



## Addressing non-revenue water as a global problem and its interlinkages with sustainable development goals

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### ABSTRACT

By 2050, over 40% of the global population could face severe water stress. The 2030 Agenda explicitly integrates water resources, supply, and sanitation, emphasizing sustainability for present and future generations. Non-revenue water (NRW) creates a barrier to sustainability through energy, water loss, and money not collected through water bills. However, NRW is well recognized by water service providers, and a comprehensive solution is lacking. Addressing NRW is vital to sustainable operations and achieving the Sustainable Development Goals (SDGs). This desk literature review investigates NRW's links with SDGs, highlighting global and local impacts, frameworiking interconnections, and revealing economic, social, and environmental consequences. The study revealed that NRW not only aligns with various SDGs, particularly SDG 6 and SDG 13, but also has synergies with other goals related to energy and sustainable consumption. Reducing NRW can achieve more sustainable and resilient water systems, and contribute to the broader SDG. The cost of NRW extends beyond the financial implications for water utilities. It also encompasses the economic impacts on industries and businesses, which impacts exceeded water productivity, increased operational costs, and economic development constraints.

**Key words:** non-revenue water, SDG 6, State of Palestine, Sustainable Development Goals

### HIGHLIGHT

- Explores new methods of planning and management of NRW by indicators.

## 1. INTRODUCTION

Water is a common resource that must be protected and access to it must be equitable and affordable. Globally, according to the World Health Organization and UNICEF, at least 2 billion people rely on drinking water sources that are contaminated with feces and 4.2 billion lack safely managed sanitation services (WHO/UNICEF 2017). The United Nations predicts that water-related threats will become more pressing over the coming years. Population growth and a rapidly developing global economy, combined with the effects of climate change, will exacerbate the lack of access to water and sanitation for domestic use (EIB 2023). The global population is increasing from the current 7.7 billion to reach 8.5 billion by 2050 (Essex *et al.* 2020). In 2016, over a billion people did not count on proper access to drinking water and forecast in the short run is that hydric stress will affect over 40% of the world population, an estimate that illustrates the dimensions of current and future problems related to access to quality water and the management of existing public water supplies (Amaral Marques *et al.* 2021).

By 2050, over 40% of the global population is likely to live in river basins under severe water stress. It is expected that more than 240 million people will remain without access to an improved drinking water source, and almost 1.4 billion are projected to remain without access to basic sanitation (EIB 2023). Increasing demand, saves energy, and reduces carbon emissions, thus mitigating climate change impacts and fostering sustainability (USAID 2015). Being one of the core topics of the United Nations' Sustainable Development Goals (SDGs) to be achieved by 2030, nowadays drinking water is recognized worldwide as an essential resource, however vulnerable, limited, and increasingly scarce, a situation which is impaired by factors such as increase in

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demand, pollution of water sources, and increasingly severe climate changes (Johnston 2016; Krehbiel *et al.* 2017). Yet, current investment levels for water are insufficient to address the challenges at stake (Amaral Marques *et al.* 2021; EIB 2023). In 2015, the UN Member States adopted the 2030 Agenda for Sustainable Development (Ortigara *et al.* 2018), an internationally recognized set of goals (17 goals) and targets (169 targets) which aim to promote development in the economy, environment, and society (Guppy *et al.* 2019; Essex *et al.* 2020). The 2030 Agenda explicitly included all aspects of water resources, water supply, and sanitation, which were built on the foundation created by the SDGs between 2000 and 2015 (Ortigara *et al.* 2018). Sustainability means ensuring adequate resources for present and future generations. Non-revenue water (NRW) is an obstacle to sustainable development due to energy and water loss. However, its problem was well identified by the water service providers until now there has not been a comprehensive method to solve it (Abueltayef *et al.* 2023). Reducing NRW has great importance in running a sustainable operation and a vital component in reaching the UN Sustainable Development Goal (SDG 6) on Clean Water and Sanitation (Johnston 2016). In the long run, ignoring the reduction of NRW would jeopardize the development of the entire region. Higher water loss levels can have severe impacts on the financial viability of water service providers and entire communities due to lost revenue and unnecessarily high operating costs (Johnston 2016). NRW, therefore, has a direct impact on the ability of water service providers to finance necessary service upgrades, carry out appropriate maintenance, and invest in new technologies (IWA 2020). NRW and water loss are a global problem, making it difficult to protect our water resources, especially in water-scarce regions. But it is also a challenge that most local water service providers face on a daily basis due to conditions such as increasing urbanization, increased demand, and aging water networks (Kamstrup 2019).

NRW is defined as the difference between the amount of water produced and the water consumed. This amount can be expressed as real and commercial losses (Johnston 2016). Also, NRW is defined as the difference between the amount of water fed into the distribution system and the amount charged to customers (Bruin *et al.* 2008; Jang 2018). It is one of the major issues, water utilities are facing in the meantime, especially in areas with severe water scarcity conditions. Water resources are increasingly under pressure from population growth, economic activity, and intensifying competition for the water among users, besides the high levels of NRW reflect huge volumes of water being lost (Kingdom *et al.* 2006). In 2006, the World Bank study estimated the global yearly physical water losses of approximately, 32 billion cubic meters, half of which occurs in countries under development. The yearly total cost to water service providers caused by NRW worldwide can be conservatively estimated at \$141 billion (Kingdom *et al.* 2006).

A reduction in NRW is thus essential to maintain the sound financial operation of a waterworks business. A high NRW usually means problems in the operational management of the facility (unmeasured quantities using water meters, leaks, and illegal use) (Berg 2014). Also, high levels of NRW reflect enormous water volumes being lost through leaks and consumed water not being invoiced to customers or a combination of both (WBG 2014). The aggregate NRW globally is 30% of water system input volume and the cost value of the water lost amounts to 39 billion per year (Kingdom *et al.* 2006; Liemberger & Wyatt 2019). If the global volume of NRW is reduced by one-third, the saved water would be sufficient for approximately 800 million people, assuming 150 liters per capita (Reddy 2021).

The interlinkage between NRW and SDGs for the year 2030 poses a significant challenge to achieving global water security, efficient resource management, and sustainable development (UN 2018c). NRW undermines progress toward multiple SDGs related to clean water access, infrastructure development, responsible consumption, climate change and economic growth (UN 2018b). The percentage of lost water varies from 20 to 50%, which is huge water quantities that did not invoice due to leakages, deteriorating infrastructure, inaccurate billing systems, deficient customer registration, inaccurate metering, reservoir overflow, and illegal connections (Beitzel 2021). Reducing NRW is also of great importance in running a sustainable operation and a vital component in reaching the UN SDG. High levels of NRW will have a serious impact on the financial viability of water utilities and whole communities due to revenue losses and unnecessarily high operating costs. Thus, NRW directly affects the water service provider's capacities to fund service expansions, provide proper maintenance services, invest in new technology, and their sustainability in providing water service (IWA 2020).

This problem highlights the urgent need to address NRW and its interlinkage with SDGs to ensure efficient water resource management, sustainable infrastructure, and the realization of the broader goals of the 2030 Agenda. A comprehensive understanding of the complexities and interdependencies between NRW and SDGs is crucial to overcoming this pressing global issue and ensuring a resilient, equitable, and sustainable water future by 2030. Moreover, NRW's impact extends beyond SDG 6, affecting other SDGs such as SDG 9 (Industry,

Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 8 (Good Jobs and Economic Growth), and SDG 16 (Peace and Justice), and SDG 17 (Partnerships for the Goals). NRW as part of SDG implementation hampers overall progress toward SDG targets. Here are some of the reasons behind that:

- NRW represents missed opportunities for resource efficiency in water supply systems. The significant water losses due to leaks (physical losses and commercial losses), unbilled water, prevent the efficient utilization of water resources leading to water scarcity, financial losses, and inadequate access to clean water particularly in urban areas with rapid population growth and aging infrastructure. Addressing NRW is crucial for achieving SDG 6's target of water-use efficiency and ensuring sustainable withdrawals and supply of freshwater resources (Kingdom *et al.* 2006; Mubvaruri *et al.* 2022).
- Lack of financial resources limits the ability of water utilities to invest in improving water infrastructure, thus perpetuating the cycle of water losses and hindering progress toward SDG 6 (USGWS 2022).
- NRW leads to substantial financial losses for water utilities, hindering their ability to invest in infrastructure upgrades, repairs, and expansion (Kingdom *et al.* 2006). The reduced revenue collection from NRW compromises the financial sustainability of water utilities, limiting their capacity to provide reliable and quality water services to communities (Frauendorfer & Liemberger 2010). This poses a significant challenge to achieving SDG 9, which emphasizes the need for sustainable infrastructure development (HLFP 2023).
- NRW is particularly problematic in urban areas characterized by population growth and aging infrastructure (Frauendorfer & Liemberger 2010). The water losses associated with NRW impede progress toward SDG 11, which aims to create inclusive, safe, resilient, and sustainable cities and communities (UN 2018d). The inefficient water management resulting from NRW hampers urban development, disrupts service delivery, and undermines the overall livability and sustainability of cities (Molinos-Senante 2018).
- NRW signifies an inefficient use of water resources, as water is produced, treated, and distributed but not effectively utilized (Beitzel 2021). This inefficiency undermines SDG 12, which focuses on promoting responsible consumption and production patterns (Cunha & Custódio 2021). The wasted water further strains limited water supplies, exacerbating water scarcity concerns, and hindering sustainable development efforts (Cunha & Custódio 2021).
- Water losses not only waste a vital resource but also necessitate additional energy consumption for pumping and treatment, resulting in increased carbon emissions and environmental impacts, special hampers efforts to achieve SDG 12 (Partiti & Arcuri 2021).
- Weak collaborative efforts among governments, water utilities, communities, and stakeholders because of lack of knowledge sharing, enhance capacity building, and allocate sufficient resources toward reducing NRW that's hindering progress toward SDG 17 (Partnerships and Collaboration) (UN 2023a).
- NRW represents inefficient water use and wastage, which is contrary to responsible consumption and production practices. NRW can postpone the progress for SDG 12 (Responsible Consumption and Production) (UN 2023a).

Therefore, this problem necessitates immediate attention, action and urgent need for integrated approaches, innovative technologies, and strategic investments in infrastructure and capacity building to ensure sustainable water management, enhance water security, and promote inclusive and resilient communities. Addressing NRW is crucial for achieving SDG 6 and other related goals, as it directly impacts water availability, financial sustainability, and the overall progress toward sustainable development (UN 2018a).

In general, it is understood that water plays a key role in creating a sustainable world. But in this study, it is important to make sure our water management is sustainable as well. Coupling NRW with the SDG agenda requires attention and improved service to convince consumers that the water has value and that the water bill is a sign of priceless and essential needs. NRW is embedded in 7 SDGs: Clean Water and Sanitation, Economic Growth and Industry, Enhance Water Infrastructure and Services, Industry, Innovation, and Infrastructure, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Promote Sustainable Consumption and Production, and Enhance Partnerships and Knowledge Sharing. It, therefore, makes sense to be addressed. Reducing NRW contributes to achieving the UN SDGs. This is especially so in the case of SDG 6 SDG 3, SDG 8, SDG 9, SDG 11, SDG 12, and SDG 17 (IWA 2020).

The main role of SDG regarding water is its availability and sustainable management of water and sanitation for all. NRW directly impacts the availability of water for communities. Studying NRW and its linkage with SDG

helps to understand the extent of water losses, their causes, and their impacts on water availability and access. This knowledge is crucial for developing effective strategies to reduce NRW, promote water conservation, and ensure sustainable water management practices. Studying NRW and its linkage with SDGs is important for promoting sustainable water management, achieving water-related goals, optimizing resource use, ensuring financial viability, adopting an integrated approach to development, and guiding policy and decision-making processes. It enables us to address the challenges posed by NRW in a holistic manner, leading to improved water security, environmental sustainability, and overall progress toward the SDGs.

The overall objective of studying NRW and SDGs is to address NRW as a global problem, and its interlinkage with SDGs. The detailed objectives were as follows: (1) to understand the scope and magnitude of NRW in a global context, which helps to gain valuable insights into water loss, (2) to study the NRW interlinkage within the SDGs and identify the crucial impacts, that helps for formulating effective interventions to reduce NRW, (3) to illustrate the economic, social, and environmental consequences of water losses, and (4) to facilitate knowledge sharing and capacity building among stakeholders involved in water management to and develop the skills and knowledge of professionals, enabling them to address NRW effectively. By studying NRW and its interlinkage with SDGs, policymakers, water service providers, and related stakeholders can gain valuable insights into water loss challenges, develop strategies, and plan actions toward the achievement of SDG targets related to water sustainability.

## 2. THE BENEFITS OF REDUCING NRW

An effective NRW Programme will obviously concentrate on reducing municipal water losses and increasing revenue, but it can also lead to other important benefits for the water utility and its customers:

- *Improve service*: Reduce stress on the available water resources, thereby allowing more people to be served by the same water source (Beitzel 2021).
- *Optimize investments*: Reducing energy consumption for the processes of abstraction, treatment, and distribution of water can be achieved by adapting the pressure to meet the demand and by treating and distributing smaller volumes of water (Brandt 2012). This approach allows for meeting the same demand for water while minimizing energy usage. By implementing such measures, there is potential to decrease investments required for developing new water sources (Brandt 2012). Additionally, optimizing investments for asset maintenance and renewal can be achieved, leading to more efficient utilization of resources. Ultimately, these efforts aim to reduce the overall demand for water resources (ADB 2013).
- *Improve performance*: Increase revenue due to the sale of saved and previously unbilled water, better support for decision-making and customer service due to new management systems (Frauendorfer & Liemberger 2010).
- *Increase supply continuity*: A more stable water supply as improved performance will provide full pressure distribution 24 hours a day, 7 days a week (Beitzel 2021).
- *Reduce leakage and their damages*: A strong basis for setting up a long-term rehabilitation and investment plan for the network and better knowledge of the water network (OCECD 2022).
- *Improved water quality*: As a result of enhanced water distribution, the management of the chlorine content in the distributed water will be more effective, thus reducing the risk of pollution caused by cloudbursts and periods of low pressure or vacuum (Beitzel 2021). Furthermore, this will lead to an improvement in the quality of tap water by minimizing contamination (Hersch 2012).
- *Conserve water resources*: Water utilities would gain access to a further USD 3 billion in self-generated cash flow.
- *Commercial losses control*: Reducing illegal connections would result in greater fairness between users.
- Utilities would become more efficient and sustainable, improving service to their customer service.
- *Job creation*: New business opportunities would create more jobs.
- *Economic protection*: Improved finances from increased water sales and reduced production provide service to more customers for longer hours, reduce the need for massive investments in treatment facilities, and increase the revenues of the services (Budget 2011).
- *Public awareness*: Increased knowledge of the water distribution system and reduced risk of contamination.
- *Environmental benefit*: Reduce the energy footprint and greenhouse gas emissions, and decrease energy needs and operational costs (USAID 2015; IWA 2020; Reddy 2021).
- At the same time, NRW reduction programs could have the following benefits for water supply operators:
- The consumption of water resources in the utility will be reduced, increasing the working capacities of the utility.



- The energy consumption will be reduced as less water will be needed to extract.
- Smaller amounts of leakages will decrease the load on sewage systems thus decreasing costs for treatment.
- Fewer leakages in pipes – less chances of water contamination (Hawle n.d.).

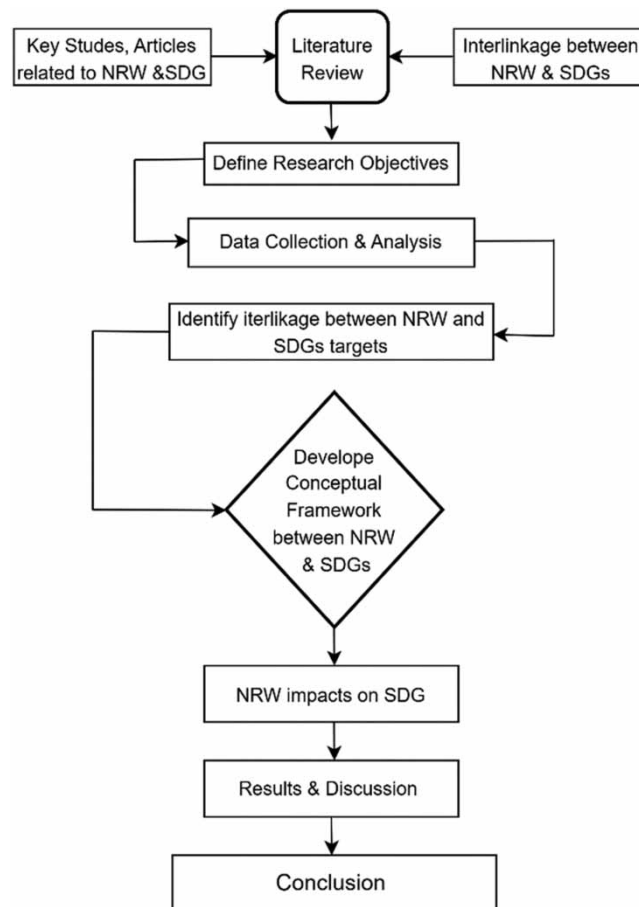
NRW management frequently offers better cost-effectiveness in comparison to supply augmentation. Additionally, the revenue generated from saved water enhances the financial performance of service providers, while reducing water abstraction improves the resilience of cities. However, the advantages derived from minimizing NRW have not yet become significant motivators for addressing this widespread issue in developing nations. The obstacles that prevent utilities from making progress include limited capacity, lack of incentives, inadequate financial discipline, and the substantial effort required to locate and repair leaks in contrast to constructing new treatment facilities (Kingdom *et al.* 2016). This has created a lethargy, which is now being shaken by pressures coming from climate change, water scarcity, and increasing expectations of consumers (Kingdom 2016).

### 3. METHODS AND MATERIAL

To study the interlinkage between NRW and SDGs, there is a need to conduct a comprehensive literature review, examine the SDGs and their associated targets to identify those directly or indirectly related to NRW and water management, analyze findings, and then develop a conceptual framework that illustrates the interlinkages between NRW and SDGs.

More than 30 articles and reports (UN, UN SDG reports, Science Direct, etc.) have been explored during the desktop already reviewed. Figure 1 describes the following steps for conducting this study:

- *Review existing literature:* Conduct a comprehensive literature review to understand the current state of knowledge on NRW, SDGs, and their interlinkages. Identify relevant key academic papers, reports, and case studies that provide insights and related to NRW, water management, SDGs, and sustainable development.



**Figure 1** | Methods of developing NRW interlinkages to SDGs.

- *Define study objectives:* Clearly outline the objectives of your paper, such as examining the relationship between NRW and specific SDGs and assessing the impacts of NRW on sustainable development to address NRW in alignment with SDG targets.
- *Data collection:* Collect relevant data on NRW, water management practices, and SDG indicators from reliable sources.
- *Analyze the interlinkages between SDGs and NRW:* Examine the SDGs and their associated targets to identify those directly or indirectly related to NRW and water management. Examine how NRW impacts the achievement of these goals and how achieving the SDGs can help reduce NRW. Consider the economic, social, and environmental dimensions of the interlinkages and explore their interconnectedness. This step will help you establish a clear link between NRW and the broader SDG framework.
- *Develop a conceptual framework:* Based on your analysis and findings develop a conceptual framework that illustrates the interlinkages between NRW and SDGs. This framework should highlight the causal interlinkage between NRW and SDGs.
- *Conclusion:* Summarize the key findings, contributions, and implications of your study. Reflect on the importance of addressing NRW within the context to achieve the 2030 Agenda. Highlight the significance of your study and potential areas for future research.

## 4. RESULTS AND DISCUSSION

Water has a key enabling role in sustainable development. It was included in the United Nations 2030 Agenda as the sixth SDG – Clean Water and Sanitation (WSRC 2020a). Reducing water losses not only conserves a scarce natural resource but also improves utility financial viability (increased revenue and reduced repair and energy costs), deferral of capital expenditure for new sources and system expansion to keep pace with increasing demand, saves energy, and reduces carbon emissions, thus mitigating climate change impacts and fostering sustainability (USAID 2015). Reducing NRW is not a standalone goal but a critical enabler for achieving multiple SDGs. By addressing NRW, countries and organizations can improve water availability, enhance water resource management, promote sustainable infrastructure, and support the broader sustainable development agenda outlined in the SDGs.

The relation between SDGs and NRW lies in their shared objective of sustainable development, specifically in the context of water management and access. The SDGs, adopted by the United Nations in 2015, provide a framework for global development and aim to address various social, economic, and environmental challenges. Addressing NRW as a global problem contributes to sustainable development by improving water accessibility, resource management, infrastructure resilience, and collaboration among stakeholders. It aligns with several specific SDGs and their targets, particularly SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). Here are some key connections between SDGs and NRW.

### 4.1. Detailed interlinkage between NRW and SDGs

The interconnection between NRW and SDGs highlights the nature of sustainable development. While NRW does not have a direct correlation with specific SDG, its border impact and relevance span across multiple goals. Understanding and addressing NRW is crucial for achieving sustainable, efficient water management practices, and integrated approaches and collaboration among relevant actors, contributing to broader development efforts outlined in the SDGs. The following tables demonstrate a detail about the NRW's contribution to SDG impacts.

#### 4.1.1. SDG 6 – Clean Water and Sanitation

SDG 6 is one of the 17 SDGs in the United Nations Sustainable Development Goals 2030 Agenda. It provides a framework that promotes universality and integration among countries, mobilizes all stakeholders, and stimulates action (Ortigara *et al.* 2018). SDG 6 focuses on the importance of ensuring sustainable water management and access to clean water and sanitation for all. NRW directly impacts this goal by reducing the availability of clean water for consumers. By addressing NRW, water utilities can improve the availability and accessibility of clean water and can help ensure a more sustainable and equitable water supply, supporting progress toward SDG 6 (Table 1). The following targets of goal six are most relevant to NRW:

**Table 1** | NRW objectives, contribution, and SDG 6 interlinkages

| SDG name and number               | NRW within SDG objectives   | NRW contribution  | NRW and SDG interlinkage   | Ref.   |
|-----------------------------------|---|---|--|--|
| SDG 6: Clean Water and Sanitation | Addresses universal access to safe and affordable drinking water and adequate sanitation                                | NRW directly affects the availability and accessibility of clean water.<br>NRW represents a loss of treated and distributed water, which reduces the availability of clean water for consumers.<br>Reducing NRW is crucial for improving access to clean water.                           | By reducing NRW, water utilities can improve the availability of clean water, thus contributing to achieving SDG 6.<br>Water utilities can improve water supply efficiency, reduce wastage, and increase the availability of clean water for domestic, industrial, and agricultural use thereby contributing to SDG 6.   | Beitzel (2021)<br>UN (2022b)                     |
|                                   | Focuses on ensuring the availability and enhancing the sustainable management of water resources and sanitation for all | This contributes to the inefficiency of water management and can hinder progress toward SDG 6.<br>NRW represents a loss of valuable water resources.<br>NRW represents a loss of treated water before it reaches consumers.   | By addressing NRW, countries can improve water resource management. It helps improve water supply efficiency and availability in communities, especially in areas where water resources are scarce.<br>By reducing NRW, more water is made available for consumption, contributing to SDG 6's target of ensuring universal access to clean water and sanitation. | UN (2022b)                                       |
|                                   | Improve water-use efficiency  | NRW represents a loss of valuable water resources as it involves the production and distribution of water that is lost before reaching consumers.<br>By reducing NRW, more water can be conserved and effectively utilized, ensuring a sustainable supply of clean water for communities. | By addressing NRW, water utilities can improve water-use efficiency and reduce wastage. This objective contributes to SDG 6's target of increasing water-use efficiency and ensuring sustainable withdrawals and supply of freshwater resources.<br>Providing universal access to safe and affordable drinking water for all aligns with SDG 6.                  | Hawle (n.d.)<br>Frauendorfer & Liemberger (2010) |
|                                   | Water security and access   | NRW can impede efforts to ensure water security and access for all.   | By reducing NRW, more water becomes available for consumption, improving water availability and ensuring equitable access to clean water for communities.  | Frauendorfer & Liemberger (2010)                 |
|                                   | Data monitoring and reporting   | Monitoring and reporting on NRW levels and progress in reducing NRW can contribute to tracking progress toward SDG 6.   | It provides valuable data on water losses, infrastructure improvements, and the effectiveness of water management strategies, aiding evidence-based decision-making and policy formulation.  | Tzanakakis <i>et al.</i> (2020)                  |

(Continued.)

Table 1 | Continued

| SDG name and number  | NRW within SDG objectives  | NRW contribution  | NRW and SDG interlinkage  | Ref.  |
|--|--|---|---|---|
| SDG 6.1: Non-Revenue Water Hampers Progress toward SDG 6.1 | Aims to achieve universal and equitable access to safe and affordable drinking water for all       | By reducing NRW, more water is conserved and made available for distribution to consumers.  | Efficient management of water resources helps improve access to water for communities, particularly in areas facing water scarcity or inadequate infrastructure.<br>NRW reduces the availability of water for distribution to consumers, impacting the goal of providing safe water to everyone.                                    | Tzanakakis <i>et al.</i> (2020)<br>IWA (2020)                   |
| SDG 6.3: NRW Affects and Water Quality                     | Focuses on improving water quality and reducing pollution  | Addressing NRW helps ensure the integrity of the water supply system, reducing the risk of leak or contamination in NRW contributes to water maintaining water quality standards.<br>Compromises the overall water quality, making it harder to achieve the target of minimizing waterborne diseases and ensuring water safety. | By minimizing leaks and unauthorized connections, NRW reduction contributes to safeguarding water quality for consumers.  | Frauendorfer & Liemberger (2010)<br>Farley <i>et al.</i> (2010) |
| SDG 6.4: NRW and Water Efficiency                          | Focuses on increasing water-use efficiency and implementing sustainable water management practices | NRW reduction contributes to water-use efficiency by minimizing losses in the water supply chain.<br>Represents a significant loss of water resources, undermining efforts to efficiently manage and sustainably use water.   | It promotes efficient use of water resources, as NRW represents wasted water that could otherwise be utilized for productive purposes or to meet the needs of communities.<br>Reducing NRW is a critical component of achieving this target, as it involves minimizing losses and improving the efficiency of water supply systems. | Tzanakakis <i>et al.</i> (2020)<br>Beitzel (2021)               |



- 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all.
- 6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.
- 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity.
- 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.
- 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes (Brogan *et al.* 2017).
- 6.A By 2030, expand international cooperation and capacity building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling, and reuse technologies.
- 6.B Support and strengthen the participation of local communities in improving water and sanitation management.

Efforts to reduce NRW contribute to achieving SDG 6 targets, improving water security, sustainable water management, promoting resource efficiency, supporting economic growth, and fostering partnerships contribute to meeting SDG targets and indicators.

#### 4.1.2. SDG 7 – Affordable and Clean Energy

SDG 7 primarily focuses on energy access and sustainability, which does not have a direct (may not be apparent) interlinkage with NRW. The adoption of energy-efficient practices, utilization of renewable energy, integrated planning, and capacity building can indirectly contribute to reducing NRW by optimizing water infrastructure operations, minimizing leaks, and improving water management practices. It highlights the importance of taking a holistic and integrated approach to achieve sustainable development outcomes across multiple sectors. Therefore, addressing energy-related challenges can indirectly contribute to reducing NRW. Table 2 demonstrates a few ways SDG 7 relates to NRW.

#### 4.1.3. SDG 8 – Decent Work and Economic Growth

NRW has a significant relation with SDG 8, and it has extreme negative impacts on investment and development: High levels of NRW can deter private investment in water infrastructure and utilities. Businesses rely on a reliable water supply may face disruptions, increased costs, or reduced productivity due to water scarcity. This can have a broader economic impact, affecting industries such as agriculture, manufacturing, and services. The presence of substantial NRW indicates inefficiencies and financial risks, making water utilities less attractive to investors. This can hinder economic development and infrastructure improvements in regions where NRW is prevalent, as shown in Table 3.

By scaling up, innovative solutions that reduce and prevent water loss and optimize usage through decent job creation, entrepreneurship, creativity, and innovation. Smart technologies and applications play an important role in improving water management and water resource by observing and presenting clear visual information on the water network system (UN Water 2020). NRW loss can strain financial sustainability, leading to reduced funding for infrastructure investment, maintenance, and expansion. These financial losses can undermine financial sustainability and hinder their ability to invest in infrastructure maintenance, repairs, and expansions.

#### 4.1.4. SDG 9 – Industry, Innovation, and Infrastructure

Sustainable infrastructure is crucial for reducing NRW. Target 9.1 of SDG 9 aims to develop resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. NRW reduction requires investments in efficient water infrastructure, utilizing innovative technologies for leak detection and management, and efficient water management systems. Therefore, addressing NRW contributes to achieving SDG 9 by promoting sustainable infrastructure and innovative approaches to water management. Table 4 illustrates SDG 9 interlinkages with NRW.

**Table 2** | NRW objectives, contribution, and SDG 7 interlinkages

| SDG name and number                   | NRW within SDG objectives                       | NRW contribution   | NRW and SDG interlinkage   | Ref.                          |
|---------------------------------------|---|--|--|-------------------------------|
| SDG 7:<br>Affordable and Clean Energy | Energy consumption and greenhouse gas emissions | NRW requires additional energy for pumping, treating, and distributing water. Increased energy consumption contributes to greenhouse gas emissions, exacerbating climate change. | By addressing NRW, energy efficiency can be improved, leading to reduced carbon footprints and progress toward clean energy targets.   | EC (2021)<br>UN-Water (2021)  |
|                                       | Real-time monitoring and leak detection         | Implementing energy-efficient technologies for real-time monitoring and leak detection in water distribution networks can help identify and address leaks promptly.              | By minimizing water losses through timely leak detection and repair, energy consumption associated with treating and pumping excess water can be reduced, indirectly contributing to both water conservation and energy savings.             | US-EPA (2013)                 |
|                                       | Technology and monitoring                       | SDG 7 emphasizes the use of modern technologies and monitoring systems for efficient energy management   | These technologies, such as smart meters, remote sensing, and data analytics, can be employed in water infrastructure to detect and monitor leaks, identify areas of high NRW, and facilitate targeted interventions to reduce water losses. | Fabbiano <i>et al.</i> (2020) |

#### 4.1.5. SDG 11 – Sustainable Cities and Communities

SDG 11 aims to create inclusive, safe, resilient, and sustainable cities and communities. NRW has a significant impact on urban areas, where most water distribution systems are located. Addressing NRW contributes to achieving this goal by ensuring efficient water management, improving the efficiency of water supply, enhancing service delivery, reducing water losses, and enhancing the sustainability of urban water systems. Table 5 shows the interconnection between SDG 11 and NRW.

#### 4.1.6. SDG 12 – Responsible Consumption and Production

SDG 12 focuses on promoting sustainable consumption and production patterns. NRW represents wasteful consumption and inefficient production of water resources. Reducing NRW contributes to responsible water consumption and sustainable water resource management, aligning with the objectives of SDG 12 shown in Table 6.

#### 4.1.7. SDG 13 – Climate Action

Climate change makes itself felt mostly through the water cycle. Strong water and sanitation utilities are essential to meeting the Sustainable Development Goal on water (SDG 6), itself a prerequisite for achieving most other SDGs. Yet many utilities, already struggling with weak operational and management approaches, inadequate resources, and deteriorating infrastructure (Atlantic *et al.* 2019). Climate change and the rising global temperatures have resulted in an elevated demand for water and placed stress on freshwater supplies worldwide. This issue is exacerbated by the substantial quantities of water lost through NRW. By preventing water loss, we can increase the availability of water without the need for developing new water sources. The primary approach will involve harnessing digital technologies in the water production and distribution process to decrease NRW and enhance operational effectiveness (Tien *n.d.*). SDG 13 aims to take urgent action to combat climate

**Table 3** | NRW objectives, contribution, and SDG 8 interlinkages

| SDG name and number                       | NRW within SDG objectives   | NRW contribution  | NRW and SDG interlinkage   | Ref.   |
|---|---|---|--|--|
| SDG 8:<br>Decent Work and Economic Growth | Supports economic growth, job creation, and industry development      | NRW has economic implications, as it leads to financial losses for water utilities and affects their ability to invest in infrastructure.<br>NRW reduces the availability of water for productive uses, potentially affecting productivity and industries reliant on water.   | By reducing NRW, water utilities can improve financial sustainability.<br>Water is a critical input for various economic activities, including industrial processes, agriculture, and commercial operations.   | Beitzel (2021)<br>Tzanakakis <i>et al.</i> (2020)  |
|   | Revenue shortfall   | NRW can hinder economic development by leading to financial losses, increased operational costs, and reduced revenue for governments, as discussed earlier.<br>NRW can result in reduced revenue for governments, as lower revenue collection from water utilities translates into reduced tax revenue or potential constraints on public budgets.<br>NRW directly contributes to a shortfall in revenue for the water utility. | By addressing NRW, resources can be allocated more effectively, supporting economic productivity and sustainable development.<br>NRW can limit the government's ability to invest in other important sectors or public services.<br>Reduced revenue collection undermines the financial capacity of the utility to maintain and improve the water supply infrastructure, resulting in a vicious cycle of deteriorating services. | Andreoni & Miola (2016)<br>Committee for Development Policy (2016)<br>Soppe <i>et al.</i> (2018) |
|   | Economic productivity loss  | NRW imposes economic costs through wasted resources, increased operational expenses, and decreased revenue collection.<br>Water shortages caused by NRW can hinder economic productivity. Businesses that rely on a reliable water supply may face disruptions, increased costs, or reduced productivity due to water scarcity.   | Addressing NRW helps create a more efficient and sustainable water supply, supporting economic growth and development.<br>This can have a broader economic impact, affecting industries such as agriculture, manufacturing and services.   | Frauentorfer & Liemberger (2010)<br>Tzanakakis <i>et al.</i> (2020)                              |
|   | Financial losses, negative impacts on investment and increased tariff | Unsustainable financial aspects of water utilities.<br>NRW represents a financial loss for water utilities since they incur costs to produce and treat the lost water without generating corresponding revenue.<br>NRW leads to financial losses for water utilities and suppliers.<br>To compensate for the revenue shortfall caused by  | Reducing NRW can lead to increased revenue collection, improving their financial sustainability.<br>NRW loss can strain financial sustainability, leading to reduced funding for infrastructure investment, maintenance, and expansion.<br>These financial losses can undermine financial sustainability and hinder  | AWWA (2019)<br>Beitzel (2021)<br>APE (2016)  |

(Continued.)

**Table 3** | Continued

| SDG name and number | NRW within SDG objectives                      | NRW contribution   | NRW and SDG interlinkage   | Ref.                             |
|---------------------|--|--|--|----------------------------------|
|                     |  | NRW, water utilities may be compelled to increase tariffs.   | their ability to invest in infrastructure maintenance, repairs, and expansions. Higher water tariffs can have a direct impact on consumers, particularly low-income households, and can lead to affordability challenges and potential social implications.                            |                                  |
|                     | Increased operational costs                    | Managing and reducing NRW requires additional operational efforts and costs. Utilities need to invest in leak detection and repair programs, metering infrastructure, and other measures to mitigate water losses. | Leaks, inefficient systems and unauthorized connections increase operational costs, including energy costs for pumping, chemical costs for treatment, and labor costs for repairs and maintenance. These additional expenses can impact the overall operational budget of the utility. | Frauendorfer & Liemberger (2010) |
|                     | Enhance economic efficiency                    | Reducing NRW has economic benefits, including increased revenue generation for water utilities and reduced operational costs.  | It helps improve financial sustainability of water utilities and enables them to invest in infrastructure development and service expansion.   | Kingdom <i>et al.</i> (2006)     |
|                     | Negative impacts on investment and development | High levels of NRW can deter private investment in water infrastructure and utilities.   | The presence of significant NRW indicates inefficiencies and financial risks, making water utilities less attractive to investors. This can hinder economic development and infrastructure improvements in regions where NRW is prevalent.   |                                  |

change and its impacts. NRW exacerbates the effects of climate change on water resources. [Table 7](#) addresses NRW and its contribution to SDG 13.

#### 4.1.8. SDG 14 – Life Below Water

SDG 14, which is ‘Life Below Water’, focuses on conserving and sustainably using the oceans, seas, and marine resources. While the direct connection between SDG 14 and NRW may not be apparent, there are some indirect interlinkages between the two. [Table 8](#) demonstrates the relation between SDG 14 with NRW.

#### 4.1.9. SDG 15 – Life on Land

SDG 15 is focused on protecting, restoring, and promoting sustainable use of terrestrial ecosystems, managing forests sustainably, combating desertification, and halting and reversing land degradation and biodiversity loss. While the direct connection between SDG 15 and NRW may not be immediately apparent, there are several

**Table 4** | NRW objectives, contribution, and SDG 9 interlinkages

| SDG name and number   | NRW within SDG objectives   | NRW contribution  | NRW and SDG interlinkage  | Ref.   |
|---|---|---|---|--|
| SDG 9:<br>Industry,<br>Innovation,<br>and<br>Infrastructure | SDG 9 emphasizes the need to build resilient infrastructure, promote sustainable industrialization and foster innovation. | Reducing NRW requires investment in infrastructure improvements, including leak detection technologies, pipeline repairs, and water management systems.   | Addressing NRW aligns with the goal of building sustainable and efficient infrastructure.   | Kingdom <i>et al.</i> (2006)                     |
|   | Improve infrastructure development, sustainability, and resilience  | NRW reduction requires investments in infrastructure improvements, such as repairing leaks, upgrading distribution systems by replacing aging infrastructure, and implementing advanced metering technologies.<br>By addressing NRW, countries can enhance their water infrastructure, reduce resource wastage, and promote sustainable industrial practices. | By addressing NRW, the objective is to invest in infrastructure maintenance, repairs, upgrades, and enhance the efficiency and sustainability of their infrastructure networks, contributing to SDG 9.<br>Reducing NRW requires investments in infrastructure upgrades, such as pipeline rehabilitation, leak detection systems, and improved metering, enhance infrastructure resilience and efficiency, contributing to SDG 9 and SDG 11. | UNOPS (2019)<br>Frauendorfer & Liemberger (2010) |
|   | Improving water management systems  | Addressing NRW requires investments in water infrastructure, such as repairing leaks, upgrading distribution systems, and implementing efficient metering and billing systems.  | SDG 9 focuses on building resilient infrastructure, promoting sustainable industrialization, and fostering innovation.  | Frauendorfer & Liemberger (2010)<br>UN (2022a)   |

interlinkages and potential impacts to be considered. Here are some ways in which SDG 15 relates to NRW shown in [Table 9](#).

In summary, while SDG 15 does not directly employ to address NRW, the efforts to reduce NRW contribute indirectly to the objectives of SDG 15 by promoting sustainable management of terrestrial ecosystems, conservation of biodiversity, and integrated water resource management can indirectly contribute to reducing NRW by improving water availability, quality, and resilience. Taking a holistic approach to water management that considers the interlinkages between SDG 15 and NRW can lead to more sustainable and effective outcomes.

#### 4.1.10. SDG 16 – Peace, Justice, and Strong Institutions

Apparently, NRW may primarily focus on governance, justice, and peace-related issues. However, there are indirect connections between SDG 16 and NRW that can be explored. To recognize the interlinkages between SDG 16 and NRW, policymakers and water sector stakeholders can integrate efforts to reduce NRW within broader initiatives for promoting good governance, accountability, transparency, and sustainable water management. These indirect connections highlight the relevance of addressing NRW for achieving the objectives of SDG 16. [Table 10](#) illustrates some potential interlinkages can be examined in several ways as follows.



**Table 5** | NRW objectives, contribution, and SDG 11 interlinkages

| SDG name and number                                 | NRW within SDG objectives  | NRW contribution  | NRW and SDG interlinkage  | Ref.  |
|---|--|---|---|---|
| SDG 11:<br>Sustainable<br>Cities and<br>Communities | Improve infrastructure and resilience<br>Aims to make cities and human settlements inclusive, safe, resilient, and sustainable                                       | Addressing NRW requires investment in infrastructure upgrades, maintenance, and rehabilitation.<br>Reducing NRW is essential for sustainable urban development. It helps ensure efficient water supply systems, reduces resource waste, and supports the availability of clean water for urban residents. | By improving water supply systems and reducing leaks, countries can enhance infrastructure resilience and efficiency SDG 11.<br>NRW reduction contributes to sustainable cities by ensuring water supply efficiency, reducing water losses, adequate water supply, improving service delivery reducing energy consumption, enhancing the resilience of urban water systems. | UN<br>(2023a)<br>PWA<br>(2003)<br>Beitzel<br>(2021) |
|   | Making cities and human settlements inclusive, safe, resilient, and sustainable<br>Improving the reliability and accessibility of water supply for urban populations | NRW is a significant challenge in urban areas due to population growth, aging infrastructure, high population density, and unauthorized connections.<br>NRW is particularly relevant in urban areas, where water demand is high   | Addressing NRW in cities can lead to improved water supply, reduced water stress, enhanced service delivery, and improved living conditions for urban populations.<br>Reducing NRW contributes to SDG 11 by ensuring reliable access to water for urban communities.  | Dodman<br>(2009)<br>Beitzel<br>(2021)               |

#### 4.1.11. SDG 17 – Partnerships for the Goals

SDG 17 highlights the importance of partnerships and collaboration to achieve the SDGs. Addressing NRW requires multi-stakeholder engagement, including governments, water utilities, civil society, and private sector entities to share knowledge, resources, and expertise. Building partnerships and collaborations to tackle NRW can contribute to achieving the SDGs collectively. [Table 11](#) discusses the connection between SDG 17 and NRW.

#### 4.1.12. SDG 3 – Good Health and Well-Being

SDG 3 and NRW are interconnected due to the complex relationship between water supply, sanitation, health, and well-being. SDG 3 aims to ensure healthy lives by reducing waterborne diseases and promote well-being for all at all ages. Conversely, advancements in SDG 3's objectives can positively influence the management of water resources and the reduction of NRW by emphasizing the importance of water quality and access. [Table 12](#) discusses the connection between SDG 3 and NRW.

In conclusion, the relationship between NRW and SDG 3 is multi-faceted. Addressing NRW not only aligns with the goal's emphasis on safe water supply, health, and well-being but also contributes to sustainable development and efficient resource management. By minimizing water losses and ensuring access to clean and safe water, efforts to reduce NRW can play a significant role in advancing the objectives of SDG 3.

#### 4.2. The interlinkage between NRW and SDGs framework

The conducted investigation illustrates that NRW is linked to both direct and indirect connections with specific numbers of SDGs.

The conducted investigation demonstrates that NRW is linked, both directly and indirectly, to certain SDGs. NRW is inherently connected to multiple SDGs within the broader framework. It has a significant direct alignment with Clean Water and Sanitation (SDG 6) including its targets (6.1, 6.3, 6.4, and 6.5) as its reduction contributes to efficient water management and improved access to clean water. Additionally, NRW intersects

**Table 6** | NRW objectives, contribution, and SDG 12 interlinkages

| SDG number                                     | NRW within SDG objectives   | NRW contribution   | NRW and SDG interlinkage  | Ref.  |
|--|---|--|---|---|
| SDG 12: Responsible Consumption and Production | Efficient resource management   | Identifying opportunities for improving water-use efficiency, reducing wastage, and optimizing resource allocation.<br>NRW represents inefficiencies in water production and distribution.   | NRW represents a waste of valuable water resources, and reducing it helps optimize resource utilization. This contributes to SDG 12 responsible consumption and decision patterns.<br>Responsible, efficient water consumption and water production practices, by promoting sustainable water use and resource efficiency, aligning with SDG 12.  | Beitzel (2021)<br>Chan <i>et al.</i> (2018)   |
|  | Focuses on promoting sustainable consumption, minimizing waste, and production patterns | NRW represents an inefficient use of water, leading to the wastage of resources, which goes against the principles of sustainable consumption and production.<br>Addressing NRW requires investment in infrastructure upgrades, maintenance, and rehabilitation.   | By reducing NRW, water utilities contribute to responsible water consumption and efficient use of resources, aligning with SDG 12.<br>By improving water supply systems and reducing leaks, countries can enhance infrastructure resilience and efficiency, contributing to SDG 9 and SDG 11.   | Berg (2015)<br>Garcia <i>et al.</i> (2023)  |
|  | Inefficient resource allocation   | NRW diverts resources that could be used more effectively elsewhere.<br>Water that is lost through leaks or other forms of NRW is essentially wasted, resulting in an inefficient resource allocation.<br>RW represents a loss of water resources, energy, and materials used in water treatment and distribution. | The financial and operational resources were lost that contributes to inefficiencies in resource allocation, limiting the ability to invest in infrastructure development or expand water services to underserved areas.<br>This can strain water supplies, particularly in regions facing water scarcity or high demand, leading to increased costs associated with finding alternative water sources or implementing water conservation measures. | Frauentorfer & Liemberger (2010)<br>Beitzel (2021)<br>Tzanakakis <i>et al.</i> (2020) |
|  | Increased energy consumption  | Addressing NRW often requires increased energy consumption. For example, higher pumping requirements to compensate for leaks or to maintain water pressure in the system can lead to increased energy costs.   | This can have a significant impact on the overall operational expenses of water utilities and indirectly affect consumer water bills.   | Kingdom <i>et al.</i> (2006)  |
|  | Economic productivity loss  | Water shortages caused by NRW can hinder economic productivity in various sectors. Businesses that rely on a reliable water supply may face disruptions, increased costs, or reduced productivity due to water scarcity.   | This can have a broader economic impact, affecting industries such as agriculture, manufacturing, and services.   | Tzanakakis <i>et al.</i> (2020)   |

**Table 7** | NRW objectives, contribution, and SDG 13 interlinkages

| SDG name and number    | NRW within SDG objectives   | NRW contribution  | NRW and SDG interlinkage   | Ref.                                       |
|------------------------|---|---|--|--|
| SDG 13: Climate Action | Climate resilience and adaptation   | NRW exacerbates the impacts of climate change by increasing water resources due to water scarcity.  | By reducing NRW, water systems become more resilient to climate variability, contributing to climate adaptation efforts and SDG 13.  | UN-Water (2021)                            |
|                        | Emphasizes the need to take urgent action to combat climate change and mitigate its environmental impacts | Addressing NRW often requires increased energy consumption and greenhouse gas emissions. For example, higher pumping requirements to compensate for leaks, and treat lost water or to maintain water pressure in the system can lead to increased energy costs. | This can have a significant impact on the overall operational expenses of water utilities and indirectly affect consumer water bills. By reducing NRW, energy consumption is reduced, leading to lower greenhouse gas emissions and minimizing the ecological footprint associated with water production and distribution. | Kingdom <i>et al.</i> (2016)<br>UN (2022b) |

**Table 8** | NRW objectives, contribution, and SDG 14 interlinkages

| SDG name and number      | NRW within SDG objectives | NRW contribution  | NRW and SDG interlinkage   | Ref.           |
|--------------------------|---------------------------|---|--|----------------|
| SDG 14: Life Below Water | Can impact water quality  | When leaks and pipe breaks allow contaminants to enter the distribution system. The infiltration of pollutants can compromise the quality and safety of drinking water sources, affecting both human health and aquatic ecosystems. | Addressing NRW helps maintain water quality standards and protect marine and freshwater environments. By reducing NRW, water utilities can maintain water quality standards, ensuring a healthy marine environment and supporting marine life. | Richard (2013) |

with SDG 7 (Affordable and Clean Energy) and has indirect connections and synergies that can be harnessed, through energy-efficient practices and renewable energy adoption in water infrastructure. NRW has a significant relation with SDG 8, and it has extreme negative impacts on investment and development. By addressing NRW, resources can be allocated more effectively, supporting economic productivity and sustainable development. Furthermore, the reduction of NRW supports SDG 9 (Industry, Innovation, and Infrastructure) by fostering improvements in water infrastructure, as well as SDG 11 (Sustainable Cities and Communities) by ensuring sustainable and resilient urban water systems.

NRW represents wasteful consumption and inefficient production of water resources. Reducing NRW contributes to responsible water consumption and sustainable water resource management, aligning with the objectives of SDG 12, which focuses on promoting sustainable consumption and production patterns. Moreover, reducing water-related energy consumption and associated greenhouse gas emissions supports SDG 13: Climate Action. By conserving water resources, ecosystems dependent on those water sources, such as wetlands, rivers, and forests, can be better sustained. These ecosystems provide important ecosystem services, such as water purification, habitat for biodiversity, and carbon sequestration, all of which are integral to SDG 15.

Apparently, NRW may primarily focus on governance, justice, and peace-related issues. To recognize the interlinkages between SDG 16 and NRW, policymakers and water sector stakeholders can integrate efforts to reduce

**Table 9** | NRW objectives, contribution, and SDG 15 interlinkages

| SDG name & number             | NRW within SDG objectives   | NRW contribution  | NRW and SDG interlinkage   | Ref.   |
|-------------------------------|---|---|--|--|
| SDG 15:<br>Life<br>on<br>Land | Water conservation, ecosystem services, and biodiversity conservation | <p>The excessive water loss leaks and overflows can damage natural environments through NRW and can disrupt the balance of ecosystems, affecting biodiversity and the natural habitats of various species.</p> <p>By minimizing leaks and losses in water distribution systems, less water extracted from natural sources. This reduction in water extraction helps in preserving freshwater ecosystems and maintaining the ecological balance in these habitats.</p> <p>Healthy ecosystems help regulate water flows, recharge aquifers, and prevent soil erosion, which can contribute to improved water availability and reduced water losses.</p> | <p>NRW reduction helps preserve water ecosystems, supports biodiversity, contributes to the efficient use of water resources, reduce the need for additional water extraction from natural sources, and maintain healthy ecosystems.</p> <p>By conserving water resources, ecosystems dependent on those water sources, such as wetlands, rivers, and forests, can be better sustained. These ecosystems provide important ecosystem services, such as water purification, habitat for biodiversity, and carbon sequestration, all of which are integral to SDG 15.</p> <p>Sustainable management of terrestrial ecosystems, including forests and water catchment areas, is essential for maintaining water resources and reducing NRW.</p> | <p>Tzanakakis <i>et al.</i> (2020)<br/>UN (2022b)<br/>UN (2023b)<br/>UNEP (2021)</p> |
|                               | Water resources and watershed management                              | <p>Conserving biodiversity supports ecological balance, including the presence of flora and fauna that contribute to water filtration, purification, and natural water storage.</p> <p>Effective management of watersheds is essential for maintaining the quantity and quality of water resources.</p>   | <p>Sustainable forest management contributes to watershed protection and prevents soil erosion. Well-managed watersheds can minimize sedimentation in water supply systems, reducing pipe damages and leaks that contribute to NRW.</p> <p>This indirectly helps in conserving water resources, especially in areas where water scarcity and competition for resources are prevalent, thus contributing to the conservation of terrestrial ecosystems.</p>   | <p>World Bank/WWF (2003)<br/>Tzanakakis <i>et al.</i> (2020)</p>                     |
|                               | Sustainable agriculture and land use                                  | <p>NRW reduction often involves addressing issues like agricultural water-use efficiency and promoting sustainable irrigation practices.</p>  | <p>Sustainable agricultural practices, such as precision irrigation and reduced water waste, contribute to SDG 15's objectives by minimizing land degradation, soil erosion, and the excessive extraction of water resources, which can have negative impacts on terrestrial ecosystems' agriculture and irrigation practices, reducing the pressure to convert additional land for agriculture and minimizing the impacts of land degradation.</p>  | <p>Frauentorfer &amp; Liemberger (2010)<br/>UN (2023a)</p>                           |

**Table 10** | NRW objectives, contribution, and SDG 16 interlinkages

| SDG name and number   | NRW within SDG objectives  | NRW contribution   | NRW and SDG interlinkage   | Ref.  |
|---|--|--|--|---|
| SDG 16:<br>Peace,<br>Justice, and<br>Strong<br>Institutions | Aims to promote just, peaceful, and inclusive societies with strong institutions. Also, emphasizes the importance of effective governance and accountable institutions | Addressing NRW requires strong governance structures and institutions within the water sector and accountability mechanisms within water utilities and regulatory bodies to ensure transparency, accountability, and proper management of water resources. | By reducing NRW, water utilities can demonstrate good governance practices and enhance their accountability to stakeholders.<br><br>Transparent and effective governance can help ensure proper management of water, including reducing NRW through efficient infrastructure maintenance and leak detection. | SWF (2020)<br>Kingdom <i>et al.</i> (2006)<br>WBG (2018)            |
|   | Emphasizes the importance of inclusivity and access to justice for all   | Addressing NRW can help improve access to water services, particularly for marginalized communities and disadvantaged groups.  | Reducing water losses and increasing the availability of clean water, efforts to address NRW contribute to social inclusion and access to basic services, aligning with the objectives of SDG 16.  | UN (2018a)  |
|   | Infrastructure development, including water systems, can contribute to conflict prevention and peacebuilding efforts   | By addressing NRW and improving water infrastructure, countries can reduce disputes over water resources and enhance stability within the communities.   | This indirectly supports the objectives of SDG 16 related to peace and inclusive societies.  | Kingdom <i>et al.</i> (2006)  |
|   | Highlights the need to build strong institutions and capacity building and technical assistance for effective government institutions                                  | Enhancing the capacity of water utilities and regulatory bodies to address NRW requires training on leak detection technologies, infrastructure management, billing systems, and financial management.   | Strengthening capacities, technical expertise and institutional capacity in NRW reduction and sustainable water management practices to the broader objectives of SDG 16 by fostering strong institutions and improving governance practices.  | Kingdom <i>et al.</i> (2006)<br>PWA (2015)<br>UNESCO & IWSSM (2019) |
|   | SDG 16 aims to combat corruption and promote accountable and transparent institutions  | NRW is often associated with inefficiencies and mismanagement in the water sector, including corruption and illegal activities.  | By addressing NRW and implementing measures to reduce illegal connections, unauthorized use, and fraudulent practices, water service providers can improve their resource management.  | Jenkins (2017)<br>PWA (2003)  |
|   | Highlights the importance of data collection,  | Engaging communities and stakeholders and  | By providing information about NRW levels,   | Susanne (2020)  |

*(Continued.)*



Table 10 | Continued

| SDG name and number | NRW within SDG objectives  | NRW contribution  | NRW and SDG interlinkage  | Ref.                                  |
|---------------------|--|---|---|---------------------------------------|
|                     | monitoring, and evidence-based decision-making and emphasizes access to information, participation, and transparency | assessing the effectiveness of NRW reduction strategies requires robust data collection systems, monitoring frameworks, management decision-making processes can contribute to NRW reduction. | causes, and strategies, and involving stakeholders in monitoring and decision-making, water utilities can enhance accountability and encourage community participation in water conservation efforts. | González de Asís <i>et al.</i> (2009) |

NRW within broader initiatives for promoting good governance, accountability, transparency, and sustainable water management. NRW has financial implications. Financial losses associated with water losses and evaluate the economic impact on stakeholders. This aligns with SDG 17, which emphasizes the importance of partnerships and sustainable financing for achieving the goals.

According to the illustrated framework (Figure 2), NRW has significant interconnection with SDGs. By addressing NRW, we can improve water resource management, promote sustainable practices, enhance energy efficiency, protect ecosystems, and contribute to multiple SDGs simultaneously. It is crucial to recognize these interlinkages and adopt an integrated approach to achieve sustainable development outcomes, ensuring efficient and equitable access to clean water and energy for all. The SDGs provide a comprehensive framework that emphasizes the need for integrated approaches and collaboration to achieve sustainable development outcomes, and addressing NRW is a critical component of this holistic approach.

The suggested framework illustrates a three-tier connection between NRW and SDGs. When SDGs are situated closer to NRW, particularly in Level-I, the relationship appears to be more meaningful and straightforward. Conversely, at Level-III, when SDGs are distant from NRW, the impact becomes more indirect and relatively weaker. Level-II serves as an intermediary, indicating a moderate relationship that falls between direct and indirect connections. By addressing NRW, we can contribute to improved water management, energy efficiency, environmental sustainability, and socioeconomic development, which are core objectives of the SDGs. Recognizing these interlinkages allows us to adopt holistic approaches and partnerships that promote sustainable water practices, enhance access to clean energy, and advance the broader SDG agenda for a more prosperous and resilient future.

### 4.3. The direct and indirect impacts of NRW global on SDGs by figures

#### 4.3.1. Direct impact

Estimating the global cost of NRW is challenging due to the complex nature of NRW and the variations in cost factors across different regions and water supply systems. According to the World Bank, the global average for NRW is around 35%. According to a study conducted by the World Bank in 2006, it was estimated that there are approximately 32 billion cubic meters of physical water losses worldwide every year. It is worth noting that half of these losses occur in developing countries (Liemberger & Wyatt 2019). Another study illustrates that the total cost of water utilities caused by NRW worldwide can be conservatively estimated at \$141 billion per year (Kingdom *et al.* 2006). Furthermore, there is an additional estimate regarding the global volume of NRW, which is approximately 346 million cubic meters per day or 126 billion cubic meters per year. Taking a conservative approach and valuing each cubic meter at only USD 0.31, the financial impact of water loss reaches a substantial USD 39 billion annually (Liemberger & Wyatt 2019).

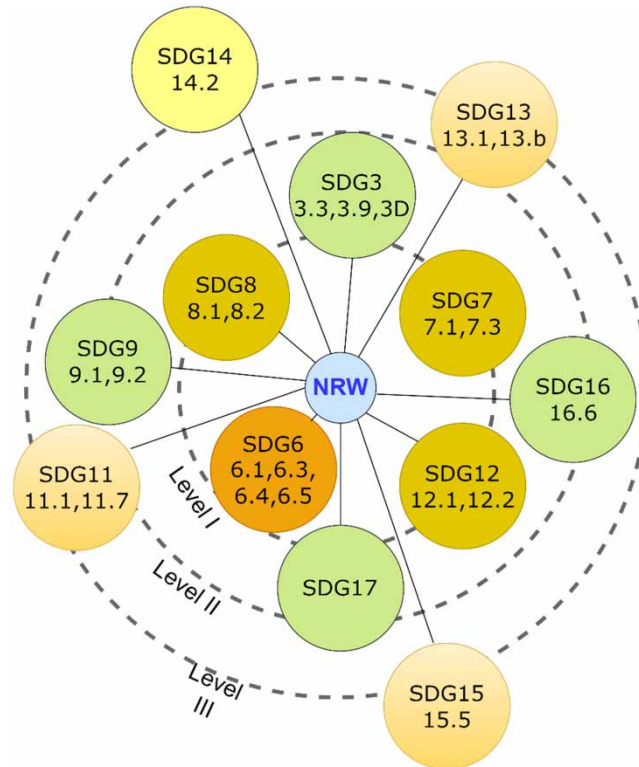
Moreover, the World Bank study estimates that the global annual volume of NRW was about 50 billion cubic meters – and the total cost of water utilities caused by higher production costs and lost revenues was estimated at US \$15 billion per year (Lai 2016). If the world's volume of NRW was reduced by only one-third, the savings would be sufficient to supply 800 million people (assuming a per capita consumption of 150 liters per day) (Liemberger & Wyatt 2019). While it may not be possible to eliminate NRW in a water utility, setting a goal

**Table 11** | NRW objectives, contribution, and SDG 17 interlinkages

| SDG name and number                                   | NRW within SDG objectives   | NRW contribution   | NRW and SDG interlinkage  | Ref.   |
|---|---|--|---|--|
| SDG 17:<br>Enhance Partnerships and Knowledge Sharing | Emphasizes the importance of partnerships and collaborations to achieve the goals | Addressing NRW requires collaboration among governments, water utilities, communities, civil society organizations, communities, private sector, international organizations, and multi-stakeholder.   | Partnerships and collaboration are vital to sharing knowledge, best practices, and experiences on reducing NRW, financial support, and mobilize resources effectively for sustainable development.  | <i>Stibbe et al.</i> (2019)<br>UNESCO (2023)   |
|   | Financial sustainability  | NRW has financial implications, and financial losses associated with water losses and evaluate the economic impact on stakeholders. Water losses result in missed revenue opportunities, increased operational costs, and reduced investment in maintenance.                           | This aligns with SDG 17, which emphasizes the importance of partnerships and sustainable financing for achieving the goals. SDG 17 supports to develop strategies to improve revenue collection, and enhance financial sustainability.  | <i>Frauendorfer &amp; Liemberger</i> (2010)<br><i>Beitzel</i> (2021)                                 |
|   | Increased operational costs   | These additional expenses can impact the overall operational budget of the utility. Leaks, inefficient systems, and unauthorized connections increase operational costs including energy costs for pumping, chemical costs for treatment, and labor costs for repairs and maintenance. | Managing and reducing NRW requires additional operational efforts and costs. Utilities need to invest in leak detection and repair programs, metering infrastructure, and other measures to mitigate water losses.  | <i>Kingdom et al.</i> (2006)<br><i>Beitzel</i> (2021)<br><i>Baghirathan &amp; Parker</i> (2017)      |
|   | Enhance economic efficiency, growth and development                               | Reducing NRW has economic benefits, including increased revenue generation for water utilities and reduced operational costs. Addressing NRW, resources can be allocated more effectively, sustainable water supply, supporting economic productivity, and sustainable development.    | It helps improve financial sustainability of water utilities and enables them to invest in infrastructure development and service expansion. NRW can hinder economic development by leading to increased operational costs, wasted resources, and decreased revenue collection. | <i>Kingdom et al.</i> (2006)<br><i>Beitzel</i> (2021)<br><i>Frauendorfer &amp; Liemberger</i> (2010) |
|   | Revenue shortfall   | NRW directly contributes to a shortfall in revenue for the water utility.  | Reduced revenue collection undermines the financial capacity of the utility to maintain and improve the water supply infrastructure, resulting in a vicious cycle of deteriorating services.  | <i>Frauendorfer &amp; Liemberger</i> (2010)  |

**Table 12** | NRW objectives, contribution, and SDG 3 interlinkages

| SDG name and number               | NRW within SDG objectives   | NRW contribution   | NRW and SDG interlinkage  | Ref.  |
|-----------------------------------|---|--|---|---|
| SDG 3: Good Health and Well-Being | Access to Clean Water and Sanitation (Target 3.3)                 | NRW contributes to a reduction in the availability of clean and safe drinking water.   | As water is lost before reaching consumers, it can lead to shortages and limited access to water supply, thereby affecting progress toward Target 3.3 of SDG 3, which aims to ‘end the epidemics of neglected tropical diseases and combat hepatitis, waterborne diseases, and other communicable diseases’.  | UNESCO (2023)   |
|                                   | Health Impacts (Target 3.9): Water Quality and Disease Prevention | NRW can lead to reduced access to clean and safe drinking water, potentially causing waterborne diseases and negatively impacting public health.<br>The inefficient management of NRW can lead to water contamination due to the ingress of pollutants into the distribution system.<br>Reducing NRW is often linked to improving water distribution systems and infrastructure. Contaminated water due to leakages or improper distribution can contribute to the spread of waterborne diseases, impacting public health. | Contaminated water sources resulting from NRW can contribute to the spread of diseases targeted by SDG 3, such as diarrheal diseases, cholera, and other water-related illnesses.<br>Contaminated water can result in waterborne diseases, which directly relate to Target 3.9 of SDG 3, aiming to ‘substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination’.<br>Addressing NRW can help prevent water contamination and improve disease prevention, aligning SDG 3’s objectives. | WDT (2023)<br>Shayan <i>et al.</i> (2022)<br>Beitzel (2021) |
|                                   | Sanitation and Hygiene  | NRW can limit the availability of water for sanitation and hygiene purposes.   | Insufficient water for personal hygiene and sanitation facilities hinders efforts to improve sanitation conditions and promote hygienic practices, which are crucial components of SDG.   | UN (2023b)  |
|                                   | Community Well-Being  | Access to clean water directly affects community well-being.   | NRW can lead to unequal distribution of water resources, disproportionately affecting vulnerable populations and hindering the progress of SDG 3 in ensuring healthy lives for all.   | UN (2022b)  |
|                                   | Infrastructure and Resilience (Target 3.D)                        | NRW reduction initiatives often involve upgrading and maintaining water infrastructure.  | Enhancing infrastructure resilience and quality is important not only for reducing water losses but also for ensuring reliable and safe water services, supporting Target 3.D of SDG 3, which emphasizes building resilient infrastructure.   | UN (2023a)  |



**Figure 2** | The interlinkage between NRW and SDGs framework.

of reducing current levels of losses by 50% in developing countries seems achievable. This reduction could result in an estimated annual cash increase of \$2 billion for the water sector, through both higher revenues and lower costs. Additionally, it has the potential to provide water services to an additional 90 million people (Lai 2016). Additionally, the reduction of NRW will have several benefits. It will enhance the reliability of water services, improve water supply for urban residents with limited access, enhance water quality, reduce energy consumption, and in certain instances, delay the need for expanding water supply capacity (Liemberger & Wyatt 2019).

According to UNESCO and UNESCO I-WSSM (2019), reducing NRW also allows municipalities to recover costs incurred in treating and pumping – this can be significant. A medium-sized city with 450 000 m<sup>3</sup> per day of produced water that loses 25% (not an unusual amount) is incurring over US\$13 million per year in non-recoverable labor, chemical and energy expenses (UNESCO & IWSSM 2019).

If we consider an average water consumption of 100 liters per person per day, it is considered that NRW is 50 billion m<sup>3</sup>:

50,000,000,000 liters/100 liters per person = 500,000,000 people, the NRW could potentially serve 500 million people per day (1,369,863 million people per year).

The direct cost of NRW is water loss, new water consumption to compensate the loss, maintenance and operations, energy cost, billings, etc.

- *NRW economic impacts* both the direct financial losses incurred by water utilities and the indirect economic, social, and environmental costs associated with water losses. The direct impact was due to water production and treatment costs, operation and maintenance costs, and revenue losses (Ndegwa 2016). A World Bank estimated that the financial cost of NRW in developing countries could range from 1 to 3% of their GDP. The costs associated with NRW include not only the direct financial losses for water utilities but also the indirect economic impacts, such as reduced revenue potential, increased energy consumption, and the need for additional investments in infrastructure (Kingdom *et al.* 2006).
- *Energy aspects*: The costs of NRW include energy costs for pumping and treating water, operation and maintenance costs for infrastructure, and the financial impact of revenue losses from unbilled or uncollected water

(Kiptala *et al.* 2019). Unfortunately, precise global figures for the energy level and cost of NRW are not readily available due to variations in water supply systems, infrastructure conditions, and energy costs across different countries and regions. The energy level and cost of NRW can vary significantly depending on factors such as the extent of water losses, the efficiency of infrastructure, and the energy sources used for water treatment and distribution. NRW has a significant impact on water availability, power consumption, and cost-recovery in a city (Reddy 2021).

However, here are some general information and estimates:

- ✓ Energy Consumption: Studies indicate that NRW can contribute to an increase in energy consumption within water supply systems by 10–30% or more, depending on the extent of water losses and system efficiency. Higher NRW levels require additional pumping energy to compensate for the lost water and maintain adequate pressure and flow rates (UN 2018c).
- ✓ Cost Implications: NRW has cost implications in terms of energy expenses incurred by water utilities. It is estimated that NRW-related energy costs can range from 20 to 50% of the total energy costs for water supply systems, depending on the efficiency of the infrastructure and management practices (UN 2018c).
- ✓ The IEA estimates that losses from water leakage and inefficient water use account for approximately 45 billion cubic meters of water annually, requiring significant energy inputs to compensate for the lost water (International Energy Agency 2016).
- ✓ The World Bank reports that energy costs typically represent 20–40% of a water utility's operational expenses.
- ✓ A study conducted in the United States estimated that the energy cost associated with NRW can range from 25 to 50% of the total operating cost for water utilities (Kingdom *et al.* 2006).
- ✓ Incorporating smart water technologies including optimized and designed to gather meaningful and actionable data, municipal leaders can make better and faster decisions about their operations, which can result in up to 30% energy savings and up to 15% reduction of water losses. Also, this allows water providers to minimize NRW by finding leaks quickly and even predictively using real-time SCADA to be compared with model network simulations (UNESCO & IWSSM 2019).

The cost of NRW extends beyond the financial implications for water utilities. It also encompasses the economic impacts on industries, businesses, and communities that rely on access to clean and reliable water (Frauendorfer & Liemberger 2010). These impacts can include reduced productivity, increased operational costs, and constraints on economic development. Obviously, the reduction of NRW contributes to improving the water security of a community. The reduction of NRW is a priority for cities in both developed and developing countries in order to ensure efficient service to the population and sustainable use of water resources. In the developing context, priority has to be given to SDG 6 (UNESCO & IWSSM 2019).

#### 4.3.2. Indirect impact

The indirect cost of NRW is infrastructure investment, negative environmental impacts, such as wastage of water resources, energy consumption associated with water treatment and distribution, and potential damage to ecosystems, social and economic implications, impacting public health and well-being.

- ✓ NRW has broader *socioeconomic* costs that affect society as a whole. These costs include the opportunity cost of the lost water, which could have been used for productive purposes, agriculture, or other economic activities. Additionally, NRW contributes to increased water stress, as more water needs to be abstracted to compensate for the losses (Kingdom *et al.* 2006). This can lead to environmental degradation, reduced water availability for other users, and increased energy consumption for water pumping and treatment (Tzanakakis *et al.* 2020).
- ✓ *Environmental impacts*: NRW can have negative environmental impacts, such as wastage of water resources, energy consumption associated with water treatment and distribution, and potential damage to ecosystems (Beitzel 2021). Assessing and mitigating these environmental impacts may require additional investments. The loss of any of this drinking water in the distribution network means producing even more to cover consumers' needs (LACROIX n.d.). The environmental impact is not without consequences: more and more raw water resources are drawn from the water supply, more electricity and chemicals are consumed, which in turn lead to higher CO<sub>2</sub> emissions (LACROIX n.d.).



#### 4.4. NRW and SDG impact in Palestine

For many years, NRW has been at the top of the agenda for the Palestinian Water Authority (PWA), in 2012 stated a strategic plan for NRW reduction, with specific objectives in order to meet their NRW strategy. The State of Palestine, like all member states in the UN, adopted the 2030 agenda for sustainable development and started aligning its priorities with the SDGs, through the establishment of a national SDG task force team via a presidential decree, to coordinate, monitor, and implement the SDGs (Ibrahim 2020). The State of Palestine has embraced SDGs set out to achieve clean, accessible, water for all despite of the water stress in the State of Palestine (Mostafa & Ayoub 2019).

According to the Water Sector Regulatory Council (WSRC) in the State of Palestine, the average rate of 33% NRW accounts for 45 million USD of more than 85 million cubic meters of fresh water lost annually. The PWA in its 2012 strategy has estimated that reducing NRW from 38 to 35% will increase revenues by 40 million USD over a period of 10 years (WSRC 2020b). WSRC in 2017 reported that NRW amounted to 53 MCM, while the NRW costs 49 million USD per year (Mostafa & Ayoub 2019). If we consider an average water consumption of 100 liters per person per day, it is considered that NRW is 85 million m<sup>3</sup>: 53,000,000 liters/100 liters per person = 530,000 people. The NRW in Palestine could potentially serve 530,000 people per day. In regard to the energy percentage of NRW, council regulatory sector water in 2020 revealed that energy cost per cubic meter of water still stands for 40% of the total cost (WSRC 2020a).

## 5. CONCLUSION

NRW has several impacts that are closely linked to the SDGs. Reducing NRW aligns with most principles of the SDGs, such as promoting sustainable resource management, reducing waste, improving efficiency, optimizing water supply systems, implementing leak detection and repair programs, and enhancing billing, revenue management, infrastructure maintenance, and consumer engagement, can help mitigate these economic impacts. It supports the efficient use of water resources, promotes environmental sustainability, and contributes to the achievement of multiple SDGs beyond those directly related to water. NRW affects everyone, and it's important to monitor and continuously improve water distribution systems. NRW reduction plans are a vital step toward lowering lost water while improving water infrastructure. Every year, billions of dollars are lost to NRW. This lost money can be used to improve infrastructure or to support the promotion of NRW initiatives and programs. NRW reduction contributes to the overall sustainability and resilience of water systems, benefiting communities, economies, and the environment. Here are some key conclusion points regarding NRW at its relation to SDGs:

- ✓ Addressing NRW aligns with various SDGs, particularly SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), but it also has synergies with other goals related to energy, biodiversity, sustainable consumption, and climate resilience. By reducing NRW, we can achieve more sustainable and resilient water systems, enhance environmental stewardship, and contribute to the broader agenda of sustainable development.
- ✓ Reducing NRW has a positive impact on energy consumption. Studies indicate that NRW can contribute to an increase in energy consumption within water supply systems by 10–30% or more, depending on the extent of water losses and system efficiency. Reducing NRW will reduce greenhouse (lower carbon footprint) gas emissions and contribute to SDG 13. The financial cost of NRW in developing countries is estimated to range from 1 to 3% of their GDP. The costs associated with NRW include not only the direct financial losses for water utilities but also the indirect economic impacts.
- ✓ NRW exacerbates water scarcity by reducing the available water supply. Water losses contribute to overall water stress, particularly in regions already facing water scarcity challenges like Palestine. So, reducing NRW helps conserve *approximately 32 billion cubic meters* of physical water resource losses worldwide every year and ensures a more sustainable water supply for communities which meets SDG 6 and its targets related to Water Scarcity.
- ✓ Reducing NRW will decrease water extraction from rivers, lakes, or underground sources that can disrupt natural water flows, alter habitats, and deplete water resources, affecting biodiversity and ecosystem health (SDG 15). If the world's volume of NRW was reduced by only one-third, the savings would be sufficient to supply 800 million people. In addition, it will prevent deterioration in water quality and less compromising

the safety and quality of the water supply. In the State of Palestine, particularly, reducing NRW will save 53 MCM (cost 49 million USD) per year which will serve about 530,000 people per day.

- ✓ Engagement and collaborations among national water ministries, departments, regulatory bodies, NGOs working in the water sector, universities, research centers, and academic institutions can play a vital role in setting policies and regulations, raising awareness, advocating for policy changes, can conduct research on NRW reduction techniques, develop innovative technologies, provide technical expertise to utilities and governments, can collaborate with utilities and other stakeholders to analyze and address the root causes of NRW, and can partner with utilities and governments to implement efficient water infrastructure and monitoring systems for NRW reduction, and making progress toward achieving SDGs.

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## CONFLICT OF INTEREST

The authors declare there is no conflict.

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