewatering.	182,500.00	0

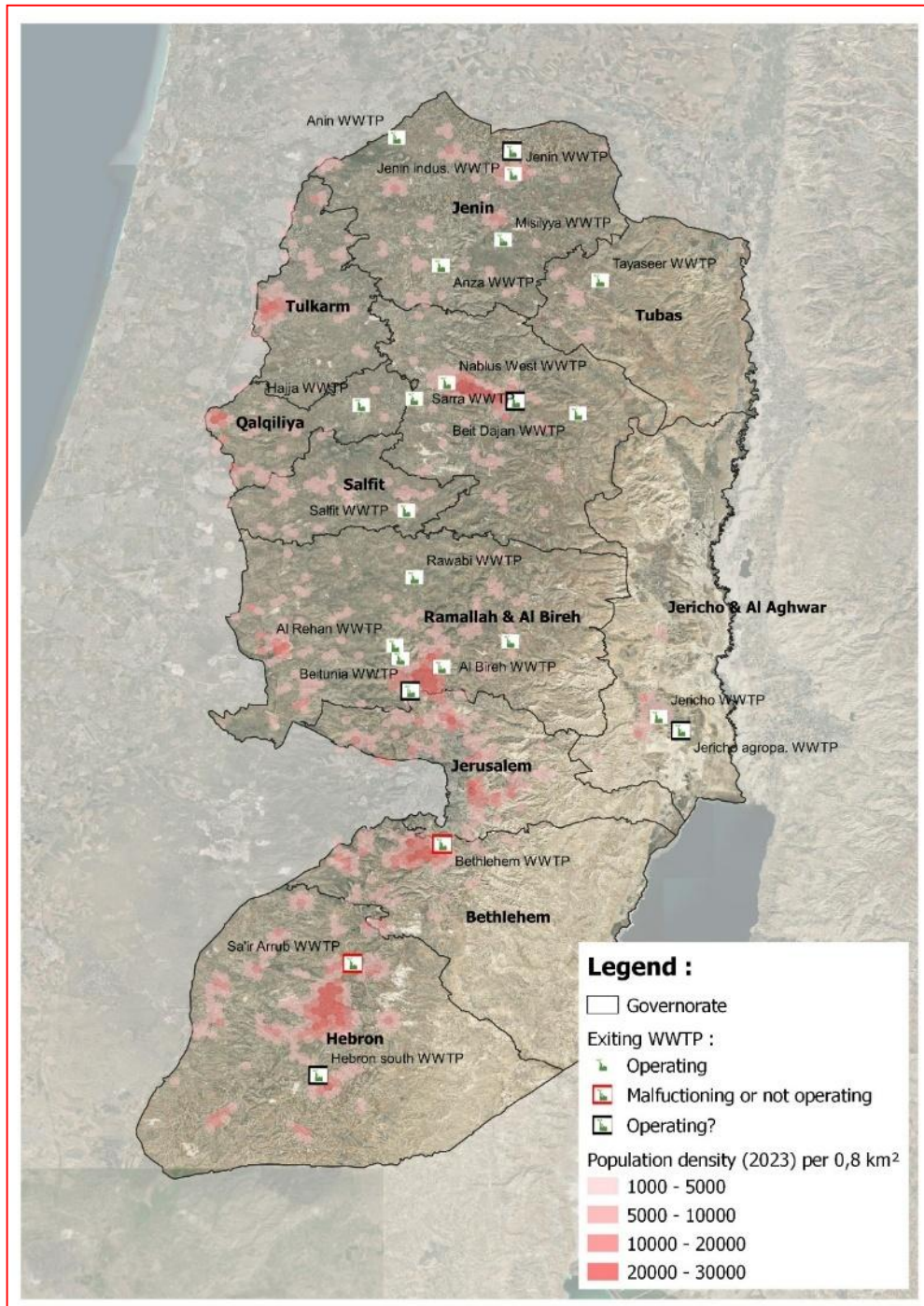
6	Salfit WWTP	Salfit	Salfit Municipality	Operating	2022	Imhoff Tank for primary treatment followed by a Trickling Filter for biological treatment.	438,000.00	0
7	Al-Tireh WWTP	Northwest Ramallah City (Al Tireh Suburb), 39%	Ramallah Municipality	Operating	2014	MBR with aerobic stabilization in the aeration tank. MPR WWTP. Sludge dewatering by centrifugation. No septage receiving station	730,000.00	182,500
8	Sa'ir Arrub WWTP	Al Arroub Camp and Shuyoukh Al arroub	North Hebron JWWSC	Operating	2016	The process includes Screening (4 mm), Activated Sludge (EAS) in the Biological Reactor, a Secondary Clarifier, Sand Filters, and Disinfection (chlorine). Sludge is treated in a Static Thickener, with future Dewatering and Composting planned.	438,000.00	146,000
9	Rawabi WWTP	Rawabi City		Operating	2015	The process uses Integrated Fixed Film Activated Sludge (IFAS) with MBBR and AGAR-IFAS reactors. It includes Pre-Treatment (PT), Secondary Treatment (ST), Tertiary Treatment (TT), and Sludge Treatment.	182,500.00	0
10	Anin WWTP	Anin	NW Jenin Water Utility	Operating	2022	Sequential Batch Reactor, SBR	146,000.00	0
11	Beit Dajan WWTP	Beit Dajan		Operating	2014	Modified Activated Sludge Filtration: Sand filter, and Chloronation Sludge treatment: Anaerobic Sludge Digestion and reeds beds	54,750.00	36,500
12	Misilyya WWTP	Misilya & Jarba		Operating	2019	Vertical and Horizontal Constructed Wetlands and storage pond	73,000.00	73,000
13	Al Rehan WWTP	Al Rehan Neighborhood		Operating	2013	Constructed wetlands, Membrane Bioreactor, MBR	36,500.00	0

14	Diplomatic Compound	The Compound		Operating	2014	Activated Sludge	182,500.00	0
15	Sarra WWTP	Sarra		Operating	2014	Constructed Wetland	102,200.00	0
16	Anza WWTP	Anza	Anza VC	Operating	2014	Modified Activated Sludge Filtration: Sand filter, and Chloronation Sludge treatment: Anaerobic Sludge Digestion and reeds beds	73,000.00	36,500
17	Taybeh - Rammun WWTP	Ramoun & Al Taybeh	Taybey – Rammoun JSC	Operating	2014	Rotating Biological Contactors for treatment, followed by Secondary Treatment with Sand Filtration and Disinfection using hypochlorite. Sludge Treatment, the system uses Drying Beds.	54,750.00	36,500
18	Beit Hasan WWTP	Beit Hasan		Operating	2013	Vertical and Horizontal Constructed Wetlands	21,900.00	0
19	Hajja WWTP	Hajja		Operating	2014	Vertical and Horizontal Constructed Wetlands	18,250.00	0

Note: PWA (2024)

Appendix D

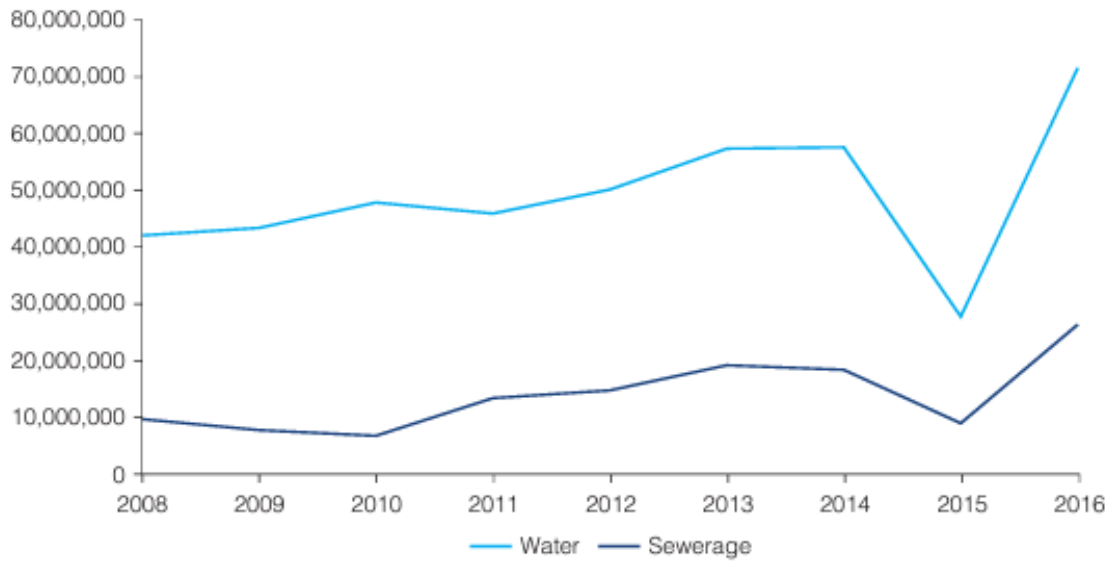
Wastewater Treatment Plants in West Bank



Note: OCHA (2019)

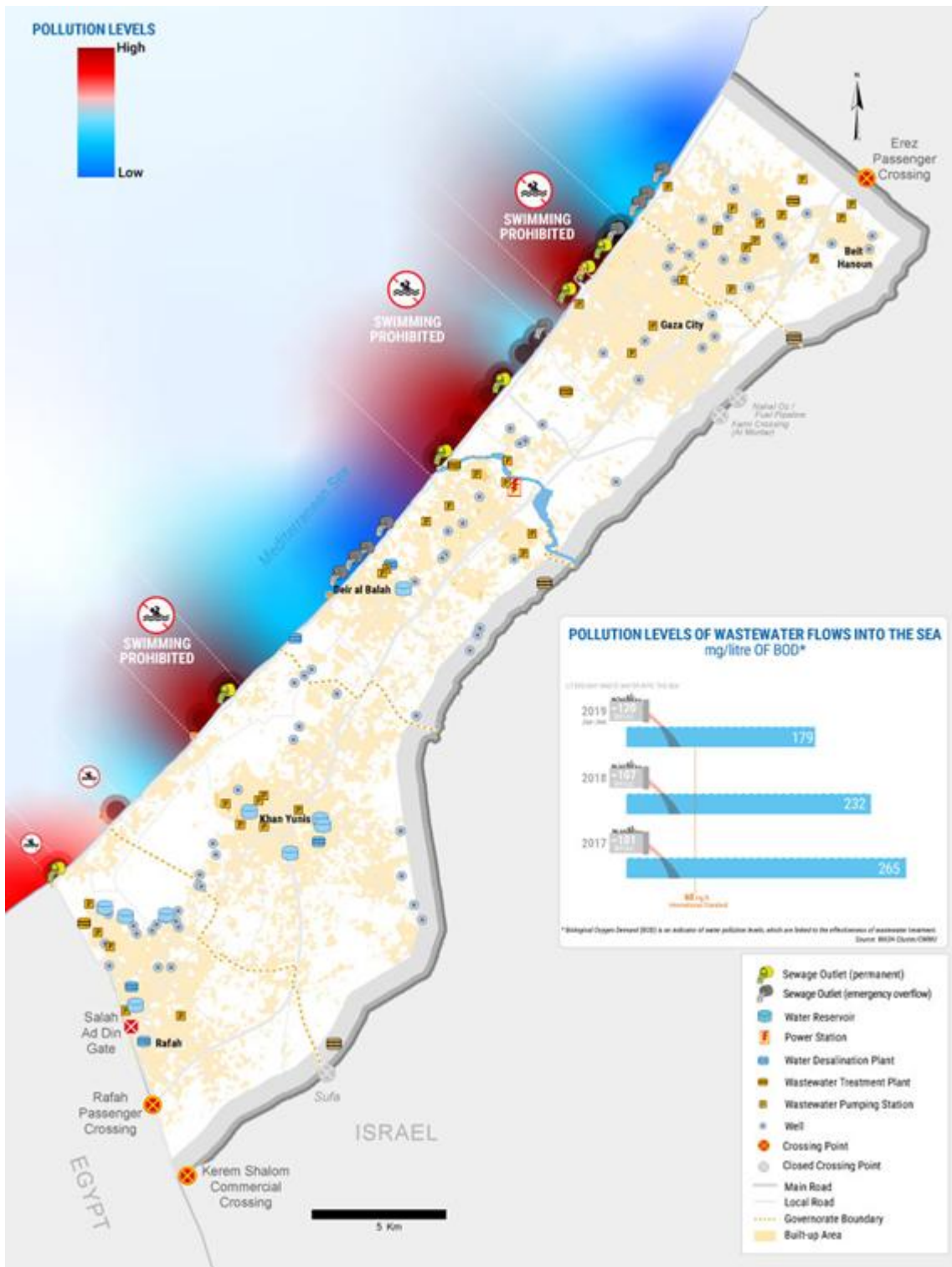
Appendix E

Trends in water and sewerage deductions from Israel 2008–2016 (USD), Source WB



Appendix F

Gaza Strip WWTP and Swage pump stations seawater pollution



Appendix G

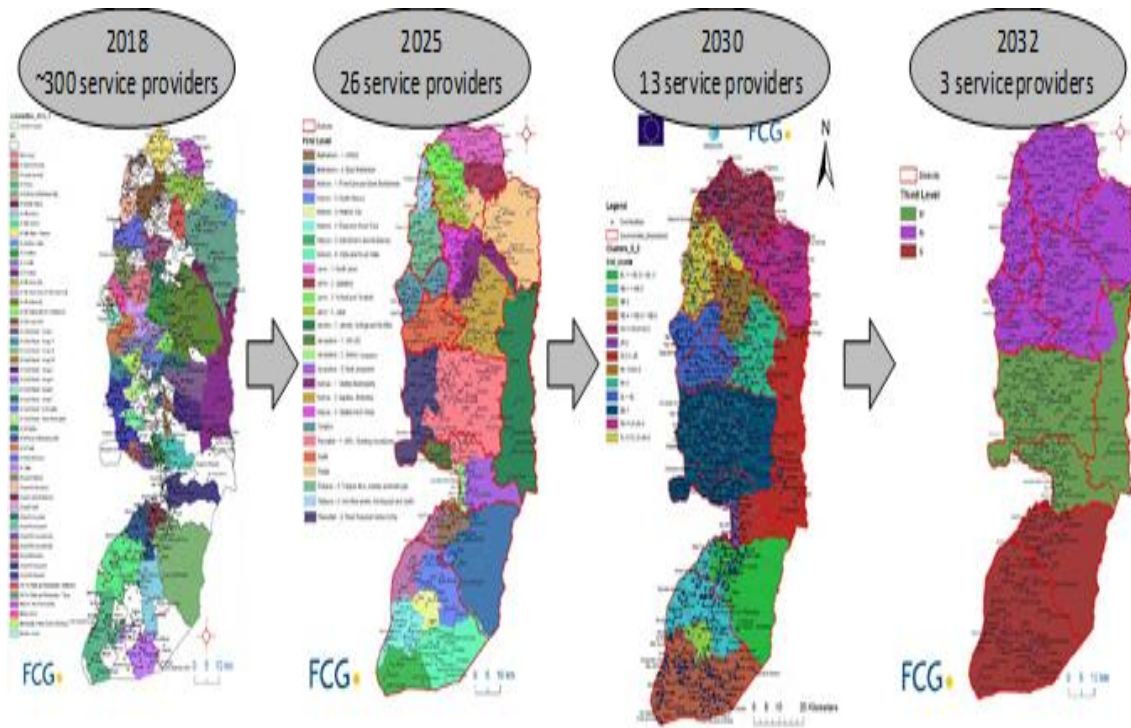
Comparison of Sludge Management Options: Applications, Benefits, Risks, and Challenges

Product/Option	Applications	Benefits	Risks	Challenges	Limitations	Cost
Land Application	Biosolids are applied to agricultural, forest, or reclamation lands.	- Sustainable recycling of organic matter.	- Pathogens, pharmaceuticals, and heavy metals pose contamination risks.	- Public perception issues.	- Limited applicability in areas without agriculture or degraded land for reclamation.	Low to Medium: Low capital investment but may involve transportation and monitoring costs.
		- Improves soil fertility and structure.	- Potential for nutrient runoff causing water pollution.	- Requires strict regulations and continuous monitoring.	- Seasonal restrictions may apply based on planting cycles.	
		- Cost-effective compared to disposal.		- Varies based on soil and crop requirements.		
Compost	Landscaping, gardening, and agriculture.	- Produces nutrient-rich compost for plants.	- Presence of pathogens or pollutants if sludge is improperly treated.	- Large space required for composting.	- May not meet agricultural standards in regions with strict fertilizer quality regulations.	Low to Medium: Capital cost for basic composting facilities is low, but operational costs depend on scale.
		- Reduces waste going to landfills.	- Odors during the composting process.	- Limited markets in some regions.	- Long decomposition time limits scalability.	
		- Enhances organic content in soils.		- Requires odor management systems.		
Construction Materials	Sludge ash or dried sludge used in bricks, cement, or asphalt.	- Divert waste from landfills.	- Chemical leaching of heavy metals into the environment.	- High processing costs.	- Limited markets for eco-construction materials in some regions.	Medium to High: Costs depend on processing technology and transportation to construction sites.
		- Replaces virgin materials in construction.	- Variability in sludge composition affects product quality.	- Ensuring consistency in material properties.	- Processing facilities must comply with environmental regulations.	
		- Reduces construction costs and environmental impact.		- Public acceptance concerns.		

Product/Option	Applications	Benefits	Risks	Challenges	Limitations	Cost
Biochar	Soil amendment and water filtration material.	- Sequesters carbon, contributing to climate mitigation.	- May contain heavy metals harmful to soil.	- Energy-intensive production process.	- Limited scalability for regions without affordable pyrolysis equipment.	Medium to High: Pyrolysis units are expensive, but operational costs are moderate.
		- Improves soil health and water retention.	- Air pollution from pyrolysis emissions.	- Market acceptance challenges for agricultural use.	- Lack of uniform standards for biochar use in agriculture.	
		- Reduces water contaminants.				
Protein and Lipid Extraction	Animal feed additives or biodiesel production.	- Adds value to waste by recovering high-value products.	- Toxins or contaminants can persist in recovered products.	- Limited scalability due to high costs.	- Requires advanced expertise and R&D investments.	High: Still in the R&D phase; industrial-scale implementation is expensive.
		- Supports biofuel production.	- Complex extraction processes require high precision.	- Emerging technologies require further research.	- Technology still in developmental stages for large-scale application.	
Biogas (Renewable Energy)	Renewable energy source for heating, electricity, or vehicle fuel.	- Generates renewable energy, reducing greenhouse gas emissions.	- Methane and CO ₂ leakage contributes to climate change.	- Requires advanced digesters and expertise.	- Limited feasibility in areas without existing wastewater treatment infrastructure.	High: Requires significant capital for anaerobic digesters and gas handling infrastructure.
		- Offsets wastewater treatment plant energy needs.	- Risk of explosion during handling or storage.	- High capital costs for facility installation.	- Biogas production can be inconsistent with varying sludge composition.	
		- Complements energy-intensive industries.				

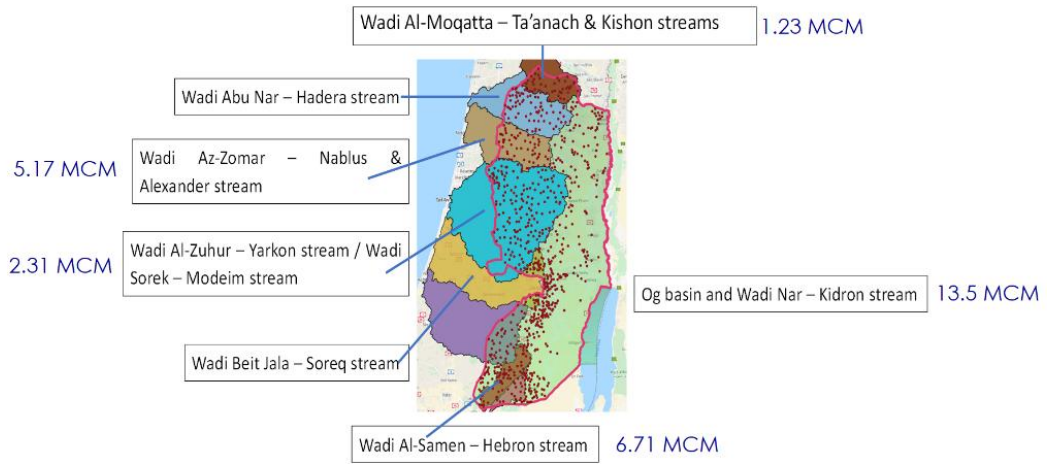
Appendix H

Road Map for the establishment of Regional Water Utilities. Source: ORGUT/FCG (2017)



Appendix I

Palestinian Transboundary Wastewater, Source AFD





جامعة النجاح الوطنية
كلية الدراسات العليا

نحو ادارة مستدامة للحمأة في فلسطين

إعداد

علي هلال سعيد عبسو

إشراف

د. عبد الفتاح حسن

قدمت هذه الرسالة استكمالاً لمتطلبات الحصول على درجة الماجستير في العلوم البيئية،
من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس - فلسطين.

نحو ادارة مستدامة للحمأة في فلسطين

إعداد

علي هلال سعيد عبدو

إشراف

د. عبد الفتاح حسن

الملخص

تهدف هذه الدراسة إلى تقييم الوضع الحالي لإدارة الحمأة المنبتقة من معالجة مياه الصرف الصحي في فلسطين، مع التركيز على التحديات السياسية والفنية والصحية والاقتصادية التي تواجه هذا القطاع. كما يتناول تحليل نظام الحوكمة، وتكنولوجيا إدارة الحمأة، والوعي المجتمعي بهذه المسائل.

استخدمت الدراسة منهجا تحليليا بتقنية أداة تقييم الحكم (Governance Assessment Tool - GAT) إلى جانب استعراض شامل للأدبيات وإجراء مقابلات مركزه مع أصحاب المصلحة، ودراسة حالات لمحطات معالجة المياه العادمة في نابلس، أريحا، والبييرة.

توصلت الدراسة إلى أن الإطار الحالي للحوكمة يعاني من تشتت واضح ونقص في التنسيق بين الجهات المعنية، مع نقص واضح في تطبيق التشريعات. كما أظهرت البحث أن التقنيات المستخدمة في معالجة الحمأة تعاني من ارتفاع نسبة الرطوبة وغياب مسارات فعالة للتخلص منها، مما يزيد من التكاليف التشغيلية والمخاطر البيولوجية بشكل كبير. كما كشفت الدراسة عن وجود عوائق اجتماعية وثقافية كبرى، خصوصا لدى المزارعين، تعتبر حائلا أساسية أمام استخدام الحمأة كسماد عضوي للزراعة.

ومع ذلك، أكدت الدراسة وجود فرص كبيرة لاستعادة الموارد من خلال تقنيات مثل إنتاج الغاز الحيوي والسماد العضوي، وهذا يمكن أن يقلل من الاعتماد على طرق التخلص التقليدية مثل المكبات، ويسهم في دعم الاقتصاد المستدير.

الدراسة توصي باتباع نهج شامل وشاسع النطاق لتحسين إدارة الحمأة، وذلك من خلال تنسيق الجهود في إطار الحوكمة، وتبني تقنيات معالجة متطورة، وتعزيز تفاعل أصحاب المصلحة، وإطلاق حملات توعية عامة لنفادي العوائق الاجتماعية وزيادة قبول المجتمع للحلول المستدامة.

الكلمات المفتاحية: الصرف الصحي، الحمأة، إدارة المخلفات، نظام الحوكمة، تجديد الموارد، دورة الحياة للموارد، فلسطين.